To the Graduate Council:

I am submitting herewith a thesis written by Michael Earl Kennedy entitled, "Low-Volume Production Design And Manufacture Of A Low-Cost Industrial Robot". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

Clement C. Wilson, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at the University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledge of the source is made.

Requests for permission for extensive quotation from or reproduction of this thesis in whole or in parts may be granted by the copyright holder.

Signature Michael E Hendry

Date 26 Apr 1991

LOW-VOLUME PRODUCTION DESIGN AND MANUFACTURE OF A LOW-COST INDUSTRIAL ROBOT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Michael Earl Kennedy

May 1991

Copyright © 1991 by Michael Earl Kennedy

All Rights Reserved

ACKNOWLEDGEMENTS

No task of any significance can be completed without the unselfish assistance and encouragement of many others. Indeed, a design and manufacturing project such as that described in this thesis requires the cooperation and assistance of many others, ranging from the ME department's top-notch machinists to helpful supplier representatives.

Family and friends have been most helpful during my graduate academic efforts, as they continue to provide both encouragement and sound advice during my graduate efforts. My faculty mentors, Drs. Clement C. Wilson, Frank H. Speckhart, Osama Soliman, James A. Euler, and Dean William T. Snyder deserve special recognition for contributing to my continuing professional development. Fellow graduate students working on the robot project effort, both past and present, deserve thanks for their contributions to the robot design. The teamwork amongst the graduate students and the faculty contributors working on the robot project has been certainly one of the most satisfying aspects of the effort.

I gratefully acknowledge the sponsorship of the IBM Corporation, Charlotte, NC, for providing an IBM Graduate Fellowship during my tenure at the University. The industrial supporters of the Superior Engineering Design Program also deserve acknowledgement for providing essential resources that were required to complete the effort.

ABSTRACT

Industrial use of robotic systems has been limited by the high cost, complexity, and difficult programming that is needed to use robotic systems effectively. Because of the high costs normally associated with a robot, many natural applications for robotic systems are not cost-effective in today's factory. If a low-cost robot was available, it could perform profitably many medium-accuracy tasks that are not now economically feasible.

University of Tennessee engineering students began work to develop a low-cost, medium-accuracy robot in 1986. Two mechanical engineering M.S. students designed and built a prototype robot, while an electrical engineering M.S. student developed a microprocessor-based robot control system. A new round of development activity commenced in 1989 after the prototype robot showed promise. The effort described in this document is part of a comprehensive effort within the University of Tennessee mechanical engineering department to design, build, and evaluate a complete industrial robotic system.

This thesis covers the author's work to improve the robot's mechanical design and to adapt it to low-volume production methods. The document describes the robot system's "theory of operation", important features and their considerations, and relevant design specifications. Assembly issues, system cost information, and recommendations for continued robot system improvement are also discussed.

TABLE OF CONTENTS

PROJECT BACKGROUND AND INTRODUCTION 1
- Project History Summary 1
- Development Of The "UT Robot" 2
- Future Efforts 4
- The Superior Engineering Design Program 5
- Scope of Thesis 7

REVIEW OF FIRST PROTOTYPE ROBOT SYSTEM 9
- First Prototype Robot General Description 9
- Evaluation of the First Complete Robot Prototype 25

ROBOT RELIABILITY ASSESSMENT 36
- Reliability Analysis Goals 36
- Reliability Assessment Procedure 37
- Reliability Assessment Results 40
- Reliability Improvement Recommendations 46

"UT" ROBOT SYSTEM OVERVIEW 48
- The "UT" Robot 48
- UT Robot Design Goals 48
- Features Retained from the First Robot Prototype Design 50
- Robot System Enhancements 52
- Design for Manufacturing Considerations 54
- New Robot Control System 56
- Design Changes/Improvements 58
- New Reliability Goals 61
- Revised Robot Cost Goals 65

HORIZONTAL POSITIONING SYSTEM 69
- Basic Mode of Operation 69
- Horizontal System Design Features 71
- Horizontal System Design Considerations 76
- Parts Design And Manufacture 89

VERTICAL AND ROTATIONAL POSITIONING SYSTEMS . 100
- Basic Mode of Operation 100
- Vertical Positioning System Design Features 108
- Vertical Positioning System Design Considerations 111
- Rotational Positioning System Design Features 120

Rotational System Design Considerations 121
Parts Design And Manufacture 129

ROBOT SUPPORT FRAME AND CONTROL SYSTEM 142
Robot Support Frame 142
Motor Control System 144

ROBOT SYSTEM COST ASSESSMENT 147
Robot System Manufacturing Cost Estimates 147
Robot Production Manufacturing Cost Assessment 151
Robot Prototype Cost Assessment 156
Casting Pattern Fabrication Costs 158
Processing Cost Totals and Comparison 161
Vendor-Supplied Parts Costs 162
Robot Assembly Costs 164
Material Acquisition Costs 164
Activity Cost Analysis 167
Cost Assessment Assumptions and Approach 171

CONCLUSIONS AND RECOMMENDATIONS 177
Results 177
Configuration Planning Tools 182
Problems 182
Robot Improvement Recommendations 185
Future Considerations 196

LIST OF REFERENCES 198

APPENDICES 201
UT Robot Software Specifications 202
Reduction Ratio Chart 208
Horizontal System Resolution Selection Charts 212
Horizontal Reduction System Belt Length Charts 218
Vertical System Resolution Selection Charts 224
Vertical Reduction System Belt Length Charts 230
Robot Horizontal Components Sizing Chart 236
Parts Cost Summary Sheets - Prototype 239
Parts Cost Summary Sheets - Projected Production 266
Horizontal System Theoretical Performance Charts 293
Vertical System Theoretical Performance Charts 302
Linear Bearing and Shaft Ordering Cost Charts 314
UT Robot Parts Assembly Listing 321
UT Robot Part Number Listing 328

UT Robot Assembly Instructions 332
"A" Size Part and Assembly Drawings 355

VITA 452

LIST OF TABLES

8.1: Potential production costs for the UT Robot. 148
8.2: Manufacturing costs for UT Robot prototype. 150
8.3: Production costs for the UT Robot's cast parts. 154
8.4: Production costs for the UT Robot's machined parts. 155
8.5: Production costs for the UT Robot's modified finished parts. 156
8.6: Prototype manufacturing costs for the UT Robot's cast parts. 157
8.7: Prototype manufacturing costs for the UT Robot's machined parts. 159
8.8: Prototype manufacturing costs for the UT Robot's modified finished parts. . 160
8.9: Fabrication costs for the UT Robot's casting patterns. 160
8.10: Prototype processing costs for the UT Robot. 161
8.11: Estimated production processing costs for the UT Robot. 162
8.12: Costs of vendor-supplied, non-modified parts for the UT Robot. 163
8.13: Materials acquisition costs for the UT Robot prototype. 165
8.14: Projected materials acquisition costs for UT Robot production. 166
8.15: Projected casting materials cost savings from using mounted tooling. 168

LIST OF FIGURES

2.1: Illustration of the first inexpensive robot prototype. 10
2.2: Product specifications for the first prototype robot 12
2.3: View of the first prototype horizontal positioning system. 14
2.4: Partial exploded view of the first prototype's horizontal drive system 16
2.5: Assembled view of the first low-cost robot 18
2.6: View of the first low-cost robot's vertical and rotational positioning systems . 20
2.7: Exploded view of the first low-cost robot's rotational positioning system. . . . 22
2.8: Block diagram of the first low-cost robot's control system. 23
3.1: Reliability versus degradation factors. 38
3.2: Reliability assessment results summary chart. 42
3.3: Reliability assessment results for the "severe" application. 44
3.4: Reliability performance predictions.. 47
4.1: Assembled view of the UT Robot. 49
5.1: The UT Robot's horizontal positioning system. 70
5.2: Attachment of the Z platform to the horizontal positioning system. 74
5.3: Motor location schematic. 78
5.4: Motor mounting orientations. 78
5.5: Views of the horizontal idler assembly. 80
5.6: Combination belt attachment-adjustment assembly. 83
5.7: Shaft-pulley attachment groove. 86
5.8: Common center versus common spacing configurations. 86
5.9: Proposed position verification system. 88
5.10: Corner support. 90
5.11: XY slider assembly. 91
5.12: XY slider casting pattern and holder. 93
5.13: Bearing cartridge assembly. 95
5.14: Bearing cartridge casting pattern and holder. 97
5.15: XY motor assemblies. 98
6.1: The UT Robot's vertical and rotational positioning systems. 101
6.2: Exploded view of the vertical drive system. 103
6.3: Exploded view of the vertical motion system. 105
6.4: Exploded view of the rotational motion system. 107
6.5: Z mast assembly. 115
6.6: Proposed Z mast assembly. 117
6.7: Z belt tension adjustment. 119
6.8: Theta system offset load problem. 124
6.9: The Z platform assembly. 130
6.10: The Z platform casting pattern and holder. 131
6.11: The theta motor mount. Finished part and casting pattern are shown. 133
6.12: The end effector mount. Finished part and casting pattern are shown. 135
6.13: The Z guide tube and theta transmission tube. 136

6.14: The Z mast and mast plate. 139
6.15: Mast plate manufacturing orientation. 141
6.16: Views of the motor-tube converter. 141
7.1: UT Robot frame assembly. 143
7.2: Block diagram of the UT Robot control system. 145
8.1: Results from Economic Order Quantity (EOQ) model 170
8.2: Sample parts cost detail for UT Robot parts. 176
9.1: Required motor speed versus desired horizontal linear velocity.. 180
9.2: Sample theoretical maximum acceleration for UT Robot horizontal system.. . 180
9.3: Required motor speed versus desired vertical linear velocity. 181
9.4: Sample theoretical maximum acceleration for UT Robot vertical system. . . . 181
9.5: Stepper motor torque comparison. 184
9.6: Screw insertion interference on Z platform. 186
9.7: Underside view of the corner support. 187
9.8: Proposed Z platform to bearing cartridge mounting. 189
9.9: Z system end stop problem. 190
9.10: Proposed Z guide tube groove location. 191
9.11: Proposed changes to Z platform. 193

LIST OF PLATES

MEK001-DDD: Support, Corner . . . . . In Pocket
MEK011: Plate, Motor Mounting, "Left-Hand" . . . . . In Pocket
MEK012: Plate, Motor Mounting, "Right-Hand" . . . . . In Pocket
MEK016: Plate, Motor Mounting, Z Platform . . . . . In Pocket
MEK021-DDD: Housing, Slider, XY. . . . . In Pocket
MEK051-DDD: Cartridge, Bearing, Right Angle . . . . . In Pocket
MEK071: Platform, Z-Theta . . . . . In Pocket
MEK081: Motor Mount, Theta . . . . . In Pocket
MEK091: Plate, Mounting, Mast . . . . . In Pocket
MEK093-ZZZ: Mast, Z Axis . . . . . In Pocket
MEK101: Pattern, Casting, Corner Support . . . . . In Pocket
MEK110: Pattern, Casting, XY Slider Housing . . . . . In Pocket
MEK115: Pattern Holder, XY Slider Housing . . . . . In Pocket
MEK131: Pattern, Casting, End Mount . . . . . In Pocket
MEK151: Pattern, Casting, Bearing Cartridge . . . . . In Pocket
MEK156: Pattern Holder, Partial, Bearing Cartridge . . . . . In Pocket
MEK171: Pattern, Casting, Z Platform . . . . . In Pocket
MEK176: Pattern Holder, Z Platform . . . . . In Pocket
MEK181: Pattern, Casting, Theta Motor Mount . . . . . In Pocket
MEK211-ZZZ: Tube, Guide, Z Axis . . . . . In Pocket
MEK231-ZZZ: Mount, End Effector . . . . . In Pocket

CHAPTER 1

PROJECT BACKGROUND AND INTRODUCTION

Project History Summary

Several University of Tennessee engineering students, under the sponsorship of the International Business Machines (IBM) Corporation, began work to develop a low-cost, medium-accuracy robot in 1986. The robot project was part of the University's participation in the IBM Technical Interchange Program (TIP), which provides project research support for projects of interest to IBM.

The first robot design concept evolved from the belief that the robots that were then available were too expensive and too complex to be used for very simple tasks. IBM engineers suggested that a cartesian motion, stepper-motor actuated robot with an open-loop control system might be able to perform simple tasks that could not be justified economically with the more complex machines. Some basic functional requirements were suggested by the IBM engineers for the proposed low-cost robot system.

During Fall semester 1986, several senior-level mechanical engineering design groups were assigned to develop some preliminary configurations for the proposed machine. After a favorable review, IBM agreed to sponsor several graduate students to design and build a prototype machine.

The initial design effort was segmented into three major sub-systems:

1) a horizontal positioning system, which provides translational motion along two perpindicular axes (labelled "X" and "Y") in the horizontal plane;
2) vertical and rotational positioning systems, which provide translational motion in the vertical ("Z") direction and rotational motions about the translational axes; and
3) a electronic control system, which issues positioning commands to the robot.

The horizontal positioning system ("X" and "Y" axes) was designed and built as a master's thesis by Mark L. Granger for The University of Tennessee Mechanical and Aerospace Engineering Department [Granger, 1988]. During the same period, Siak Yeo of the University of Tennessee Electrical Engineering Department developed an electronic controller for the robot [Yeo, 1988].

Lawrence M. Garrett revised selected aspects of Granger's prototype as he designed and constructed a system to provide vertical translation ("Z" axis) and rotation about the vertical axis ("theta" rotation). The other two rotational motions were eliminated from the product specifications. Garrett's design effort is detailed in his University of Tennessee M.S. thesis in Mechanical Engineering [Garrett, 1989].

Development Of The "UT Robot"

The first prototype robot successfully demonstrated the inexpensive robot concept, but also exhibited several weaknesses. For example, early testing of the horizontal

positioning system showed that more reliable components were needed to improve the robot's operational reliability. The control system did not provide enough flexibility for the robot to be used easily in many applications. Several other design improvement opportunities were also identified.

Based on a assessment of the first prototype, several University of Tennessee faculty and students initiated a major design and evaluation effort to investigate the technical potential of an improved "UT Robot". This effort, sponsored by the Superior Engineering Design Program, was to utilize the basic design and "lessons learned" from the initial prototype to create a commercially-viable product. An informal program was initiated to identify potential customers and to determine their robotic use needs. A successful UT Robot system would potentially be sold to industrial customers to perform operations such as loading machines or manipulating small production tools.

Improvements and enhancements were identified for the robot's design, manufacturability, and control. M.S. students were assigned to redesign robot components for better performance and low-volume manufacturing techniques, to prepare manufacturing tooling for CNC machining of robot parts, and to provide a system for simple user-directed control of the robot. Other M.S. students were selected to perform a formal reliability assessment of the initial prototype, to prepare a system for automatic manufacture of robot structural support frames, and to perform a comprehensive robot performance evaluation.

Future Efforts

Following construction of the "UT Robot" prototype, a comprehensive evaluation of the robot system, both hardware and software, is planned as part of another master's thesis effort. The first prototype likely will also be used for hardware test comparisons and for software evaluation. The test program will be oriented toward assessing the "basic" capabilities of the overall robot system and identifying any additional work that is needed to prepare the system for an actual industrial application.

Work continues to complete the fixturing and machine tool control programming to automate the manufacture of many major robot components. Manufacturing systems planning will be completed to assure proper and economic parts acquisition and handling. A robot support frame, designed for automated manufacture, should be completed sometime late in 1991. The automated frame welding and the automated parts machining will be performed in the Flexible Manufacturing Center, located in the Mechanical and Aerospace Department at The University of Tennessee.

If the robot test results are positive, an industrial test site will be sought to evaluate the robot's usefulness and reliability in an actual industrial application. Two potential test applications are being studied. A senior-level mechanical engineering design group is completing a configuration study for the automated testing of medical laboratory test tube samples. Automated loading and unloading of small armatures from a solenoid

manufacturing line is being investigated by several M.S. students. Other potential sites and applications will also likely be considered.

If the site testing is successful, it is anticipated that additional commercial applications for the robot system could be identified and that robots could be sold to interested industrial customers.

The Superior Engineering Design Program

In 1987, University of Tennessee Mechanical and Aerospace Engineering Department initiated an integrated program to improve significantly the teaching of engineering design. This undertaking, named the Superior Engineering Design Program (SEDP), is a comprehensive program in which both undergraduate and graduate students are involved directly in designing, evaluating, and manufacturing products for a competitive marketplace. The undergraduate senior design course involves product design projects that result in the implementation and evaluation of hardware. Graduate theses feature comprehensive product or process development projects. The UT robot development project described in this thesis is sponsored by the SEDP. Other sponsored efforts include medical devices and a remote-controlled vehicle.

The SEDP has four major laboratories, including the Engineering Design Center, the Flexible Manufacturing Center, the Current Engineering Practice Laboratory, and the Performance Evaluation Laboratory. Two core courses include an Electromechanical

Design Course and a Superior Product and Process Development Course. Additionally, the program sponsors graduate research in product development.

The Engineering Design Center consists of eight modules for engineering teams of four students each. An IBM PS/2 Model 80 is provided for the team leader and PS/2 Model 70's are used by the three team members. Software includes IBM CAD, Lotus 1-2-3, WordPerfect, QuickBasic, Continuous System Modeling Program, MTabSAP86 finite element program, SMARTCAM tool path generating software, and the American Society of Metals Materials Database. Additionally, other specialized programs are also available. Parts designed in the Engineering Design Center can be manufactured in the Flexible Manufacturing Center, which currently consists of a computer-controlled milling machine, a robotic welder, and two assembly robots.

The robot development project has extensively utilized many of the SEDP's facilities, especially the Engineering Design Center and the Flexible Manufacturing Center. Assembly layouts and part design drawings for the robot have been created using the IBM CAD software in the Engineering Design Center. Lotus 1-2-3 has been used to generate parts lists, to control vendor part orders, and to compute robot size configuration requirements. Written documentation, such as assembly instructions and this document, has been made using WordPerfect. The Center's token ring network file server has been used to store the "latest-level" part and assembly drawings so that all robot team members could access drawings at any time.

Many robot parts will be machined in the Flexible Manufacturing Center, which will be discussed in detail by robot development team member Devendra Sahu in his forthcoming master's thesis. Sahu has used the SMARTCAM software in the Engineering Design Center to create the tool path instructions needed to machine robot parts. The tool path file is transported by diskette and loaded onto a computer in the Flexible Manufacturing Center. Finished parts are machined by the CNC mill using the SMARTCAM-generated tool path instructions. The SMARTCAM tool paths have been generated directly from the IBM CAD design geometry data in the robot part drawings. Custom or specialty parts, such as casting patterns or special "one-time" brackets, are machined in the mechanical engineering department's conventional machine shop.

Indeed, the Superior Engineering Design Program provides an integrated environment for engineering and manufacturing, and has proven to be very effective for both teaching and executing product development practices. The capabilities of the Superior Engineering Design Program facilities have been successfully demonstrated during this comprehensive design and manufacturing project.

Scope of Thesis

This thesis details the mechanical design and construction of the new UT robot. It covers the author's work pertaining to the following aspects of the robot system:

1) "Theory of operation" for the robot system, including design rationale, important features and their considerations, and relevant design specifications;
2) Design modifications to the first prototype design to facilitate low-volume manufacturing (the initial design was based on large production quantities);
3) Design enhancements and alterations, including change recommendations made by the previous developers, that were made to increase the versatility and usefulness of individual robot component parts and of the system as a whole;
4) Design and manufacture of "pattern" parts needed to manufacture cast components for the robot system;
5) Cost assessment for a "typical" robot system;
6) Prototype assembly instructions;
7) Recommendations for continued robot design, manufacturing and use improvement.

Mechanical specifications for the robot design, including engineering drawings, configuration specifications, and production costs are included in the presentation. Additionally, some efforts that were undertaken to identify potential customers and their needs are also discussed.

Some other robot system design and evaluation activities are discussed in Johnson (1990) and Walker (1990). Other theses are expected to come from the robot project effort in the near future.

CHAPTER 2

REVIEW OF FIRST PROTOTYPE ROBOT SYSTEM

Before beginning a discussion of the "new" UT Robot design, it is helpful to review the progress and lessons of the first prototype. This chapter describes the important features of the first prototype robot, reviews problems that have been observed with this prototype, and presents the new goals used in the UT Robot design.

First Prototype Robot General Description

The first prototype of the low-cost, industrial robot is a four-degree-of-freedom, cartesian-motion system with open-loop control. The robot's end effector mount can translate along two perpendicular horizontal axes ("X" and "Y") and a vertical axis ("Z"), as well as provide rotational motion about the vertical axis ("Theta").

The first complete robot prototype is pictured in Figure 2.1. The robot itself rests on a supporting frame. Corner supports, one at each corner of the frame, hold four shafts that extend from corner to corner along the outside of the work space. Sliders move along these outside "guide" shafts to control the robot's horizontal ("X" and "Y") motion. The sliders hold the "control" shafts that direct the horizontal position of the Z-platform assembly. As the sliders move the control shafts, the Z-platform, end effector, and payload are moved to the desired horizontal position within the robot's work space.

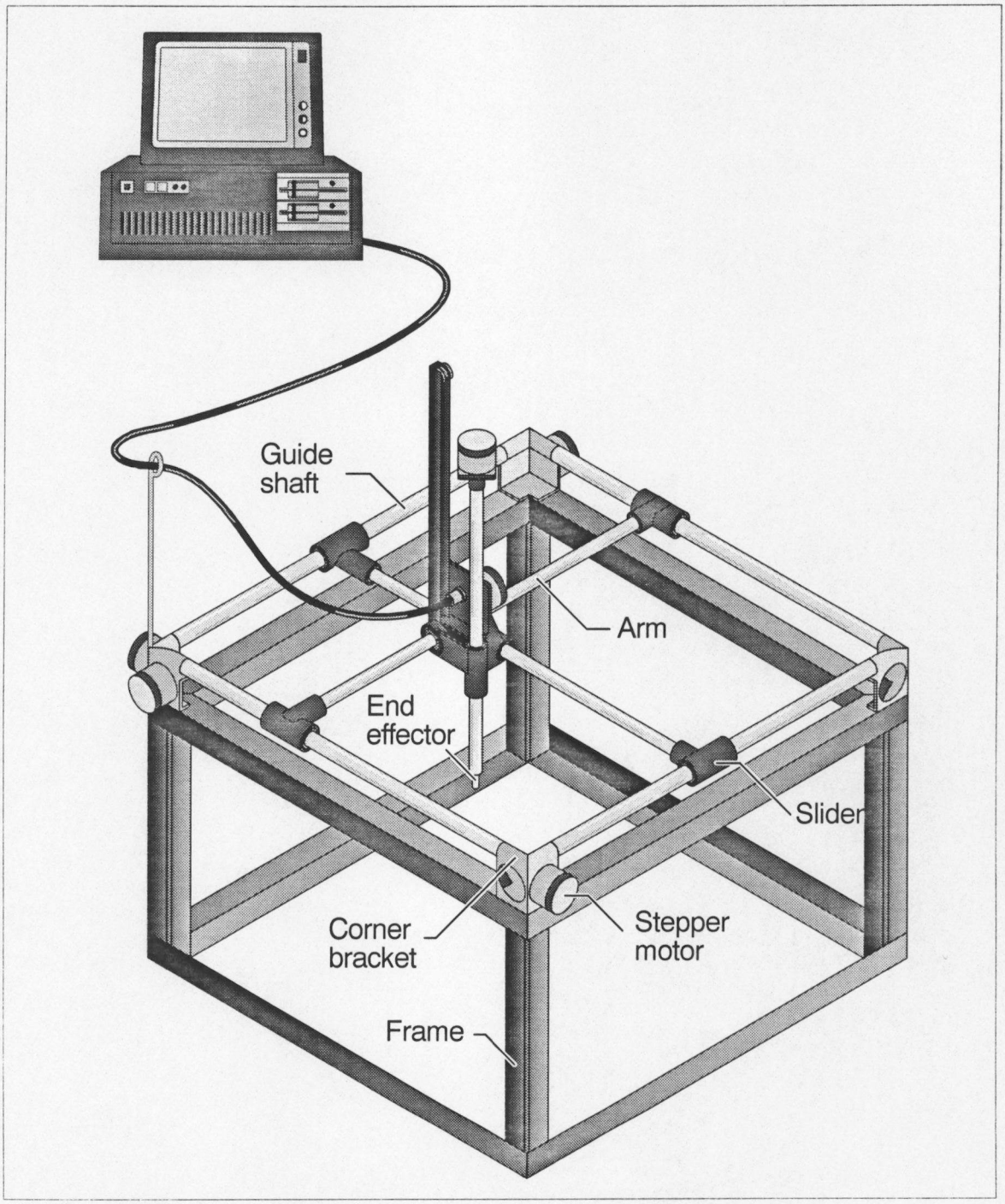


Figure 2.1: Illustration of the first inexpensive robot prototype.

Source: Bill Stack, "A Generic Robot Takes Shape", *Industry Week*, May 21, 1990, p. 55. Illustration by Bruce Carillon, Knoxville News-Sentinel.

The Z-platform supports the hardware needed to move the robot end effector vertically (in the "Z" direction) and to rotate it about the vertical axis ("Theta"). A mast extends upward from the Z-platform to provide the necessary structural support for vertical motion. The drive system for the rotational ("Theta") motion is located inside of the vertical tube that moves through linear bearings mounted in the Z-platform.

A timing belt drive system driven by stepper motors is used to move the robot throughout its work space. A specially-designed electrical control system originally controlled the robot's motion [Yeo, 1988], but this system was later replaced by a personal computer [Johnson, 1990].

First Prototype Robot Specifications

The initial specifications and design goals for the UT Robot were described by Granger (1988) and are presented in Figure 2.2. The primary focus of the project was to provide a low-cost, capable robot that could be used in industrial applications of simple to moderate difficulty. Since it would be inexpensive, the robot system could then be marketed to firms with robot applications that could not be economically justified using more expensive machines. The marketing advantage that would derive from this strategy is that the "UT robot" would compete by expanding the robot market and by finding a "market niche", rather than by competing with a similar product against much better established competitors. The cost goal established for the project was complemented by

First Prototype Robot Functional Requirements

Rectilinear Workspace; Cartesian Motion

Six Degrees of Freedom: 3 linear, 3 rotary

Average velocity of 39 inches/second over a 12 inch move

Positional accuracy of within 0.118 inches

Settling time of less than 0.1 seconds

Limited number of pre-defined moves

Design Goals

Low Cost: less than $500 for parts, labor, and overhead

High Speed

Simple, Modular Design

Stepper Motor, Open Loop Control

Error Detection

Figure 2.2: Product specifications for the first prototype robot.

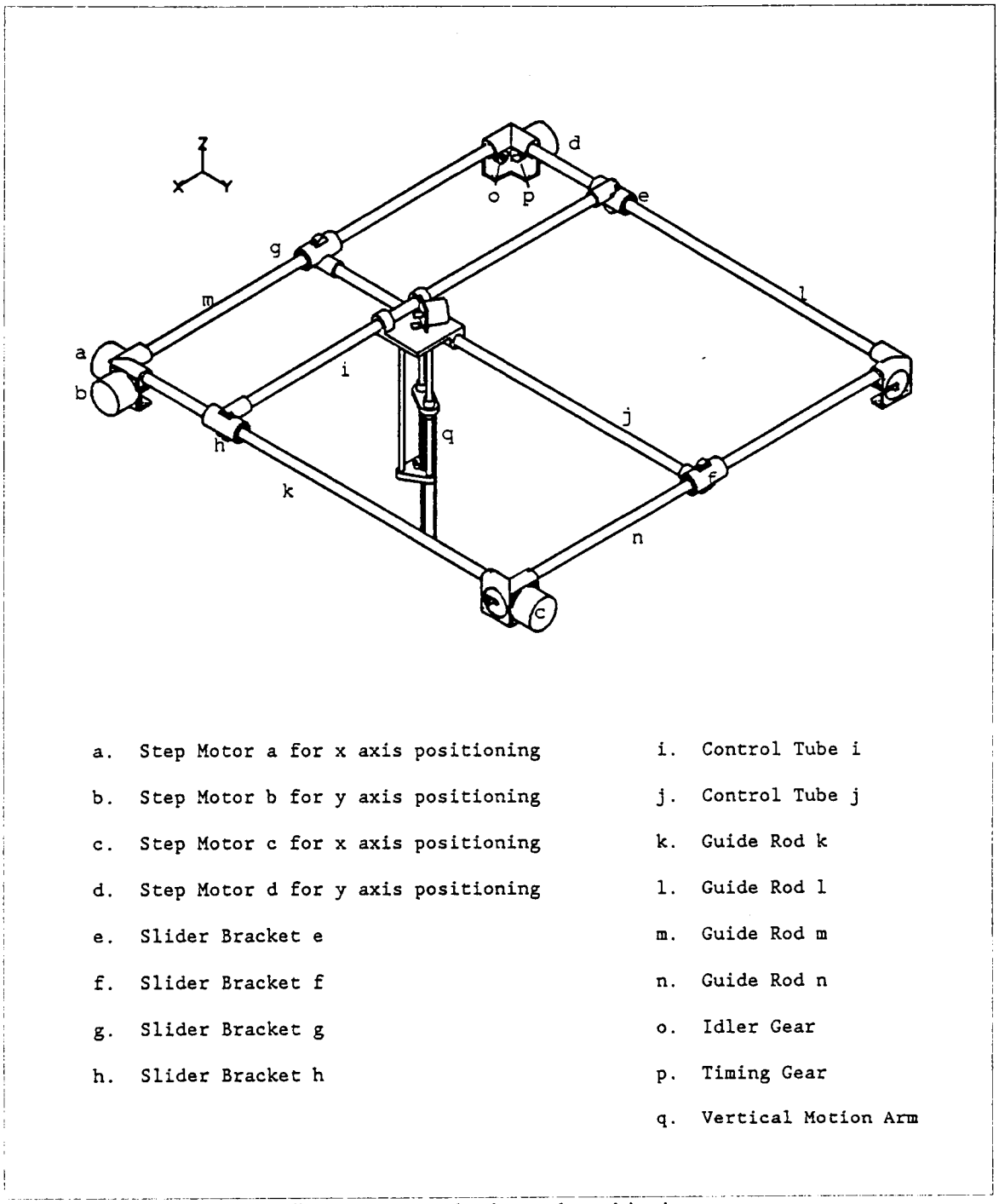
Source: Mark L. Granger, *The Design and Prototyping of The Horizontal Positioning Mechanism Used In A Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, June 1988, p. 2.

the goals for a simple, modular design using an open-loop control system. Stepper motors were selected for the drive system because they are common, inexpensive, open-loop mechanical power devices. A rectilinear workspace using a cartesian-coordinate motion system was selected to simplify (and to reduce the cost of) the robot mechanical design and its control system. Restricting the robot to a limited number of pre-defined moves also served to reduce the complexity of the robot control system.

The other requirements and goals were specified to meet the needs of potential robot users. Six degrees of motion were specified to provide the needed manipulative and orientation capability to perform many industrial tasks. The speed, settling, positional accuracy, and error detection requirements were selected to give the robot sufficient capability to meet difficulty robot application requirements without creating specifications that would lead to a high-cost design.

The First Prototype Horizontal Positioning System

Mark L. Granger designed the first horizontal positioning system for the UT Robot as a master's thesis at the University of Tennessee [Granger, 1988]. His design is shown in Figure 2.3. It features a belt-drive, stepper-motor drive system mounted on four corner supports. The "PLUS" configuration, so named for the way the control shafts in the center of the robot cross each other in a "+" shaped pattern, provides horizontal position control for the robot's end effector and payload.



a. Step Motor a for x axis positioning
b. Step Motor b for y axis positioning
c. Step Motor c for x axis positioning
d. Step Motor d for y axis positioning
e. Slider Bracket e
f. Slider Bracket f
g. Slider Bracket g
h. Slider Bracket h
i. Control Tube i
j. Control Tube j
k. Guide Rod k
l. Guide Rod l
m. Guide Rod m
n. Guide Rod n
o. Idler Gear
p. Timing Gear
q. Vertical Motion Arm

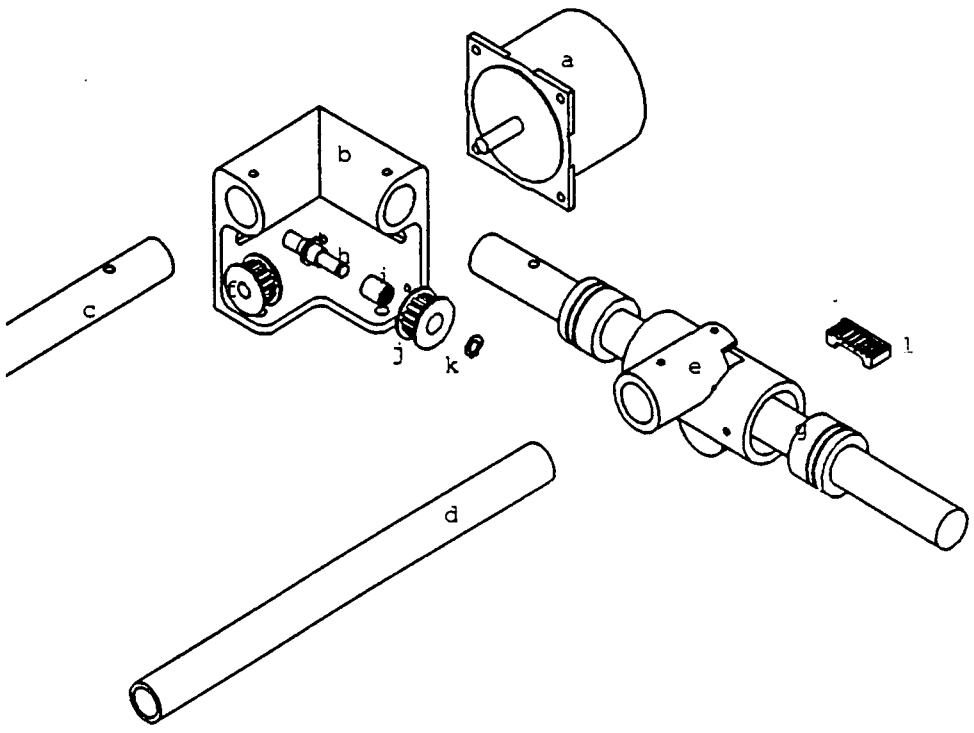
Figure 2.3: View of the first prototype horizontal positioning system.

Source: Mark L. Granger, *The Design and Prototyping of The Horizontal Positioning Mechanism Used In A Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, June 1988, p. 6.

The outside guide rods (Figure items k, l, m, n) are supported by four corner supports and guide the robot's translating parts along two perpendicular horizontal axes. The sliders (Items e, f, g, h) are free to move along these guide shafts. Control shafts (Items i, j) mount to the sliders and extend across the work space. The control shaft centerlines are positioned with a small vertical offset versus each other so that the shafts can cross each other without interfering.

In Granger's figure (Figure 2.3), the vertical motion arm (Item q) located near the "cross over" of the control shafts represents the vertical motion hardware and payload. The control shafts for both axes pass through the arm's support structure, which contains bushings so that the block can slide along both shafts. The vertical arm's horizontal location is controlled by positioning the control shafts so that the shafts "cross-over" at the desired location. In building his prototype, Granger used a solid cube to represent the Z platform and its associated hardware.

Figure 2.4 shows an exploded view of a portion of the first horizontal drive system. The control shaft's position is regulated by moving the sliders along the outside guide shafts. Sliding bushings (Figure item g) are mounted inside the sliders to facilitate the slider's motion along the guide shafts. A timing belt (not shown) attached to the underside of each slider pulls the slider along the guide shaft. The belt extends around a timing belt pulley (Item f) that is attached directly to the stepper motor shaft (Item a). The motor, is held in the proper location by the corner support. An idler pulley (Item j) is mounted



a. Step Motor
b. Corner Bracket
c. Stationary Guide Rod
d. Control Tube
e. Slider Bracket
f. Motor Gear
g. Linear Motion Bearing
h. Idler Shaft
i. Roller Bearing
j. Idler Timing Gear
k. Snap Ring
l. Belt Aligner

Figure 2.4: Partial exploded view of the first prototype's horizontal drive system.

Source: Mark L. Granger, *The Design and Prototyping of The Horizontal Positioning Mechanism Used In A Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, June 1988, p. 9.

to the corner opposite the stepper motor to hold the timing belt in place. A slot in the corner bracket enables the idler pulley to be adjusted so that the proper timing belt tension can be attained.

The First Complete Prototype Design

Lawrence M. Garrett designed and constructed a system to provide vertical ("Z") translation and rotational motion ("theta") about the vertical axis. The other two rotational motions were eliminated from the robot's product specifications [Garrett, 1989]. An overall view of the first completed prototype robot is shown in Figure 2.5. While the primary focus of Garrett's design effort was the creation and implementation of the first "Z" and "theta" systems, he also made some significant modifications to the horizontal positioning system.

Horizontal system modifications. To solve several operational problems and to improve high-volume manufacturability, Garrett made several important changes to the initial horizontal system prototype. The sliders were redesigned for easier injection molding and are made from plastic. Also, Garrett replaced the friction bushings in the slider and in the Z platform with linear ball bearings. The drive belt attachment to the sliders was altered, as was the offset spacing of the control tubes. The technical basis for these changes are discussed in more detail in subsequent sections.

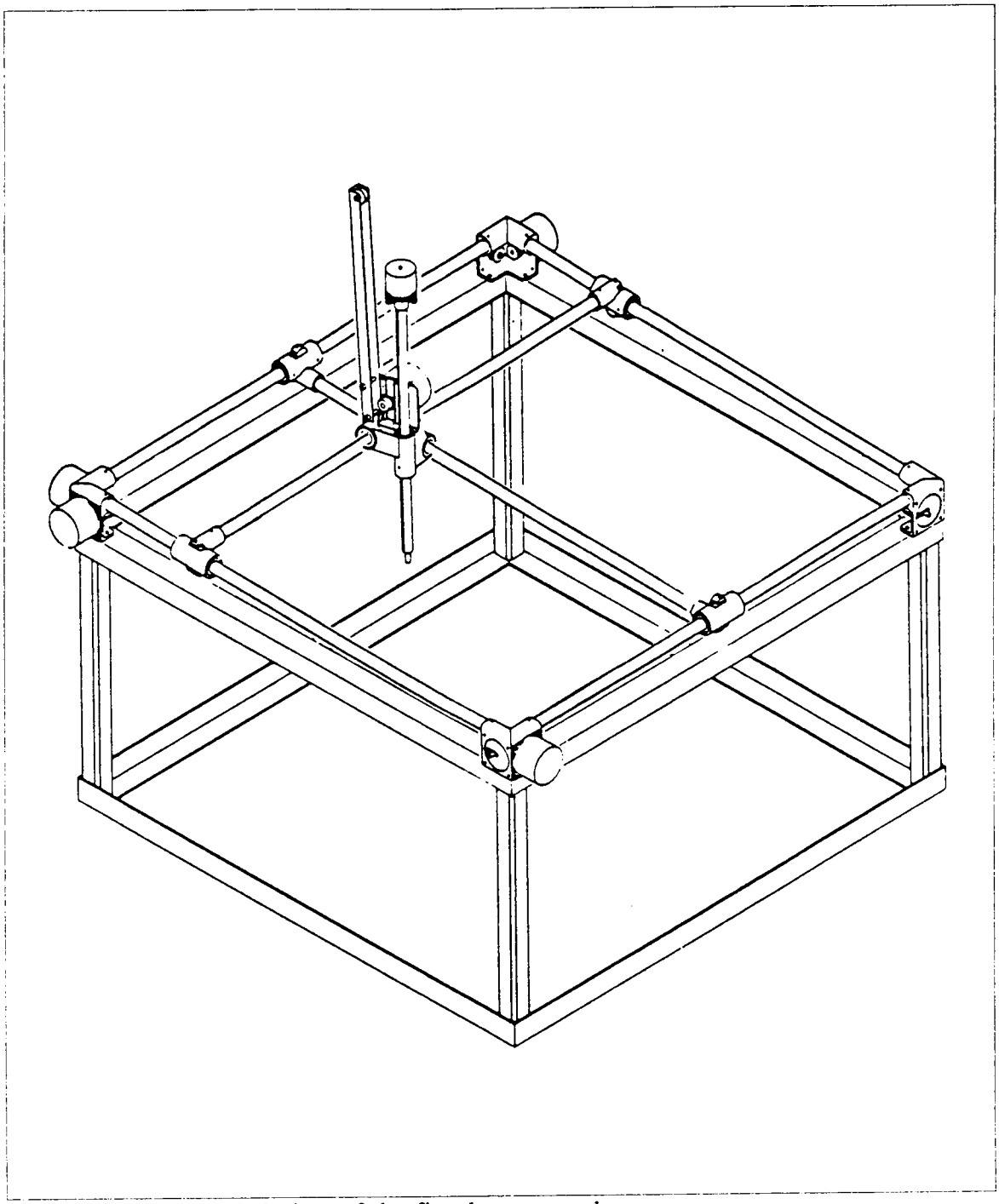


Figure 2.5: Assembled view of the first low-cost robot.

Source: Lawrence Mancil Garrett, *The Design and Prototyping Of A Four Degree Of Freedom, Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, May 1989, p. 7.

Vertical and Rotational Systems. A close-up view of the first vertical and rotational positioning systems is shown in Figure 2.6. The Z platform (Item 7) is installed on the horizontal system control tubes so that the platform can be moved to any horizontal position in the work space. Linear ball bearings are used in the Z platform so that the Z platform can move easily along the control shafts. The Z platform supports an aluminum mast (Item 9), a stepper motor (Item 5), and also has a vertical hole in which two additional linear ball bearings are placed. The stepper motor has a drive pulley (Item 8) attached to its output shaft.

A continuous timing belt (not shown) is wrapped around the idler pulley and the drive pulley (Item 8). The mast holds the idler pulley in proper position so that the belt can be attached to the tube mount (Item 3). The tube mount holds a smaller stepper motor (Item 2), which is used for the rotational system. The tube mount also connects to the vertical guide tube (Item 4), which supports the drive spindle (Item 6).

The end effector for the robot (which depends on the particular application) is connected to the drive spindle. To move the end effector vertically, the large stepper motor (Item 5) rotates the drive pulley (Item 8) and causes the drive belt to move. Since the tube mount is attached to the belt, moving the belt causes the tube mount (Item 3) to move. The tube mount, in turn, moves the vertical guide tube (Item 4), which moves the drive spindle (Item 6). The linear bearings in the Z platform (Item 7) constrain the guide tube so that the tube can move only in the vertical direction.

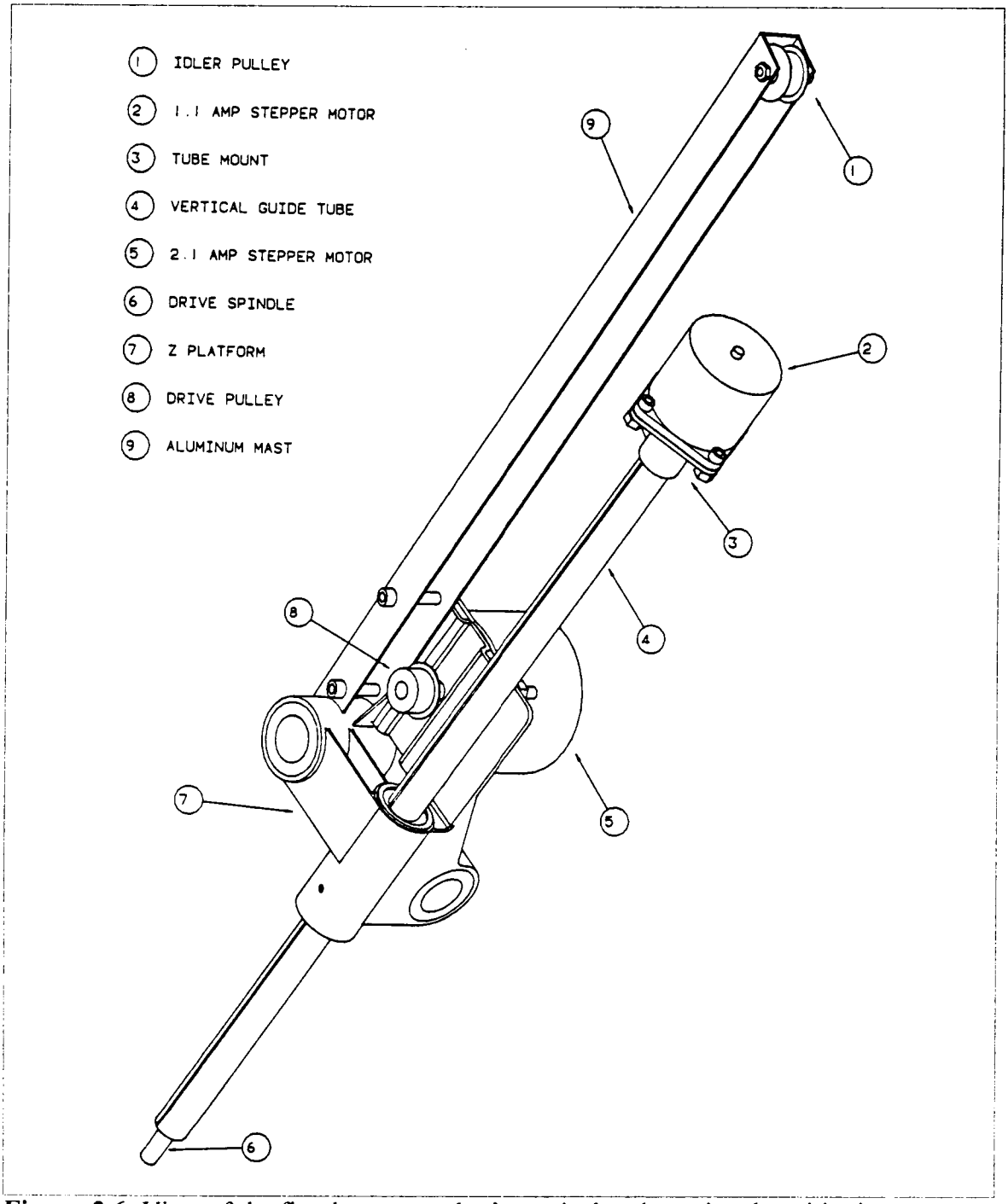


Figure 2.6: View of the first low-cost robot's vertical and rotational positioning systems.

Source: Lawrence Mancil Garrett, *The Design and Prototyping Of A Four Degree Of Freedom, Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, May 1989, p. 6.

The rotational system hardware is contained mostly within Z system drive tube, as shown in Figure 2.7. The purpose of this hardware is to transmit the rotation of the theta stepper motor (Item 1) to the drive spindle (Item 8) which extends from the bottom of the vertical guide tube (Item 7).

When the theta motor turns, the rigid coupling (Item 2) also turns, which causes the drive tube (Item 3) to rotate. A drive plug (Item 4) is mounted to the end of the drive tube, and, when the theta system is assembled, the groove in the plug engages the tongue on the spindle (Item 8). Thus, when the drive tube rotates, the drive plug and spindle rotate also. A bearing cartridge assembly (Items 9, 10) holds the assembly in the z guide tube and permits the spindle to rotate. For the theta rotation to work properly, the Z guide tube (Item 3) must not be allowed to rotate. A row of balls in the Z platform linear bearings engage a groove in the Z guide tube to keep the tube from rotating.

First Prototype Robot Control System

While Granger designed the first horizontal positioning system, Siak Yeo of the University of Tennessee Electrical and Computer Engineering Department designed an electronic controller for the robot as an M.S. thesis in Electrical Engineering [Yeo, 1988]. The basic scheme of his control system is shown in Figure 2.8.

As shown in Figure 2.8, an IBM PC-AT personal computer is the control system's "main controller". The robot's operator uses the PC-AT to construct data sets that describe the

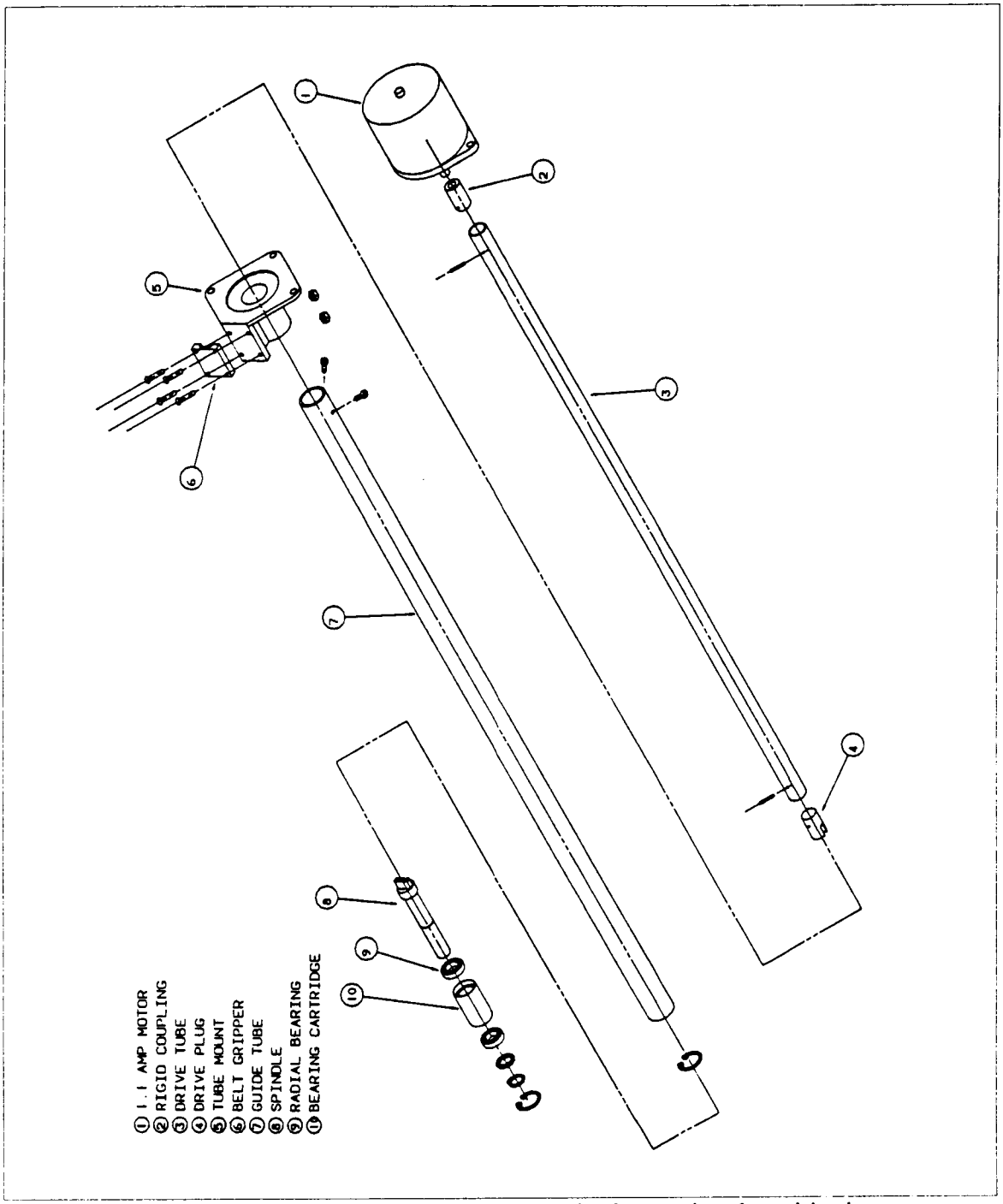


Figure 2.7: Exploded view of the first low-cost robot's rotational positioning system.

Source: Lawrence Mancil Garrett, *The Design and Prototyping Of A Four Degree Of Freedom, Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, May 1989, p. 15.

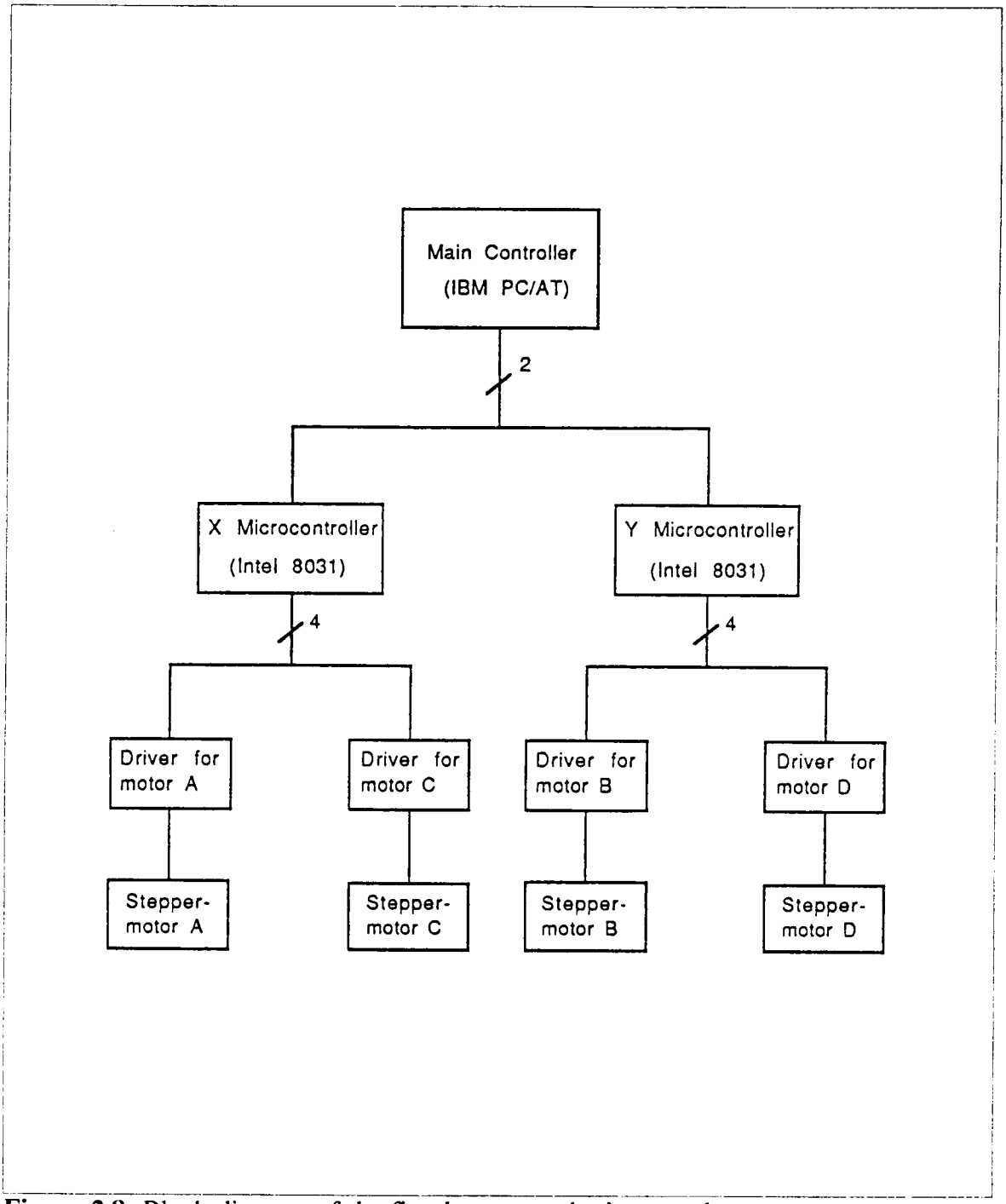


Figure 2.8: Block diagram of the first low-cost robot's control system.

Source: Siak Thong Yeo, *The Use of Embedded Microcontrollers in the Design of a Low-Cost Industrial Robot*, M.S. Thesis in Electrical Engineering, The University of Tennessee, Knoxville, TN, June 1988, p. 5.

desired motion for the robot. These path instruction sets then are sent via the PC-AT's serial port to the microcontrollers for execution.

The Intel 8031 microcontrollers actually control the motion of the robot's X and Y axes. One microcontroller is used to control each axis. The Intel 8031's receive the path instructions from the PC-AT, interpret them, and then issue step and direction commands to the stepper motor drivers. The stepper motor drivers accept the signals from the controller and provide the appropriate current to the motor windings. For the prototype device, modified IBM Proprinter circuit boards (which have stepper motor driver circuitry) were used as the motor drivers.

To use the robot, the operator has to describe the desired path terms of the coordinate points of the robot system. A point at one corner of the robot's work area is defined as "home" and is assigned the coordinates (0,0). All other positions are expressed in relation to this "home" coordinate. If it is desired to put the robot arm at a position 6 inches away from the "home" position in the X direction and 3 inches away in the Y direction, then the desired coordinate is (6,3). The operator defines all the points for the desired robot motion in this way.

Once the robot points are defined, the operator executes a BASIC program created by Yeo to enter the robot position data in a format acceptable to the microcontroller. The desired robot velocity between the points is also entered. The program has several

built-in check features to assure that the position and velocity data is valid. Once all the points are entered, the data are saved in a file. By running another BASIC program, the operator then sends the data file to the microcontrollers for execution.

Evaluation of the First Complete Robot Prototype

The first complete prototype robot successfully demonstrated the inexpensive robot concept, but also displayed several design weaknesses. Both Granger and Garrett both made important recommendations for improving the initial robot system. Additional needs have been discovered from meeting with potential customers, from prototype testing, and from a formal reliability assessment. A review of some of these robot design problems, customer needs, and desired improvements is useful before presenting the new robot design and is presented below. The reliability assessment is comprehensive, so it is discussed separately in the next chapter.

Evaluation of the First Horizontal Positioning System

Merits. The simple design of the first horizontal positioning system, shown previously in Figure 2.3, provides several excellent design, manufacturing, and marketing advantages. For example, the robot's horizontal work area can be lengthened or shortened easily by extending or shortening the shafts and drive belts. This feature allows the robot to be sized specifically for each customer's needs, and/or enables the manufacture of an entire robot family using the same base hardware. The robot's simple rectangular coordinate

system makes it simple to size the robot and also makes it easier for customers to learn how to program the robot's path [Granger, 1988].

Commercially-available components, such as stepper motors and friction bushings, are used whenever possible in the design to minimize the total design and manufacturing effort. Timing belts and pulleys were used in the robot's drive system because they were commercially available from commercial stock and because they were much less costly than other drive methods such as ball screws.

Part symmetry was used effectively to minimize the number of different parts needed for the assembly. For example, the same corner support design is used on all four corners, and the same drive components (timing pulleys, etc.) are used for both "X" and "Y" axes. The slider was designed for either "right-side-up" or "upside-down" orientation so that the same part can be used on all four guide shafts.

Problems. The first horizontal system design experienced several serious problems, many of which were found by testing the prototype. Granger described in his thesis several important problems that he encountered, and made significant recommendations for improving the system. Some of the problems included [Granger, 1988]:

- Friction binding of slider bushings on the robot's guide shafts;
- Lack of straightness on the guide shafts;
- Difficulty in attaining proper timing belt tension;

- Difficulty in maintaining proper shaft alignments;
- Set screw loosening on timing belt drive pulleys

To correct these problems, Granger made six (6) general improvement recommendations [Granger, 1988]:

- Use low friction bearings;
- Determine parallelism, straightness, and stiffness specifications (for the guide and control shafts);
- Eliminate set screws in timing gears (pulleys);
- Install rubber boots on ends of guide rods and control tubes;
- Use quality roller bearings in the idler (pulley assembly).

Perhaps the most serious problem of those noted is the slider's friction binding on the outside guide shafts. The first horizontal system design used sliding bronze bushings so that the sliders could move along the guide support shafts. Testing quickly revealed that even small deviations in shaft straightness or any shaft misalignment would cause the bushings to bind up against the shafts, and would stop the system. Additionally, the shafts and bushings had to be lubricated frequently to slide properly even on straight shafts with no shaft misalignment [Granger, 1988]. The arrangement was clearly unacceptable.

As noted earlier, Garrett revised the slider to accept linear ball bearings, and the new sliders were installed on the prototype machine. The slider was also modified to facilitate plastic injection molding. The new bearings greatly reduce slider-guide shaft friction, and have proved to be very satisfactory. Unfortunately, the linear ball bearings are also much more expensive than the bronze bushings.

Garrett also changed the original method for tightening the horizontal drive system's timing belts. In the original design, a slot was provided in the corner support so that the idler pulley position could be adjusted to tighten the timing belt, but it was difficult to get the idler pulley into the proper position, and the idler pulley assembly tended to slip out of position as it was tightened in the slot. To correct this problem, the modified prototype fixes the location of the idler pulleys, then sets the belt tension by using an adjustable turnbuckle that is attached to each end of the belt. The turnbuckle has to be positioned at the correct location in the belt line so that it does not over either the idler or drive pulleys.

Evaluation of the First Vertical and Rotational Positioning Systems

Merits. The first complete robot prototype is most impressive to view. A prominent feature of the design is how the robot's parts were designed to facilitate high-volume plastic injection molding processes. To model the look of these parts on the prototype, Garrett had the parts machined from polyvinyl chloride (PVC) plastic. Part features were cut from a PVC block, then epoxied together to create the modeled part. After painting

the parts, the effort resulted in a practical and very aesthetic model of his injection molded parts. The part designs have been highly optimized so that the injection molds could be created at the least possible cost.

The overall design is very compact, as the Z system components are located in close proximity to each other and most of the theta system parts are hidden within the Z guide tube. It is clear that Garrett performed a significant amount of development work to assure that all of the parts to be assembled can be mounted without interferences. As with the horizontal system design, the vertical and rotational systems use commercially available parts wherever possible to minimize the number of custom manufactured parts.

Problems. Garrett noted several design problems that he encountered during the construction and testing of the first complete prototype. Some of these problems included [Garrett, 1989]:

- Difficulty in assembling the robot system;
- Damage to the robot from a programming error;
- Need for a hardened surface on the Z guide shaft; and
- Need for hard endstops at the ends of the vertical motion.

The two largest problems in assembling the robot occurred with the theta system components inside the guide tube and with the final system assembly. The theta system assembly problem arises from having to insert multiple components deep within the

vertical "Z" guide tube (Figure 2.7). The internal snap rings used to support the bearing cartridge hardware are particularly difficult to install. Insertion of the theta shaft tongue into the drive spindle groove also is very difficult, since the theta tube cannot be controlled easily as it is inserted into the "Z" tube.

The system assembly problem derived from the nature of the "Plus" horizontal control scheme. For the horizontal positioning system to function properly, the Z platform must be "captured" by the two control tubes that extend over the work area. However, the control tubes also must be mounted into the sliders and the corner supports must engage the guide tubes. Unfortunately, all of these tube-hole engagements must be made at the same time during assembly, so assembling the system is not simple. While it is somewhat difficult to assemble the horizontal system using the cube as a proxy for the Z platform, the assembly problem is greatly compounded when the actual Z platform assembly is used. Several people are needed to hold the Z platform and the tubes so that the assembly can be completed.

The robot's control system contributed to several significant problems. On one particular occasion, an incorrect command to the robot caused the robot's sliders to strike the corner supports at full speed. The resulting impact fractured the plastic Z platform and delayed testing of the robot.

The positional control problem also demonstrated the hazards of not having mechanical endstops at the upper end of the vertical stroke. In the up direction, the Z system runs out of belt travel before the Z guide tube hits a mechanical stop. If commanded to move higher than the idler pulley at the top of the mast, the Z drive system attempts to pull the tube mount around the pulley, even though the tube mount is contrained to move only in the vertical direction. The result is an event that stretches the timing belt, and can damage belt and/or the idler pulley. On the down stroke, the tube mount makes contact only with a small part of the Z platform.

Proper timing belt tensioning also has been somewhat elusive with the modified system. It was noted earlier that adjustable turnbuckles were installed on the horizontal drive system timing belts to make it easier to adjust the belt tension. While the turnbuckles do improve the ease of tightening, they also have a recurring tendency to loosen during operation.

Evaluation of the First Robot Control System

Merits. A prime task of the first design was to provide "stand-alone" robot operation. The personal computer is used to generate the robot path, but is not needed to run the robot once the path file has been created. Thus, once the robot path data is sent to the microcontrollers, the personal computer is free to perform other tasks. The control program also computed the proper stepper motor acceleration and deceleration ramps, so

that the robot operator need not be concerned with the technical aspects of operating the stepper motor drive system.

Drawbacks. The initial control scheme appears to be inadequate for enabling successful robot use in general industrial applications. To be fair, the design goals for the first controller were confined to a specific "stand-alone" operation and thus was restricted to a limited number of pre-defined moves. While it is not needed to operate the robot once it was programmed, a personal computer is still required to download new motion instructions whenever the robot's path was to be changed.

The downloading operation proved to be inconvenient, and the finite point-to-point capability limits the robot's usefulness for certain applications. Actual robot path programming is difficult, as paths have to be programmed in a data code structure and downloaded to the robot controller. Thus, a trial and error procedure is necessary to verify each new path.

The first control system prototype provided only the two axes of control needed to operate the X and Y axes, and did not, as constructed, have the capability to drive the vertical Z and Theta rotational systems. To add the additional axes, more Intel 8031 microcontrollers are required, since one is used for each axis.

To his credit, Yeo managed to develop a workable, if rudimentary, control system without having an Intel macro assembler system for verifying the microcontroller programming. Without this system, Yeo had to use a trial and error approach to program verification without being able to step through his program, inquire about the processor's status, etc. The lack of such a diagnostic system is a serious handicap, and Yeo himself expressed serious reservations about anyone proceeding further without acquiring an assembler system.

As noted earlier, the drive motors were powered by IBM ProPrinter motor drivers. While they proved to be adequate laboratory devices, it is clear that the "doctored" boards are far from a production-level driver package that would be acceptable to customers.

Additional Discoveries

Subsequent to the initial work, several other problems have been observed with the modified UT Robot prototype. A few of these are discussed below.

Guide and control shaft oxidation. The guide and control shafts on the modified prototype became significantly oxidized after condensate from an air handling unit located above the prototype dropped onto the shafts. Other "routine" contaminants such as dust or airborne dirt also tend to adhere to the shafts. These contaminants are a potentially serious hazard to the linear ball bearings that move along these shafts.

Pulley-shaft set screw loosening. On the modified prototype, the timing belt pulleys used to drive the positioning systems are secured to the motor shafts by means of two cup-point set screws. On several occasions, these set screws have loosened so much that the pulleys have slipped versus the motor shaft and caused positioning errors. If this error were to occur undetected in a customer environment, the other positioning systems could could continue their motion, causing damage to the end effector, fixturing, or personnel near the work space.

Insufficent theta system holding torque. In one test application, a problem occurred while moving a load that was offset from the center of the Z guide tube. When the Z platform is accelerated in the horizontal direction, the rotational system has to restrain the any torque developed by the acceleration of the offset load at the effective offset distance ("moment arm" distance). Considering the potential loads and offsets that might occur in industrial applications, the theta system restraining (or "holding") torque was found to be inadequate.

Calibration problems. On several occasions, the modified robot has had difficulty in repeating paths after the robot system has been turned off and restarted. This problem was characterized by how the robot would follow the prescribed path correctly, but that the robot's positions would have some small offset versus the specified points. Even though this phenomenon occurred only sporadically, it was traced to variances in the initial "power-up" detent of the drive system's stepper motors. Robot design team

member Anthony Williams has solved this problem, and his solution likely will be described in his upcoming master's thesis.

CHAPTER 3

ROBOT RELIABILITY ASSESSMENT

A formal reliability assessment of the UT Robot was performed by David A. Walker during his development of a "Reliability in Design" tool. His assessment, fully detailed in Walker (1990) and Walker, Kennedy, and Wilson (1991), was conducted after the completion of the first robot prototype, but during the early phases of the UT Robot prototype design effort and of the PC-based control software development work. A review of the assessment approach, goals, and results is presented below, and is drawn extensively from Walker, Kennedy, and Wilson (1991).

Reliability Analysis Goals

Reliability is increasingly recognized as a key to creating and maintaining quality products and processes, in providing public and operator safety, and to promote a firm's competitiveness in world markets. Unfortunately, reliability analyses traditionally have been limited in improving products and processes because the analyses are usually performed after the design is completed. Since changes made during design are more effective and are less costly than those made later, a concerted effort was made to perform a reliability assessment early in the design of the new prototype robot.

The goal of the UT Robot design effort, of course, is to develop a system with "adequate" reliability. In this context, "adequate" does not reflect mediocrity, but rather entails meeting a set of defined goals that are established from product specifications, company and industrial standards, competitive benchmarking, and/or governmental regulations. The reliability effort is focused on encouraging inquiries into potential system failures and corrective design, manufacturing, and operation actions, not on generating complex statistical evaluations.

The reliability of the robot design in two extreme applications was assessed and compared. Potential design and manufacturing improvement opportunities were identified, and these opportunities were evaluated and ranked according to their potential for improving the reliability of the robot. The focus of the effort was to gain the maximum feasible reliability improvement in the robot system, and not just to estimate some numerical failure rate.

Reliability Assessment Procedure

Approach

The reliability of a product or process must be incorporated into a system during its design, and then maintained through manufacturing, installation, and use. The design determines the maximum inherent reliability of the product; this maximum reliability may then be reduced by manufacturing and field degradation factors (Figure 3.1). Thus, the

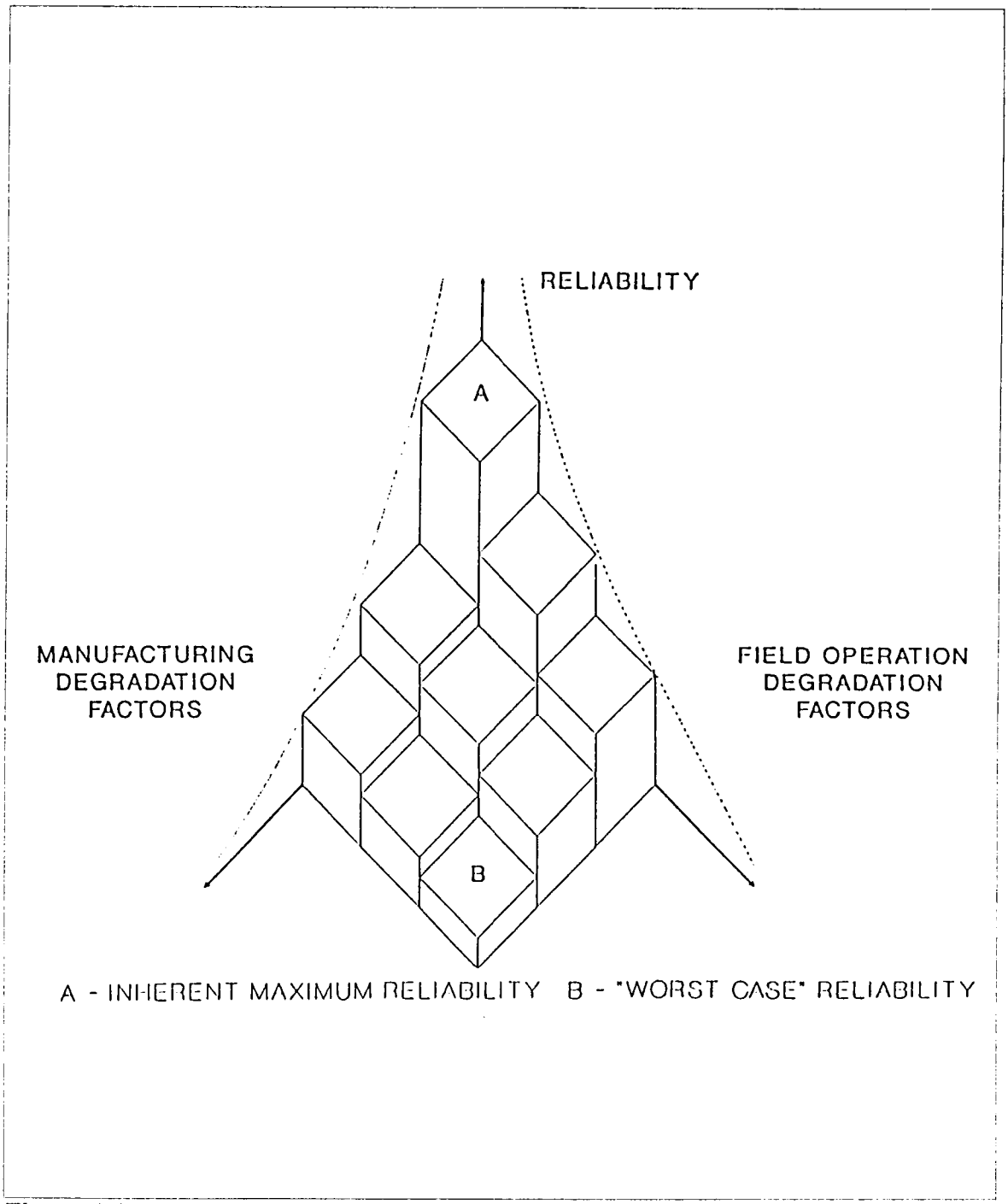


Figure 3.1: Reliability versus degradation factors.

Source: David A. Walker, *Creating Reliability in the Design Process: An Evaluation Approach, Design Tool, and Example Application*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, August 1990, p. 20.

reliability that is achieved during actual customer use can be (and usually is) less than the design's maximum inherent reliability. This view of reliability, then, leads to two fundamental approaches to improve reliability: one can work to increase the inherent maximum reliability of the system, and/or reduce its degradation factors so that the system operates at its maximum inherent reliability.

System failures result in both economic and safety consequences. These "costs of failure" can be categorized into equipment damage costs, repair costs, and business interruption costs. Equipment damage costs are incurred to replace equipment damaged by a system failure, while repair costs are associated with repairing the failure (such as repair technician labor). Business interruption costs refer to the costs incurred due to loss of production or system function. Beyond economic consequences, system failures also can injure or kill users, operators, and the public.

Historically, the reliability of many engineered systems has been shown to follow a "generalized Pareto principle"; that is, most of a system's reliability characteristics are controlled largely by a relatively small number of potential failure modes [Ireson and Coombs, 1988]. If the "important few" potential failure modes can be identified, then changes can be made to most greatly reduce the occurrence and consequence of robot failures. This "important-ones-first" approach makes the most efficient use of time and economic resources.

The "Reliability in Design" Tool

The ability to improve reliability during design has been hindered by the lack of an easy-to-use "reliability during design" approach. To meet this need, Walker (1990) developed a design tool to help designers evaluate and improve reliability during the design phase. This tool was used to perform a reliability assessment of the UT Robot.

The Walker "Reliability In Design" tool is based on Failure Modes and Effects Analysis (FMEA). FMEA enables the identification and description of system failure modes and their associated corrective actions by using a structured table. Quantitative evaluation of the failure modes is also possible. The accumulated failure mode analyses can be organized into different tables, charts, and graphs to help with the reliability assessment. This table, chart and graph generation is supported automatically in Walker's software.

Reliability Assessment Results

Test Case Selection

Two "extreme" robot applications were evaluated: a "favorable" application and a "severe" application. The "favorable" application was defined as an intermittent "pick-and-placement" of circuit boards. Loads are small, and the surrounding workspace is clean and dry. The "severe" case was selected to be the controlled path motion of an expensive cutting tool in a harsh production environment. The applications were selected to provide a relative assessment between the robot system's inherent maximum reliability versus the

degradation factor effects; that is, it was desired to "bracket" the robot's performance by assessing its likely "best" and "worst" performances.

Ninety-four (94) potential failure modes were identified during the reliability analysis of the robot system. Overall failure risk for the robot system was computed from the individual failure modes; a results summary is presented in Figure 3.2. Substantial business interruption costs are incurred for robot failures in both applications. In the "severe" application, where expensive equipment could be damaged during a failure, business interruption costs are still much higher than equipment or repair costs. (It is interesting to note that the business interruption costs would not even be considered in many design-cost analyses, although this analysis demonstrated that these costs are very significant.) Including the business interruption costs in the analysis enabled the robot project team to assess design options based on "total" or "customer" costs, rather than merely on manufacturing or material costs. This "customer cost" viewpoint is a critical element in many quality programs.

A very large risk differential was observed between the "severe" and "favorable" robot applications, indicating that the robot's initial design is very sensitive to manufacturing and field operation factors. The difference also suggested that the initial design could be modified to attain a substantial "in use" reliability improvement. While recognizing that the failure frequency and risk values were estimates (and thus should be treated as such), it was apparent that the initial design was not adequate for a "severe" application. The

SUMMARY RESULTS FOR "UT ROBOT" RELIABILITY ANALYSIS		
Number of Potential Failure Modes Evaluated : 94		
	APPLICATION TYPE	
STATISTIC	"Favorable"	"Severe"
Expected Number of Failures[1] per year	8	23
Failure Risk Costs ($ per year):		
- Equipment Damage	1,197	14,154
- Repair	651	4,867
- Business Interruption	1,090	63,636
TOTAL RISK ($ per year)	2,938	82,657
Estimated MTBF[1] (days)	50.5	16.1

[1] MTBF = Mean Time Before Failure. In this analysis, "failure" is defined as any undesired robot motion or action, so that the MTBF is an indication of the mean time to some robot malfunction. The MTBF, as used here, is NOT a measure of the robot hardware's useful life.

Figure 3.2: Reliability assessment results summary chart. Results based on evaluation of early design concept for the UT Robot.

Source: David A. Walker, Michael E. Kennedy, and Clement C. Wilson, "Creating Reliability During The Design Process", *Proceedings of the Design Productivity International Conference (Volume Two)*, Honolulu, HI, February 1991, p. 777.

estimated annual failure risk is over eight (8) times the robot's anticipated purchase price, and an error can be anticipated every sixteen (16) days, on average. It was clear that actual "in use" results anywhere near these estimates was not economically feasible.

Nonetheless, the "favorable" case analysis suggested that the robot could potentially have better reliability if the proper improvements were made. These improvements not only would reduce the degradation factor effects, but also would increase the maximum inherent reliability of the robot. Thus, the next step was to evaluate the most significant failure modes and to determine the necessary design actions to eliminate or reduce those modes.

The failure modes were ranked according to risk to identify the "important few" failure modes that had the largest reliability effects on the robot system. From this ranking, sixteen (16) failure modes were identified as "high-risk". As predicted by the Generalized Pareto Principle, these few "high-risk" failure modes cause most of the failure frequency and risk (Figure 3.3). Failure of the robot's peripheral equipment (such as software, main power source, and operator actions) dominate the list of the highest risk failure modes. The high risk ranking for the peripheral equipment might be anticipated, as peripheral design and use issues often do not receive sufficient consideration during the early design phases.

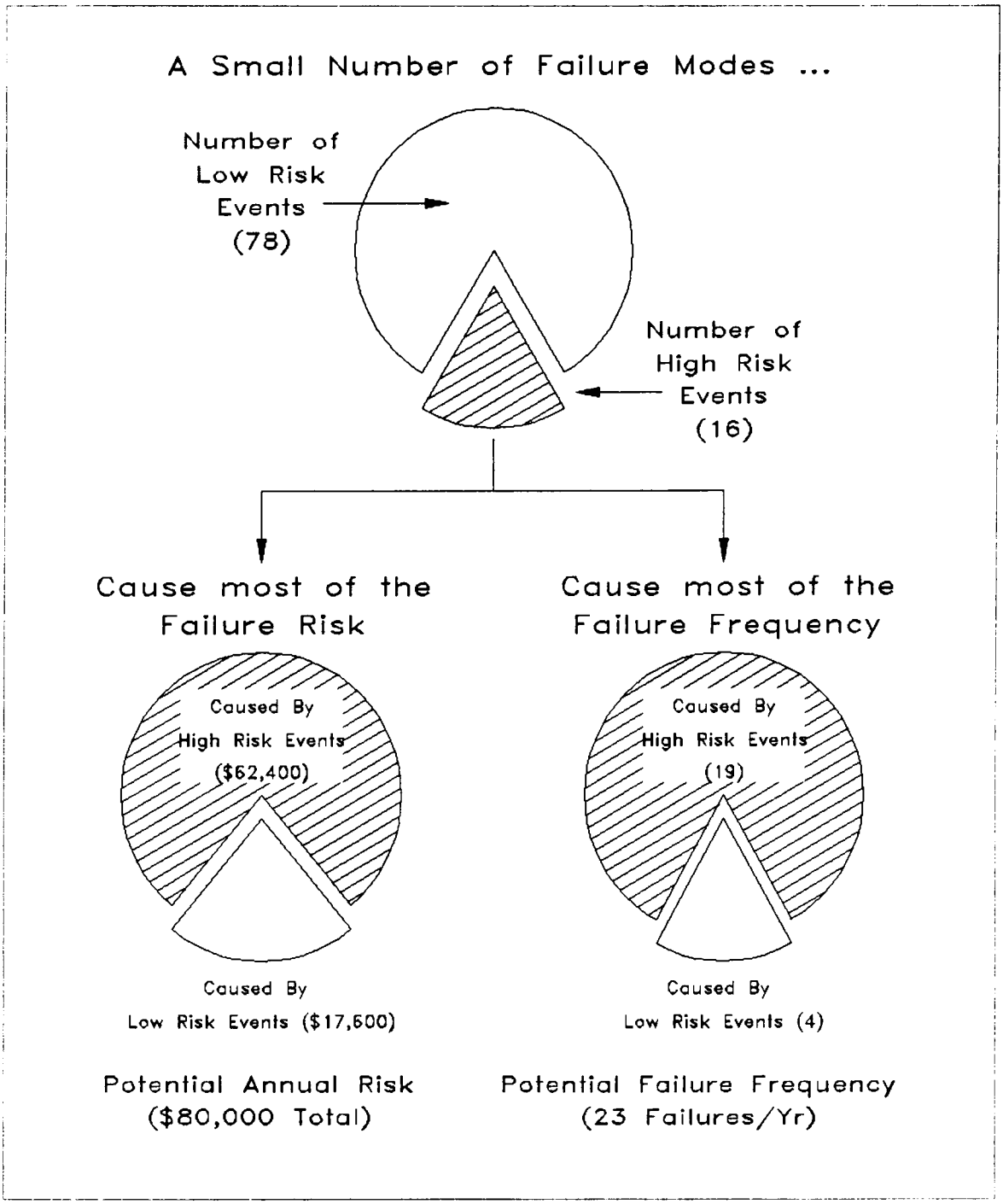


Figure 3.3: Reliability assessment results for the "severe" application. Results illustrate the generalized Pareto principle.

Source: David A. Walker, Michael E. Kennedy, and Clement C. Wilson, "Creating Reliability During The Design Process", *Proceedings of the Design Productivity International Conference (Volume Two)*, Honolulu, HI, February 1991, p. 777.

Many high risk contributors are related to the operator and his/her interface with the robot and the control software. Some of the identified failure modes include failure to begin robot operation from the proper starting position, failing to account for changes in robot loading (such as when lifting objects), or entering an incorrect robot path. Failing to disable the robot system after an error and initiating robot operation at the wrong time (such as with a person in the work space) are also identified as potential reliability hazards. The large contribution of these failure modes to the overall robot's failure rate led the design team to create new software design requirements (Chapter 4).

After the robot's peripheral risks, some horizontal ("X" and "Y" axes) drive components have the next highest failure risk. In particular, the timing belts, shaft-pulley connections, and radial bearings (used on the new design) rank as the highest risk hardware. Although the individual component risks are small, the overall system risk is relatively high because these components are utilized repeatedly throughout the robot design. Recognition of these issues led the design team to consider improvements and protection for the drive systems and to detect failures quickly when they occur.

The results of the reliability analysis appear to be accurate in predicting modes and frequency for system failures. During various demonstrations and experiments with the first prototype robot (over about an eighteen month period), the robot experienced seventeen (17) "failure modes", all of which are identified in the reliability analysis. All

but three of the failure events are classified as "high risk" modes. The failure frequency of the robot system also appears to be within the range that is predicted by the analysis.

Reliability Improvement Recommendations

Based on the reliability analysis, Walker compiled fourteen (14) comprehensive recommendations to improve the robot system's design and operation [Walker, 1990]. Some of the more significant items included:

- Verification of a reliable power supply source;
- Addition of position verification system for all motion axes;
- Addition of a locking mechanism for the vertical "Z" axis to prevent accidental lowering when motor power is interrupted;
- Comprehensive software improvement items, and a software verification test program;
- Protection of drive system components (belts, pulleys, etc.);
- Need for protection of guide and control shafts.

The reliability analysis has been modified to incorporate proposed hardware and software design improvements (including some others not discussed here). Figure 3.4 clearly displays that the robot's reliability can be improved significantly. As will be seen during the discussion of specific robot systems, many of Walker's recommendations were incorporated into the new robot's hardware and software designs to reduce the frequency and severity of potential robot failure mechanisms.

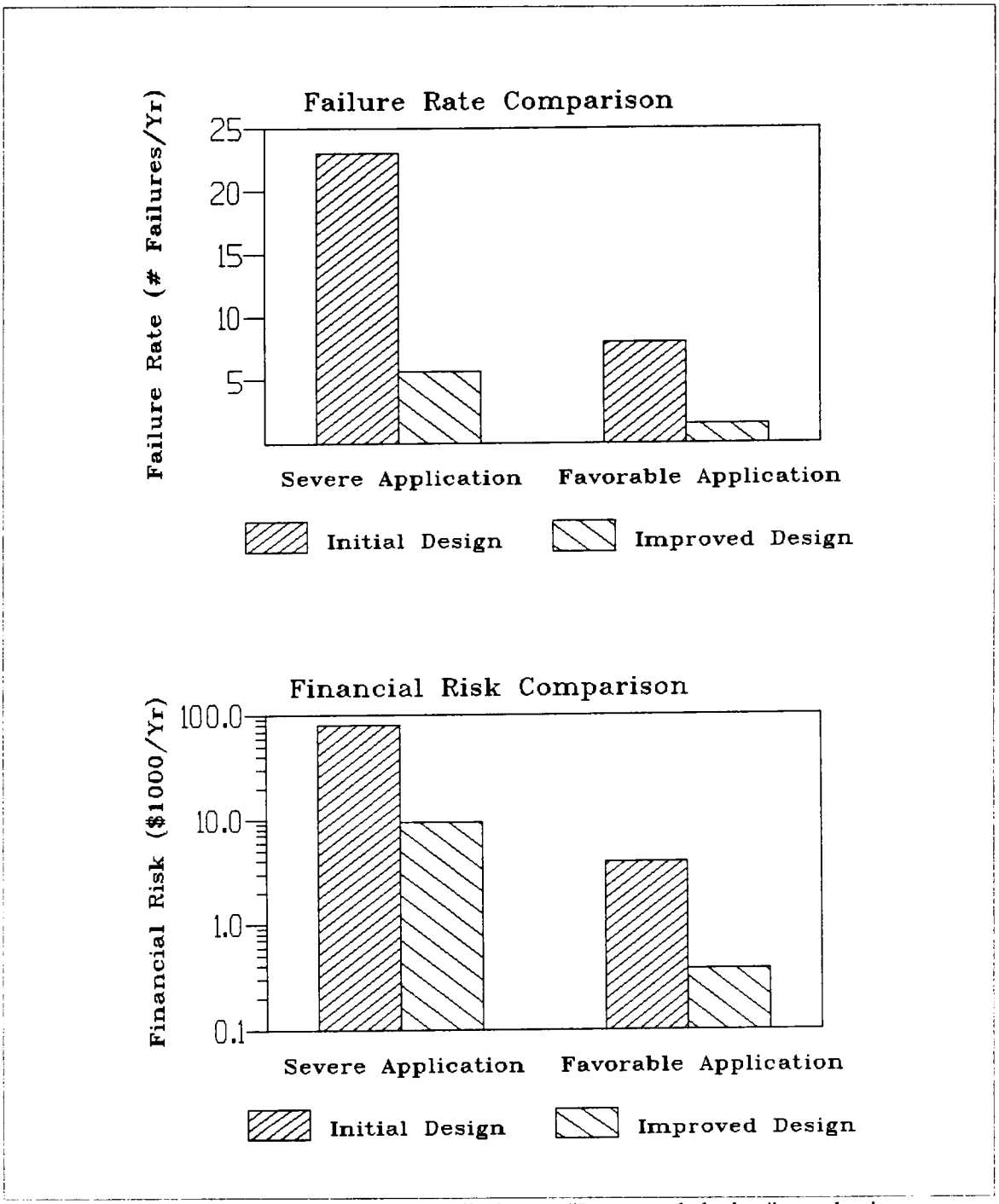


Figure 3.4: Reliability performance predictions. "Improved design" results incorporate recommended reliability improvements.

Source: David A. Walker, Michael E. Kennedy, and Clement C. Wilson, "Creating Reliability During The Design Process", *Proceedings of the Design Productivity International Conference (Volume Two)*, Honolulu, HI, February 1991, p. 778.

CHAPTER 4

"UT" ROBOT SYSTEM OVERVIEW

The "UT" Robot

An overall view of the "UT" Robot design is shown in Figure 4.1. This second-generation robot maintains the same basic configuration as the earlier version, but has additional features, incorporates needed design improvements, and corrects many of the problems that were discovered on the first prototype robot.

The UT Robot has the same basic horizontal (X and Y), vertical (Z), and rotational (Theta) motions as the first prototype robot. The robot, as shown in the figure, rests on a metal support frame. The positioning systems are arranged similarly to the first prototype. As with the first prototype, much of the rotational system hardware resides inside the vertical guide tube, although the parts are arranged quite differently (Chapter 6).

UT Robot Design Goals

The basic design of the first robot prototype was found to be very effective in many areas, so major changes to most robot systems were not necessary. The basic approach to the new UT Robot design can be summarized along five major concepts:

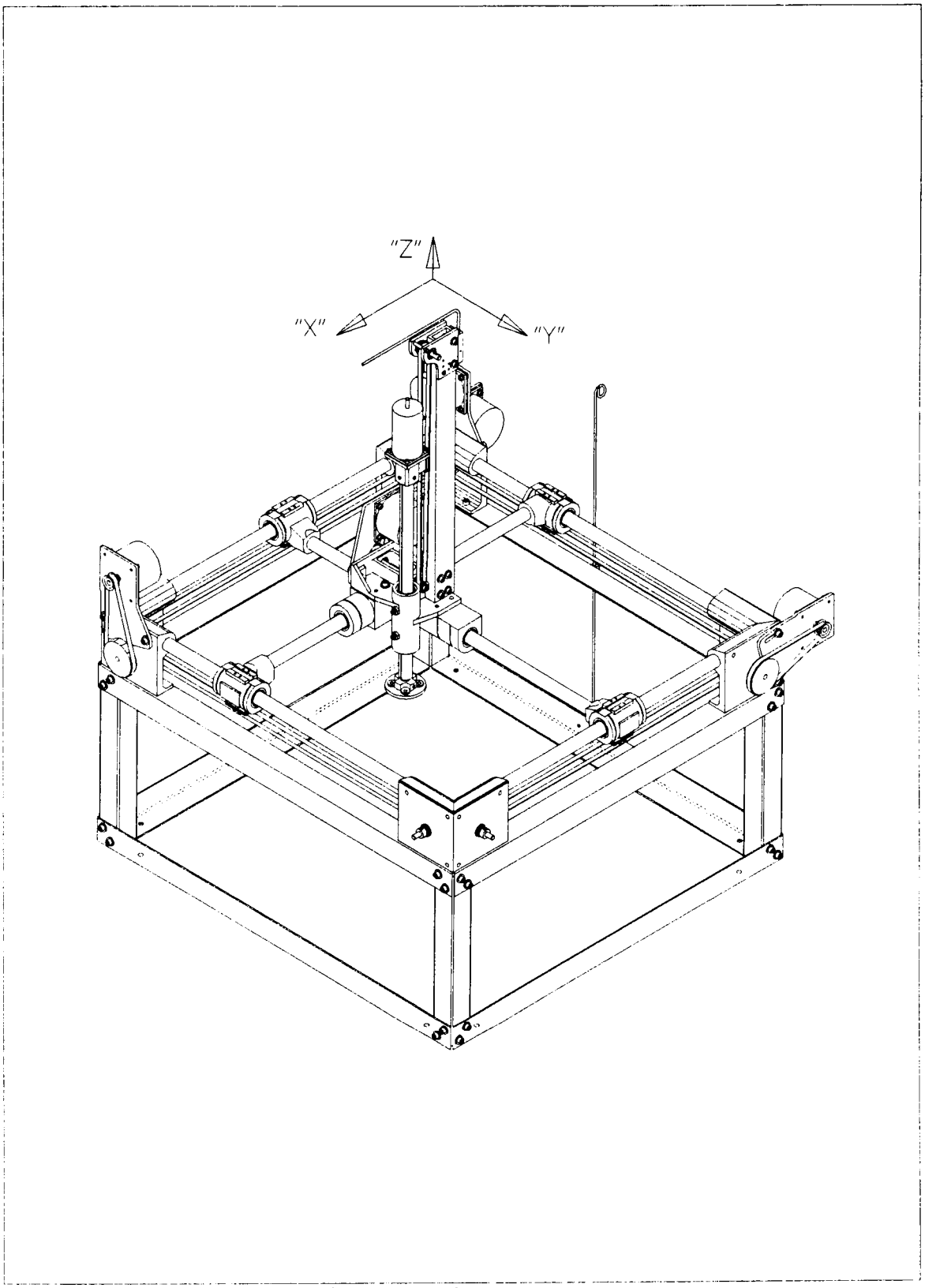


Figure 4.1: Assembled view of the UT Robot.

- Utilize excellent features and concepts used to develop the first prototype robot;
- Provide for enhanced robot configuration customization;
- Design for economical small quantity manufacture;
- Provide better robot control and ease-of-use;
- Improve overall robot system reliability;
- Fix errors found in the first complete robot prototype.

Robot configuration and design decisions that were made throughout the development process were based on these general themes. Overall design goals and general approaches are discussed in the subsequent sections of this chapter; detailed discussion of the new design itself is presented in detail in the following three chapters.

Features Retained from the First Robot Prototype Design

One very important design approach used in developing the UT Robot was to use the excellent features, characteristics, and basic part designs that were used in the first robot system. Some of the major features and design approaches of the first robot system that are used in the UT Robot are discussed below.

Basic Mechanical Configuration

The UT Robot shares the same basic configuration as the first robot system prototype. The robot system's horizontal, vertical, and rotational motions are achieved using the same concepts that were developed on the first system. The "Plus" configuration is used

to provide horizontal motion, the Z system utilizes an overhead mast for support, and the theta rotation is supplied from a motor that is mounted on top of the Z guide tube. Many of the parts on the new system appear very similar to those on the first prototype, even though the part designs have been modified somewhat to meet new requirements.

Basic Drive System Components

The stepper motor drive system used in the first prototype has been retained in the UT Robot, although the electrical and control systems have been changed rather dramatically from that used on the first prototype. The same basic drive components from the first prototype, timing belts and pulleys, are used on the robot to transmit the power from the stepper motors to the robot's moving parts.

Variable Work Area Capability

A strong feature of the first prototype is that the robot's horizontal work area can be changed simply by adjusting the lengths of the shafts and drive belts. Thus, the robot can be made longer or shorter easily to meet individual customer's needs. This feature is a significant product feature, so this capability was maintained in the new design.

Use of Linear Ball Bearings

As discussed previously, the first horizontal system prototype experienced serious problems with frictional binding of the bronze bushings on the guide and control shafts. This problem was solved by replacing the bushings with linear recirculating ball bearings,

and by replacing the original, inexpensive guide shafts with more expensive, precision shafts [Garrett, 1989]. The new shafts, in addition to being straighter than the previously used shafts, also are case hardened to Rockwell 60-65 C to assure adequate shaft and linear ball bearing life. Although these changes add significantly to the robot cost, the resulting product is much more reliable, so linear bearings and hardened shafts are used in the new design.

Use of Standard Parts

A primary design strategy carried over from the first prototype design is to utilize standard, commercially available components whenever possible. Thus, the drive system components (motors, pulleys, radial ball bearings) and some structural members (support shafts, linear bearings) are standard mechanical components that are procured from commercial sources.

Robot System Enhancements

Based on an assessment of potential customers, the design team concluded that additional robot capability and versatility was needed to enable the UT Robot to meet a larger range of customer needs. Some of these system enhancements include:

- The ability to select positioning system step size, force, or speed characteristics;
- The ability to select and mount three different support shaft diameters; and
- The ability to use regular or extra precision bearings.

Selectable Motion Characteristics

To increase the number of potential robot users, it was desired to provide the UT Robot with an increased range of potential payload capacities, speeds, and positioning resolutions. To attain this desired flexibility, a selectable drive reduction system has been added to the translational (X, Y, and Z) systems. The drive systems' stepper motors are no longer connected directly to the drive belts, but instead are connected through reduction pulley drive systems. Up to a 6:1 reduction can be selected by installing the proper pulley and belt combinations. With the variable reduction, the robot's payload capability, positioning resolution, or speed can be customized for each customer application by adjusting the reduction ratio. For example, a cutting tool application may dictate that the robot be capable of manipulating a heavy tool. The reduction ratio can be adjusted higher than usual to enable the robot to move the tool. On the other hand, the reduction ratio may be set lower for a light-weight machine loading application where speed is more important.

Selectable Guide and Control Shaft Diameters

In keeping with the desire to expand the potential application range, the UT robot could reasonably be expected to adapt to widely varying loads over widely varying work spaces. Obviously, a light payload application over a small work space requires less structural support than a heavy payload with long travel spans. To accommodate this diversity, it was desirable to provide the ability to select and use larger or smaller diameter guide and control shafts. Thus, the UT Robot is designed to accommodate the original shaft

diameter of 1.00", or can be modified easily to use a smaller 0.75" or a larger 1.25" shaft. Since the smaller linear bearings and shafts cost less, the robot's cost can be reduced for the smaller diameter shaft configuration. The robot might be configured with the more expensive larger diameter shaft for a long travel or heavy lifting application.

Regular or Extra-Precision Configuration

The design of parts containing linear bearings has been adjusted to enable either "regular" or extra precision linear bearings to be used. The extra precision bearings, which would be used along with extra precision guide and control shafts, might be needed in applications that required extra accuracy or more robot rigidity. Since the extra precision bearings and shafting are significantly more expensive than the regular ones, the extra precision configuration would be sold at a premium versus the "regular" version.

Design for Manufacturing Considerations

Design for Low-Volume Production

The product goals for the first robot design called for an ultra low-cost, mass-produced machine. Thus, the first robot prototype was designed for economical high-volume production techniques. For example, it was noted earlier that the prototype was custom designed for plastic injection-molding. Since injection-molding entails very high initial tooling costs, this production method is economical only for high-volume production runs. Marketing risk can be high, since high-volume production implies that there are a large

number of customers interested in purchasing the product. If the product cannot be sold in sufficient quantities, significant financial losses are incurred. In addition to the marketing and financial risk, technical risk is high since any design change to the robot requires expensive changes to the plastic molds.

Given the available resources and adversity to risk, a high-production approach was not feasible. To reduce the financial resources required and the risks involved, production estimates were scaled back from the original estimate of 200,000 units [Granger, 1988] to a small production quantity of about 10 to 50 units. Clearly, the production estimate change dictates an entirely different design and manufacturing strategy. High-volume processes, like plastic injection molding, are no longer feasible, since development and tooling costs must be amortized over a small number of units.

Design For Specific Manufacturing Processes

While a primary design goal of the UT Robot project is to use standard parts whenever possible, some unique structural parts are needed to complete the design. These custom robot components have been designed to be made from commonly-used stock materials whenever possible, or, when necessary, from locally-manufactured custom castings. Sand casting was used extensively for many of the structural components because parts can be produced economically in small quantities. All robot parts and castings are designed so that they can be machined successfully either in the Mechanical Engineering machine shop or in the University of Tennessee's Flexible Manufacturing Center [Speckhart and

Wilson, 1991]. Except for the sand casting, parts features or characteristics that would require manufacturing capability not available at the University have been avoided. Thus, the available machining capabilities have been considered in all part designs.

University of Tennessee M.S. student Devendra Sahu is responsible for the automated manufacturing of most of these custom robot components, which is performed on a computer-controlled milling machine located in the Flexible Manufacturing Center. His efforts include developing the computer-controlled machining instruction codes, obtaining necessary tooling fixtures, and designing any needed fixtures. Details of this effort will be presented in Sahu's upcoming M.S. thesis.

New Robot Control System

As discussed in Chapter 2, the robot control system on the first robot prototype was somewhat primitive and appeared to be inadequate for use as anything other than an experimental device. New control hardware and software was indicated to implement a dramatic change in the control approach. Detailed discussion of this control development effort is beyond the scope of this thesis, and is covered extensively in Johnson (1990). A brief discussion of some of the software control issues, however, is useful to gain insight into the overall robot system design philosophy.

First, commercially-available stepper motor drivers were acquired to replace the unwieldy IBM ProPrinter circuit board drivers. The microcontroller control approach, whereby

independent microcontrol processors direct each motion axis semi-independently, was scrapped and was replaced with direct personal computer (PC) control.

There were many reasons for abandoning the microcontroller scheme, but perhaps the primary reasons were to enable the use of a "teaching" mode and to add controlled path motion capability. In the teaching mode, the operator need only move the robot to the desired positions using the keyboard's directional keys, then tell the PC to "memorize" the points. A teaching mode was not feasible using the microcontroller system, since specific point data had to be transmitted through the PC to the microcontrollers before any move could be executed.

In controlled-path motion, the robot must follow a specific path profile as it moves. A controlled path motion is needed in many applications such as cutting, scribing, etc,. where a curved surface is desired. One control method often used to attain controlled path motion is to discretize the path into a large number of points. Since the first microcontroller system is limited to 90 moves per program [Yeo, 1988], its ability to accomplish such controlled-path tasks is extremely limited.

An additional rationale for changing to direct PC control is the continuing decline in the cost of PC's. One of the driving forces in the original control approach was to free the PC for other tasks, the premise being that the PC was too expensive for controlling the robot and thus should be made available for other uses. The problem with the

implementation of this approach is that, although the PC can be used while the robot is running, the PC still occasionally needed to download path data to the microcontrollers. Also, since microcontrollers must be purchased and wired, the first control system contains significant additional costs. When compared to the total costs of building the custom microcontroller system, the PC is now very inexpensive. Additionally, the PC has far more processing power capability.

Based on a customer needs assessment, a new set of robot control software requirements was developed. These requirements are presented in Appendix A. Key goals for the new PC-based system are to improve user ease of use, provide effective control of both point-to-point and controlled path motions, and to implement a "teaching" mode. University of Tennessee M.S. student Steven Johnson then developed a robot motion control program based on these goals [Johnson, 1990].

Design Changes/Improvements

Many features on the first prototype robot were quite useful, even though in some cases the features as actually implemented showed a need for improvement. In these cases, the original design was modified in an attempt to improve the overall performance of the UT Robot system. These needed improvements include:

- An increase in allowable end effector and payload weights;
- Increased modularity for simpler assembly and maintenance;
- Expanded, selectable range for robot work space;

- Providing positive, "hard" endstops for all travel axes;
- An increase in vertical system positional "stiffness"; and
- An improved drive belt attachment and tightening method.

Increased Payload Capability

The drive reduction system and the ability to select from three available shaft diameters enables the UT Robot to support significantly more payload than the first prototype. Whereas the first robot was designed to lift 3-5 pounds, the UT Robot should be capable of manipulating 15-20 pounds, given the appropriate reduction ratio.

Increased Modularity

The robot design is made more modular by separating the vertical positioning system from the horizontal positioning system. The separation is effected by splitting the original Z-Platform into two parts. The new part, named the "right-angle bearing cartridge", holds the linear bearing that move along the control shafts. The Z-platform, which attaches to the bearing cartridge, consists of the vertical and rotational positioning systems. The separation of the horizontal system from the vertical and rotational systems means that the systems can be built and tested independently. System assembly is also easier, since the vertical positioning hardware need not be present while the horizontal system is being assembled.

Expanded Selectable Travel Range Capability

Vertical Travel Selection Capability. While the first horizontal system design provides for changing easily the robot's work area, the vertical system has no such feature. As noted earlier, the ability to customize the robot work space is a significant competitive feature, so the capability for adjusting the vertical travel was integrated in the new design.

Extended Range. As discussed earlier, the ability to use larger guide and control shaft diameters allow the robot's work area to be extended further with little loss of machine rigidity. The smaller diameter shaft capability makes a small travel configuration more economical than with the first prototype machine.

Positive Travel Endstops

Control system or operator errors, such as starting a program from the wrong location or running into an obstruction in the work space, can cause the robot to attempt to move beyond its designated travel range. Secure, solid limiting features are needed at the each end of the robot's travel range are needed to prevent damage to the robot. The first horizontal system has solid endstops, but, as discussed in Chapter 2, the vertical system does not. The new UT Robot design has solid endstops for all three (X, Y, and Z) translational systems. Software controls on the robot's travel reduce the frequency of possible impact with the endstops.

Additional Positional System Rigidity

A robot's accuracy and repeatability is a strong function of the "stiffness" or "rigidity" of its positioning systems. Inspection and analysis of the first prototype robot showed that the Z platform interface with the horizontal control system lacked sufficient rigidity; that is, the mounting allowed the end effector to move excessively. The interface was lengthened on the new UT Robot to increase the stiffness of the overall system by adding two linear bearings at the horizontal system "Plus" crossover point. A more complete discussion of this addition is discussed in Chapter 5.

Improved Drive Belt Attachment and Tensioning

Since the two methods used for tightening the horizontal drive belts on the first prototype proved to be unreliable, the new robot system features a new combination attachment-adjustment assembly. The new approach provides a secure belt attachment to the appropriate robot parts, and also permits the belt tension to be adjusted. The technical details of the new belt attachment are discussed in Chapter 5.

New Reliability Goals

The robot design team used the reliability assessment results discussed in Chapter 3 to initiate three major robot design improvement strategies:

- alteration of the hardware and software design to create a partially "closed-loop" positioning control system;

- enhancement of the operator-software interface to assure proper robot path control at all times, including the need to verify that the operator has followed good robot path design practice; and
- enhancement of protection features for critical robot hardware to prevent problems arising from harsh manufacturing environments, or from accidental impacts, and to eliminate or reduce the potential for operator injury.

Control System Reliability

Position Verification System. The reliability assessment described in Chapter 3 clearly demonstrates the inadequacy of a purely open-loop control system. The assessment identified numerous failure modes and some potentially high failure risks for the robot because of the control system's inability to verify the robot's position within the work space. Thus, a new design aim of partially "closing the loop" was established for the new UT Robot. The major intent of this new goal is to stop the robot immediately after any robot positioning errors, before the robot can damage fixtures within the workspace, operators, or itself.

Both hardware and software alterations are needed to implement the new "position verification system". New robot hardware is needed to provide positioning data, and the control software must be modified to check the positioning data to detect errors caused by missed steps, robot impacts with misplaced fixtures, or from failure of the drive system. While the verification scheme does not reduce the failure frequency of these

events, it does substantially reduce the costs of these failures. Improved robot control and positioning verification also reduces the potential for robot impacts with its endstops such as that which damaged the first robot prototype.

The new position verification system has yet to be placed on the new robot, but specific design features have been provided on the robot to facilitate its installation. Responsibility for the hardware implementation of the position verification system has been assigned to Anthony Williams, who will report on his efforts in his upcoming master's thesis.

User-Computer Interface. The failure costs associated with the operator-software interface caused the design team to extend its vision of the software design. While issues such as motor step timing remain important, operator control has been identified as a prime contributor to the robot's reliability. The reliability analysis has accelerated the development of specific operator-software interface procedures to assure that the robot executes correct paths, begins its motion at the proper location, and begins at the proper time. For example, a slow-speed "test run" will be required before initiating an automated program sequence to assure that the software and fixturing are correct. Software-assisted "calibration" procedures will be enacted whenever the operator starts the robot or begins a new program. Also, a configuration menu has been created to improve path programming accuracy. These issues (and many others) were incorporated into the new software specifications [Johnson, 1990].

Hardware Reliability

The reliability analysis also identified several desirable hardware enhancements. The fundamental issue derived from the reliability analysis is to protect the machine from environmental extremes and supporting system failures.

Bearing Protection Features. Along with the use of linear ball bearings comes the need to protect those bearings from damage and contamination. Linear bearing seals have been added to all assemblies containing linear bearings. Extra attachment material was left on several cast components to permit the future installation of protective bellows. Also, per the reliability assessment recommendations (Chapter 3), sealed radial bearings are used in the horizontal drive reduction system to reduce the potential for bearing contamination.

Safety. The reliability assessment discussed in Chapter 3 identified several potential safety hazards. One of the most significant potential safety hazards is associated with the undesired results of an unexpected electrical power failure. The vertical system of the first robot prototype requires that power be applied to the Z system drive motor at all times to support the end effector and payload weight. If the electrical power is interrupted, the Z arm drops to its lower endstop position, and in the process could potentially damage the end effector, fixtures or other items within the work space. The UT Robot has design features so that a ratchet lock can be installed on the vertical drive system. The lock would activate in the event of a power failure and lock the Z system

in place. Actual implementation of the ratchet lock feature is beyond the scope of this thesis, but is to be completed by M.S. student David Paulus.

It should be noted that other safety features beyond those currently completed will be necessary to protect the robot's operator and other workers. For example, shields will be needed to cover the reduction system drive belts, since the reduction drive belts are external to the machine envelope. The shields would protect the drive system from external damage and would prevent the operator from coming in contact with the pulley system's pinch points. Guide shaft shields can be installed on the UT Robot to prevent accidental impacts with nearby machinery, to increase operator safety, and to provide some contaminant protection for the guide shafts and linear bearings.

Revised Robot Cost Goals

The need for new robot features, increased capability and reliability requirements, and the reduction in projected production volume has prompted increases to the UT Robot's production cost estimates and goals. The original robot specifications () specified a system cost of less than $500 [Granger, 1988], although by the time the first complete prototype was completed the system's cost (minus the control system) was estimated at $1066 [Garrett, 1989]. The reasonably low cost of this robot system, however, was based primarily on the ability to produce and sell several hundred thousand robots made largely of inexpensive plastic injection molded parts. Clearly, such a bold approach is not

appropriate to a small university research program because of its substantial capital requirements and high risk.

Additionally, industrial customers want equipment that is simple to use, easy to maintain, and very reliable. Indeed, the reliability analysis (Chapter 3) showed that the robot system's unreliability costs (costs of failure, such as equipment damage, repair time, and lost production during downtime) cost a robot customer far more than the additional sales cost incurred by using more reliable robot components and control systems.

In fact, the reliability versus cost problem became an issue well before the reliability analysis was conducted. The horizontal system binding problem described in Chapter 2 pointed out quite clearly that the forced use of inexpensive components (caused by an unrealistically low cost target), without regard to the operational reliability of the machine, could easily create a robot system that would not work, at least not for very long. The solution, to replace the inexpensive friction bushings with much more expensive linear ball bearings, forced a relaxation of the robot's cost target, since it would have been impossible to use the more expensive but more reliable bearings and still meet the original product cost goal [Garrett, 1989].

While it was clear that the UT Robot's overall system cost would have to increase, the cost problem is somewhat mitigated by the general perception that robots are very costly, complex devices requiring expensive technical support. With an average cost of $75,000

each [Lee, 1989], a reliable, easy-to-use robot that sold for $7,500 might seem very inexpensive to the potential customer. The key requirement, however, is that the robot system meet the needs of its customers. An inexpensive robot that is not capable of performing the job is a worthless machine. The product goals and features described in this chapter have been developed to enhance the probability that the UT Robot can be adapted to numerous tasks.

Early in the new design, a crude cost estimate was performed. After appraising high-cost components (motors, etc.) purchased at low-volumes, and forecasting the possible casting and machining costs, the total parts cost to build new UT Robot of similar configuration to the first prototype was estimated to be about $4,500. It should be noted that this cost estimate did not include control system hardware and also did not include developmental costs.

After considering the above factors and interviewing several knowledgeable experts, an initial product sales price target range was set between $5,000 and $10,000. Using a sales price to product manufacture cost ratio of 2.5, a manufacture cost target of $2,000 to $4,000 was established. Based on a early cost assessment to purchase needed robot materials, it was expected that the production manufacturing cost would end up on the high end of this range. Some cost variation is built into the robot's design, since parts acquisition costs vary depending on the robot's travel, shaft diameter, and whether regular

or precision linear bearings are used. A cost assessment of the UT Robot is presented in Chapter 9.

CHAPTER 5

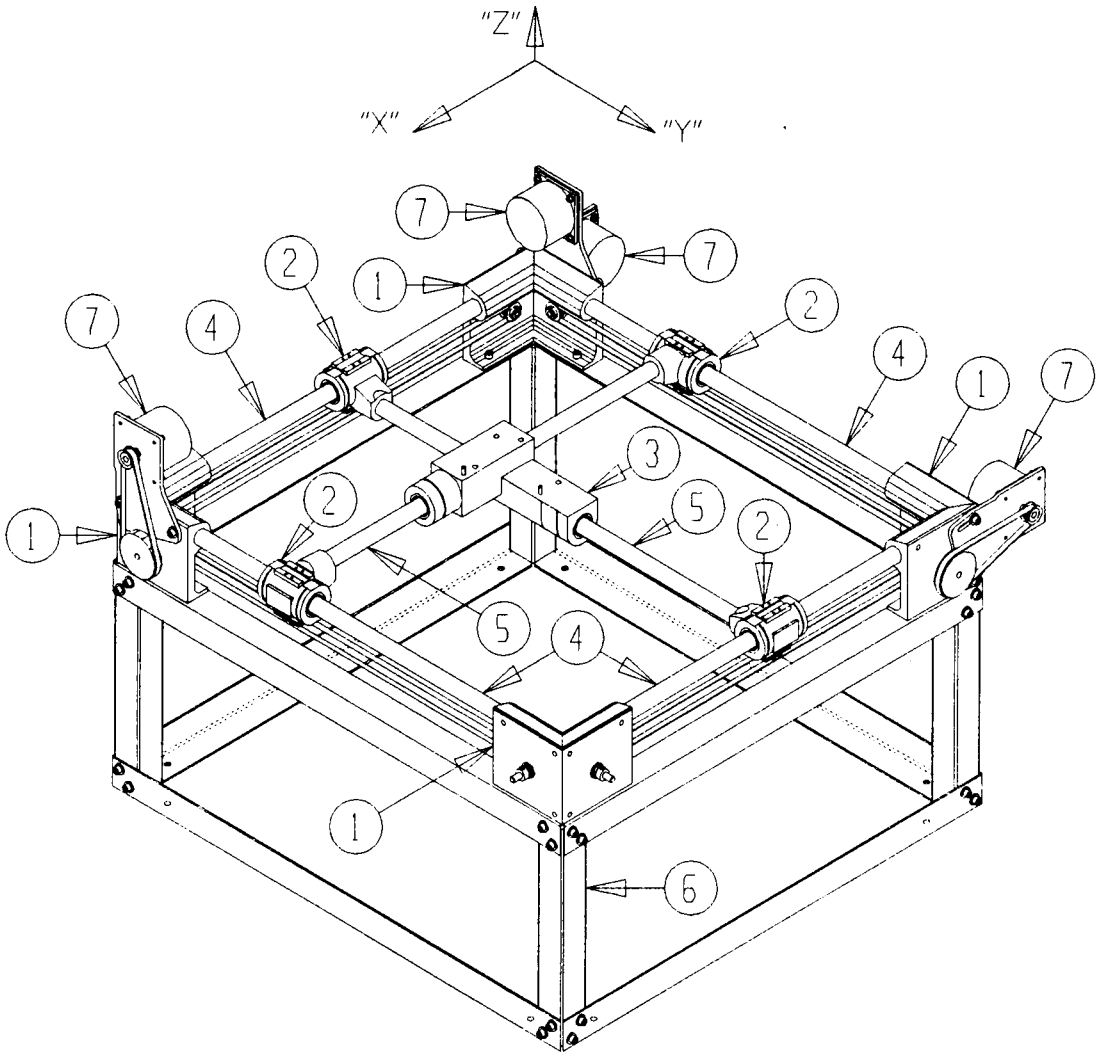
HORIZONTAL POSITIONING SYSTEM

Basic Mode of Operation

The purpose of the horizontal positioning system is to position the robot's end effector and payload at the desired horizontal position in the robot's work space. To accomplish this task, the horizontal system must have sufficient capability to move and position other robot parts, such as those used in the vertical and rotational systems. The system must be powerful and light enough to move at an adequate speed while being rigid enough to support all of the robot hardware that is used to lift and manipulate the machine's payload.

The design for the UT Robot's horizontal positioning system is shown in Figure 5.1. The system's basic configuration is modeled after the "PLUS"-type system that was used successfully on the initial prototype, but has been modified to provide additional features.

Like the first prototype, most horizontal system components are mounted to the four corner supports located outside each corner of the work space. The corner supports (Item 1) provide mounting features for the horizontal motor assemblies (Item 7), locate drive system components, and hold the outside guide shafts (Item 4). Linear ball bearing containing sliders (Item 2) move along the guide shafts and locate the control shafts (Item



ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	4	MEK001-000	SUPPORT, CORNER
2	4	ASY521-000	ASSEMBLY, XY SLIDER
3	1	ASY541-000	ASSEMBLY, BEARING CARTRIDGE
4	4	VEN406-RRR	SHAFT, HORIZ. GUIDE, X AND Y
5	2	VEN407-RRR	SHAFT, HORIZ. CONTROL, X AND Y
6	1	ASY300-RRR	ASSEMBLY, FRAME
7	4	ASY531 & 532	ASSEMBLIES, XY MOTOR

Figure 5.1: The UT Robot's horizontal positioning system.

5) that extend across the top of the work area. An offset in the control shafts' heights allow them to cross each other over the work area without interfering. A bearing cartridge (Item 3) is "trapped" at the intersection of the control shafts so that it moves under the direction of the control shafts. The robot itself mounts on a supporting frame (Item 6), which can be customized easily to meet the mounting needs of each individual customer.

The horizontal system is powered by four stepper motors that are mounted either off the end or off the top of the corner supports. A timing belt pulley attached to the motor's output shaft drives a timing belt that connects to a reduction pulley. The reduction pulley is attached to a drive shaft that extends through the wall of the corner support. The drive shaft rotates the timing belt pulley located "inside" the corner support, which then moves the drive belt. This drive belt is attached to the underside of each slider, so that the slider moves as the drive belt does. As the sliders move the control shaft, the bearing cartridge moves to the desired position. An idler pulley is located at the corner support at the end opposite of the motor to hold the drive belt in position.

Horizontal System Design Features

The basic design of the horizontal positioning system used on the first prototype was found to be very practical, so major changes to the basic design were not needed. However, in response to the customer needs and product goals outlined in the previous

chapter, several product enhancements have been incorporated into the UT Robot's horizontal positioning system.

Selectable Drive Reduction System

To increase the robot's load capability and use flexibility, a selectable drive reduction system has been added to the horizontal positioning system. The stepper motors are connected through a reduction pulley drive system. Up to a 6:1 reduction over the first prototype robot can be selected by installing the proper pulley and belt combination. The reduction improves the robot's step resolution and multiplies the force applied to the positioning system, but also decreases the speed of the system. All three issues must be considered when specifying a reduction ratio for a given application.

Selectable Guide and Control Shaft Diameters

The new UT robot's horizontal positioning system is designed to accommodate guide and control shafts of 0.75", 1.00" or 1.25" diameter. Smaller shafts can be used for light load applications, while the larger diameter shaft can be utilized for more demanding applications. The horizontal system design minimizes tooling and production costs by using the same base castings for all three shaft diameter sizes. Only a tool change during machining is needed to make the parts for each particular version. Since the linear bearings and shafts are high cost items, the smaller diameter shaft configuration can be used to make an inexpensive version of the machine.

Increased Modularity

The increased modularity goal for the new UT Robot is achieved by separating the horizontal positioning system from the vertical and rotational systems. To accomplish this, the original Z platform is divided into two parts, a new modified Z platform and the right-angle bearing cartridge. The bearing cartridge is considered to be part of the horizontal positioning system (previous figure) and its job is to move to the desired horizontal position within the robot's work area. The new Z platform mounts to the bearing cartridge using the screw holes and dowel pins provided on the bearing cartridge Figure 5.2.

Additional System Rigidity

Two more linear bearings were added to the vertical positioning system mounting area near the "Plus" intersection interface to increase the "stiffness" of the robot system. This change from the first design was prompted by analysis and observation that the Z platform tended to rotate excessively about the control shafts.

The platform rotation occurs because of the small clearances that are needed between the control shafts and the linear ball bearings. The rotation induced by these clearances can be minimized, however, by increasing the length of bearing contact on the control shafts. The extra bearings in the new design improves the repeatability and stiffness of the robot by reducing the amount that the Z platform can rotate about the control shafts.

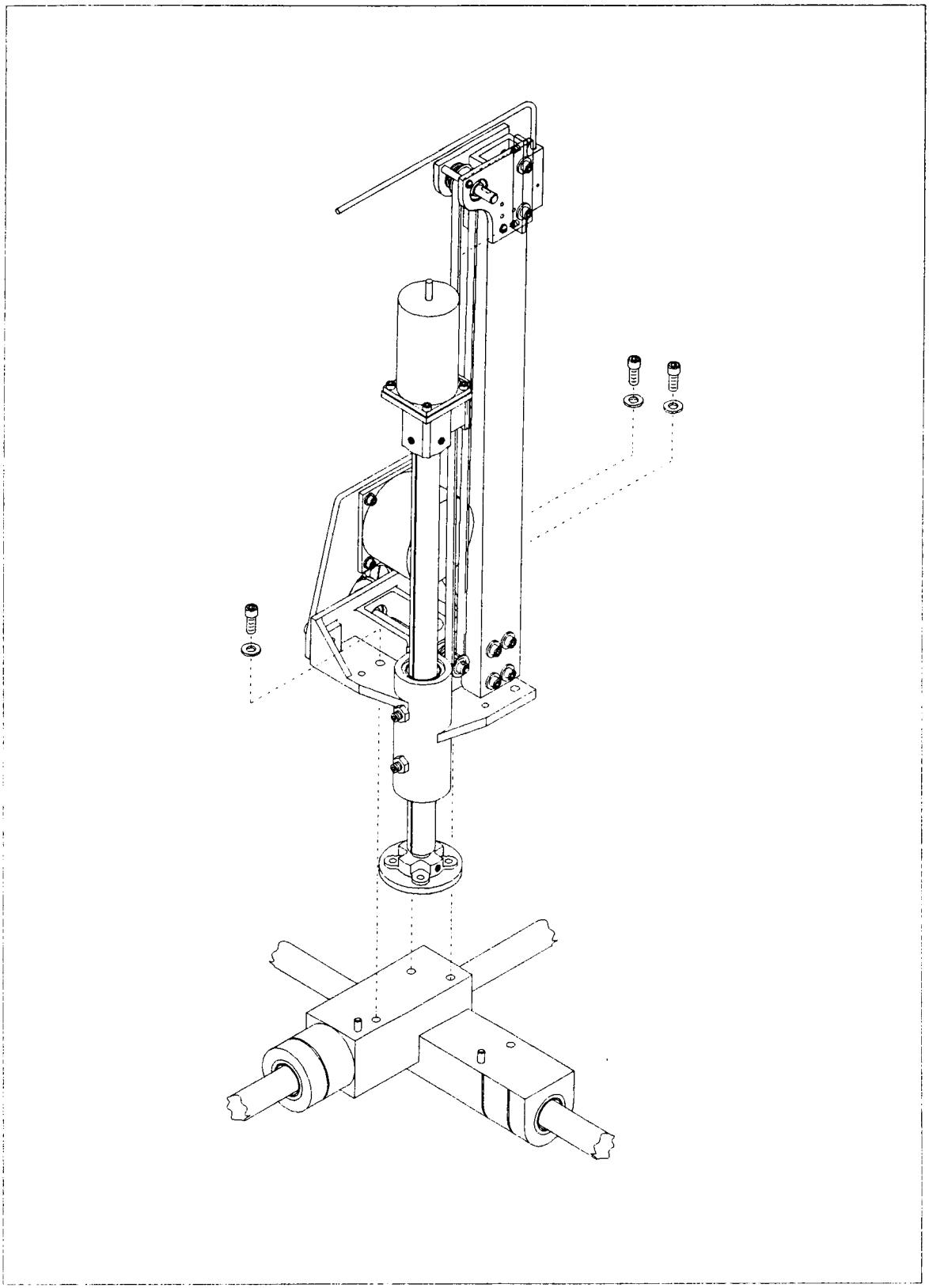


Figure 5.2: Attachment of the Z platform to the horizontal positioning system.

Improved Drive Belt Attachment and Tensioning

As discussed previously, the two methods used for tightening the horizontal drive belts on the first prototype proved to be unreliable. Additionally, the method for attaching the drive belts to the sliders was not entirely satisfactory. The new horizontal positioning system features a combination attachment-adjustment that mounts directly to the slider and also permits belt tensioning.

Improved Shaft-Pulley Attachment

On several occasions, the first robot prototype robot has failed because the set screws that secure the timing belt pulleys to the motor shafts have loosened. To combat this problem, the new UT Robot features a specially-designed shaft groove that conforms to the shape of the set screw tip while still permitting lateral adjustment of the pulley.

Selectable Work Area Capability

One of the strong advantages of the first horizontal system design is that the robot's work area can be changed simply by adjusting the lengths of the horizontal shafts and drive belts. Thus, the robot can be made longer or shorter easily to meet individual customer's needs. This feature provides a significant competitive advantage, so this capability was maintained in the new design.

Horizontal System Design Considerations

Many issues had to be considered during the design of the new horizontal positioning system to assure that the product goals could be achieved, that the parts could be manufactured economically, and that the parts would assemble properly. Some of the major points and considerations related to the completion of the new horizontal system design are discussed in the following sections.

Low-Volume Production Design

The horizontal positioning system design is adapted to the low-volume production strategy outlined in the previous chapter. Thus, parts designed for high-volume plastic injection molding on the first prototype were modified to facilitate sand casting or other low-volume production methods. Sand casting was used extensively for custom manufactured components because it is quite economical for a very small number of parts but can also be adapted somewhat to be reasonably economical medium-volume production quantities.

Design of the Selectable Drive Reduction System

The first major task in the design of the selectable drive reduction system was to select how the reduction was to be accomplished. Several methods were available, including various gearing alternatives, a timing belt and pulley scheme, or commercially available reducers. The timing belt and pulley method was chosen because the reduction ratios can be changed easily, the design and assembly can be made very simple, and required parts are quite inexpensive.

The layout of the new belt reduction system provided several significant challenges. First, the drive component spacing must be such that the full 6:1 reduction desired for the new horizontal positioning system can be attained. Provisions must be made for tightening not only the drive belt, but also the reduction belt. Finally, the parts must all be arranged so the components do not interfere with each other or with parts in other systems.

Motor Location Requirements. The design of the reduction system was complicated by the desire to maintain drive system symmetry. In the plus configuration, each slider is moved with its own motor drive system. To maintain drive symmetry the motors must be located at the same end of the robot with respect to its drive direction (Figure 5.3). This arrangement leads to an imbalance in the hardware requirements at each corner support, since one corner must support two drive systems, two corners support one, and one corner supports no motors. The motor mounting imbalance caused considerable design difficulty, since it was desired to use one common corner support design at all four corners.

Reduction System Arrangement. The motor support problem was solved by providing features that permit the motors to be mounted either "off-the-end" or "off-the-top" of the corner supports (Figure 5.4). The alternative mounting was required to prevent motor and belt interferences on the "home" corner, which has to accommodate two motor reduction systems. The reduction pulleys and the belt are mounted "outside" of the corner support,

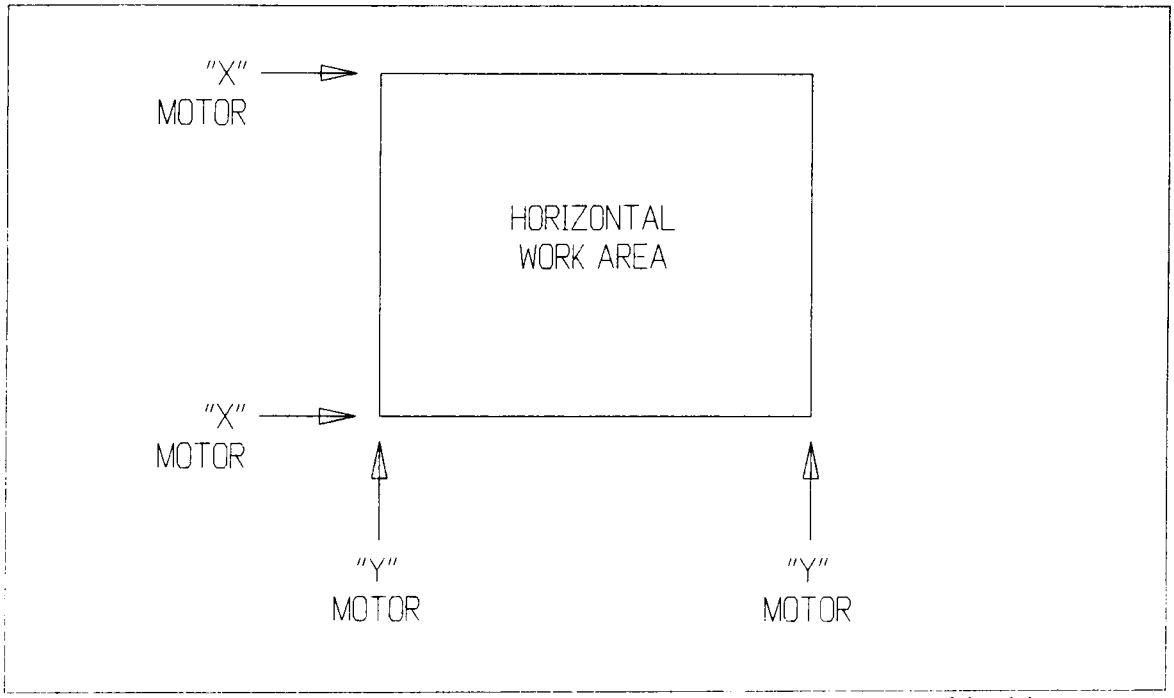


Figure 5.3: Motor location schematic. Motors must be located to provide drive system symmetry.

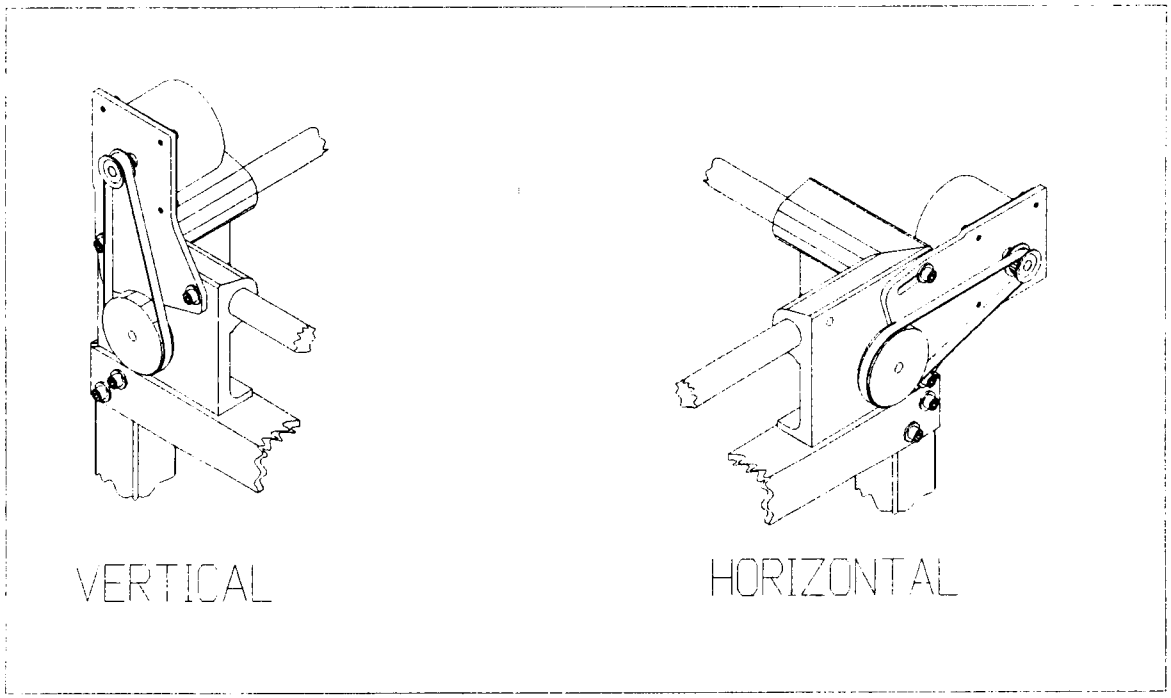


Figure 5.4: Motor mounting orientations. Both orientations are needed to avoid interference at the corner holding two motors.

while a drive shaft, supported by radial bearings, extends through the corner support wall. The drive shaft rotates the drive pulley located inside the corner support.

At the end opposite to the drive system, an idler pulley is installed (Figure 5.5). The idler shaft extends through the corner support wall to accommodate the future mounting of the position verification system.

Proper tensioning of the reduction timing belt is accomplished by rotating the motor mounting plates about a pivot point on the corner support. A groove is cut in the motor plate to facilitate this adjustment. The location and orientation of the reduction components were such that a 15° rotation was needed to tighten a standard length belt around any given allowable combination of reduction pulleys. Components also are located so that the same motor plate designs can be used in either mounting orientation, and so that motor plate mounting screws do not interfere with drive belt during installation or operation.

Motor Selection. Stepper motors were selected for the new horizontal positioning system, based on the success of using them on the first system and the needs of the control system. The same size stepper motors as were used on the first horizontal system prototype were selected for the new system, although the identical model and rating is no longer available.

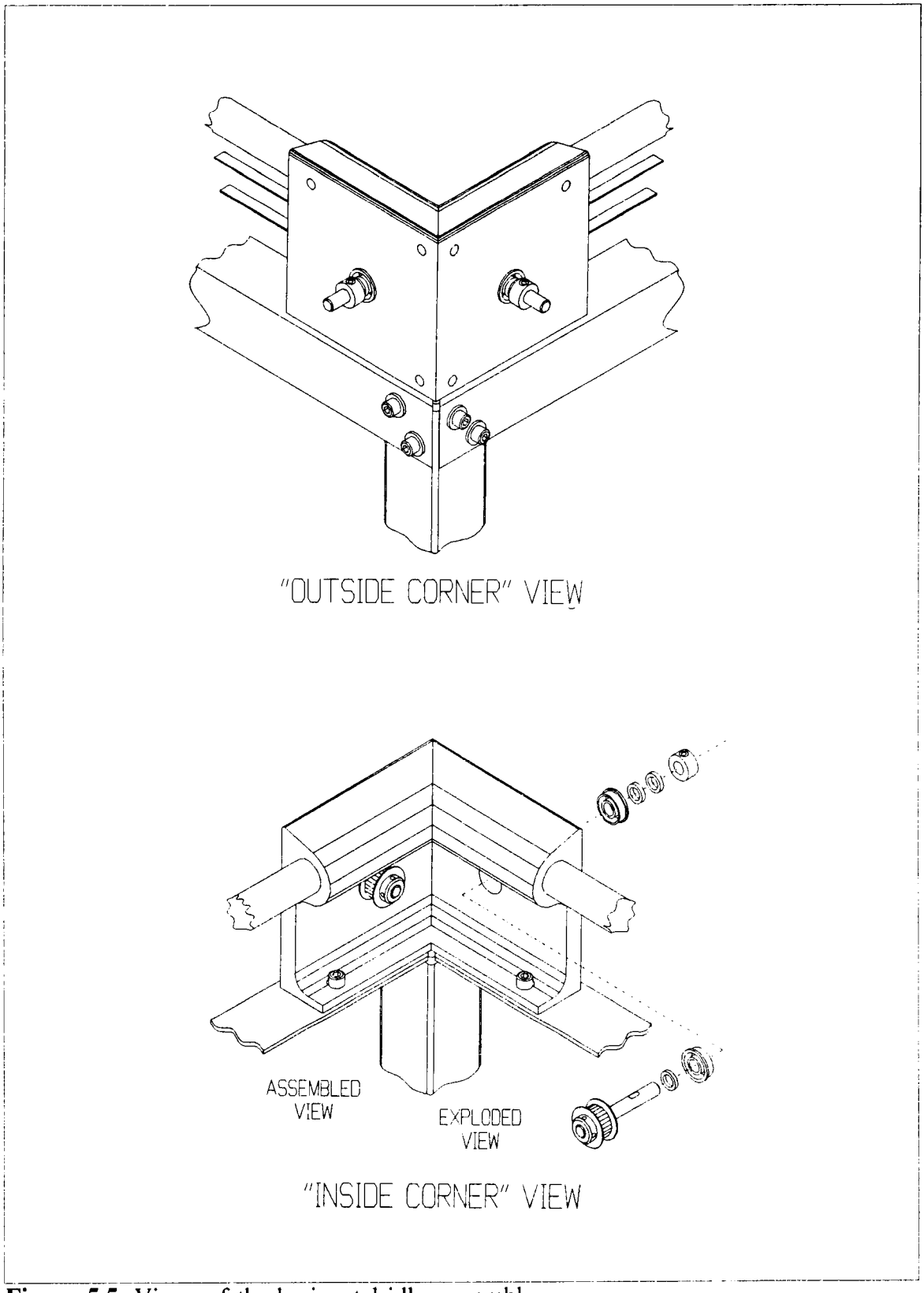


Figure 5.5: Views of the horizontal idler assembly.

The key requirement for the motors is that they must supply sufficient torque both at standstill and during moves so that the motors do not lose phase as the robot's load is moved within the work space. Load inertia matching, the process of matching the motor rotor's inertia to some multiple of the load inertia, is also important, although the ability to adjust the reduction ratio (and thus the effective load inertia) made this issue less important.

A size 34, one stack, 1.8° (200 steps/revolution) stepper motor from Anaheim Automation was selected for the horizontal positioning system. To minimize the number of different parts to be ordered, it was desired to use the same motor type for both the horizontal and vertical positioning systems. Thus, both system's need were considered in the motor selection process.

Reduction Ratio Selection. The first prototype robot's horizontal positioning system is designed to move at 0.015" per step, assuming a 1.8° (200 steps/revolution) stepper motor. While this is sufficient for many tasks, better resolution can be attained on the new UT Robot by adjusting the reduction ratio. The ratio adjustment also multiplies the force delivered to the horizontal system components, but reduces the maximum speed of the system. Thus, all three issues must be considered in the selection of the drive reduction ratio.

While many possible reduction ratios are theoretically possible, it is recommended that the reduction factor be chosen to provide a motor step resolution of a "round" value, such as 1.5:1 (0.010" resolution), or 3:1 (0.005" resolution). Charts have been developed (Appendices B, C) to assist in the selection of an appropriate reduction ratio.

Radial Bearing Protection. Per the reliability assessment recommendations in Chapter 3, sealed radial bearings are used in the horizontal drive reduction system to reduce the potential for bearing contamination.

Design of New Drive Belt Attachment and Tensioner

Since the first two methods used on the first prototype for tightening the horizontal drive belts proved to be unreliable, the new horizontal positioning system features a combination attachment-adjustment assembly, shown in Figure 5.6.

The belt attachment is mounted directly to the slider housing using the four screws shown. The two ends of the timing belt are inserted into the cut teeth in the belt attachment, which correspond to the teeth on the timing belt. Belt tension adjustment is accomplished by adjusting the position of the "top" part of the attachment until the proper belt tension is achieved, then tightening the four mounting screws securely. The adjustment is designed to move slightly greater than one pitch length of the timing belt so that any belt can always be tightened, first by selecting the engaging the correct belt teeth in the adjustment, then by moving the adjustment plate.

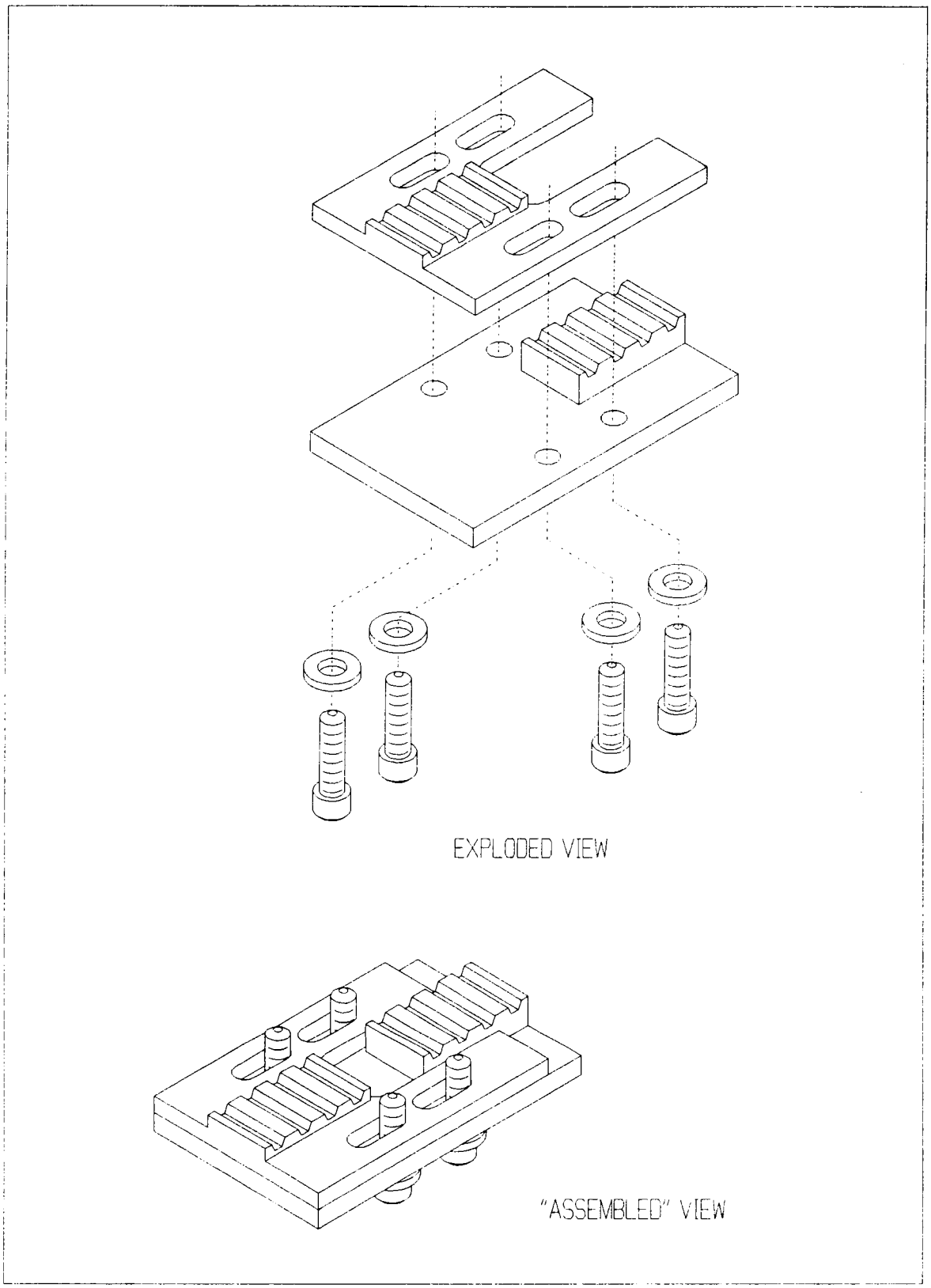


Figure 5.6: Combination belt attachment-adjustment assembly.

The new attachment method provides several advantages. First, since the belt attachment assembly mounts directly to the slider, there are no free hanging parts on the drive belt, as there is when a turnbuckle is used. The part performs both mounting and tightening, so that fewer parts are required. Third, the attachment "sandwiches" the adjustable part of the attachment assembly between the fixed part and the slider, so that the adjustment is tightly secured once it is set.

Use of Linear Ball Bearings

In keeping with the friction reduction and binding solution goals discussed in Chapter 4, linear recirculating ball bearings and hardened shafting were used in the horizontal system design. The bearings are used in the sliders and the bearing cartridge, and the guide and control shafts are precision shafting, case hardened to Rockwell 60-65 C.

Regular or Extra-Precision Configuration. The slider and bearing cartridge designs were adjusted to enable either "regular" or extra precision linear bearings to be used.

Linear Bearing Protection Features. Linear ball bearings used in the slider and bearing cartridge are protected from outside contamination by linear bearing seals. Extra attachment material also was left on these cast components to permit the future installation of protective bellows.

Improved Shaft-Pulley Attachment

The use of set screws to attach pulleys to round shafts has been unreliable because the screw-shaft contact area is small and the screw often tends to loosen over time. In an attempt to eliminate this persistent problem, all motor, drive, and idler shafts on the new robot have a specially-designed shaft groove, an example of which is shown in Figure 5.7. This groove is designed to match the angle of the timing belt pulley's set screw tip so that it makes better contact with the shaft. Where no lateral adjustment is needed, a spot drill is used, whereas a groove is used when some lateral adjustment of the pulley is needed. In addition, "nylok" set screws are used on most timing belt pulleys to reduce the tendency of the set screws to loosen.

Shaft Locations and "Cross" Spacing

Because the new design is to accommodate three potential guide and control shaft sizes (0.75", 1.00" and 1.25" nominal diameters), an important question arose as to how to specify the guide shaft mounting on the corner supports and how to define the "cross" spacing of the "Plus" system's control shafts. The shafts could be located by specifying common shaft center locations for all diameter shafts, or a single shaft "gap" spacing for all diameter shafts could be defined (Figure 5.8).

As the figure indicates, the common spacing scheme would require that corner bracket that the shaft or linear bearing mounting holes be at different locations. The holes could

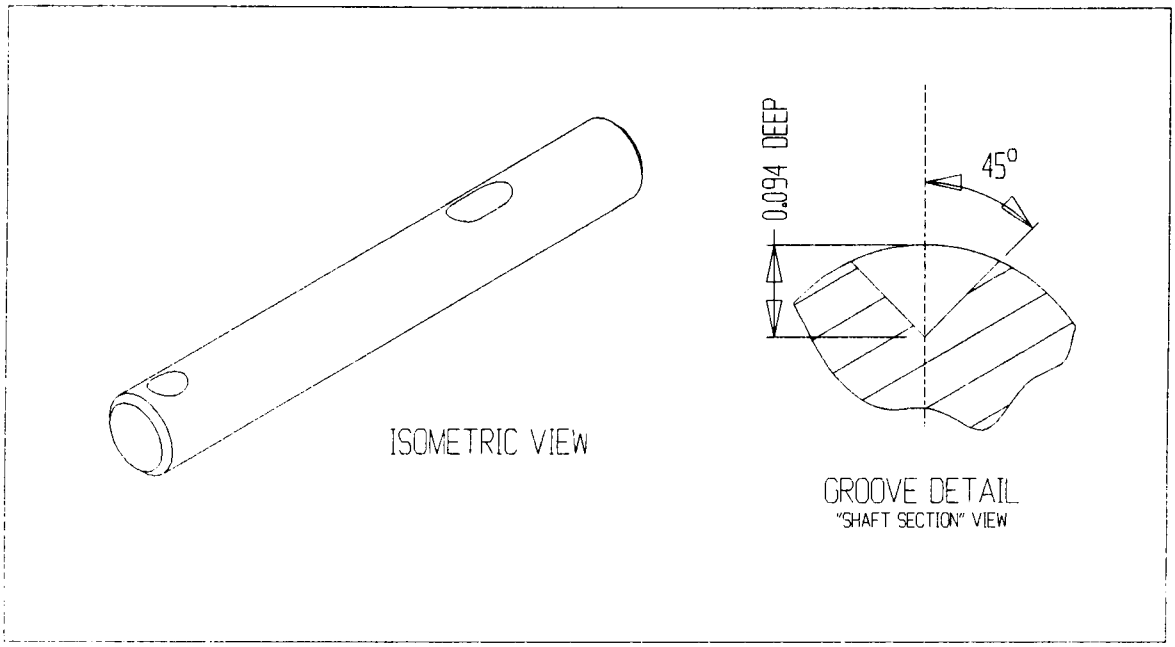


Figure 5.7: Shaft-pulley attachment groove.

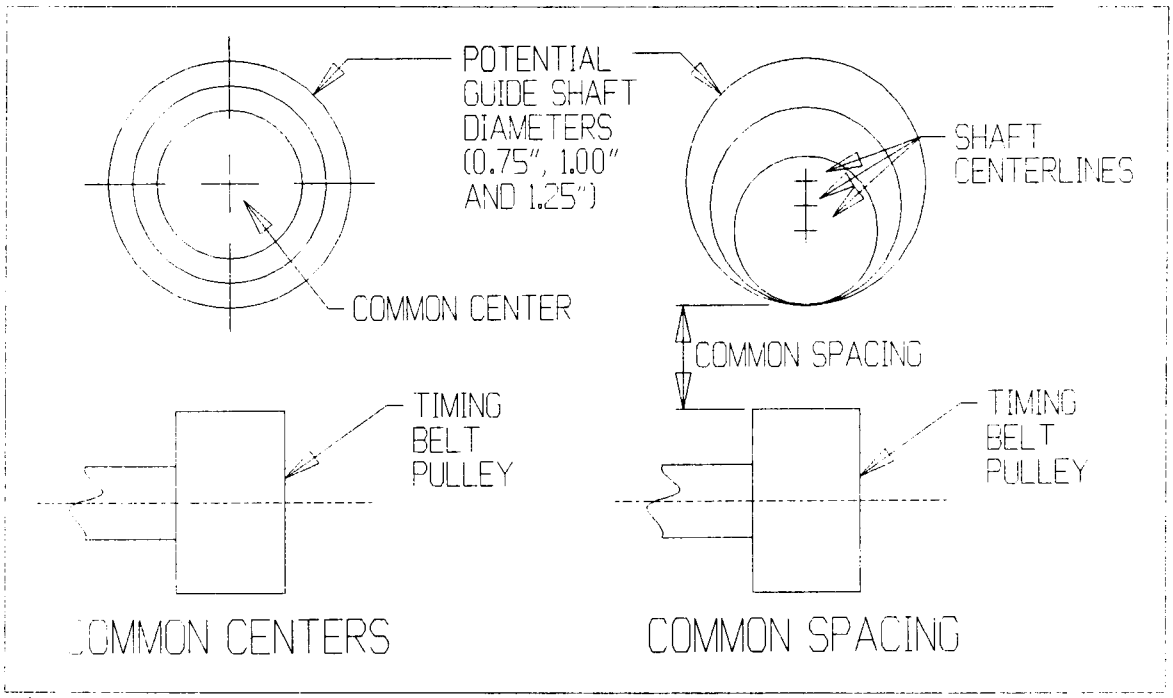


Figure 5.8: Common center versus common spacing configurations.

not be cored easily, and separate machining instructions would be necessary for each version, since the centerline of the holes would be in different locations.

Thus, the common center method was chosen for the design. This approach results in a good general purpose part. If coring of the casting proves to be economical, the core can either be sized generically for the smallest diameter option, or a core set can be created for each diameter using the same base mold. New CNC machining instructions are not necessary, except for a change in the specified drill/reamer diameter.

Position Verification System

A diagram showing part of a proposed "position verification system" is shown in Figure 5.9. This "encoder-style" scheme provides periodic (and automatic) verification of actual versus commanded robot position over a specified "grid".

The equipment is positioned on the drive system's idler end, rather than on the motor end, so that the positioning system can detect belt and pulley-shaft connection failures in addition to motor errors and accidental impacts. This advantage is significant, as belt and pulley-shaft failures are identified as high-risk events. While not currently installed, the UT Robot prototype can be adapted easily to accept the new hardware, since the idler shaft was designed to extend through the corner support. M.S. student Anthony Williams is designing the actual mounting hardware for the position verification system.

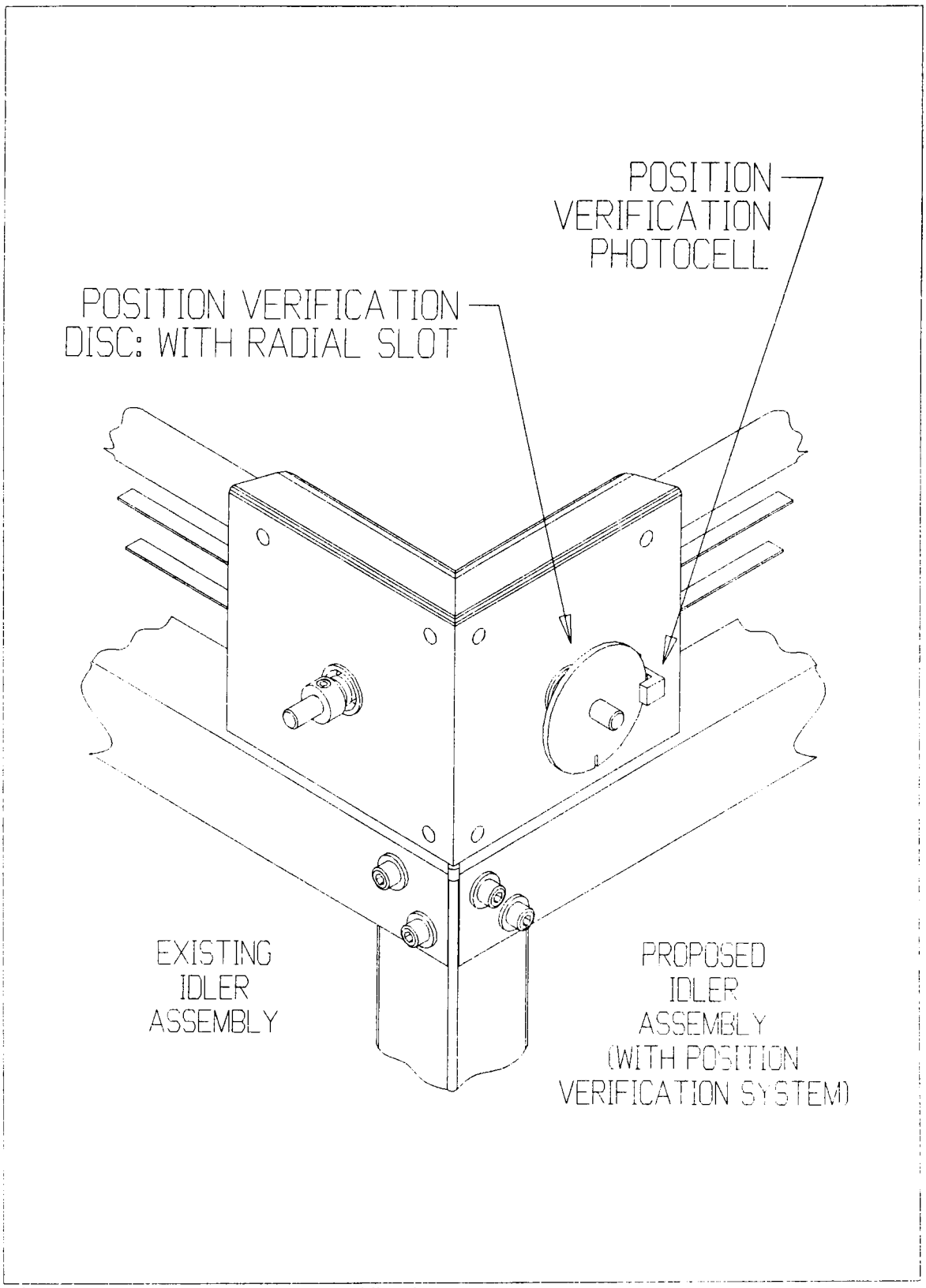


Figure 5.9: Proposed position verification system.

Parts Design And Manufacture

Corner Support

Design. The robot's corner support, part number MEK001-DDD, is shown in Figure 5.10. This part supports the horizontal guide shafts, enables the robot to be mounted to a frame, and holds the horizontal drive reduction system components. Like its predecessor, the new UT Robot's corner support is designed to be used on all four corners, even though each corner has its own unique mounting hardware. Earlier illustrations (Figure 5.4 and Figure 5.5) provide views as to how the corner support adapts to the various parts mounting and orientation that is needed to assure that the one corner design can be used on all four corners of the UT Robot.

Manufacture. A casting pattern, part number MEK101-DDD, was designed by mechanical engineering student Steven King to sand mold the corner support. The part is cast at a 45° orientation (Figure 5.10) to minimize the number of surfaces requiring draft.

XY Slider Housing

Design. The XY slider assembly, P/N ASY521-DDD, is shown in Figure 5.11. The slider housing, P/N MEK021-DDD, holds a linear bearing that moves along the robot's guide shaft, supports a control shaft over the robot work space, and has an attachment feature for connecting to the horizontal drive timing belt.

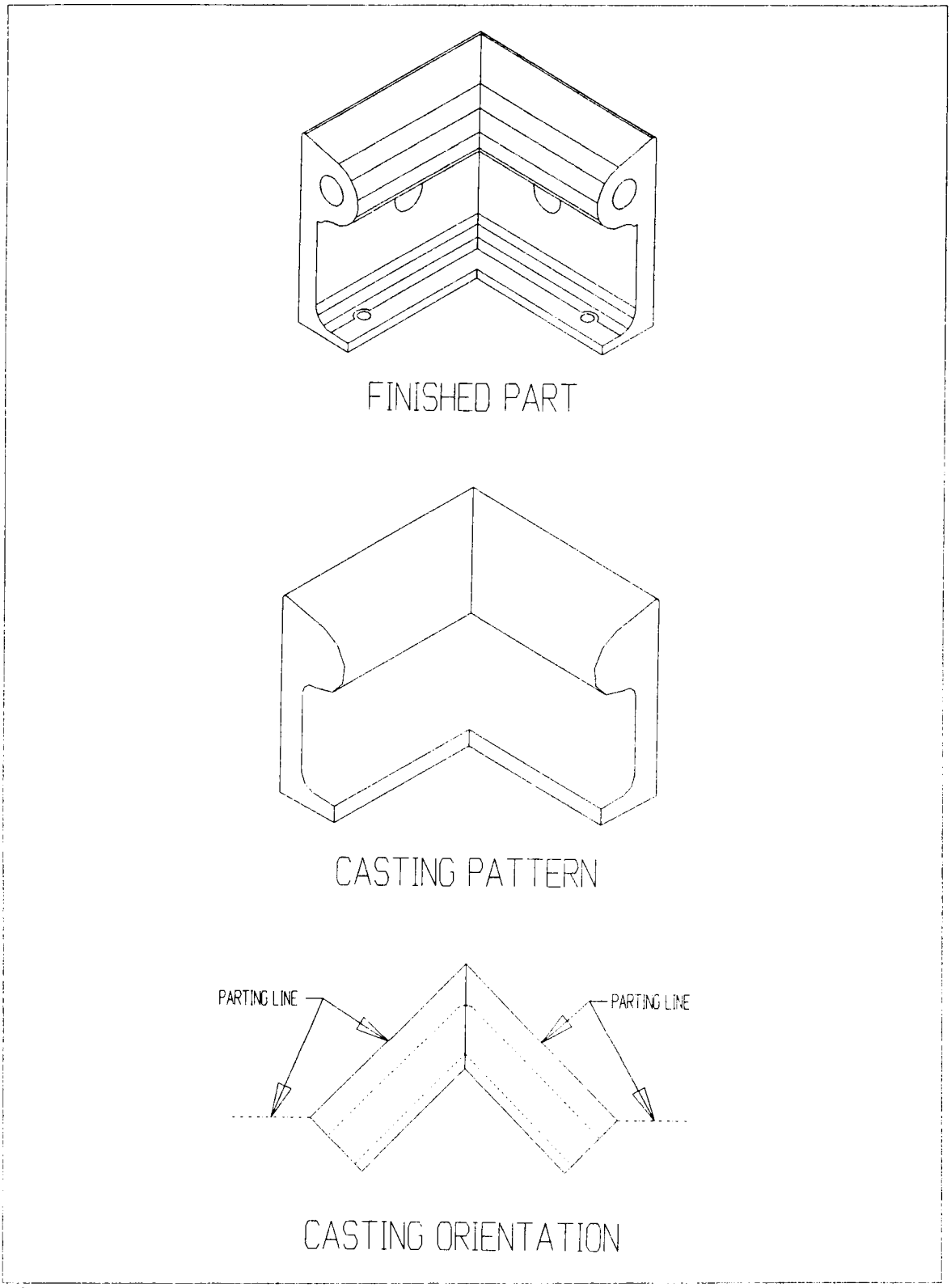


Figure 5.10: Corner support. Views of finished part, casting pattern, and casting orientation.

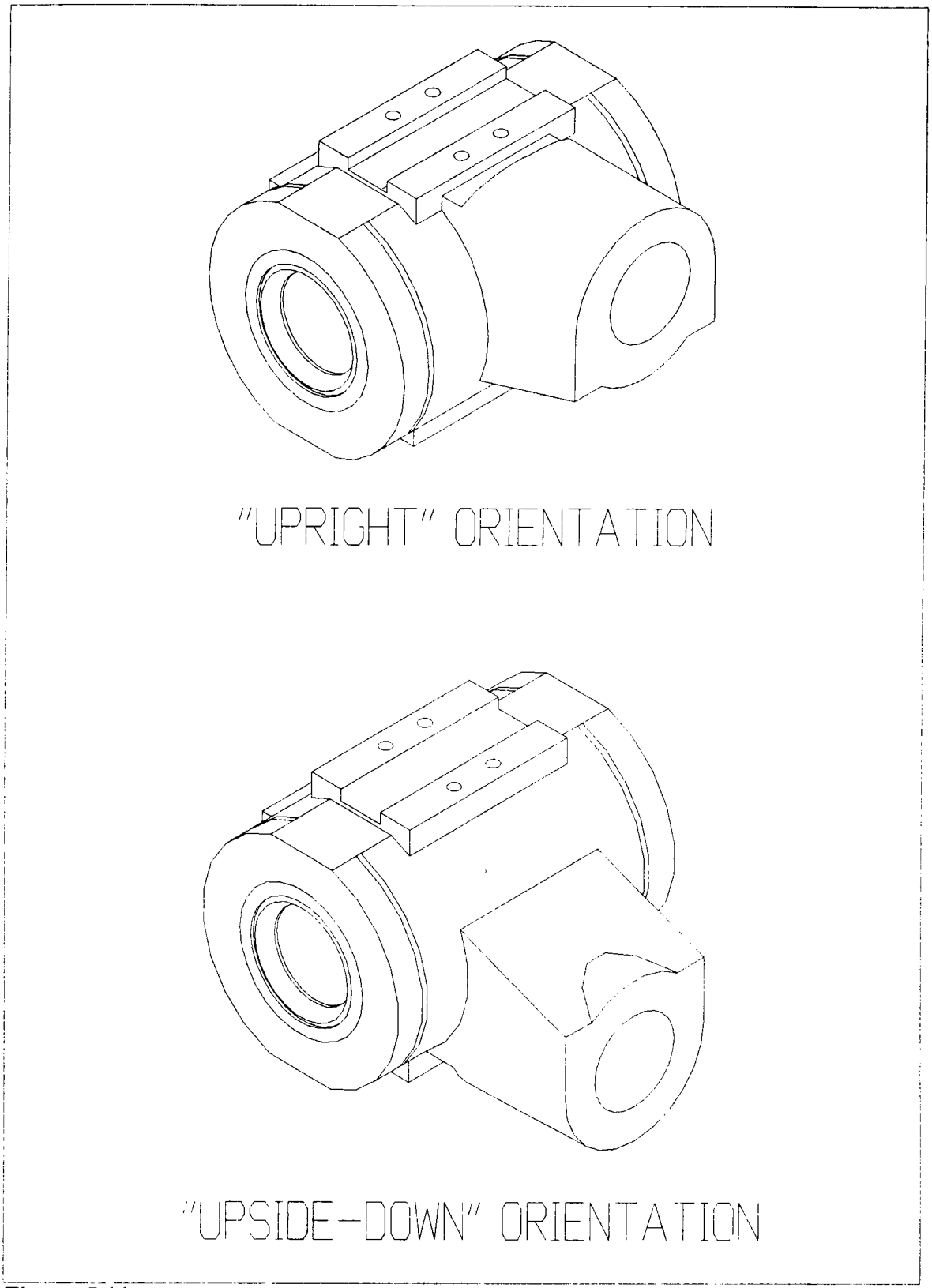


Figure 5.11: XY slider assembly. Slider mounts in either of two orientations.

The slider is designed for use in both "upright" and "upside-down" orientations, as shown in Figure 5.11. The ability to use this part in both orientations enables the part to be used for both axes of "Plus"-type horizontal system. The slider casting is large enough to accommodate all three linear bearing and control shaft sizes (0.75", 1.00", and 1.25" nominal diameter shafts). Any of the three size versions can be made from the same casting simply by machining the correct hole sizes for that version. Since the smaller diameter bearings are also shorter than the "regular" bearings, the slider can be sawed off at the proper length using specific part features as a guide.

The bore dimension for the linear bearing has been increased slightly to a slight slip-fit rather that the first robot's press fit. This change makes bearing installation easier, reduces any potential for overloading the bearing with an excessive press fit, and allows one to use extra precision bearings if desired. Bearing seals are press-fit into the each end to hold the bearings in place and to protect the bearings from contamination.

Manufacture. The pattern and holder used to create the XY slider casting, part numbers MEK110 and MEK115, are shown in Figure 5.12. The pattern is used directly to create the sand mold for the slider casting. The pattern holder holds the slider pattern in the proper orientation and establishes the parting line in the sand mold. The tapered surface of the holder provides easier sand mold separation, and reduces the amount of labor needed to cast the part. A non-functional flat area has been added to the side opposite the control shaft bore to provide a needed machining datum.

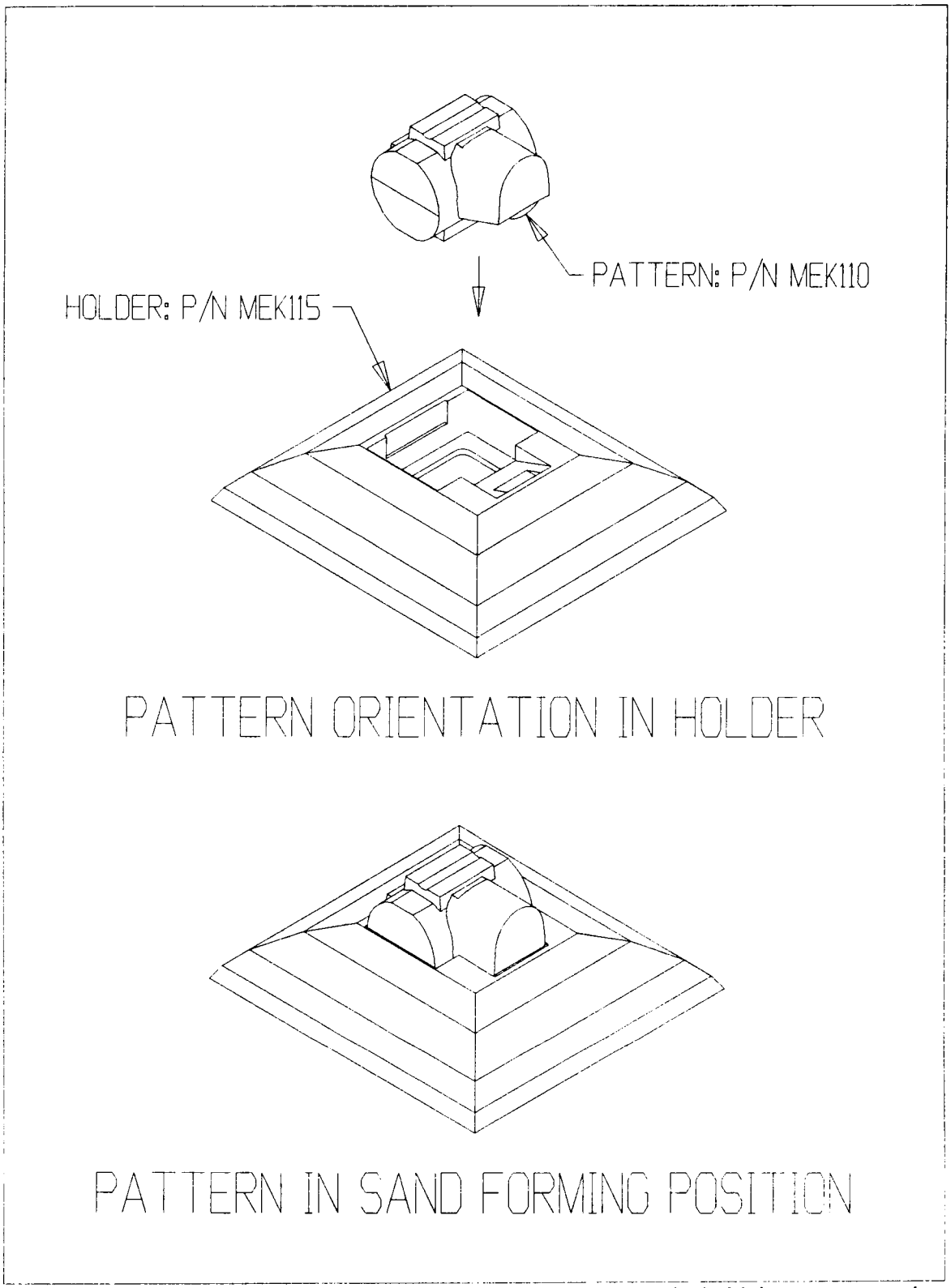


Figure 5.12: XY slider casting pattern and holder. Pattern is held in proper casting orientation by the holder.

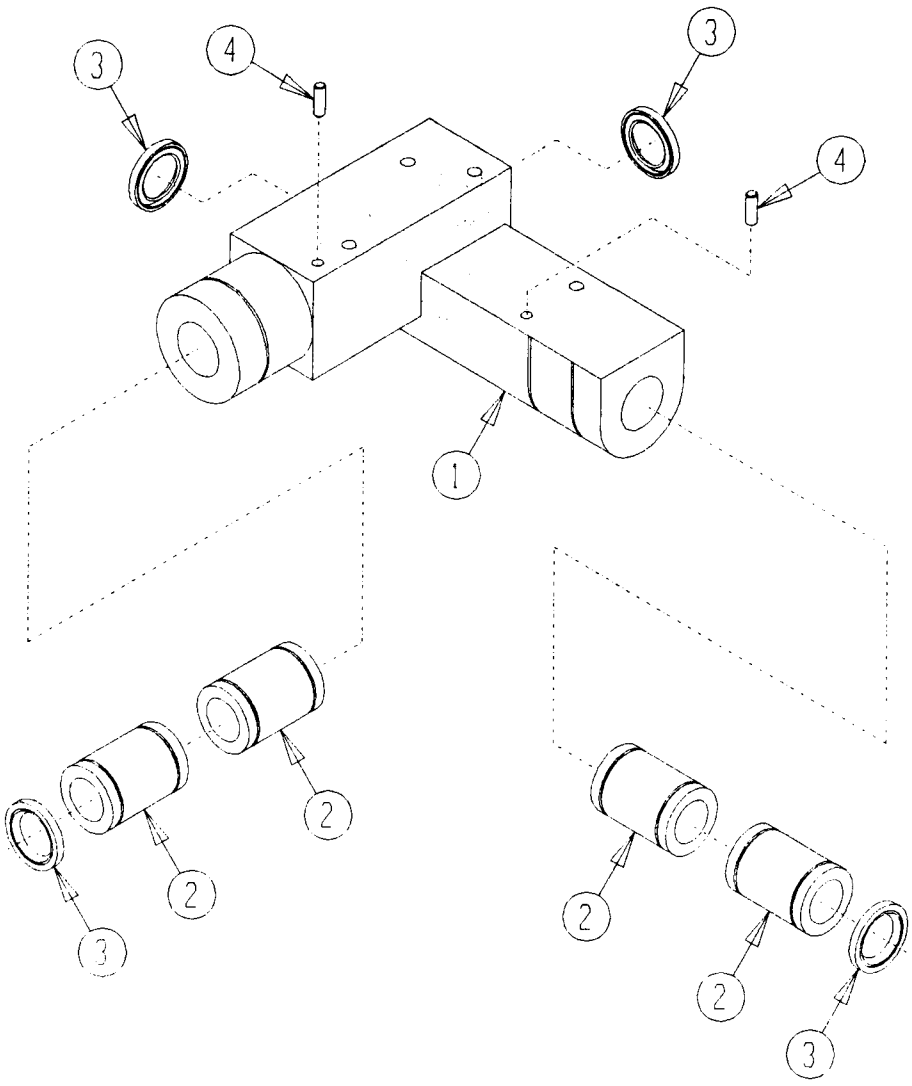
Bearing Cartridge

Design. The design of the bearing cartridge assembly, part number ASY531, is shown in Figure 5.13. The bearing cartridge is to provide smooth horizontal movement and positioning along the control shafts that are inserted through the part. The bearing cartridge provides a secure interface from the horizontal positioning system to the other robot systems with two locating dowel pins and several mounting screw holes.

To get the desired increase in system stiffness, four linear bearings are inserted into the cartridge's bores (Figure 5.13), instead of just the two used in the first Z platform design. Like the slider assembly, a slight slip-fit hole, instead of the press-fit used in the first prototype, is used for the linear bearing bores. Two seals are press-fit into the bores to hold the bearings in place, while two seals are inserted into the opposite ends of the cartridge to protect the bearings from outside contamination.

The same base casting can be used for the three alternative shaft diameters, simply by machining the proper size bore. Recalling that the smaller diameter bearings are shorter than the "regular" bearings, the cartridge can also be cut to the proper length. The length of the "back" end of the lower axis is longer by 1" to protect vertical system components from impacts with the horizontal guide rods or the sliders.

Manufacture. Like the corner support and the slider housing, the bearing cartridge is designed for sand cast molding. The cartridge pattern and its partial support holder are



ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK051-000	CARTRIDGE, BEARING, RIGHT ANG
2	4	VEN401-000	BEARING, LINEAR BALL
3	4	VEN402-000	SEAL, LINEAR BALL BEARING
4	2	VEN496-075	PIN, DOWEL, Ø0.250, 0.750 LNG

Figure 5.13: Bearing cartridge assembly.

shown in Figure 5.14. The partial holder holds the bearing cartridge pattern at the proper orientation, and also establishes the parting line for the pattern along the length of the holder. The support used for the pattern is only a partial holder because of the bearing cartridge pattern's large size. Additionally, since only one bearing cartridge is needed per machine (versus four each for the corner and slider), the manufacturing cost savings that can be achieved with a complete holder are much less than that for the corner or slider.

The bearing cartridge pattern has its parting line along the top of the lower axis and long the centerline of the upper axis (Figure 5.14). Since these two lines are not at the same height, there is a slight shift in the parting line as it moves across the part. While the non-constant height parting line makes the casting process slightly more difficult, it greatly reduces the complexity of the pattern and part designs.

Motor Plate

Design. The purpose of the XY motor plate is to hold a horizontal system stepper motor in place, to enable tightening of the reduction timing belt, and to provide for motor mounting either above or outside of the corner support. The motor plate assemblies, part numbers ASY531 and ASY532, are shown in Figure 5.15.

The plates are designed for mounting in either corner support mounting orientation. To avoid any potential frame or other robot mounting interferences, the motor plate is not permitted to extend any lower than the bottom of corner support, in either the nominal

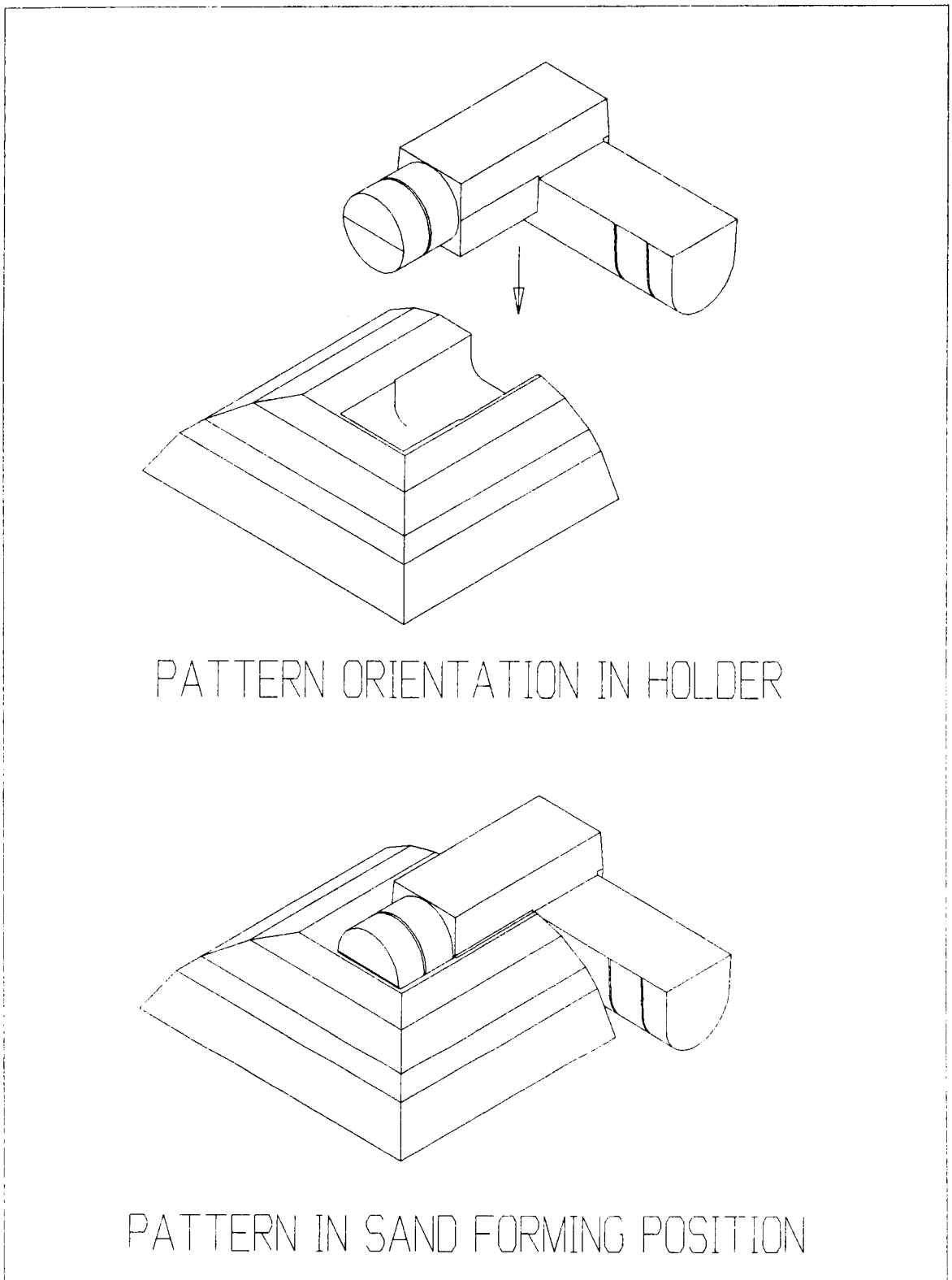


Figure 5.14: Bearing cartridge casting pattern and holder. Pattern is held in proper casting orientation by the holder.

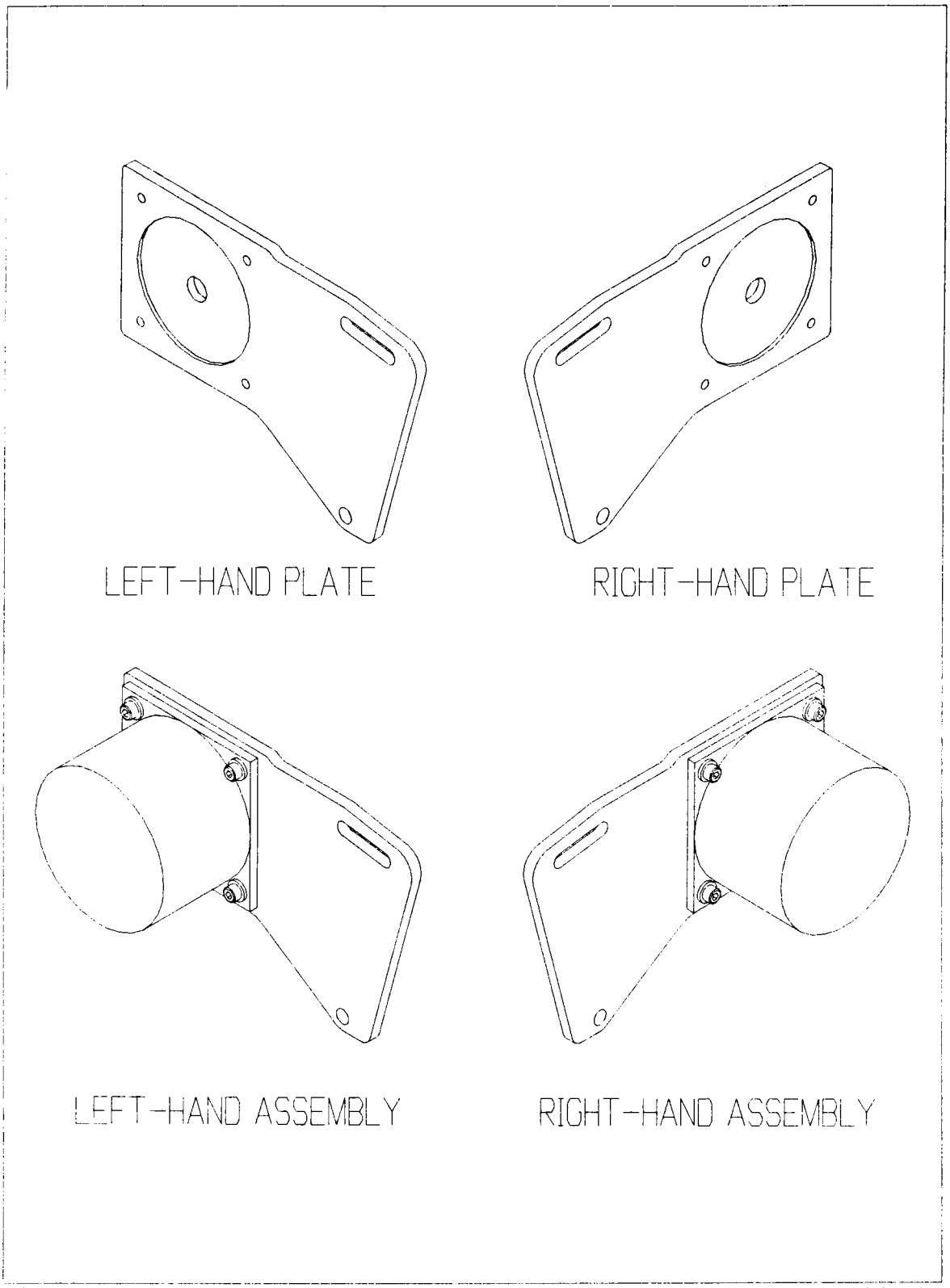


Figure 5.15: XY motor assemblies. Both the assemblies and motor plates used in the assemblies are shown.

or the rotated position. For the home corner, where two motors are mounted, the plates have a cutout section above the groove adjustment to avoid interfering with each other. The circular groove in the plate provides the adjustment for tightening the reduction belt. The contact zone of the plate with the corner support has to be large enough so that mounting screws are not stripped out of the corner support if the motor is struck inadvertently.

Manufacture. The motor plate is designed for automated manufacture on a CNC mill from 0.25" aluminum plate. The two plate designs are mirror-images of each other so that a "flip" feature in the computer-aided manufacturing system can be used to make both parts from one basic program setup.

CHAPTER 6

VERTICAL AND ROTATIONAL POSITIONING SYSTEMS

Basic Mode of Operation

The purposes of the vertical and rotational positioning systems are to position the robot's end effector and payload at the desired vertical and rotational position within the robot's work space. The vertical system must have sufficient capability to lift the moving vertical system parts, the end effector, and the payload. The rotational system must be capable of supporting and rotating the end effector and payload weights.

The UT Robot's vertical and rotational positioning systems are shown in Figure 6.1. The vertical system's basic configuration is modeled after the first prototype's mast-based design, while the rotational system follows the established approach of housing most of its components within a vertical tube. Additional features have been added to both systems in conjunction with the expanded goals enumerated in Chapter 4.

The overall assembly basically consists of a platform assembly, a vertical mast assembly, a rotational assembly, a reduction drive set, and two motors. The Z platform (Item 2) supports the systems' components and is designed to mount to the horizontal positioning system's bearing cartridge. This attachment allows the vertical and rotational systems to be assembled and tested independently of the horizontal positioning system. Special

ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY551-ZZZ	ASSEMBLY, THETA MOTION
2	1	ASY571	ASSEMBLY, Z PLATFORM
3	1	ASY591-ZZZ	ASSEMBLY, MAST
4	1	MEK081	MOTOR MOUNT, THETA
5	1	ASY538	ASSEMBLY, THETA MOTOR
6	1	ASY536	ASSEMBLY, Z MOTOR
7	1	ASY540	ASSEMBLY, BELT ATTACHMENT

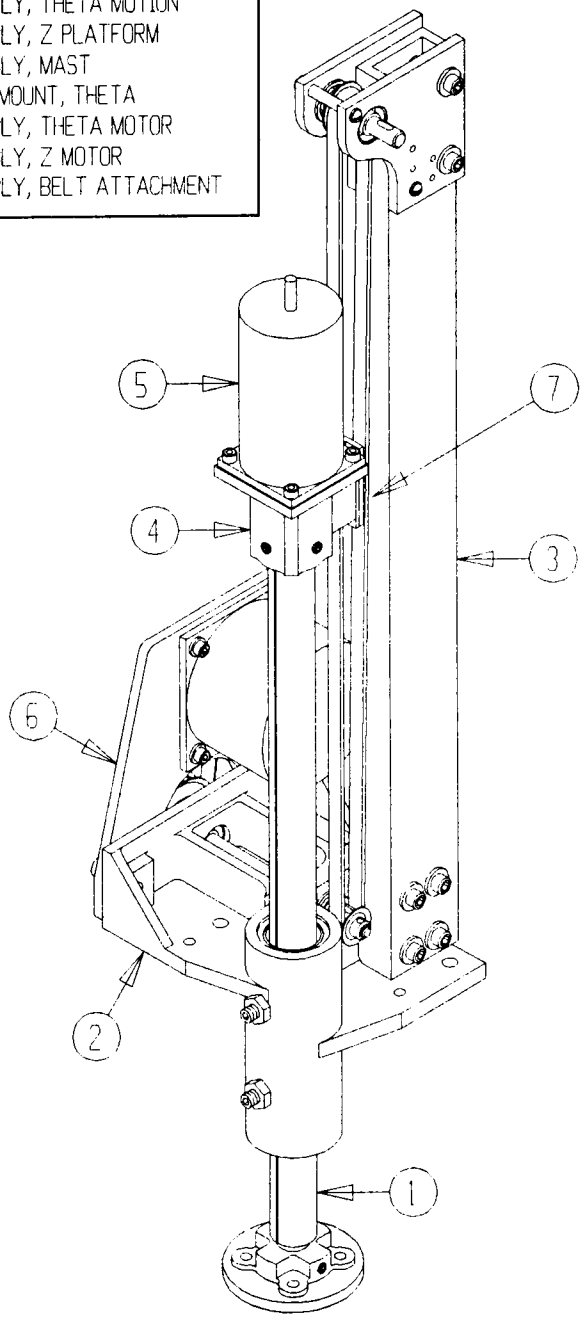


Figure 6.1: The UT Robot's vertical and rotational positioning systems.

linear bearings in the platform's long vertical bore allow the vertical guide tube (Item 1) to move only in the vertical direction. A mast assembly (Item 3) supports the drive belt that is used to lift the vertical guide tube. The vertical guide tube supports the rotational system components, while the end effector mount at the bottom of the guide tube serves as the end effector attachment.

The Vertical Positioning System

The vertical positioning system functions similarly to the first version, except that a reduction assembly has been inserted into the drive system and some parts designs have been modified slightly to attain desired improvements.

The vertical positioning system is powered by a stepper motor that is mounted from the back of the Z platform (Figure 6.2). A timing belt pulley attached to the motor's output shaft drives a timing belt and reduction pulley. The reduction pulley is attached to a drive shaft that extends through to the front of the platform. The pulley attached to the end of the drive shaft moves the Z axis drive belt that ranges from the drive pulley to the top of the Z mast. This drive belt is attached to a translating tube assembly, so that the vertical position of the robot can be controlled. An idler pulley assembly is mounted at the top of the Z mast to hold the drive belt in position.

The Z mast assembly has built-in features that provide a tensioning adjustment for the Z drive belt, and can be sized differently so that the Z travel range can be selected for each

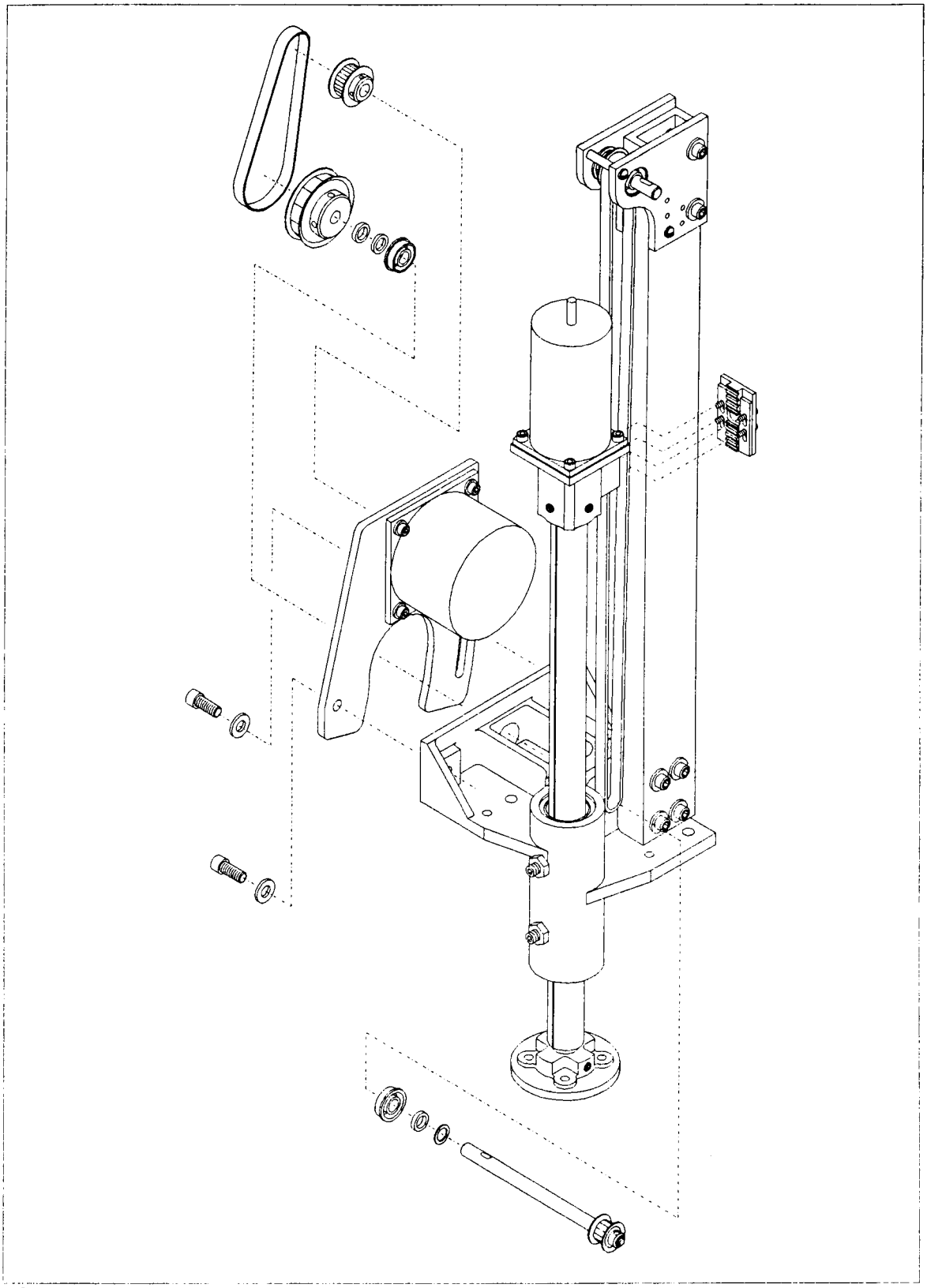


Figure 6.2: Exploded view of the vertical drive system.

application. The mast assembly attaches to the Z platform by means of four socket head cap screws (Figure 6.3).

Some of the hardware involved in vertical positioning also are utilized to execute the theta rotational motion. The theta motor mount, Z guide tube, and end effector mount serve this dual role in the design. The theta motor mount provides an attachment for the Z drive belt as well as for the theta system's stepper motor. The guide tube is secured to the theta motor mount with two half-dog point set screws, so that the motor mount and tube move vertically as a unit under the control of the Z drive belt.

The Z guide tube, shown as part of the theta motion assembly, has a groove running along its length. "Super" (brand name of Thomson Industries product) linear ball bearings in the platform's long vertical bore provide rolling contact with the Z guide tube and restrict the tube to movement only in the vertical direction. Rotation of the Z guide tube is prevented by using the two adjustment screws on the Z platform to set one of the linear bearing's ball tracks in the guide shaft's groove.

The New Rotational Positioning System

The rotational assembly is driven by a stepper motor that is mounted at the top of the Z guide tube. A roll pin inserted through the theta motor's shaft is inserted into the grooved member at the top of the theta assembly. Parts internal to the guide tube transmit the motor power to the end effector mount at the bottom of the guide tube.

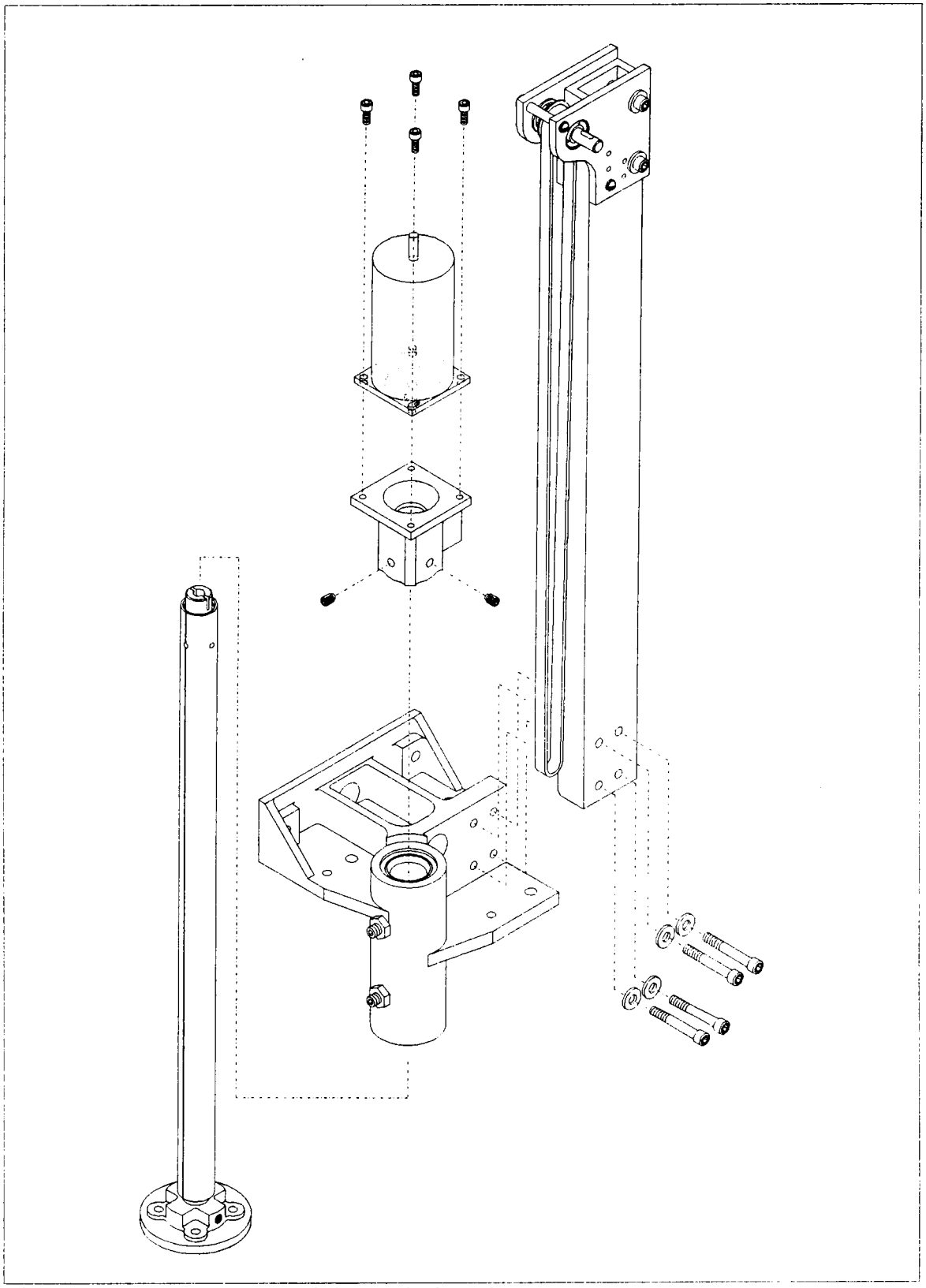


Figure 6.3: Exploded view of the vertical motion system.

A view of the theta motion assembly is provided in Figure 6.4. The motor-tube converter (Item 1) transmits the theta rotation from the motor to the theta transmission tube (Item 3) through a roll pin (Item 2) that runs through holes in the converter and the tube. The transmission tube extends through the middle of the Z guide tube (Item 5) down to the end effector mount set (Item 6), which is secured to transmission tube by two half-dog point screws (Items 7). The end effector mount transmits the rotational motion to an attached end effector (not shown).

In addition to transmitting the desired rotation, the theta transmission system must also support the weight of itself, end effector mount, end effector and payload. Vertical loading is transmitted from the end effector through the end effector mount and theta transmission tube to the motor-tube converter. A radial bearing (Item 4, top) supports the motor-tube converter and transmits the vertical loads to the Z guide tube, while still permitting the converter to rotate. The Z guide tube, in turn, transmits the loads to the vertical positioning system through half-dog point set screws that are inserted into the holes at the top of the Z guide shaft.

Shims (Items 8) are inserted between the end effector mount and the lower bearing to accommodate any tolerance stack-ups in the assembly and to remove any backlash.

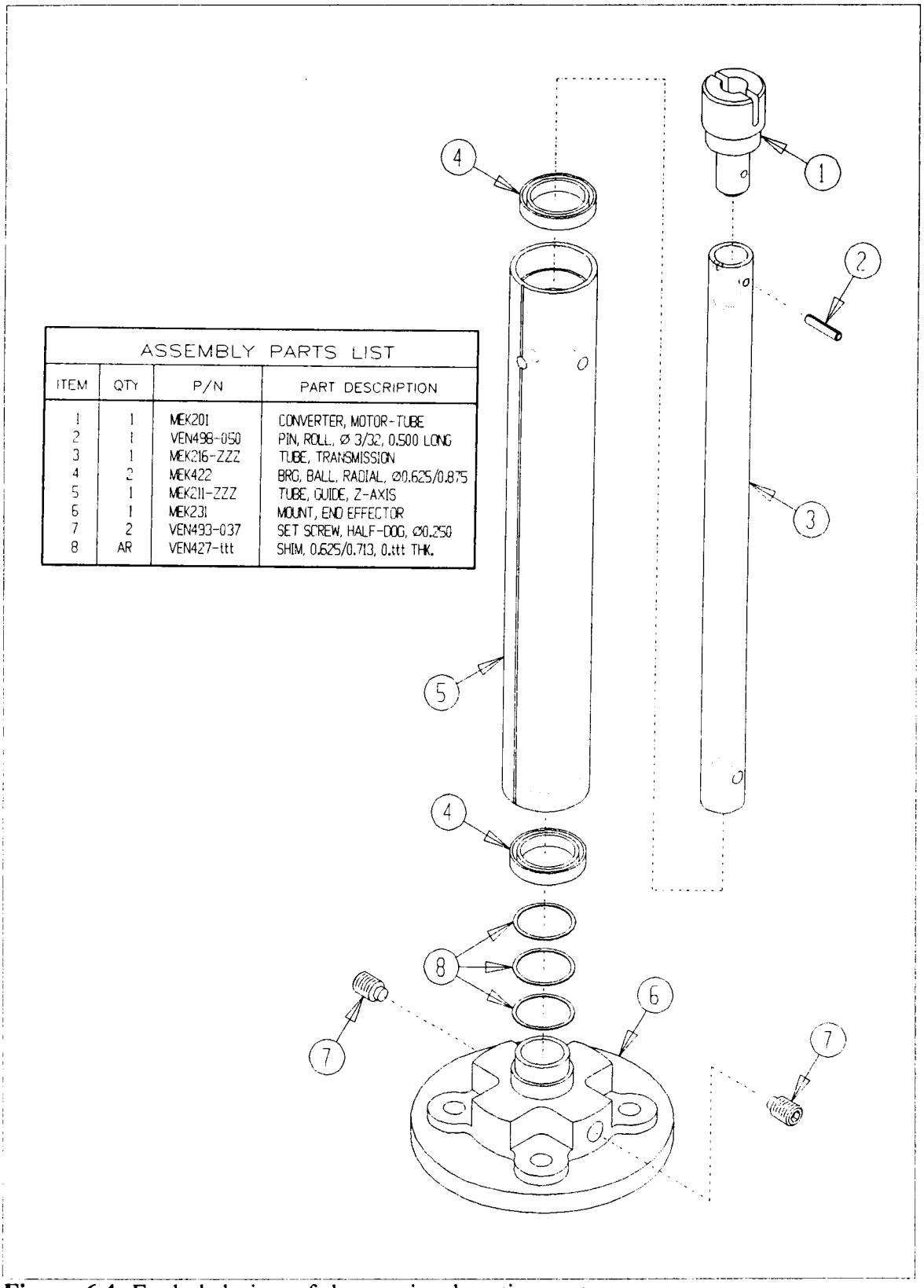


Figure 6.4: Exploded view of the rotational motion system.

Vertical Positioning System Design Features

The basic design of the first vertical positioning system was found to work reasonably well, so a major configuration change was not indicated. However, several needed enhancements were identified for the vertical system during the assessment described in Chapter 4.

Selectable Drive Reduction System

A selectable drive reduction system similar to that created for the horizontal positioning system has been added to the vertical positioning system to increase the robot's payload capacity. The Z system stepper motor is connected through a reduction pulley drive system attached to the Z platform. Up to a 6:1 reduction over the first robot prototype can be selected by installing the proper pulley and belt combination (Appendices B, E). The reduction improves the robot's step resolution and multiplies the force applied to the positioning system, but also decreases the speed of the system. All three issues must be considered when specifying a reduction ratio for a given application.

Selectable Vertical Travel Capability

One of the problems with the first vertical system design is that the robot's vertical travel can not be changed easily. The new UT Robot's vertical system features selectable vertical travel to complement the selection of the horizontal travel. With the new design, only the lengths of the mast, vertical tubes, and drive belt need to be modified. No other

machining instruction, casting, or design changes are required, although a higher drive reduction may be desirable for longer system lengths.

Vertical Positioning System Lock

The first vertical positioning system was deemed inadequate by the reliability assessment (Chapter 3) because continuously applied motor torque is required to hold the system in position (assuming that the Z system is not resting on its lower travel endstop). During a power loss, which can be more frequent than one might believe, the Z axis falls to its lowest position, and could damage parts, fixtures, or itself. To mitigate this failure mode, provisions for a vertical system locking mechanism have been made to lock the arm in position on any detected error, power outage, or unanticipated program termination.

Position Verification System

Provisions for a proposed vertical ("Z") axis "position verification system", similar to that proposed for the horizontal system, have been integrated into the new vertical positioning design. The "encoder-style" verification system can be installed on the vertical drive system's idler end, at the top of the mast, to detect more potential failure modes than if it were installed on the drive end.

Increased Modularity

As shown in Chapter 5, the UT Robot separates the vertical and rotational positioning systems from the horizontal systems. To accomplish this, the original Z platform is

divided into two parts, a modified Z platform and the right-angle bearing cartridge. This Z platform, which supports the vertical and rotational system hardware, mounts to the bearing cartridge using screw holes and two dowels. Additionally, the rotational system can be separated from the vertical system.

Improved Shaft-Pulley Attachment

The set-screw groove attachment discussed in Chapter 5 is also utilized on vertical system components to provide greater security in attaching timing belt pulleys to drive and motor shafts. The idler shaft has the same groove to provide better attachment security for the proposed Z-arm axis lock. A spot drill is used in cases where the pulley location is known, while a groove is used in areas where lateral adjustment of the pulley may be necessary.

Improved Drive Belt Tensioning

The vertical positioning system features an improved, secure method for tightening the Z drive belt. Special features at the top of the mast pivot so the drive belt can be tightened to the desired tension. A series of offset holes allow the adjustment to be locked in place without relying on contact friction to hold the adjustment in place.

Larger, Hardened Z Guide Shaft

The UT robot's vertical positioning system utilizes a 1.00" diameter guide shaft, rather than the 0.75" diameter shaft used on the first prototype, to provide greater lateral

stiffness and to facilitate design changes made to the robot's rotational positioning system. The Z tube is made of case hardened 52100 steel tubing to provide a hard surface on which the linear ball bearings can roll, since the first robot's soft stainless steel tube has not provided an adequate surface for the bearings.

Vertical Positioning System Design Considerations

The design of the vertical positioning system required careful consideration of many different design factors, particularly those concerned with parts layout. Much hardware had to be located in a very small space, while also meeting the new product goals outlined in Chapter 4 and assuring that the parts could be manufactured economically. Some of the considerations related to the completion of the new vertical system design are discussed in the following sections.

Low-Volume Production Design

The new vertical positioning system design is adapted to the low-volume production strategy outlined in Chapter 4. Thus, plastic injection molded parts on the first prototype, like the Z platform, were modified for low-volume production methods. As with the horizontal system, sand casting is used often for the custom manufactured components because of its economical small quantity production but also because it can be adapted to medium-volume quantities.

Design of the Selectable Drive Reduction System

As with the horizontal positioning system, a timing belt and pulley drive reduction system was selected for the vertical drive system. The goal of the reduction is to increase the allowable payload (and compensate for the additional system weight caused by certain design changes) by multiplying the force delivered to the Z arm by the Z system stepper motor.

Although the initial goal was to attain a maximum torque multiplication ("drive reduction") of 3:1 to 4:1, it became clear that up to 6:1 drive reduction could be obtained with proper component spacing. It was known at the beginning of the project that some additional Z arm lifting capability would be needed simply to overcome other design changes that increase the lifted weight of the Z system. For example, the high-volume, lightweight plastic parts of the first prototype are replaced by heavier aluminum castings, and the original thin-walled Z guide tube had to be changed to a thicker (and heavier) tube to get the needed surface hardness. Later, it was discovered that a larger (and heavier) theta motor would be required. Even with the additional weight, however, it is estimated that the UT Robot is capable of lifting up to about 15-20 pounds in a low speed application. This value compares favorably to the first robot's payload of about 3 pounds.

Reduction System Arrangement. The design of the reduction system was greatly complicated by the need to mount all of the parts to a relatively small Z platform.

Additionally, the timing belt reduction pulleys have to be located where they can be changed easily. The drive components have to be spaced to get the maximum 6:1 reduction that is desired. The drive belt and the reduction belt have to be tensioned properly. Also, the parts must all be arranged so the components do not interfere with each other or with parts in other systems.

A view of the vertical drive reduction system was shown previously in Figure 6.2. The reduction pulleys and the belt are mounted "outside" of the platform, for easy access. A drive shaft, supported by radial bearings, extends through two walls in the platform to reach the drive belt. The drive pulley mounted to the end of the drive shaft controls the position of the Z drive belt.

Similar to that performed on the horizontal system, proper tensioning of the reduction timing belt is accomplished by rotating the motor mounting plate about a pivot point on the platform. A groove is cut in the motor plate to facilitate this adjustment. A 15° rotation was found to be sufficient to tighten a standard length belt around any given allowable combination of reduction pulleys. Components also are located so that the motor plate mounting screws do not interfere with drive belt during either installation or operation.

Motor Selection. As was noted in Chapter 5, the same stepper motor used with the horizontal positioning system is used on the vertical positioning system to minimize the

number of different parts needed to complete the robot system. Thus, a size 34, one stack, 1.8° (200 steps/revolution) stepper motor from Anaheim Automation is used to provide power to the vertical positioning system.

Variable Vertical Travel Capability

One weakness of the first vertical system design is that the robot's vertical travel can not be changed easily. On the first prototype, the Z mast rises at an angle to the vertical, so that it intersects with the vertical drive belt at the top end of the Z travel. Mounting holes are drilled in the mast at a specified offset so that the mast attaches to the Z platform at the required angle. Thus, a separate mast mounting arrangement must be designed for each desired travel. (The lengths of the vertical shafts and drive belts also must be altered, but these are simple changes).

The UT Robot's Z mast assembly is shown in Figure 6.5. The mast mounts upright with respect to the Z platform, regardless of the desired travel. The lengths of the mast, vertical tubes, and drive belt can be sized to the travel needs of each customer. The Z mast mounting configuration is identical for all travel lengths. No changes, other than with part lengths, are required to change the travel. The selectable travel feature, however, does require an increased number of parts at the top of the mast. This disadvantage is mitigated somewhat in that these parts are also used for other purposes (discussed below).

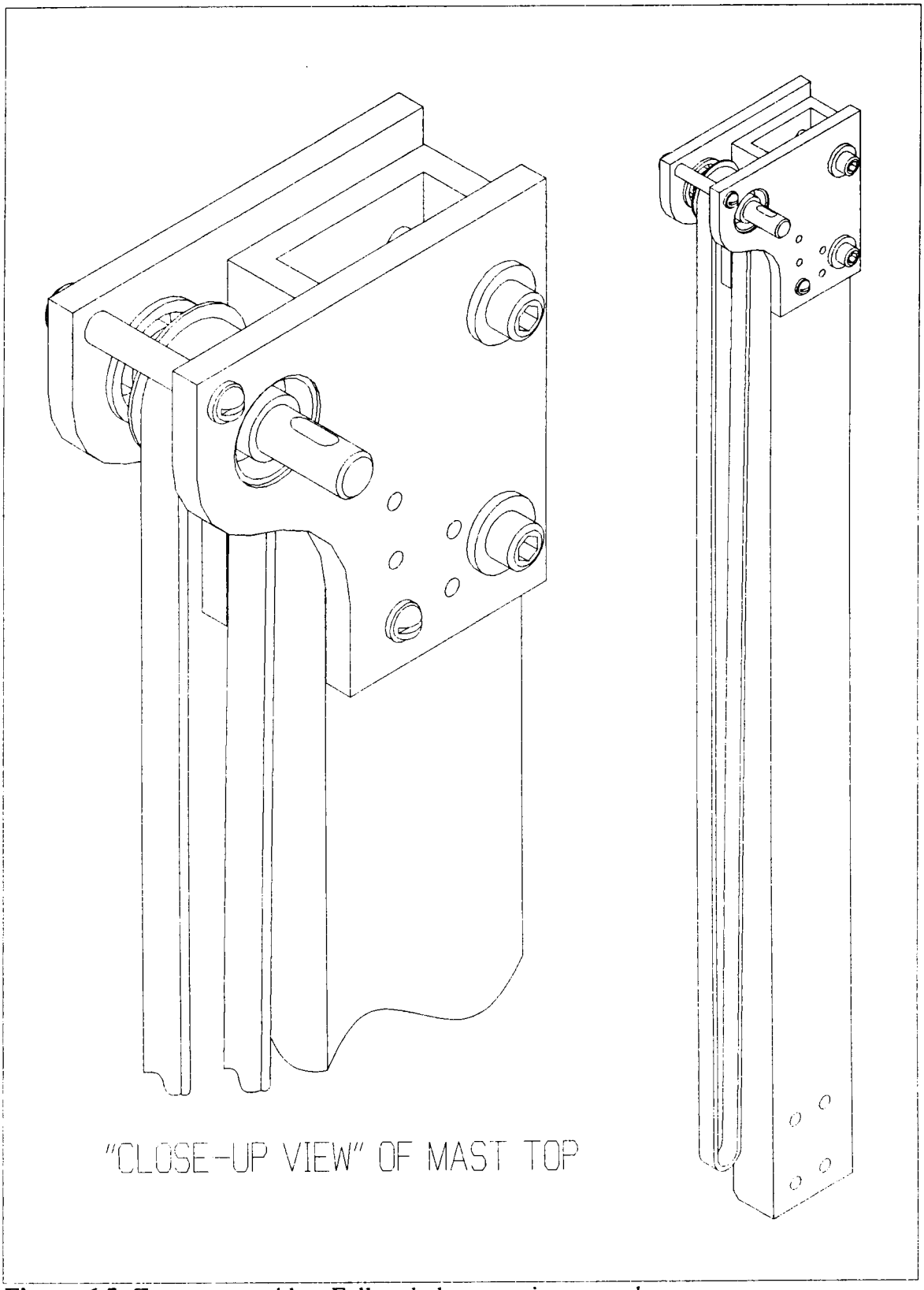


Figure 6.5: Z mast assembly. Full and close-up views are shown.

Position Verification System Design

A proposed vertical axis "position verification system" is shown in Figure 6.6. The system utilizes the same "encoder-style" scheme that is proposed for the horizontal systems. As shown in the figure, the device is installed at the top of the Z mast, so that it can detect not only motor positioning errors, but also drive and reduction belt failures. Although the verification system has not been mounted to the UT Robot prototype, provisions have been made in the mast design for its future attachment. The idler shaft of the prototype is extended through to the outside part of the mast assembly to position verification system calibration disc. M.S. student Anthony Williams will install the actual mounting hardware for the position verification system.

Vertical Positioning System Lock Design

The mounting of a proposed vertical system locking mechanism is also shown in Figure 6.6. The purpose of the lock is to hold the arm in position on any detected error, power outage, or unanticipated program termination. A solenoid-activated ratchet and pawl arrangement is suggested. The ratchet would be attached to the Z idler shaft at the top of the mast. The pawl, actuated by the solenoid, would be mounted to the side of the Z mast or mast plate, and would engage to lock the drive system in place upon any detected error. M.S. student David Paulus is slated to install the actual mounting hardware for the Z arm system lock.

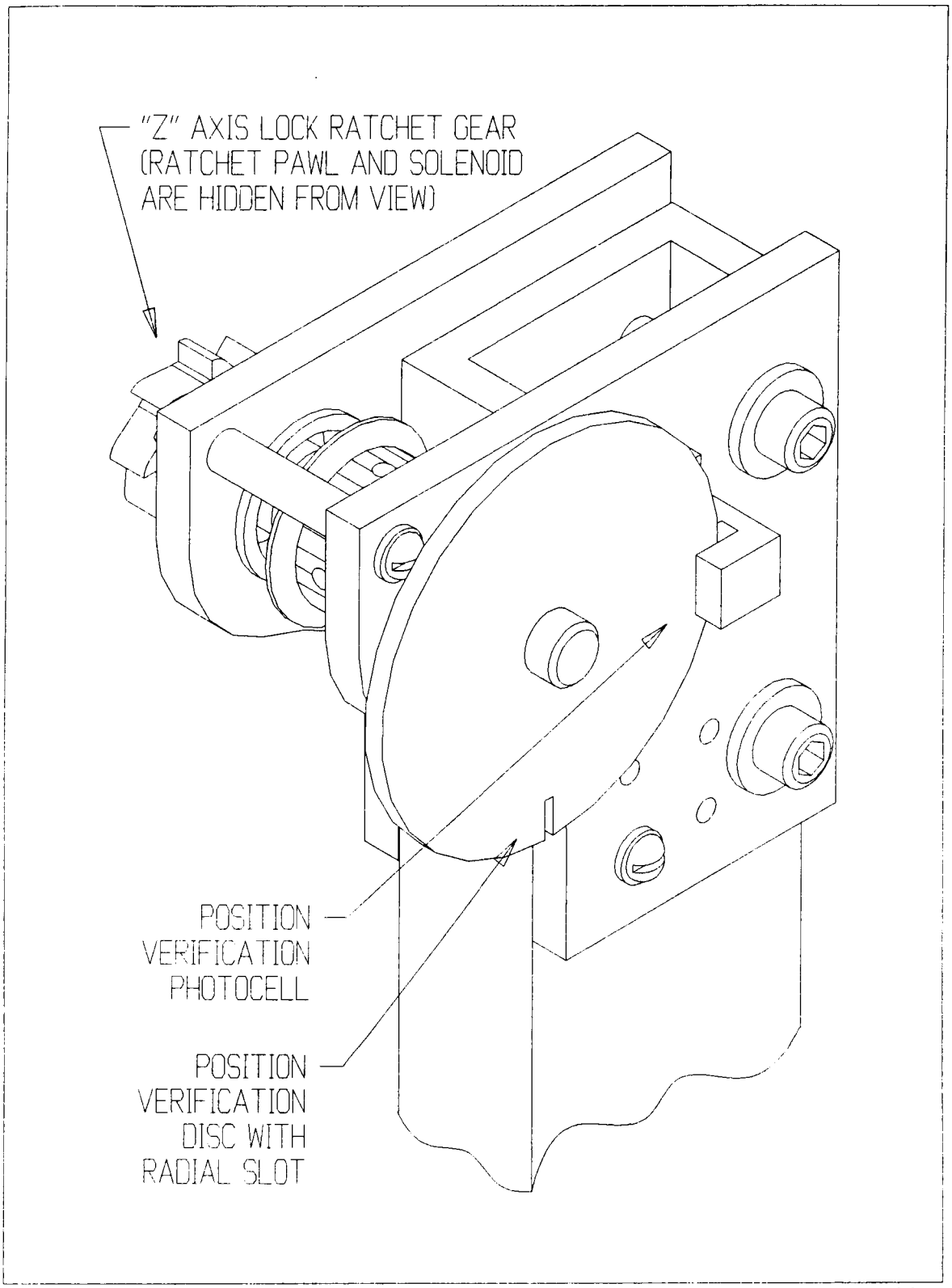


Figure 6.6: Proposed Z mast assembly. Proposed assembly features a position verification system and a mechanical system lock.

New Z Drive Belt Tensioning Adjustment Design

In addition to having poor capability for adjusting the vertical travel, the first robot prototype does not have a good method for tightening the Z drive belt. Tension on the first prototype's continuous belt is adjusted by rotating the mast about its Z platform attachment, then tightening the mast attachment screws. While this method worked adequately on the prototype, the method is not desirable for the production-level product.

The robot's improved method for tightening the Z drive belt is shown in Figure 6.7. The mast plate and idler pulley assembly can rotate about the top mounting screw in the mast. As shown in the figure, there are five small holes in the mast plates into which a long screw can be inserted. The corresponding holes in the mast plates are offset from those in the mast to provide five different tensioning positions. The belt is tightened by rotating the assembly upwards until the long screw can be inserted into the nearest set of mast-mast plate holes. The larger mounting bolts are tightened to complete the procedure.

The primary advantage of the new attachment method is that it does not rely on friction to hold the adjustment in place. The tension setting is "locked in" by the screw that is inserted through the mast and mast plates. The setting cannot slip over time as can friction dependent attachments.

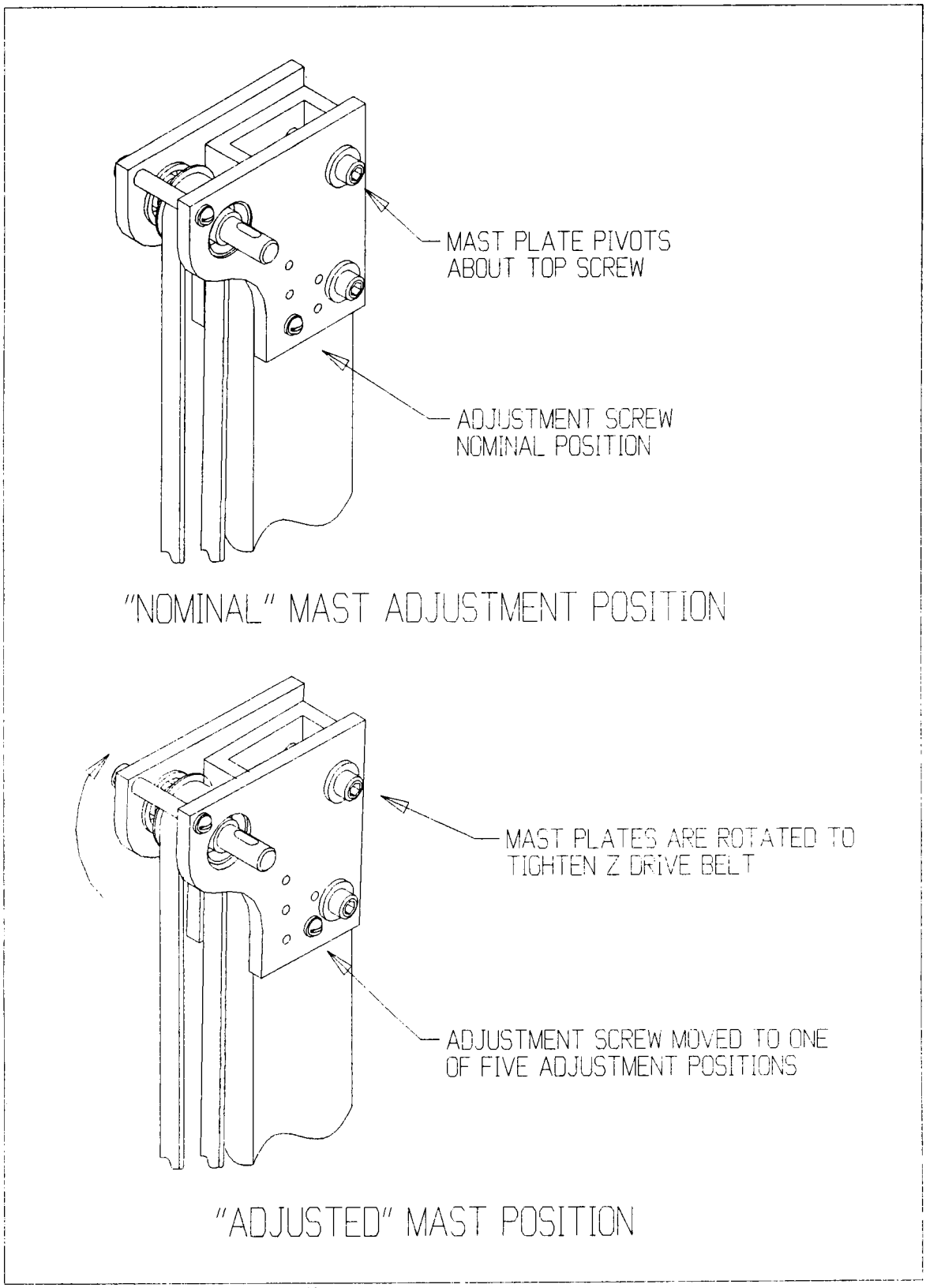


Figure 6.7: Z belt tension adjustment.

Larger Z Guide Shaft

The new UT robot's vertical positioning system utilizes a larger-than-original 1.00" diameter guide shaft. Even though the larger shaft does provide some additional lateral stiffness, the primary motivation of this change is to use a vendor-supplied case hardened tube of sufficient inside diameter to accommodate the necessary theta system components. The case hardened shaft was dictated from experience on the first robot prototype which showed that a hardened shaft was necessary to prevent the linear bearing from indenting the guide tube. The tube vendor also cuts the axial groove used to restrain the tube's rotational motion.

Rotational Positioning System Design Features

The design of the rotational positioning system is a significant departure from the first prototype, even though it retains much of the appearance of the original. The new configuration was required to address the capability, assembly, and operational difficulties that were revealed during the UT Robot assessment discussed in Chapter 4.

Higher System Torque

A larger motor has been installed on the UT Robot to triple the torque of the rotational positioning system. The larger torque is required to restrain loads that are offset from the centerline of the theta motion system.

Design for Assembly / Reduced Part Design

The UT Robot design has significantly fewer parts in its than does the first prototype machine. Additionally, the new configuration assembles much easier than the first prototype by eliminating some difficult-to-install parts.

Increased Stiffness

The UT Robot's rotational positioning system features a "tighter" design with less backlash than the first system. The motor torque is transmitted through a roll-pin generated press fit to minimize backlash in the rotational system. Lateral stiffness is enhanced by increasing the spacing of the bearings used to support the system. Vertical direction backlash can be nearly eliminated during assembly.

Increased Modularity

The theta system has been redesigned so that all rotating parts (except for the theta motor itself) can be constructed as one assembly. The system can be assembled and evaluated independently of the other systems, although it should be noted that the tube lengths are dependent on the required vertical travel specified for the robot.

Rotational System Design Considerations

The design of the rotational (theta) positioning system was somewhat more difficult to complete than was the design of the other positioning systems, primarily because the new theta system design is greater departure from the first system design than that which

occurred with the other systems. Also, the rotational system design interacts strongly with the Z system design, so proposed elements for the theta system had to be considered also within the context of its impact to the vertical system design. As with the vertical system, much of hardware had to fit in a small space, so parts layout was a constant concern. Finally, the new product goals outlined in Chapter 4 and assuring that the parts could be manufactured and assembled economically need to be considered. Some of the concerns related to the completion of the new rotational system design are discussed in the following sections.

Low-Volume Production Design

The rotational positioning system design is also adapted to the low-volume production strategy outlined earlier. Sand casting was used for the theta motor mount and end effector mount parts as it is quite economical for a very small number of parts. Most other parts of the theta assembly are "as-is" or modified commercially-available components.

Need For Higher System Torque

The rotational system torque on the new UT Robot is tripled over that of the first prototype. A "triple-stack" motor has been installed on the new machine to increase the robot's capability of picking up "offset loads". This serious problem can occur when the end effector's and payload's center of mass lies off-center from the center of the Z guide

tube. When the robot is accelerated in a horizontal direction, a large restraining torque can be necessary to keep the load in the desired orientation (Figure 6.8).

The "triple-stack" motor is taller than the first prototype's motor, so that the Z mast length had to be increased so that the new motor would not strike the mast assembly. The "offset" problem can be reduced by limiting the permitted acceleration in the horizontal direction.

Design Impact on System Stiffness

The new theta system design eliminates several earlier performance problems that were observed with the first prototype. The result is a "tighter" design that contains less system backlash than the first prototype system. For example, the first machine used a tongue-in-groove scheme to transmit the motor torque to the end effector. A small clearance is needed to install the parts, and this clearance causes backlash in the theta system. In the new design, the motor torque is transmitted by a roll pin in a groove. The roll pin contact generates a press fit to minimize the backlash in the connection.

The lateral stiffness of the new system is also enhanced by increasing the spacing of the radial bearings. In the new design, the bearings are located at each end of the Z guide tube, rather than close together at the bottom, as was the case in the first prototype design.

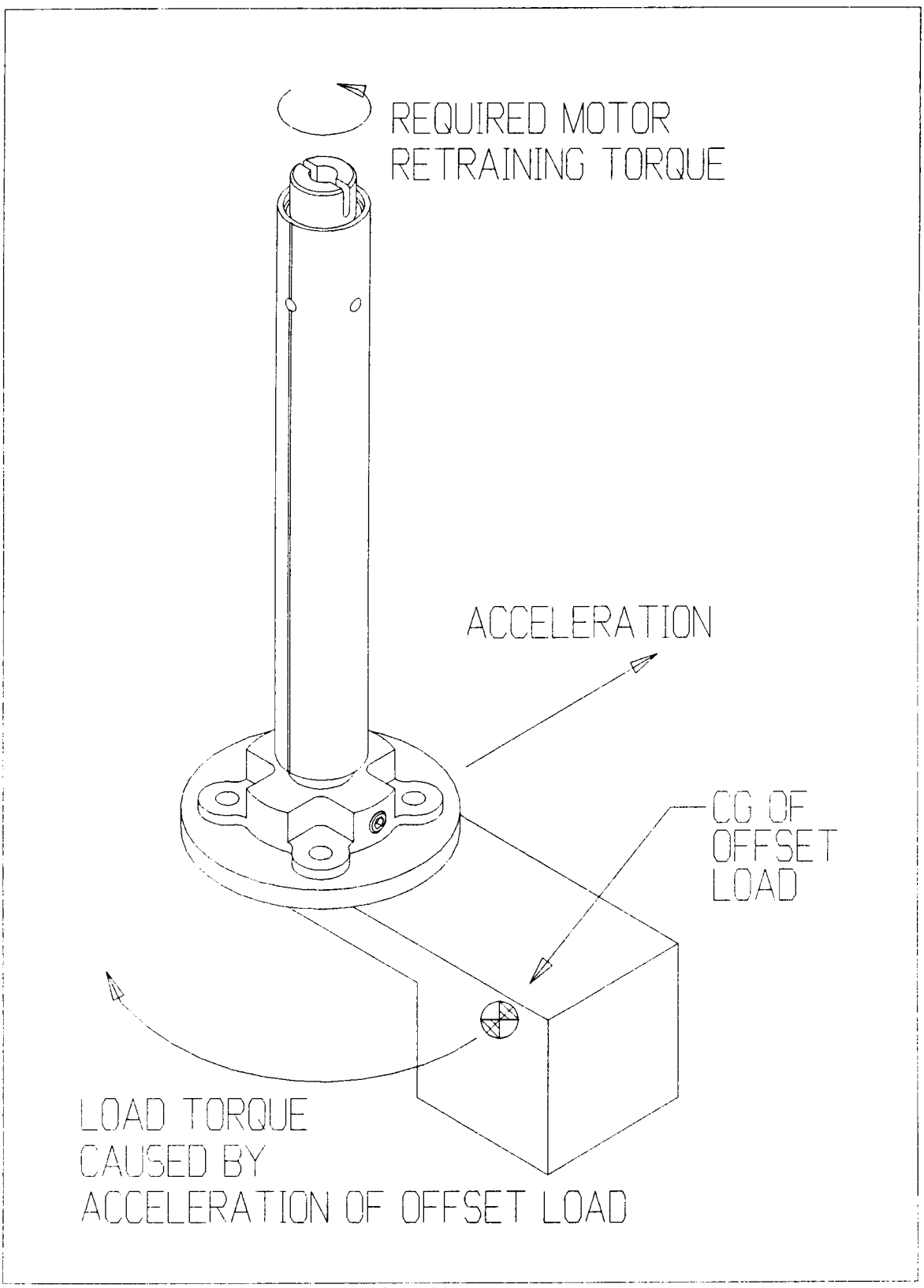


Figure 6.8: Theta system offset load problem.

As was shown previously in Figure 6.4, a shim stack is required to accommodate tolerances in the manufacture of theta motion assembly system parts. The shims are inserted between the end effector mount and the lower bearing to remove any vertical clearances that may exist between the inner shaft and outer shaft portions of the assembly. Vertical direction backlash can be nearly eliminated during assembly with the proper shims. The part dimensions are established such that the proper assembly can be achieved with the shims even with the "worst-case" tolerance.

Theta Motor Loading

A prime consideration in the design of the new theta system is to assure that the theta motor in not overloaded in the axial direction. For example, it is undesirable to connect the end effector mount directly to the motor because the motor bearings would have to carry the entire vertical load (payload, end effector weight, etc.). At the same time, the system must not be overconstrained such that the bearings are overloaded when the system is assembled.

In both the first prototype and current designs, the theta system is constructed so that the motor bearings need only support a few lightweight components and is not overloaded at assembly. The new design puts a roll pin through the motor shaft, then inserts the pin into a groove to drive the theta rotation. The payload and equipment weights are carried by the radial bearings in the theta motion assembly, not by the motor.

Modularity

The theta system is now designed so that all rotating parts (except for the theta motor itself) can be constructed as one assembly. The system can be assembled and evaluated independently of the other systems, although it should be noted that the tube lengths are dependent on the required vertical travel specified for the robot.

The theta assembly can be tested independently by attaching the theta motor mount and theta motor to the top of the Z guide tube without inserting the tube through the Z platform.

Design for Assembly / Reduced Part Design

One key reason for developing a revised configuration was to eliminate the assembly problems inherent in the first theta system design. One way that this is accomplished is to reduce the number of parts in the assembly. For example, the internal snap rings used in the first design were difficult to assemble. The new design features machines diameters inside the Z guide tube so that the snap rings are no longer needed.

The parts reduction did have one slightly negative impact, however. Whereas in the first design the weight loads are supported by the larger Z guide shaft, the weight loads in the new theta system must be supported by the much smaller theta transmission shaft.

Impact on the Vertical Positioning System

As noted throughout this chapter, the vertical and rotational positioning systems are quite interrelated. Since the theta system is "carried" by the vertical system, any part weight increases in the theta system (such as the larger theta motor) adversely affect the vertical system. Part layouts had to be examined carefully to avoid inter-system interferences, such as assuring the theta motor cannot strike the Z mast assembly.

Perhaps the biggest inter-system effect, however, occurred in the diameter selection for the Z guide tube. A case hardened surface is needed on the outside surface so that the linear bearing will roll well on the tube. The ball groove, needed for rotational restraint but part of the vertical system, is a special manufacturing operation best performed by the bearing and shaft vendor. The tube's inside diameter must be large enough to accommodate the theta transmission tube, but the small inner diameters provided on the vendor's tubing selection necessitates a larger diameter tube. A larger tube for the theta system then increases the weight to be carried by the theta system. Several deep inter-dependencies like the one described occurred in the design of the vertical and rotational systems.

Theta Design Alternatives

The rotational design selected for the new UT Robot was not the only alternative that was considered. One other option was to retain the first design, but modify it slightly to solve

some of the assembly problems that occurred with the first machine. Another, and most extreme, option totally changed the system configuration.

The radical alternative was a most interesting concept that would have moved the theta motor off of the moving part of the Z arm. Instead, the motor would be mounted to the Z platform, and would drive a gear or pulley to rotate the Z platform's linear bearings, which would then rotate the Z guide tube. The rotational resolution and torque could be selected by adjusting the gear or pulley sizes. The robot's allowable payload could be increased, since the theta motor weight would not have to be lifted by the vertical positioning system. Finally, the assembly problems experienced with the first prototype would be eliminated since no parts would have to be installed inside the Z guide tube.

The radical design option had several dramatic benefits, but had its share of problems. Since the design was totally unproven, there would be significant design risk in making a complete configuration change. To complete the design, several large, thin bearings would be required, and early estimate indicated that they might be quite expensive. Finally, the new configuration had not been totally developed and was somewhat complex, and it was feared that an "unsolvable" problem could occur later in the design. Thus, it was concluded that a more conservative design should be chosen.

Several unsuccessful attempts were made at improving the first design without making any major modifications. The basic approach of the first design, that of putting the motor

on the top of the Z system and transmitting torque through the Z guide tube, was obviously retained in the new rotational system.

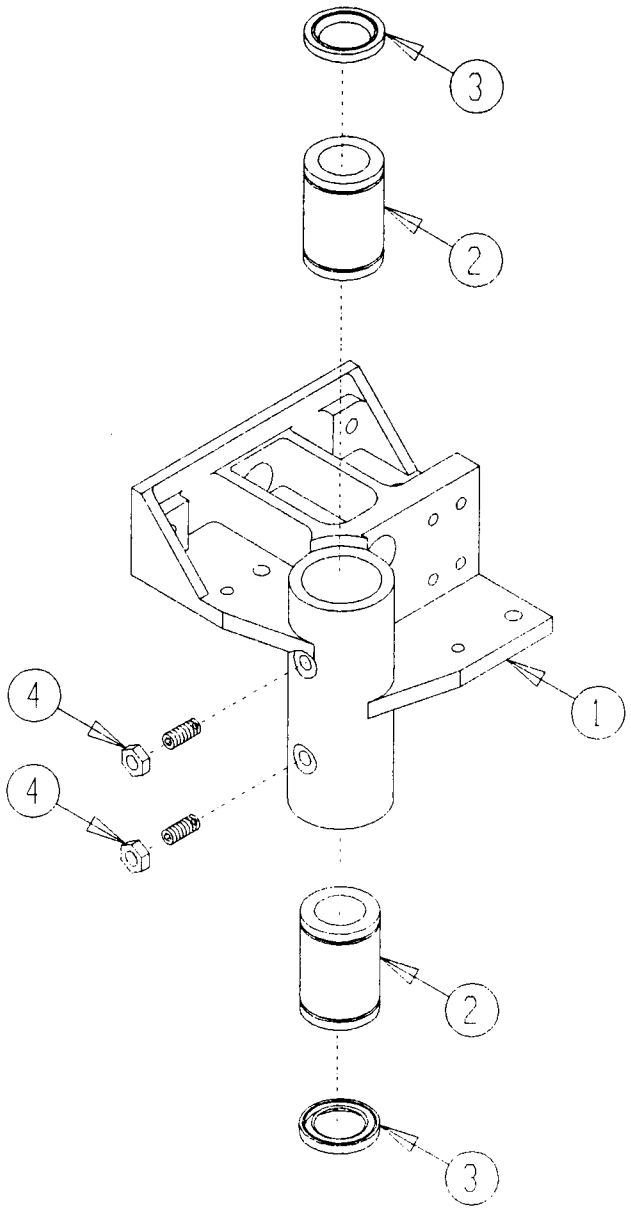
Parts Design And Manufacture

Z Platform

Design. The vertical system's Z platform, part number MEK071, is shown as part of the Z platform assembly in Figure 6.9. This part is the major structural support for the vertical system, holding the vertical system motor, reduction drive system, the Z mast, and restraining the Z guide shaft. The platform also provides the vertical system attachment to the horizontal positioning system.

A cylindrical bore in the Z platform holds the Thomson brand "SUPER" bearings that are used to guide the Z guide tube. Two threaded holes in the side of the bore hold the bearing adjustment screws used hold one bearing ball track in the Z guide tube's ball groove. The mast attaches to the platform using the four long screws that thread into the wall of the platform. The Z system's reduction drive system mounts to the horizontal bearing holes near the top of the platform. The Z motor assembly attaches to the platform's back wall with two screws.

Manufacture. The Z platform is machined from aluminum alloy castings that are made from the pattern and holder arrangement depicted in Figure 6.10. The pattern is quite



ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK071	PLATFORM, Z-THETA
2	2	VEN403-100	BRG, LINEAR, "SUPER", 1.00 TUBE
3	2	VEN402-100	SEAL, LINEAR BRG, 1.00 TUBE DIA.
4	2	VEN404	ASSY, SCREW ADJUSTING

Figure 6.9: The Z platform assembly.

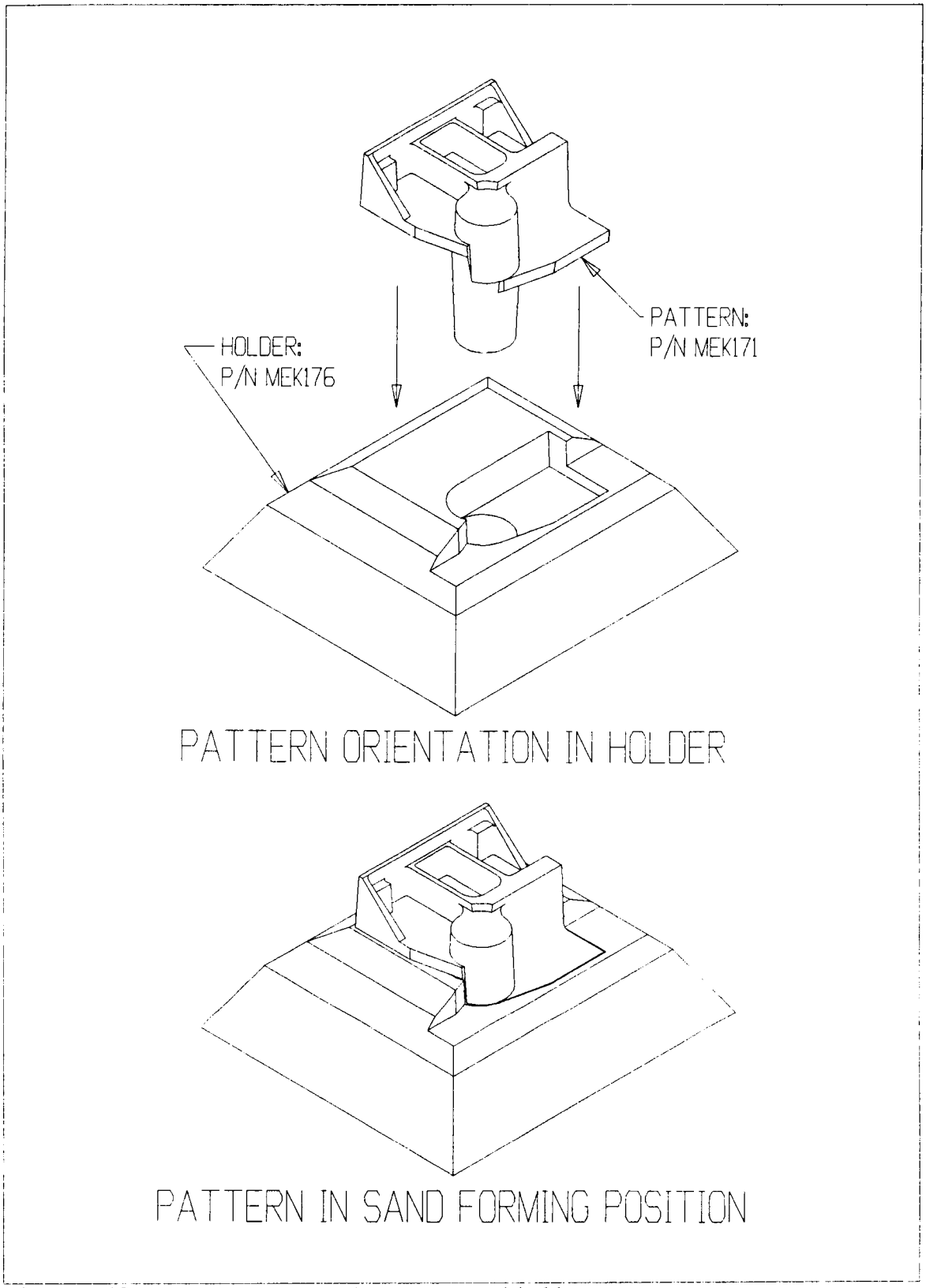


Figure 6.10: The Z platform casting pattern and holder.

complex, reflecting the diverse design functions of the Z platform part. The pattern has a complex parting line, which necessitates the steep slopes which can be seen in the pattern holder. The outer contour of the pattern holder is used to facilitate the casting process.

The casting is machined on the CNC milling machine in the Flexible Manufacturing Center. The long bore for the linear bearings is too long to be performed on the automated mill, so it is performed in the standard machine shop. A "starter" hole is drilled automatically on the CNC mill to assure that the bore is located accurately.

Theta Motor Mount

Design. A view of the theta motor mount is shown in Figure 6.11. The theta mount hold the theta stepper motor in place, provide a mounting for the Z drive belt, and mounts to the Z guide tube. The extended flanges at the bottom of the part also serves as the lower endstop for the vertical positioning system.

Manufacture. The theta motor mount is cast from the casting pattern shown in Figure 6.11, then machined on the automated CNC mill. A pattern holder is not needed, since the parting line runs along the top of the casting.

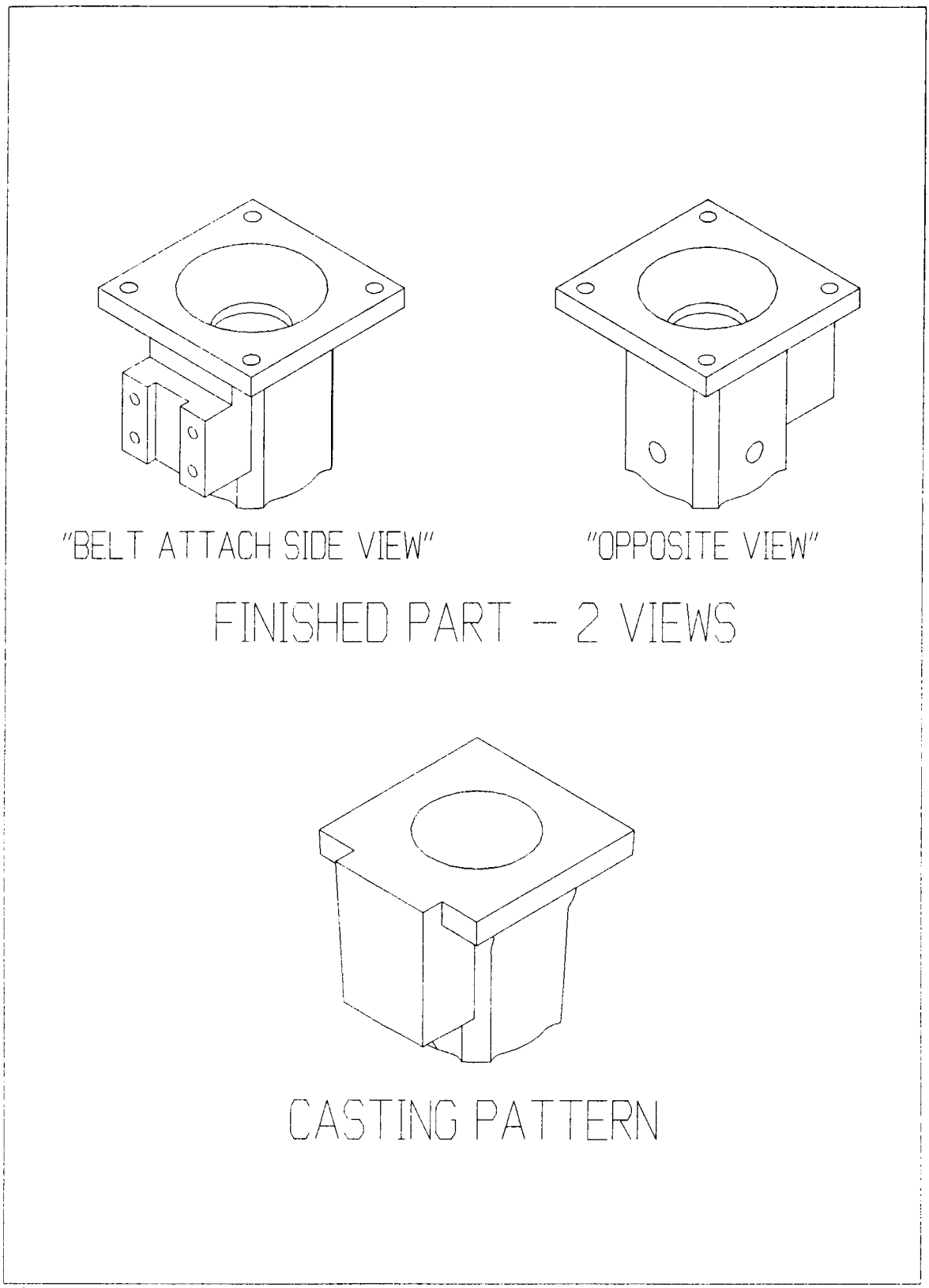


Figure 6.11: The theta motor mount. Finished part and casting pattern are shown.

End Effector Mount

Design. The multiple-function end effector mount ("endmount"), part number MEK231, is shown in Figure 6.12. The endmount has mounting features for any end effector, provides a positive endstop for the vertical system in the upward direction, and transmits vertical and rotational loads to the theta transmission tube.

A flat bottom and four mounting screw holes are provided for attaching an end effector to the robot. The turned diameter at the top of the endmount is sized to conform to the inner race of the theta system's bottom radial bearing. The through hole is sized for the theta transmission shaft to be inserted through the part. Two threaded holes in the side of the endmount accept the half-dog point set screws that secure the endmount to the theta transmission tube. The "plus" shaped extensions on the endmount at the threaded holes provide full thread engagement for the dog point screws and also serve as the upward direction endstop for the vertical system.

Manufacture. The endmount is cast from the pattern shown in Figure 6.12, then machined on a CNC mill. No pattern holder is necessary for this casting, since the parting line for this casting resides along the bottom of the part.

Z Guide Tube

Design. The Z guide tube (Figure 6.13) is the major moving part of the vertical positioning system. The tube moves vertically through linear bearings that are mounted

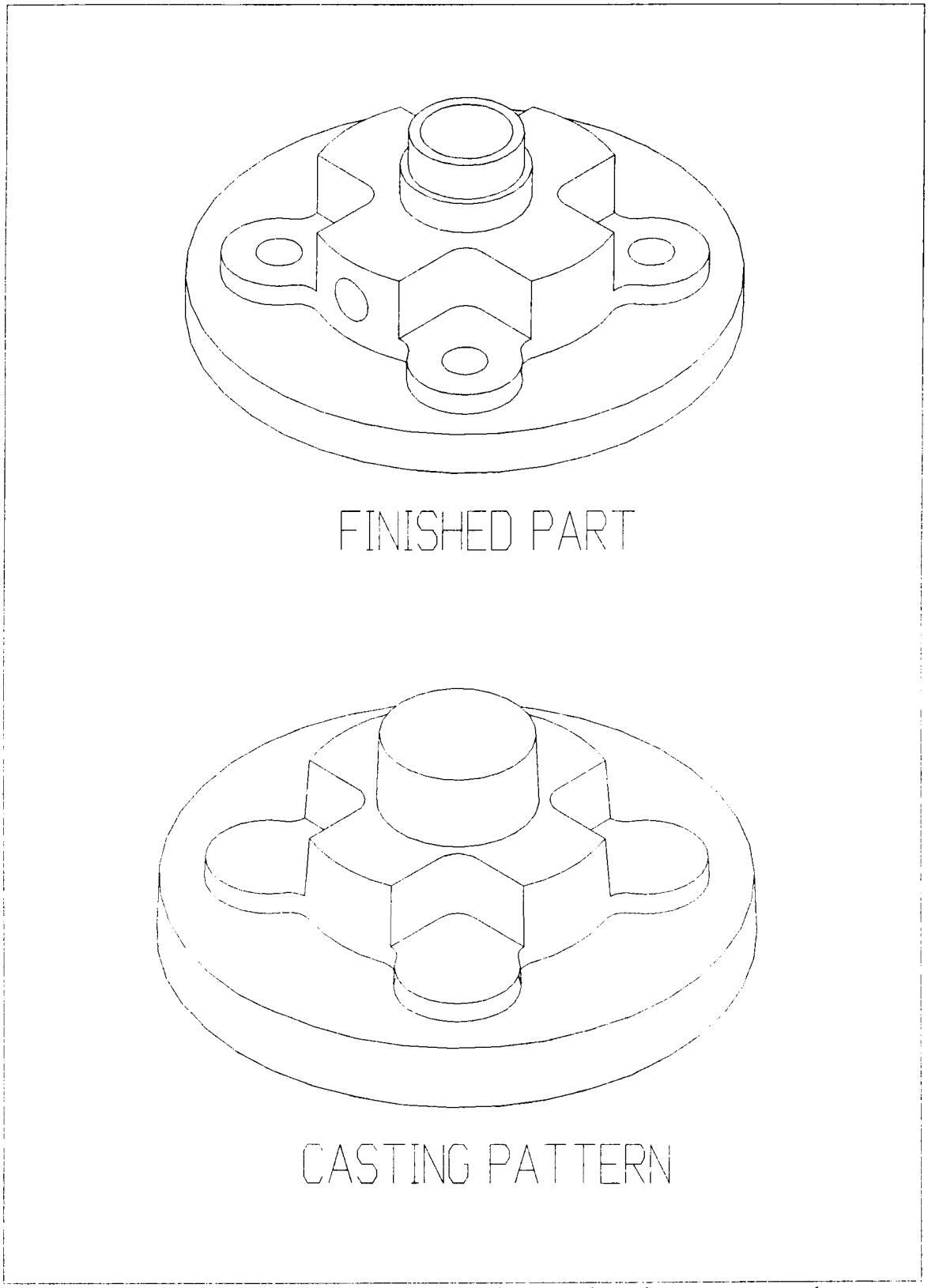


Figure 6.12: The end effector mount. Finished part and casting pattern are shown.

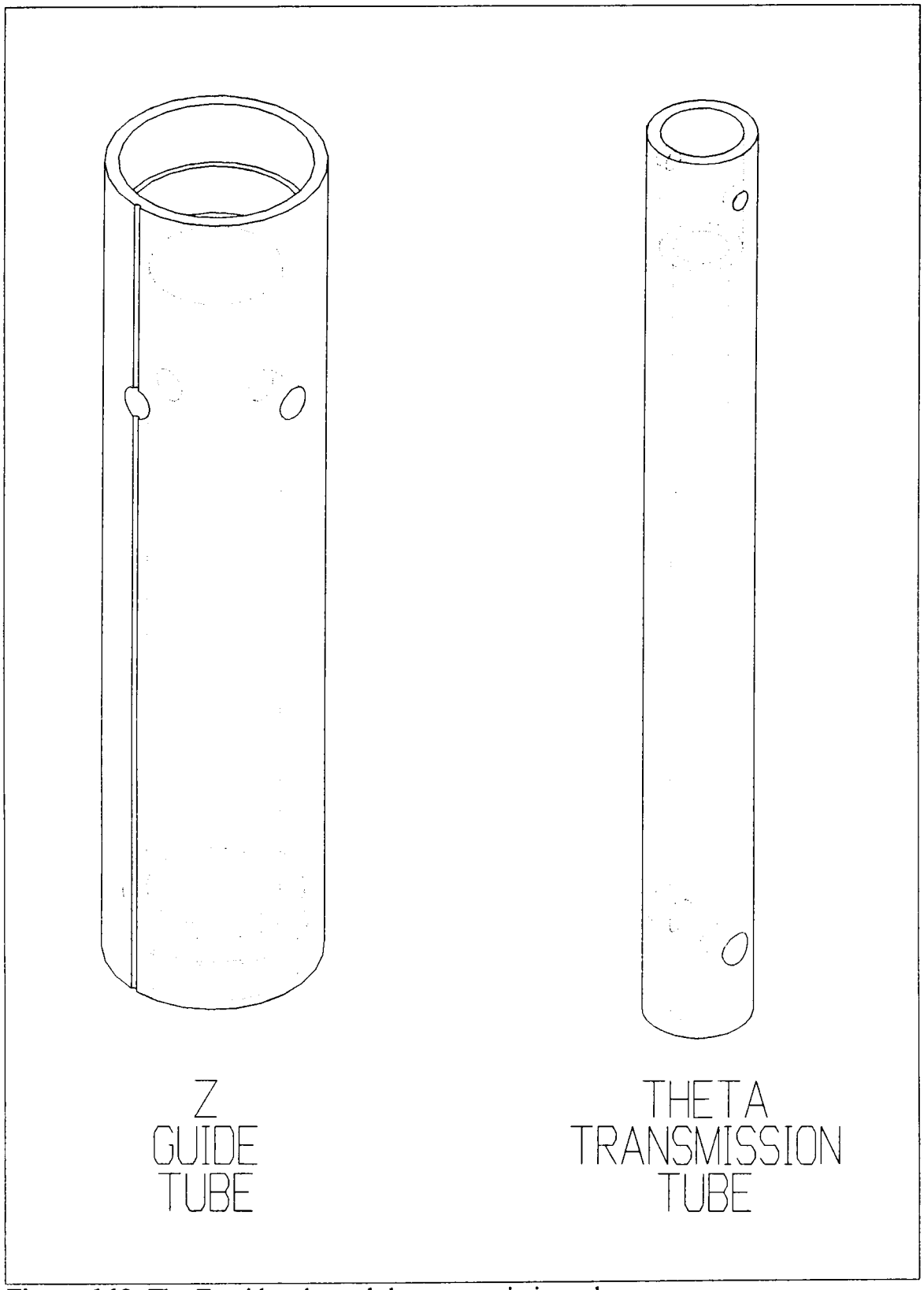


Figure 6.13: The Z guide tube and theta transmission tube.

in the Z platform. A small ball groove cut into the outer surface of the tube mates with a row of ball in the Z platform's linear bearings to keep the tube from rotating. The tube holds two radial bearings, and the top of the tube attaches to the theta motor mount.

The length of the tube depends on the desired vertical travel for the robot. The turned diameters at either end of the guide tube hold the radial bearings used in the rotational motion assembly. The two holes at the top of the tube secure the tube to the theta motor mount by accepting the points of two half-dog set screws that are screwed into the theta motor mount.

Manufacture. The case hardened and pre-grooved shaft is purchased from Thomson Industries, which also supplies the linear bearings. A lathe is used to cut the needed radial bearing mounting surfaces. A carbide drill is used to drill the holes at the top of the shaft that for dog-point hole at top of tube. Some care must be exercised not to "crack" the case hardened surface of the tube during machining.

Theta Transmission Tube

Design. Figure 6.13 also provides a view of the theta transmission tube, P/N MEK216. The primary purpose of this tube is to transmit the rotary motion of the theta motor to the end effector mount, but it must also withstand the weight of the endmount, end effector, and payload. The inside diameter is turned so that the end of the motor-tube converter can fit into it. The small through hole accepts the roll pin that holds the converter to the

tube. The two larger holes at the opposite accept the ends of the half-dog point screws that are inserted into the end effector mount. The tube's length is sized so that it will not extend beyond the mounting face of the end effector mount when it is installed.

Manufacture. The theta transmission tube is machined manually from aluminum tube stock. The inside diameter is turned on a lathe, while the through holes are machined on the mill.

Mast and Mast Plate

Design. The mast and mast plates (Figure 6.14) locate the idler pulley assembly, which keeps the Z drive belt in place. The mast's length can be sized to accommodate different Z travel requirements. The plates do not change when the travel length changes.

The two large holes in the mast and plate accommodate socket cap screws to hold the plates to the mast. The five smaller holes provide the Z drive belt tensioning adjustment, as the holes in the mast are slightly offset from those on the plates so that each hole pair aligns at different orientations. The large round hole in the plate holds the radial bearing used in the Z idler assembly. The smaller hole near the bearing mount accepts a small screw, which is used to hold the idler assembly between the plates.

Manufacture. The mast is made from aluminum square tube stock, while the mast plate is machined from aluminum plate. Both the mast and mast plates are machined

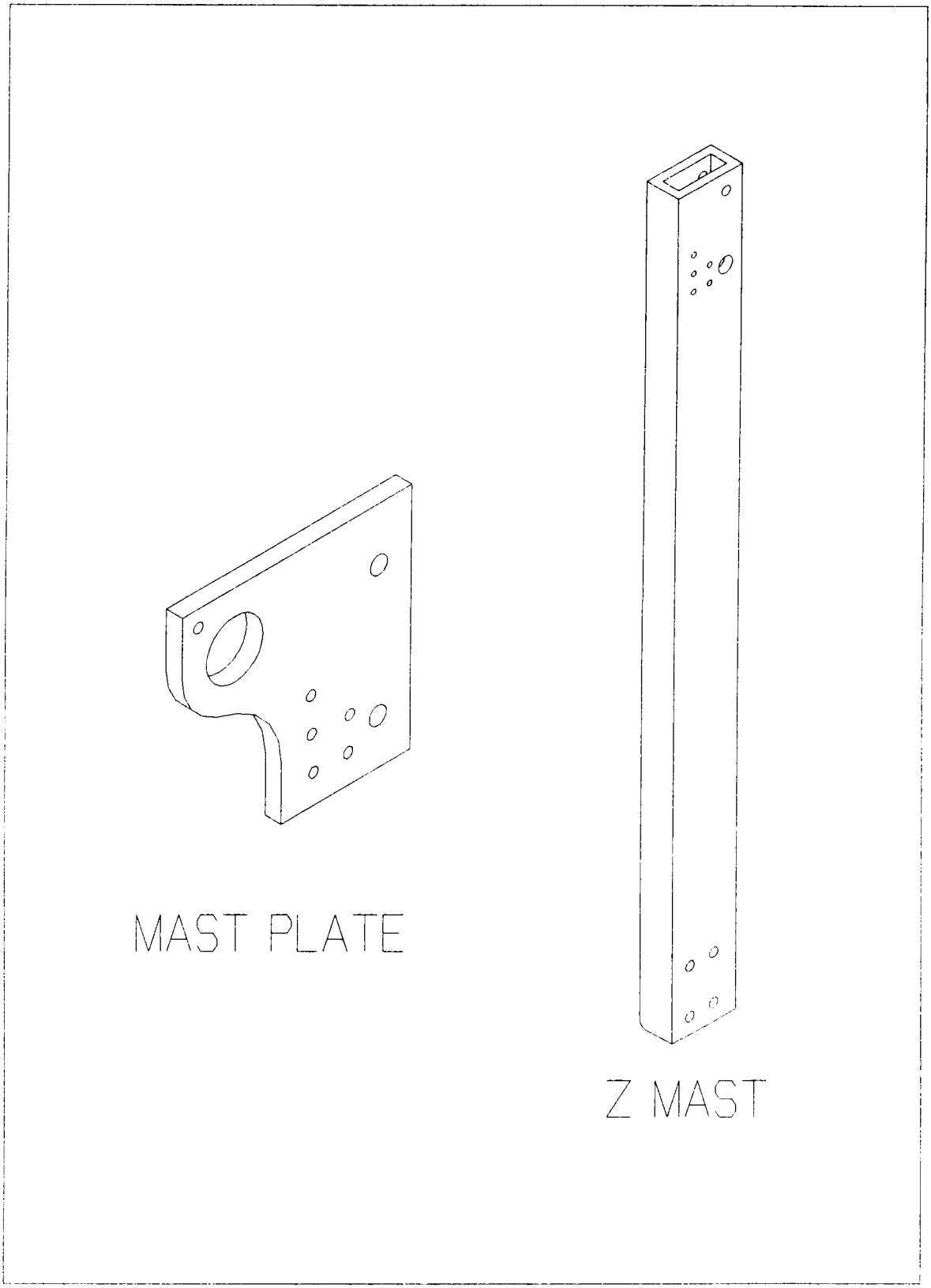


Figure 6.14: The Z mast and mast plate.

automatically on a CNC mill. The mast plates have been designed so that they can be machined in pairs, as shown in Figure 6.15.

Motor-Tube Converter

Design. The purpose of the motor-tube converter (Figure 6.16), as its name implies, is to transmit motor torque to the theta transmission tube. It also supports vertical loads and provides mating features so that it can be inserted into the theta system's radial support bearing. The groove at one end of the converter is designed to accept the roll pin that goes through the theta motor output shaft. The roll pin transmits the torque from the motor to the converter. The through hole at the other end of the converter accepts a roll pin that transmits the torque to the theta transmission tube.

The converter is made from drill rod, because it provides some material toughness for the two roll pin attachments. The turned diameters on the converter are sized to mate with inner race of the top theta system radial bearing, and to fit inside theta transmission tube. The large hole near the groove provides needed clearance for the end of the theta motor shaft.

Manufacture. The motor-tube converter is machined manually from 0.75" diameter drill rod. The needed diameters are cut on a lathe, while the groove and roll pin through hole are machined on a mill.

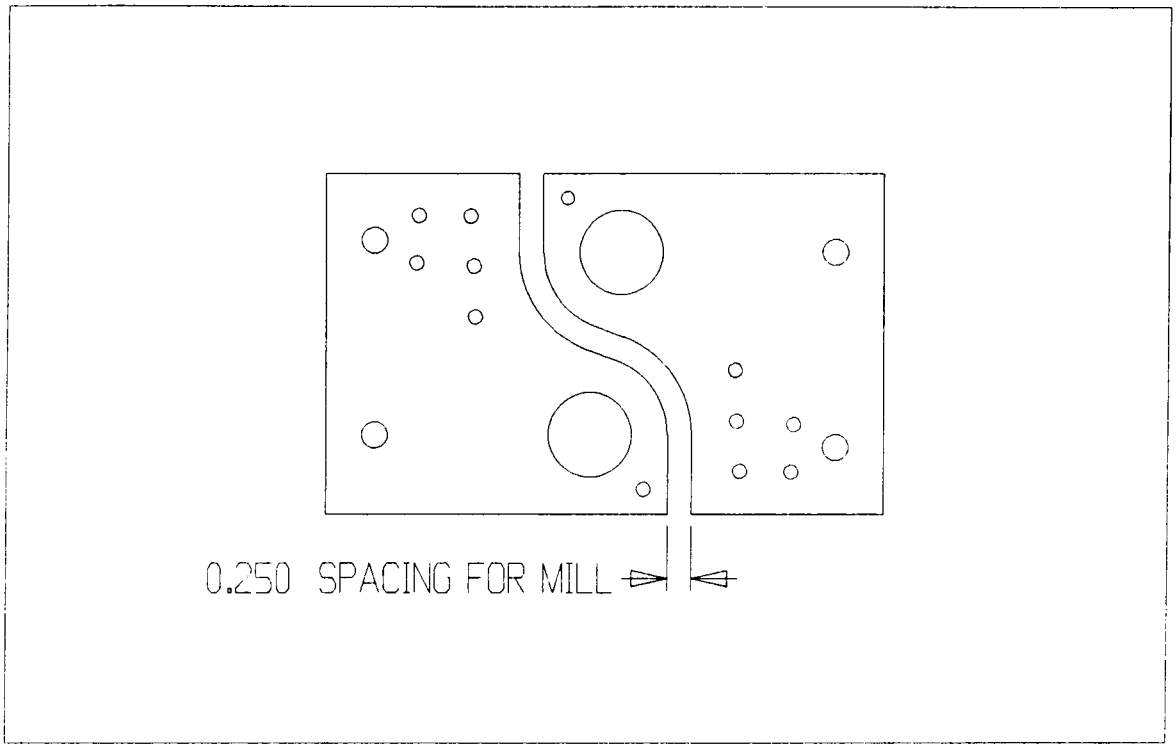


Figure 6.15: Mast plate manufacturing orientation.

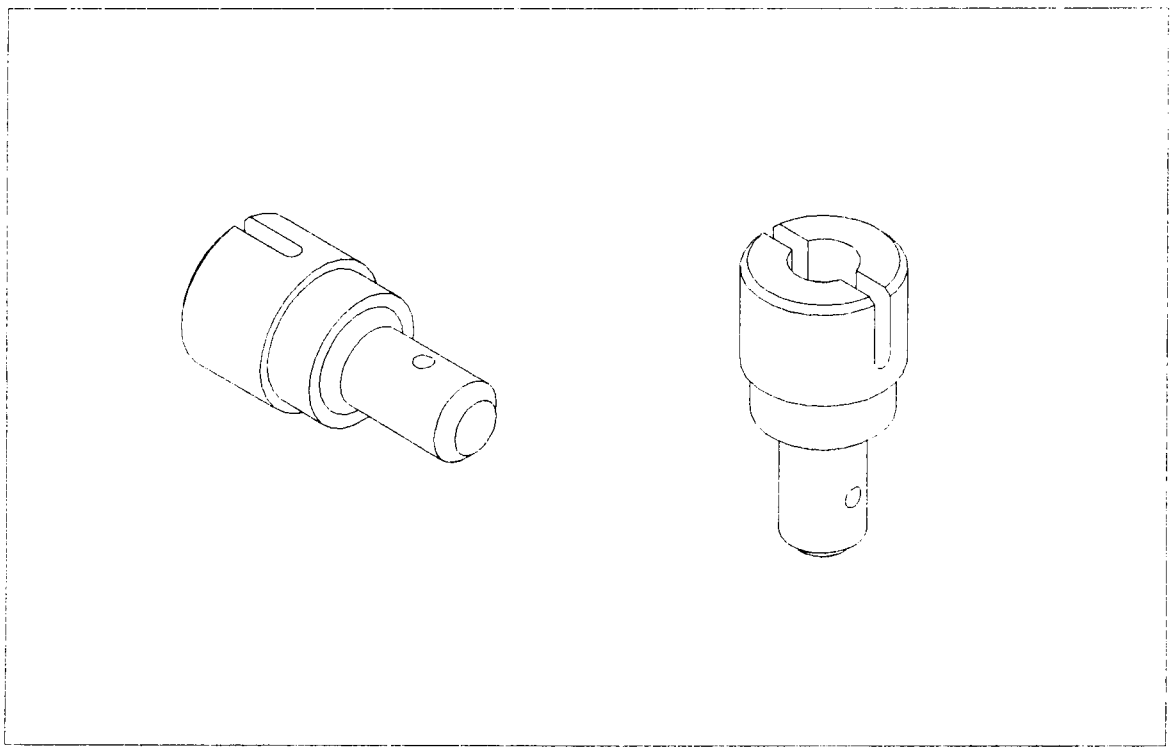


Figure 6.16: Views of the motor-tube converter.

CHAPTER 7

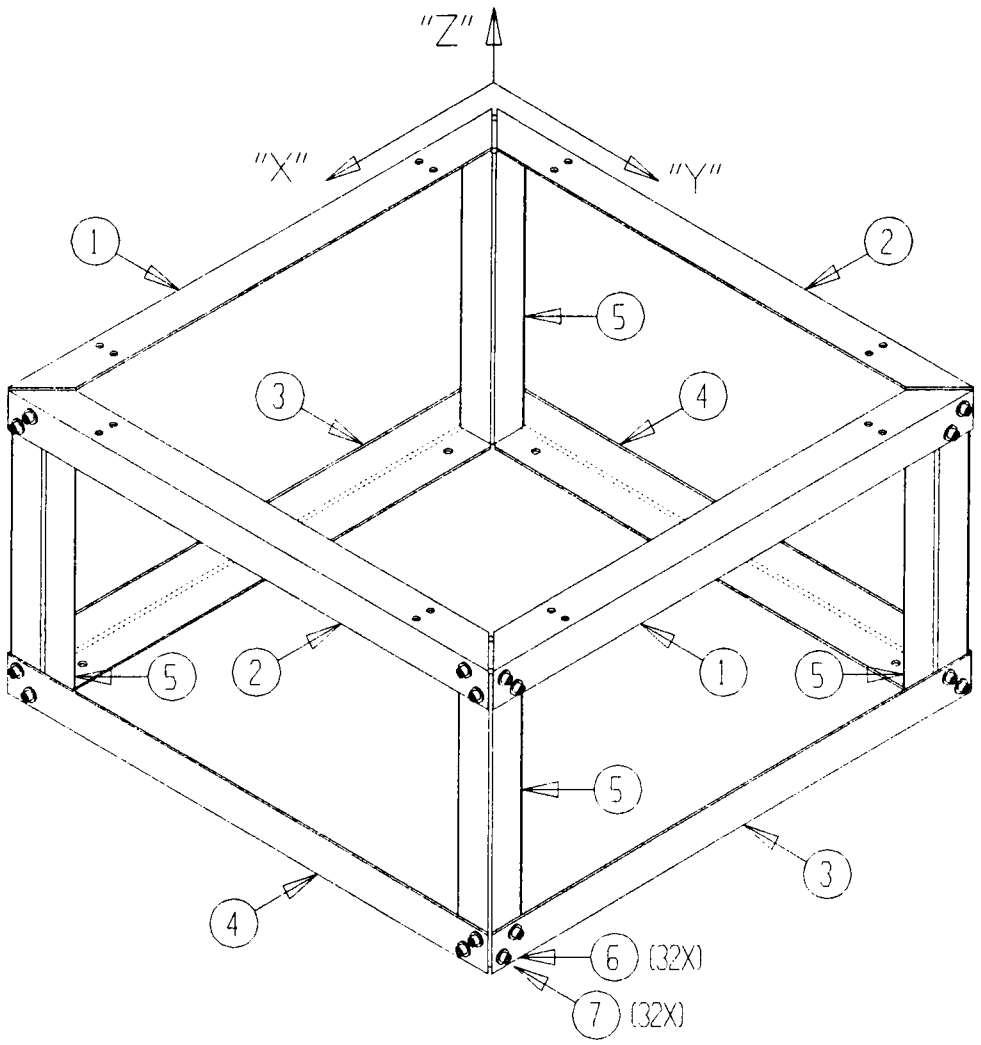
ROBOT SUPPORT FRAME AND CONTROL SYSTEM

Robot Support Frame

Frame Description

The basic configuration of the robot support frame is shown in Figure 7.1. The frame provides mounting holes so that the robot's corner supports can be attached to the frame. The frame is comprised of two basic structural components: the vertical support members are made of 2" square steel tubes with 0.25" walls, while the horizontal support members are made of 2" angle bar with 0.25" thickness. Socket head cap screws are used to hold the support members together.

The design is virtually identical to that used for the first prototype robot, except that the frame members are larger and have a slightly thicker cross-section. The larger cross-sections were selected because they are more commonly-used (and thus less expensive) than the original frame members. The new frame is longer because the travel range of the UT Robot prototype is longer than the first prototype design. The additional frame weight caused by the thicker sections was considered unimportant because the frame is fixed once installed and does not have to be lifted or manipulated by the robot. The additional weight does add some to the final product weight, and hence increases shipping



ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	2	MEK301-XXX	MEMBER, MOUNT, "X" DIRECTION
2	2	MEK302-YYY	MEMBER, MOUNT, "Y" DIRECTION
3	2	MEK303-XXX	MEMBER, BASE, "X" DIRECTION
4	2	MEK304-YYY	MEMBER, BASE, "Y" DIRECTION
5	4	MEK306-ZZZ	MEMBER, VERTICAL "Z"
6	32	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
7	32	VEN487	WASHER, FOR 0.312 SCREW

Figure 7.1: UT Robot frame assembly.

costs slightly, but this increase is likely offset by the "special size" pricing of the lighter members. The extra thickness may also contribute to the perception of the UT Robot as a strong and sturdy machine.

Future Frame Design and Manufacturing Efforts

University of Tennessee mechanical engineering M.S. student Anthony Barrett is developing methods and tooling to automate the manufacture of the robot's support frame. His goal is to weld a complete top frame using the robotic welder located in the University of Tennessee's Flexible Manufacturing Center. It is anticipated that the top part of the frame, that is, the sections that attach to the robot's corner supports, will be the "official" robot frame part number, as opposed to a complete structure like that shown in Figure 7.1. A welded "top" frame will be sufficient to securely mount the horizontal positioning system while providing much flexibility as to how the robot is installed. Any other frame attachments needed to secure the robot will be custom designed to meet the mounting needs of each customer. Barrett's efforts will be described in a future master's thesis.

Motor Control System

As noted in Chapter 4, the robot motion management for new UT Robot is performed by a personal computer (PC) based control program. A general block diagram of the control system is shown in Figure 7.2.

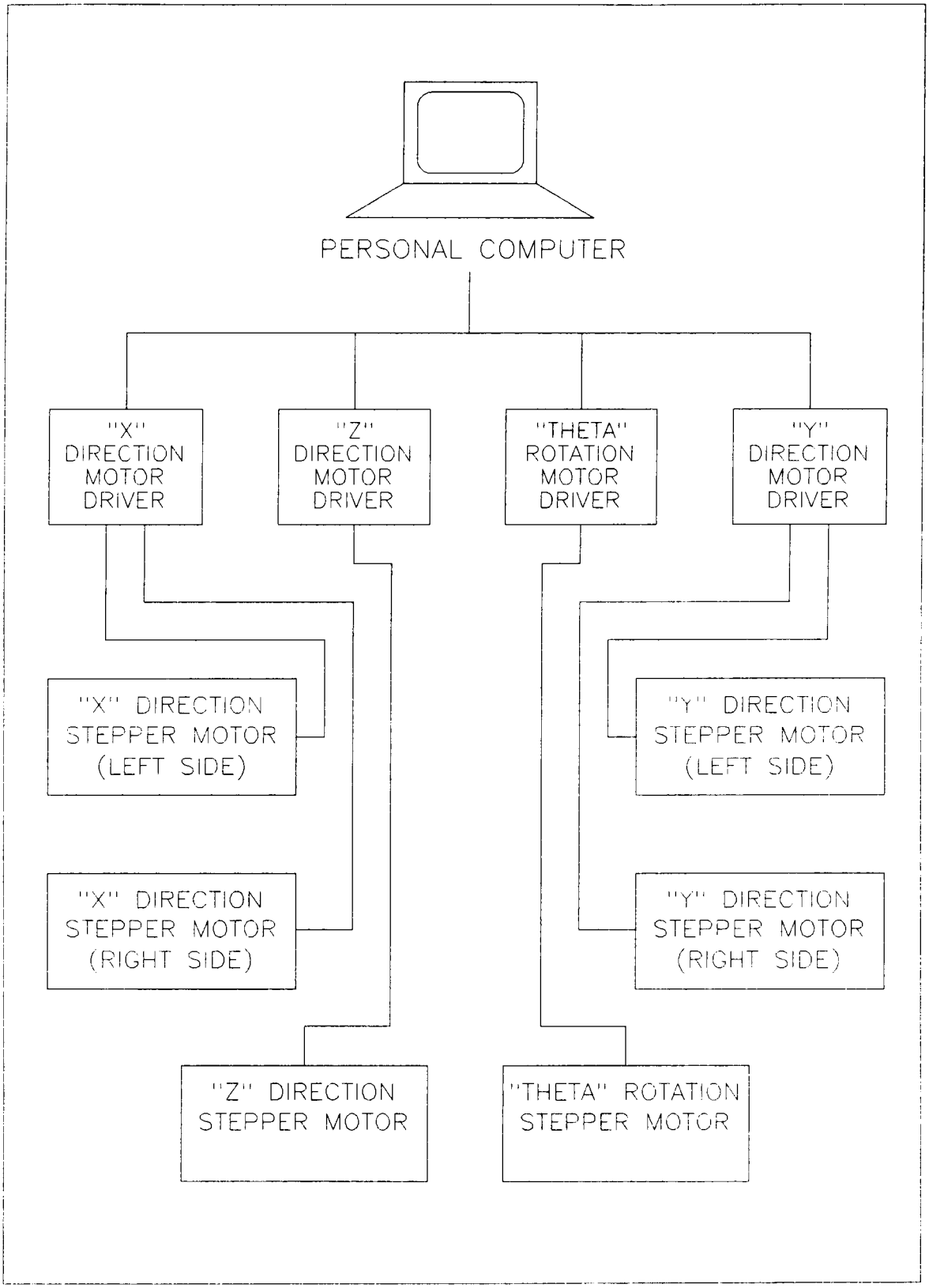


Figure 7.2: Block diagram of the UT Robot control system.

The control software, written by Steven Johnson [Johnson, 1990], runs on the IBM PC. The software provides a menu-based interface to the robot's operator, computes needed motion characteristics, and generates command signals to the stepper motor drivers. Some built-in safety features reside in the software to prevent the user from running the robot beyond its operating range. Using the PC's parallel port interface, the software sends motor direction and step signals to the motor drivers to control the position and speed of the motors. The position of the stepper motor is controlled by the number of step pulses sent, while the motor velocity is regulated by the rate at which the pulses are sent. The new software program computes and controls the robot's motion through these signals.

The stepper motor drivers accept the step and direction signals from the computer, and convert them into the proper motor phase sequence. The phase signals are amplified to the desired motor current to rotate the motor shaft. The drivers control the power delivered to the stepper motors by "chopping" the power at the desired current level. Current limiting is required to avoid overheating the motors. Intelligent Motion Systems (IMS) model IB463 drivers are used on the new prototype.

The external DC power supply is connected to the stepper motor drivers to provide the necessary DC power. A schematic diagram of the electrical wiring used on the new UT Robot is provided on robot assembly part number ASY601, which is in the Appendix.

CHAPTER 8

ROBOT SYSTEM COST ASSESSMENT

Robot System Manufacturing Cost Estimates

The cost to produce the UT Robot has been estimated. Material, processing, and tooling costs have been assessed for the acquisition and manufacture of parts needed to complete the construction of the UT Robot. Assembly costs have been estimated. Cost data has been collected from actual manufacturing experience attained in building the prototype, from knowledgeable estimates, and production volume price quotations, where possible.

The explanation of how costs are derived is an integral part of the analysis, so that the system costs presented immediately below need to be taken in their proper context. Some potentially significant "overhead-type" costs are not included in every analysis. Additionally, the cost of the personal computer and software used to operate the robot is not included in the analyses, unless otherwise noted.

Projected Production Cost

The projected UT Robot production cost, assuming one (1) robot is built at a time and amortizing pattern tool costs over ten (10) robots, is shown in Table 8.1. A 42"x42" horizontal travel, using 1" diameter shafts, and a 24" vertical travel is assumed so that estimated production costs can be fairly compared to those for the constructed prototype.

Table 8.1: Potential production costs for the UT Robot.

CATEGORY		COST ($/robot)
Materials		$2,476.
Processing		$847.
Tooling		$384.
Assembly		$100.
	SUBTOTAL	$3,807.
Motor Drivers & Power Supply		$766.
	SUBTOTAL	$4,573.
Personal Computer		$1,000.
	SUBTOTAL	$5,573.
Development Cost Allowance		$2,400.
	SUBTOTAL	$7,973.
Margin (based on 1.5x factor)		$3,987.
TOTAL.....		$11,960.

Various cost partitions are presented in the summary to obtain perspectives on how costs are generated.

Neglecting the development cost and margins momentarily, the production cost of one robot is estimated to be about $5,573 with a PC, and $4,573 without a PC. The development and margin costs (explained below) represent over one-half of the "theoretical" costs to produce the robot. The materials costs are based largely on the cost of materials for the prototype robot, but since a production batch of one is assumed, costs should be similar. Full cost details for the cost categories of materials, processing, and tooling are available to the analyst with the software developed to perform the cost analysis. Some significant cost details are discussed in subsequent sections of the chapter.

The processing and assembly categories are internal activities performed in the University's machine shop, test lab, of the Flexible Manufacturing Center. The materials, motor drivers, and personal computer are outside supplies that must be purchased to build the robot. The development cost allowance accounts for the cost of two (2) graduate student assistantships, amortized over ten (10) robots. The "margin" value is based on 1.5 times product cost, and attempts to account for other overhead costs not considered, variation in performance, and profit. Using two students in the development cost computation is based on the need to account for already-incurred expenses for software and manufacturing system development. In an actual industrial development project, other development costs not included here would have to be assessed.

Prototype Manufacture Cost

A separate computation was performed to evaluate the costs incurred to build the new prototype robot (Table 8.2). The configuration for the robot is 42"x42" horizontal travel, with 1" diameter shafts, and 24" of vertical travel. The cost of this particular system is larger than the estimated cost of a production robot because more manual (and more expensive) machining was used to make the parts. Assembly costs are not assessed, since the prototype was built as part of the development effort and assemblers were not used. A pattern cost assessment of 10% (amortization over 10 robots) is included in the tooling costs.

Table 8.2: Manufacturing costs for UT Robot prototype.

CATEGORY		COST ($/robot)
Materials		$2,330.
Processing		$2,848.
Tooling		$384.
	SUBTOTAL	$5,562.
Motor Drivers & Power Supply		$766.
	SUBTOTAL	$6,328.
Personal Computer		$1,000.
TOTAL.....		$7,328.

The "basic" prototype cost of $5,562 is about $1,000 higher than was estimated at the beginning of the project. Without the casting pattern allowance, the cost is $209 less, for a total of $5,353. The personal computer cost was not actually incurred, since a lab unit was available, but has been entered in the table to make the prototype cost reflect the cost of a complete product.

Robot Production Manufacturing Cost Assessment

A parts cost assessment was performed for all major components of the UT Robot. The assessment was built on a series of Lotus 1-2-3 worksheets so that certain cost and production parameters can be altered to assess their effects on the robot's costs. Manual, automated (CNC), and combination machining approaches can also be evaluated.

For organizational ease, the analysis was separated into three major part categories:

- custom cast and machined parts ("custom cast" parts);
- parts machined from raw material ("custom machined" parts); and
- slightly modified finished parts ("modified finished" parts).

Custom cast parts are those parts created by custom casting pattern. Custom machined parts are those machined from bar stock, tubing, plate, etc. An example of in the modified finished category would be the purchased motors (finished items) that have a set-screw groove (modification) machined into their output shafts.

The manufacturing parts cost is divided into the three major categories of material costs, processing costs, and tooling costs. Materials costs include the cost of acquiring raw materials, lot charges, minus any quantity discounts. Processing costs count setup and machining time charges for both manual and automated operations. The time rate charges for the various processing activities (setup and machining, manual or automated) can be adjusted in the analysis. Tooling costs account for wear and replacement of standard tools, and, for cast parts, assess part of the cost of the pattern equipment. The number of robots over which the pattern costs are to be amortized is adjustable in the analysis. While not performed in this analysis, the number of robots to be produced at one time (the "lot" or "batch" size) can also be adjusted in the analysis.

Unless otherwise noted in the chapter, the cost of building one (1) robot at a time is considered. Standard machine shop time (setup and machining) is costed at $20.00 per hour, while automated operations are priced at $10.00 per hour for setup activity and $6.00 per hour for machining time.

Custom Cast Parts Cost

Custom cast parts are those which are machined from custom-designed castings. Machining of the raw castings is performed either in the department's standard machine shop and/or in the Flexible Manufacturing Center. The actual casting is performed by a local vendor. Incorporated into the tooling cost of each finished part is a portion of the costs incurred to manufacture the pattern equipment. While the number of robots over

which the patterns are amortized can be adjusted in the analysis, an assumption of ten (10) robots were used in these analyses. The casting pattern ("tooling") cost is computed similarly to the method by which the custom machined parts are determined (explained below).

The projected production cost summary for the UT Robot's cast parts is displayed in Table 8.3. The cost of the castings is based on a part purchase sufficient to build one robot using the already-available "loose" patterns. Machining costs are estimated "production" costs using mostly automated machining operations in the Flexible Manufacturing Center. Actual processing expenses incurred to build the prototype were much higher than the production values because most of the parts were machined manually.

Custom Machined Parts Cost

Custom machined parts are those that are machined or fabricated from "raw" stock, such as tubing, angle iron, and plate. Machining of these materials may be performed either manually in the standard shop and/or automatically in the Flexible Manufacturing Center. Materials are purchased from regional material suppliers.

Table 8.4 shows the estimated costs for producing the UT Robot's machined parts. The estimated "production" cost is based on using automated machining operations where possible.

Table 8.3: Production costs for the UT Robot's cast parts. ($/robot)

CAST PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
Corner Support	4	$193.60	$82.40	$64.70	$340.70
XY Slider	4	$106.80	$56.00	$66.31	$229.11
Bearing Cartridge	1	$58.30	$64.00	$51.73	$174.03
Z Platform	1	$57.25	$80.00	$75.64	$212.89
Theta Motor Mount	1	$11.15	$10.80	$16.73	$38.68
End Effector Mount	1	$7.85	$9.00	$9.93	$26.78
TOTALS		$434.95	$302.20	$285.03	$1,022.18

Table 8.4: Production costs for the UT Robot's machined parts. ($/robot)

MACHINE PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
XY Motor Plates	4	$14.40	$15.00	$11.20	$40.60
Z Plate	1	$3.69	$6.00	$2.80	$12.49
Belt Attach Parts	10	$2.70	$27.00	$7.00	$36.70
XY Red. Shaft	8	$15.36	$48.00	$13.60	$76.96
Z Red. Shaft	1	$4.00	$8.00	$1.90	$13.90
Z Idler Shaft	1	$2.08	$6.00	$1.70	$9.78
Mast Plate	2	$1.89	$9.40	$2.00	$13.29
Z Mast	1	$8.52	$5.20	$1.50	$15.22
Frame Brackets	2	$0.40	$24.00	$2.00	$26.40
Mast Braket	1	$0.41	$12.00	$1.00	$13.41
Hanger Rod	1	$0.60	$2.00	$0.75	$3.35
Frame Rod	1	$1.76	$10.00	$0.50	$12.26
Mtr-Tube Converter	1	$0.38	$46.00	$2.50	$48.88
Z Guide Tube	1	$96.88	$46.00	$4.50	$147.38
Theta Trans Tube	1	$8.82	$36.00	$1.50	$46.32
Frame Mbr, Horizontal	8	$13.44	$128.00	$20.00	$161.44
Frame Mbr, Vertical	4	$31.68	$80.00	$10.00	$121.68
TOTALS		$207.01	$508.60	$84.45	$800.06

Modified Finished Parts Cost

The only parts in this category for the UT Robot are the stepper motors. Table 8.5 shows the cost breakdown for these parts. As opposed to the other two categories, the processing costs here are small compared to the parts costs.

Table 8.5: Production costs for the UT Robot's modified finished parts. ($/robot)

PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
Motor, Rotational System	1	$167.00	$6.00	$2.50	$175.50
Motor, Translation System	5	$559.00	$30.00	$12.50	$601.50
TOTALS		$726.00	$36.00	$15.00	$777.00

Robot Prototype Cost Assessment

Custom Cast Parts Cost

The estimated costs to produce the cast parts for the UT Robot prototype are displayed in Table 8.6. The casting materials cost is based on a part purchase sufficient to build one robot using the already-available "loose" patterns. Machining costs are estimated

Table 8.6: Prototype manufacturing costs for the UT Robot's cast parts. ($/robot)

CAST PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
Corner Support	4	$169.40	$840.00	$64.70	$1,074.10
XY Slider	4	$92.60	$416.00	$66.31	$574.91
Bearing Cartridge	1	$80.35	$320.00	$51.73	$452.08
Z Platform	1	$61.20	$260.00	$75.64	$396.84
Theta Motor Mount	1	$8.70	$76.00	$16.73	$101.43
End Effector Mount	1	$7.85	$52.00	$9.93	$69.78
TOTALS		$420.10	$1,964.00	$285.03	$2,669.13

costs from using entirely manual machining operations. As noted earlier, prototype processing expenses are much higher than that expected in production.

Custom Machined Parts Cost

The estimated costs to produce the UT Robot's prototype custom machined parts are summarized in Table 8.7. Machining costs are estimated using the actual mix of manual and automated machining used to create the parts used on the prototype machine.

Modified Finished Parts Cost

Again, the only parts in this category are the stepper motors. Table 8.8 shows the cost breakdown for these parts. The processing costs are the same as predicted for production since the machining operations are performed manually. The anticipated production costs for the motors are higher than that for the prototype because of recent motor price increases.

Casting Pattern Fabrication Costs

The cost to fabricate the pattern equipment used in the production of the robot's custom castings has been computed using a method similar to that used to assess the cost of parts manufactured from stock materials. A summary of the estimated pattern fabrication costs is presented in Table 8.9.

Table 8.7: Prototype manufacturing costs for the UT Robot's machined parts. ($/robot)

MACHINE PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
XY Motor Plates	4	$14.40	$280.00	$11.20	$305.60
Z Plate	1	$3.69	$80.00	$2.80	$86.49
Belt Attach Parts	10	$2.70	$27.00	$7.00	$36.70
XY Red. Shaft	8	$15.36	$48.00	$13.60	$76.96
Z Red. Shaft	1	$4.00	$8.00	$1.90	$13.90
Z Idler Shaft	1	$2.08	$6.00	$1.70	$9.78
Mast Plate	2	$1.89	$9.40	$2.00	$13.29
Z Mast	1	$8.52	$5.20	$1.50	$15.22
Frame Brackets	2	$0.40	$24.00	$2.00	$26.40
Mast Braket	1	$0.41	$12.00	$1.00	$13.41
Hanger Rod	1	$0.60	$2.00	$0.75	$3.35
Frame Rod	1	$1.76	$10.00	$0.50	$12.26
Mtr-Tube Converter	1	$0.38	$46.00	$2.50	$48.88
Z Guide Tube	1	$96.88	$46.00	$4.50	$147.38
Theta Trans Tube	1	$8.82	$36.00	$1.50	$46.32
Frame Mbr, Horizontal	8	$13.44	$128.00	$20.00	$161.44
Frame Mbr, Vertical	4	$31.68	$80.00	$10.00	$121.68
TOTALS		$207.01	$847.60	$84.45	$1,139.06

Table 8.8: Prototype manufacturing costs for the UT Robot's modified finished parts. ($/robot)

PART NAME	# per robot	MATERIAL COSTS ($/robot)	PROCESS COSTS ($/robot)	TOOLING COSTS ($/robot)	TOTAL COST ($/robot)
Motor, Rotational System	1	$102.00	$6.00	$2.50	$110.50
Motor, Translation System	5	$492.50	$30.00	$12.50	$535.00
TOTALS		$594.50	$36.00	$15.00	$645.50

Table 8.9: Fabrication costs for the UT Robot's casting patterns.

PATTERN for	MATERIAL COSTS	PROCESS COSTS	TOOL COSTS	TOTAL COST
Corner Support	$51.00	$350.00	$6.00	$407.00
XY Slider	$28.00	$190.00	$3.30	$221.30
XY Slider Holder	$8.75	$140.00	$1.00	$149.75
End Effector Mount	$4.00	$68.00	$2.30	$74.30
Bearing Cartridge	$31.00	$270.00	$6.30	$307.30
Brg. Cartridge Holder	$31.00	$90.00	$1.00	$122.00
Z Platform	$51.00	$400.00	$3.30	$454.30
Z Platform Holder	$51.75	$160.00	$2.30	$214.05
Theta Motor Mount	$24.00	$110.00	$3.30	$137.30
TOTALS	$280.50	$1,778.00	$28.80	$2,087.30

Table 8.9 clearly shows that pattern fabrication is a very significant development cost for the UT Robot. As noted earlier, the pattern's total cost is used in the manufactured parts analyses as the basis for the pattern cost allowance computation. In the cases where a pattern holder was fabricated, the part's pattern cost is considered to be the sum of the pattern and pattern holder fabrication costs.

Processing Cost Totals and Comparison

The total processing costs of the cast, machined ("stock"), and modified finished parts for both the prototype and projected production cases are listed in Table 8.10 and Table 8.11, respectively. It can be observed that the production processing costs are much lower, due mostly to the large cost savings effected by automating the machining of the cast parts.

Table 8.10: Prototype processing costs for the UT Robot. ($/robot)

CATEGORY	COST ($/robot)
Cast Parts	$1,964.
"From Stock" Parts	$848.
"Modified" Vendor Parts	$36.
TOTAL.....	$2,848.

Table 8.11: Estimated production processing costs for the UT Robot. ($/robot)

CATEGORY	COST ($/robot)
Cast Parts	$302.
"From Stock" Parts	$509.
"Modified" Vendor Parts	$36.
TOTAL.....	$847.

Vendor-Supplied Parts Costs

Vendor-supplied costs are those direct expenses to procure vendor-supplied finished components (belts, standard pulleys, fastening hardware, etc.). No supplemental manufacturing operations are performed on these parts. Thus, since all motors used on the machine have secondary operations performed on them, they are listed under manufactured parts, although one recognizes that the motors are "almost the same" as purchased. Minor items not requiring machine tools, such as cutting belts to length, stripping wires, etc., are considered assembly operations, so that the belt and wire materials costs are considered here. A vendor parts total versus manufactured parts total is valuable for estimating the balance of "system integration" activity (assembling standard components) versus "manufacturing" (casting, machining) activity.

A summary of costs for non-modified, vendor-supplied parts used on the UT Robot is shown in Table 8.12. The costs listed can change with the manufacturing (or, more specifically, the parts ordering) batch size, but do not vary versus internal operations (e.g. automated versus manual machining), because no "manufacturing" operations are performed on them.

Table 8.12: Costs of vendor-supplied, non-modified parts for the UT Robot. ($/robot)

CATEGORY	COST ($/robot)
Linear Bearings	$344.
Linear Bearing Shafts (XY)	$227.
Radial Bearings	$191.
Pulleys, Belts	$263.
Miscellaneous Electrical	$50.
Miscellaneous Mechanical	$33.
SUBTOTAL	$1,108.
Motor Drivers & Power Supply	$766.
SUBTOTAL	$1,874.
Personal Computer	$1,000.
TOTAL.....	$2,874.

Robot Assembly Costs

Robot assembly costs are estimated based on experience gained in building the prototype robot. Compared to the materials and processing costs incurred to build the robot, assembly costs are not significant. For the robot system estimate, two working days to complete robot assembly has been assumed. Using a student rate of about $6 per hour, assembly costs account for about $100. Packing and shipping costs are not included.

Material Acquisition Costs

Material acquisition costs are direct expenses incurred to procure raw material used for internal manufacturing operations (raw castings, bar stock, etc.) or to purchase of vendor-supplied components (motors, finished shafts, screws, etc.). These costs provide a basis for estimating the monetary resources necessary to purchase sufficient material to build a certain number of machines. A ratio of the total finished cost or the robot sales price versus the parts acquisition costs also can be used to assess the internal "value-added" effort.

The parts acquisition costs for the UT Robot are shown in Table 8.13 and Table 8.14 for the prototype and production cases, respectively. It can be clearly seen that motors, drivers, and power supply are the highest cost purchased components of the robot system. The total "base" production part acquisitions cost of $2,476 is over 65% of the cost to produce the base production robot system, while the total system parts cost (including drivers, power supply, and PC) of $4,096 comprises 73% of the total system production

Table 8.13: Materials acquisition costs for the UT Robot prototype. ($/robot)

CATEGORY	COST ($/robot)
Raw Castings	$420.
Linear Bearings	$344.
Linear Bearing Shafts	$324.
Radial Bearings	$191.
Stepper Motors	$595.
Pulleys, Belts	$263.
Frame Materials	$45.
Other Raw Materials	$65.
Miscellaneous Electrical	$50.
Miscellaneous Mechanical	$33.
SUBTOTAL	$2,330.
Motor Drivers & Power Supply	$766.
SUBTOTAL	$3,096.
Personal Computer	$1,000.
TOTAL.....	$4,096.

Table 8.14: Projected materials acquisition costs for UT Robot production. ($/robot)

CATEGORY		COST ($/robot)
Raw Castings		$435.
Linear Bearings		$344.
Linear Bearing Shafts		$324.
Radial Bearings		$191.
Stepper Motors		$726.
Pulleys, Belts		$263.
Frame Materials		$45.
Other Raw Materials		$65.
Miscellaneous Electrical		$50.
Miscellaneous Mechanical		$33.
	SUBTOTAL	$2,476.
Motor Drivers & Power Supply		$766.
	SUBTOTAL	$3,242.
Personal Computer		$1,000.
TOTAL.....		$4,272.

manufacturing cost of $5,573. The production cost estimate is higher than the prototype cost because of recent price increases for some components.

One area in which the design team has some direct control over part acquisitions cost is in the price of the castings, since the castings are built to the team's custom design. In addition to potential design changes, casting materials costs can be reduced by changing over from loose patterns to mounted tooling Table 8.15. However, additional tooling expenses would be incurred to execute the change, so that part cost, tooling cost and projected volume and batch purchase sizing must all be considered. Additionally, it may be possible to modify or redesign the motor drivers so reach a reduced cost of about $400.

Activity Cost Analysis

John B. Fuqua, an M.S. student in University of Tennessee's Industrial Engineering Department, has performed an activity-based cost analysis of the new UT Robot [Fuqua, 1991]. The Activity Cost Analysis tries to assess the costs of those activities undertaken in the process of producing a product, with the objective of relating the activities to specific goals and costs. Fuqua's analysis includes an economical order quantity (EOQ) model, which is used to determine optimum part order quantities. The EOQ is used to take advantage of volume quantities, while also considering resource constraints and carrying costs.

Table 8.15: Projected casting materials cost savings from using mounted tooling. ($/robot)

CAST PART NAME	# per robot	$ Saving per Robot with Mounted Tooling 1	2	5	10
Corner Support	4	$53.60	$56.60	$53.20	$40.60
XY Slider	4	N/A	N/A	N/A	N/A
Bearing Cartridge	1	$20.40	$16.80	$14.75	$14.75
Z Platform	1	$21.95	$21.95	$21.90	$20.40
Theta Motor Mount	1	N/A	N/A	N/A	N/A
End Effector Mount	1	$3.10	$3.45	$2.85	$3.10

Some of the results of the activity cost analysis are presented in Figure 8.1. The production quantity ("prod. qty.") is the assumed number of robots to be built at one time. Material costs are, as one might expect, the cost of finished materials needed to construct the robot. Resource costs are allocated costs needed to perform the work, such as part of the cost of the CNC mill, work area, etc.

Considering that the EOQ model assumed a smaller robot (and used older cost data), the material cost per robot for a production quantity of one ($4,593) reasonably matches the earlier estimated cost of $5,573. The $8,322 "total" cost from the EOQ model approaches the earlier parts cost estimate of $7,953. These favorable comparisons, using different accounting methods, appear to indicate fairly the cost to produce the UT Robot.

It should be noted the EOQ's resource costs contain more costs than are included in the earlier analysis. For example, the EOQ model accounts for wear on the manufacturing equipment, and directly includes assistantship stipend costs of students working on the project. That the EOQ's total cost estimate is higher than the parts cost model, then, is not surprising.

PROD. QTY	PER (MO)	TOTAL RESOURCE COST	TOTAL MATERIAL COST	TOTAL CAPITAL REQUIRED	RESOURCE COST PER ROBOT	MATERIAL COST PER ROBOT	TOTAL COST PER ROBOT
1	1.2	$3,729	$4,779	$8,508	$3,729	$4,593	$8,322
2	2.4	$7,352	$8,899	$16,251	$3,676	$4,380	$8,056
3	3.6	$11,008	$13,034	$24,042	$3,669	$4,314	$7,983
4	4.8	$14,658	$17,148	$31,806	$3,664	$4,276	$7,940
5	6	$18,321	$20,997	$39,318	$3,664	$4,200	$7,864
6	7.2	$21,974	$25,159	$47,133	$3,662	$4,201	$7,863
7	8.4	$25,639	$29,268	$54,907	$3,663	$4,195	$7,858
8	9.6	$29,292	$33,205	$62,497	$3,662	$4,169	$7,831
9	10.8	$32,958	$37,259	$70,217	$3,662	$4,161	$7,823
10	12	$36,612	$41,128	$77,740	$3,661	$4,137	$7,798

Figure 8.1: Results from Economic Order Quantity (EOQ) model.

Source: John B. Fuqua, *UT Robot Design Project*, Unpublished M.S. Project in Industrial Engineering, The University of Tennessee, Knoxville, TN, April 1991.

Cost Assessment Assumptions and Approach

Manufacturing and Tooling Costs

Cost estimates for many of the manufacturing operations and tooling were developed based on the UT Robot team's experience in building the new prototype machine. Setup and machining estimates were assigned with the assistance of Daniel Graham, senior instrument maker, of the University of Tennessee Mechanical and Aerospace Engineering Machine Shop. In addition to his extensive machining experience, Mr. Graham has personally machined most of the manufactured parts used in building all of the UT Robot prototypes.

Tooling Costs. Several options are available to account for the tooling costs incurred to produce the new UT Robot. The costs can be categorized as development expenses at the system level, or they can be amortized directly into the individual parts cost. The direct approach was selected over the development method to gain a better perspective on production costs incurred to make each individual part on a production-type basis.

The primary element in the tooling cost category is the manufacture of patterns and patterns holders used for sand casting. Cost allowances for the pattern tooling are required because of the high expenses incurred to fabricate the pattern equipment. In the manufacturing cost computations, the "total" cost of the pattern equipment is amortized over a specified number of robots and expensed into the production cost of the part for

which the pattern is used. For example, the manufacturing cost of each corner support includes a tooling cost allowance for the cost of the corner support pattern used to make the support casting. The number of robots over which the tooling cost is amortized is established (and can be adjusted) in the part cost analysis.

The allowance for the use of machining tools (bits, endmills, etc.) is computed based an "average" life of the tools used to machine the part if it were to be used exclusively for producing that part. Some special tooling was purchased to complete specific manufacturing operations on some robot components, and these are listed separately in the cost detail computations. These tools are expensed in the same way as are the standard tools.

"Missing" Costs

Several major robot costs are not included in the robot part cost assessment procedure. These "missing" costs are resources that are needed to develop or operate the robot, but are not directly accounted for in the parts cost assessment.

Control Software. The software used to control the robot has significant value, but it can be difficult to assess what this value is. One can evaluate the costs of hardware and software that perform similar or less-complex tasks to estimate a reasonable value. Or, one can amortize the cost incurred to develop the software as an assessment of its value.

Since the software is not sold as a stand-alone product, but is instead an integral part of the packaged system, the development cost method is probably preferable.

Since the software does not directly impact a specific part's cost, the software development cost probably should be added at the system level. The software cost could be amortized over a number of production units in a manner similar to the way the casting patterns are assessed. As was seen earlier, an estimate of these amortized costs has been added to the bottom of the product cost summary table.

Development Costs. One fairly large gap in the cost analysis is that many engineering and manufacturing development costs are not included in the cost model. Engineering design, manufacturing system development, testing, and other development costs are not assigned to the parts cost summary. For example, the author's fellowship stipend, faculty consulting time, and some graduate assistantship costs of the other students working on the project are not accounted for in the parts cost assessment. Development support equipment, parts storage and space costs are also neglected.

One reason that development labor costs are not charged to specific parts is because it can be difficult to assess the time spent to design each part. While the cost to create an engineering drawing and to set up a CNC machining program for a part can be assessed at the part level, it is much more difficult to charge system design time. Should the time required to decide if a feature should be put on part A instead of part B be assigned to

part A or part B? Also, work estimates of this type are difficult to estimate unless extensive work records are maintained throughout the development process.

These "overhead" costs, although not accounted for in the parts cost model, are quite significant. An additional difficulty in this cost assessment, however, is that not all of these development expenses are incurred directly by the project. For example, the author's fellowship stipend is not charged to the project, but is funded from other sources. Costs for work space, some lab equipment, etc. is provided by the University. Additionally, the UT Robot project has educational goals as its primary focus, not financial goals. The purpose of the project is to provide students with excellent product development and manufacturing experience, not just to make money. Revenues from the robot program, should there be any, will be used to support graduate student work, research, and other Superior Engineering Design Program projects. Thus, the "return on investment" or other financial criteria are not as critical in this effort as they might be in an industrial environment.

Cost Reduction Analysis / Cost Component Details

The tables presented in this chapter are summaries of the major cost categories of materials, processing, tooling, and assembly. The computer worksheets used to perform the cost analysis is constructed of a much more detailed cost division for each major category, and these detailed costs breakdowns are available to the analyst at various levels

of detail. Figure 8.2 shows an example of a more detailed assessment for the prototype corner support. Other assessments can provide an even lower level of analysis.

These capabilities have been created because effective cost assessment analysis and product cost reduction activity often require such specific information to identify high cost areas for improvements. It is expected that the worksheet will be used by the design team to identify cost improvements for future UT Robots. The parts cost summary sheets for manufactured parts used in the construction of the latest UT Robot are provided in Appendix H. Parts summary sheets for the estimated production costs of the UT Robot are located in Appendix I.

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................      MEK001-DDD
PART NAME ................................ Corner Support (m,l)

Quantity Required / Robot        (# pieces)                  4
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $42.35
   Order Charge Assessment       ($/part)             $0.00
   Volume Discount, Total        ($/part)             $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $42.35


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)             $0.00
   Unit Setup, Total ............($/part)            $80.00
   Machining, Total .............($/part)           $130.00

   Manual Operations, Total .....($/part)           $210.00
   Automated Operations, Total ..($/part)             $0.00
                                                  ----------
PROCESSING SUBTOTAL ......................          $210.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $1.00
   Disposables ..................($/part)             $5.00
   Casting Pattern Allowance ....($/part)            $10.18
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $16.18

                                                  ==========
PART COST, TOTAL (unit) ..................          $268.53
                                                  ==========
PART COST, TOTAL (per robot) .............        $1,074.10
```

Figure 8.2: Sample parts cost detail for UT Robot parts. Shown is cost detail for the prototype corner support.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

Results

A prototype of the UT Robot has been manufactured successfully. The robot, along with the PC control software, substantially meets the design and customer use goals established for the UT Robot system.

Expanded Application

With its new options, the UT Robot is more able to meet the additional customer needs that will make the robot useful over a broader application base. The drive reduction system implemented on the X, Y, and Z systems enable each robot to be customized to desired step resolution, force or velocity characteristics. The variable work space capability enables either both small and large robots to be manufactured utilizing the same baseline parts. Alternative guide and control shaft diameters allow the robot to be configured for light or heavy duty jobs.

Cost

The $5,573 cost of the UT Robot (including motor drivers, power supply, and personal computer) is 39% over the developmental cost target of $4,000. It is quite likely that this cost can be reduced to a value near the target with some additional effort. The $1,000

personal computer cost allocation probably can be reduced by about 25% ($250). Some development work on the high cost motor drivers and power supply may result in a more reliable system at significantly less expense.

Manufacturability

The UT Robot design successfully utilizes small quantity production methods, particularly sand casting. All cast parts have been molded and machined successfully, using available machining equipment. Many robot parts already have been machined automatically using a CNC milling machine. While some special machining tools are required, all have either already been procured commercially or made in the standard machine shop. As shown in Chapter 8, the Flexible Manufacturing Center makes it possible to manufacture robots parts at relatively low cost.

Assembly

The UT Robot has been successfully designed to assemble easier than its predecessor machine. The theta system has been redesigned for simple assembly, and can be built and tested separately from the vertical positioning system. The vertical and rotational systems have been separated from the horizontal system so that these assemblies can be built independently. Completing the assembly of the UT Robot is relatively simple, and requires no special tools.

Performance

As of this writing, a performance problem (discussed below) with the robot's stepper motors has prevented a complete demonstration of the robot's payload and speed capability. When the motor power problem is resolved, the UT Robot is expected to be capable of wide spectrum of dynamic characteristics, depending on the specified reduction ratio. Some typical theoretical performance characteristics for the horizontal positioning system are shown below in Figure 9.1 and Figure 9.2. Figure 9.1 shows the correlation of motor speed to robot velocity for various reduction ratios, and can be used to assess the robot's maximum horizontal speed, given the maximum feasible motor speed. Figure 9.2 shows the theoretical maximum X or Y acceleration for a robot with a 3:1 reduction, assuming a linearized motor torque-speed curve (shown later) and no friction. The 3:1 reduction ratio selected for Figure 9.2 corresponds to the horizontal system reduction ratio installed on the prototype robot.

Theoretical vertical positioning system characteristics are shown in Figure 9.3 and Figure 9.4. The 2.0 reduction ratio selected for Figure 9.4 corresponds to the vertical system reduction ratio on the prototype robot. The acceleration for the upward acceleration direction is shown in the figure, because gravity effects make the upward travel the most difficult. Projected performance charts (for both horizontal and vertical positioning systems) for the UT Robot are shown in Appendices J and K.

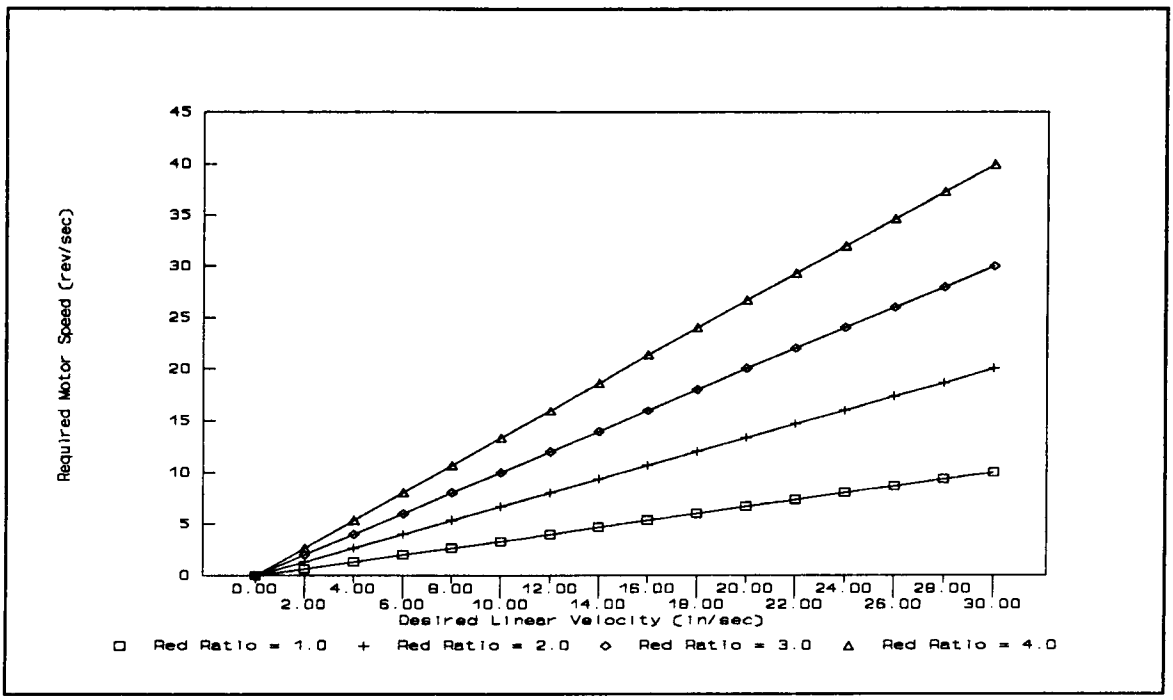


Figure 9.1: Required motor speed versus desired horizontal linear velocity. Plotted for different belt reduction ratios.

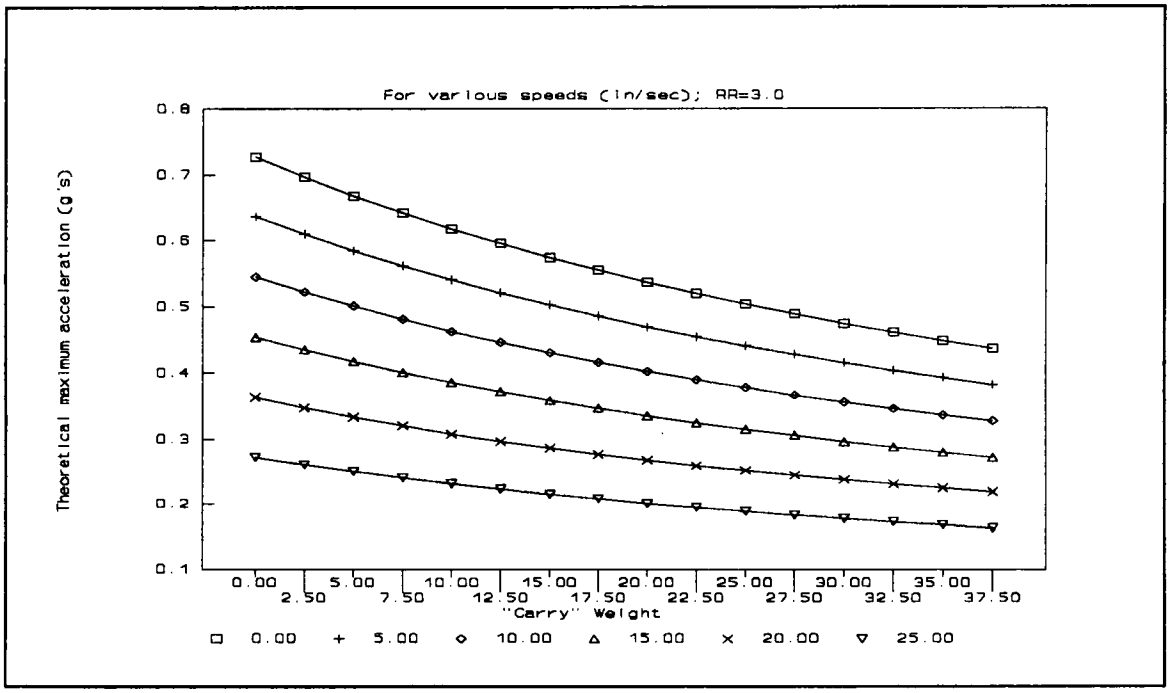


Figure 9.2: Sample theoretical maximum acceleration for UT Robot horizontal system. Plotted for different linear velocities. Reduction ratio is 3.0; "carry" weight includes end effector and payload.

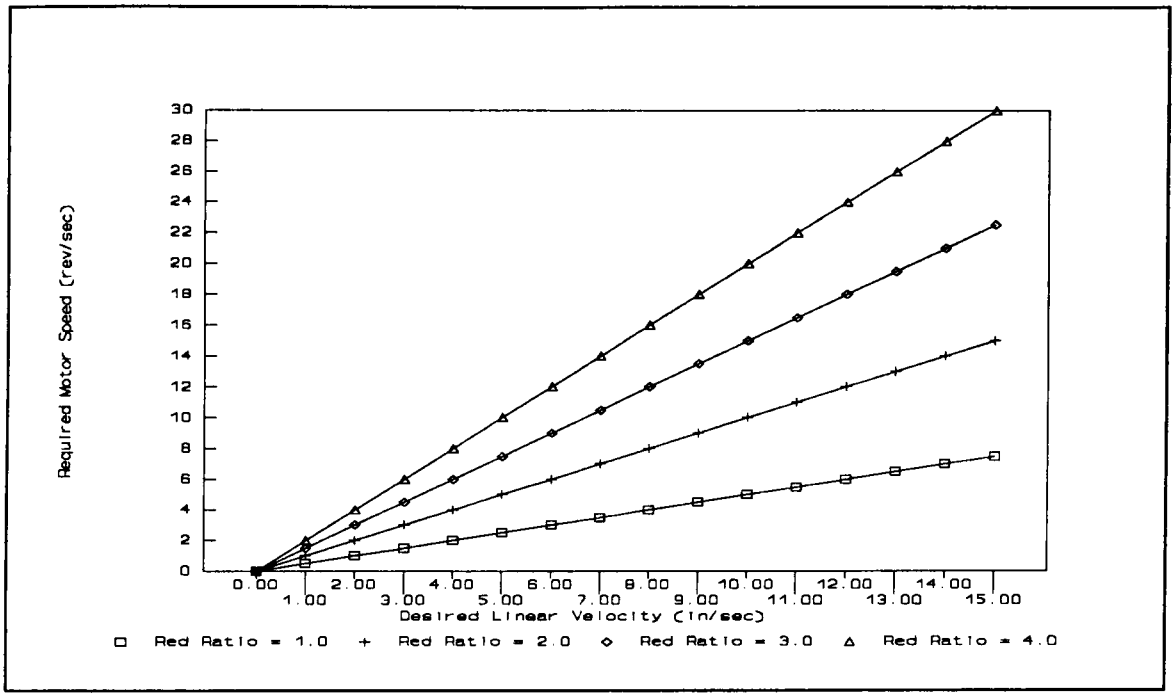


Figure 9.3: Required motor speed versus desired vertical linear velocity. Plotted for different belt reduction ratios.

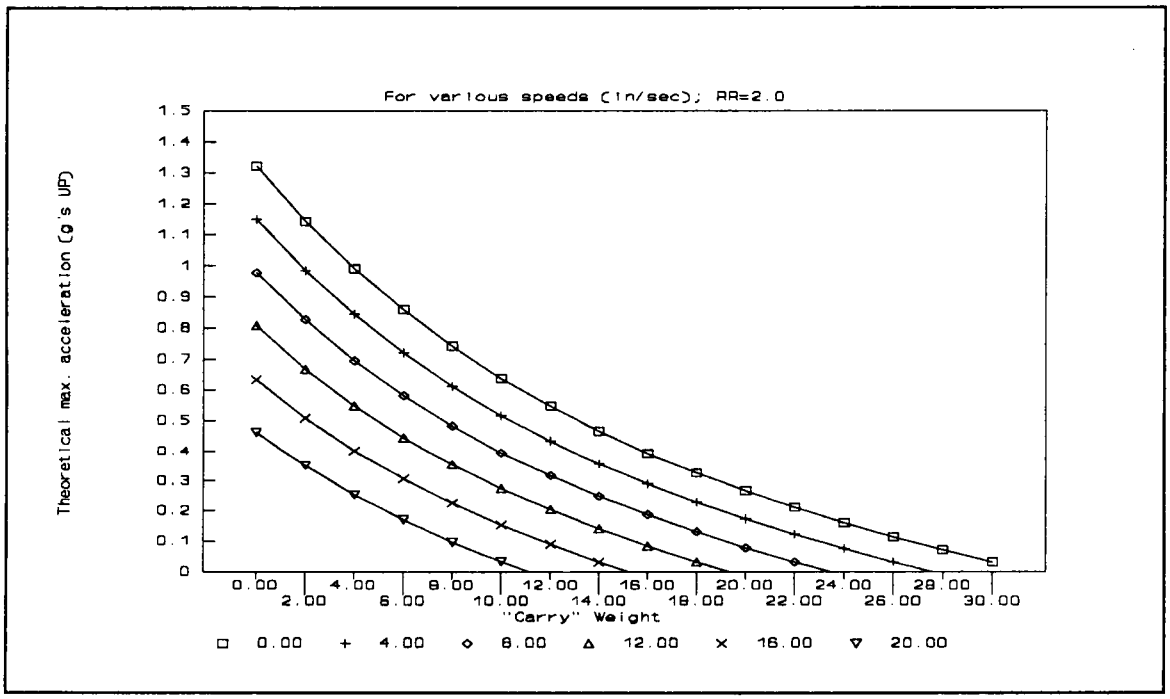


Figure 9.4: Sample theoretical maximum acceleration for UT Robot vertical system. Acceleration is in the "up" direction. Plotted for different linear velocities. Reduction ratio is 2.0; "carry" weight includes end effector and payload.

Configuration Planning Tools

Several robot sizing and resolution tools have been created to assist the system engineer in defining each robot's travel, resolution and speed capabilities. In Appendix G, a chart is provided to define required shaft and frame lengths to attain specified travels, given a specified shaft diameter. Appendix L contains typical outputs from a Lotus spreadsheet used to compile purchase needs and costs to acquire the needed shafts, tube, and linear bearings. These outputs can be used directly to order the needed parts, or can be looked up from the shaft and tube parts drawings themselves. (Included on the drawings of parts that vary based on travel or shaft size are charts for specifying the proper sizes or part numbers for many "typical" robot configurations.)

Appendix C (horizontal system) and Appendix E (vertical system) contain data pertaining to the positioning resolution obtained for various pulley combinations (reduction ratios). The required belt size ranges for various pulley combinations are included in Appendix D (horizontal system) and Appendix F (vertical system).

Problems

One serious and several minor problems have been discovered during the manufacture of the first UT Robot. Some of these problems are discussed below.

Drive System Problem

As of this writing, the UT Robot has been limited to low velocity moves and light (or no) payloads because the stepper motors have failed to deliver their advertised torque-speed characteristics. The ability of the power supply, motor driver and motor to deliver the necessary power to drive the robot are critical to successful robot operation, and thus need to be understood. Along with the possible customization of the driver hardware, the characteristics and interactions of these electrical components should be a focus for immediate efforts. Without the required torque-speed characteristics (Figure 9.5), the robot will not be able to meet its speed and payload objectives.

Theta System Problems

Two minor problems were observed during the assembly of the theta positioning system. First, the inside diameter of the Z guide tube, as received from the vendor, was lined with loose metal particles and oxide. Some of this material was knocked off as the theta transmission tube was inserted down the middle of the guide tube. The loose material in the tube thus presents a possible contamination hazard to the theta system's radial bearings. Second, the theta transmission tube was not straight enough, so that it rubbed against parts of the Z guide tube's inner diameter.

Finally, during initial theta system testing, a "rubbing" noise was found to emanate from the top part of the theta drive system. This noise was traced to near the theta motor's roll pin connection to the motor-tube converter. It is anticipated that adding a grease

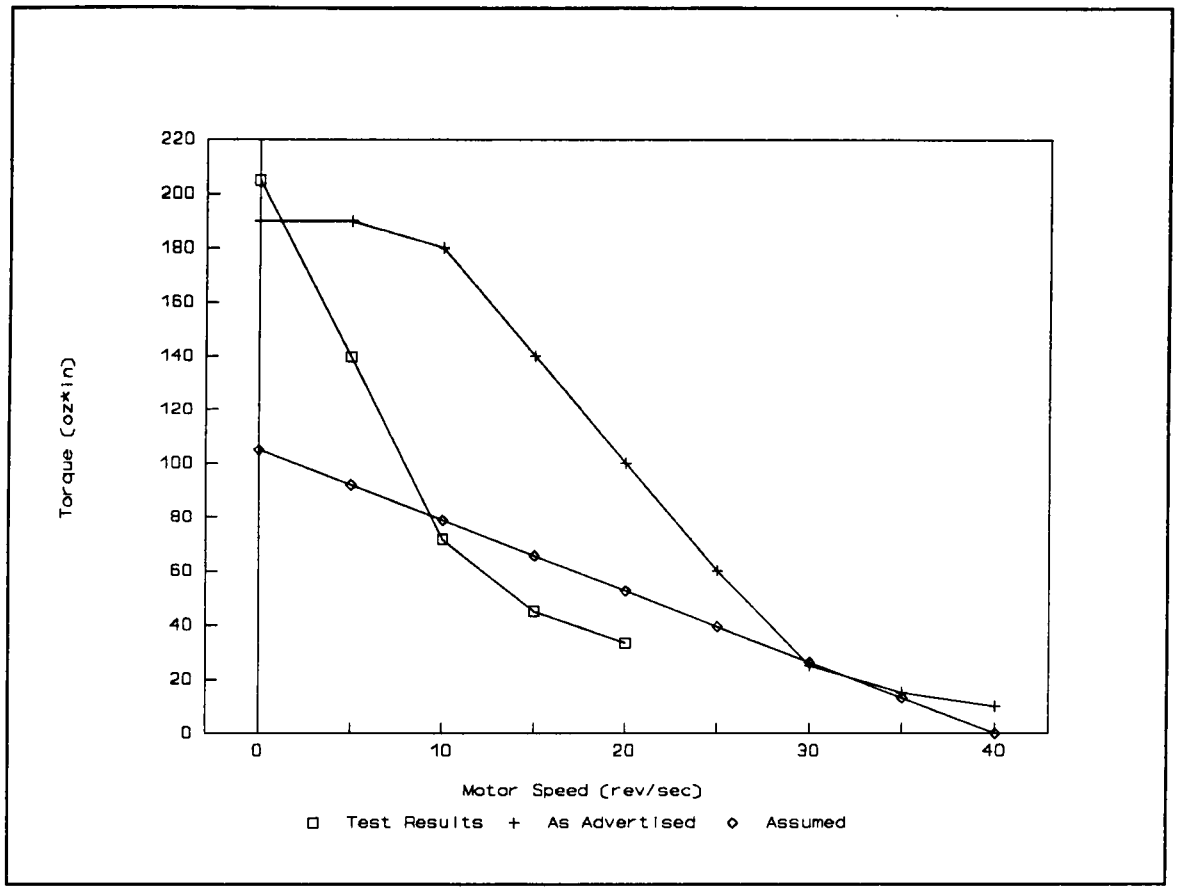


Figure 9.5: Stepper motor torque comparison. "As advertised" values are from vendor literature; "assumed" values are used to compute theoretical performance. Test results are from testing at the University of Tennessee.

lubricant to the connection will reduce the noise. This noise should be investigated thoroughly during the experimental evaluation of the UT Robot.

Z Platform - Bearing Cartridge Attachment

During the attachment of the Z Platform to the bearing cartridge, an interference was discovered with the socket head of a Z mast attachment screw and the location of one of the platform-to-cartridge mounting screws (Figure 9.6). Since the three other mounting screws are available to secure the platform, this interference problem does not impair the robot's performance.

Robot Improvement Recommendations

Horizontal Positioning System Recommendations

Corner Support Attachment. The corner support provides two alternative mounting arrangements to the support frame (Figure 9.7). A mounting screw can be inserted through a clearance hole at the corner's bottom flange, or a screw can be inserted up through the frame into a threaded hole in the bottom of the corner. Using the threaded hole at the bottom to secure the robot to the frame has proven to be difficult, since the frame member obstructs vision of the hole, and it is hard to align the robot over the hole without gouging or stripping the threads. Since the threaded hole has not been useful, it can be removed from the design to eliminate a drill and tap operation.

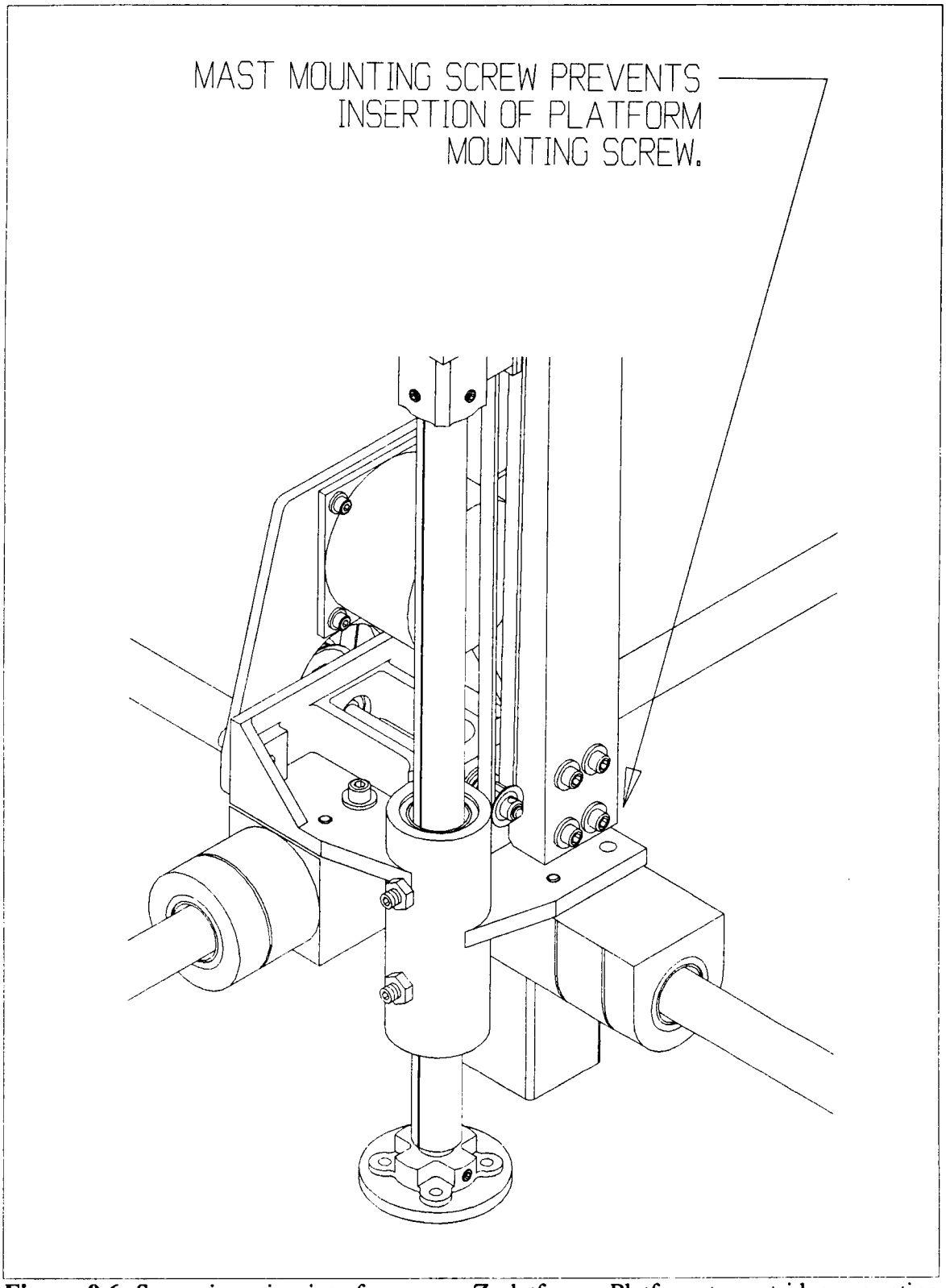


Figure 9.6: Screw insertion interference on Z platform. Platform-to-cartridge mounting screw cannot be inserted because a mast attachment screw interferes.

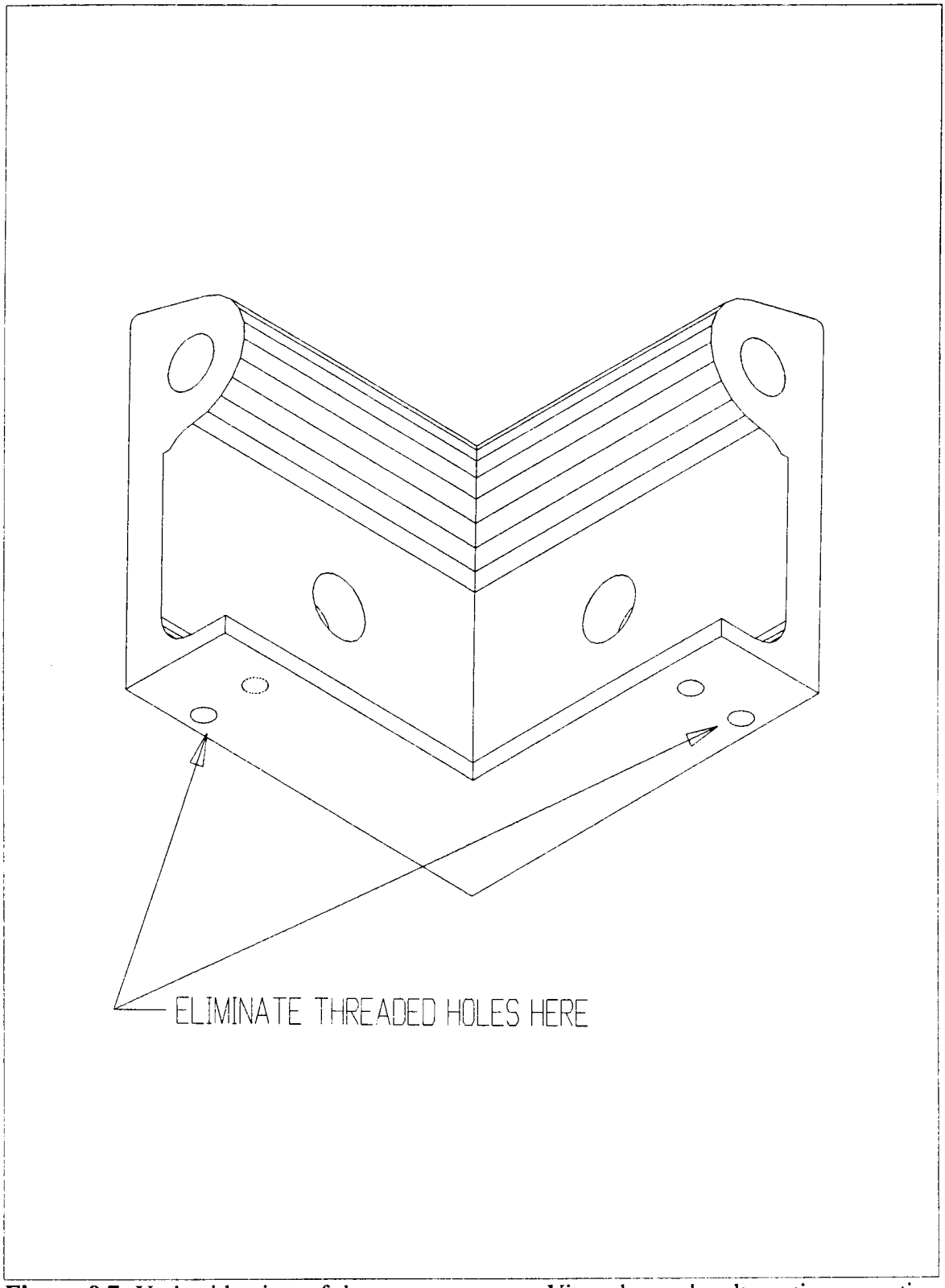


Figure 9.7: Underside view of the corner support. View shows the alternative mounting holes.

Z Platform - Bearing Cartridge Mounting.

The Z platform to bearing cartridge mounting screw interference can be eliminated by swapping the location of the nearby dowel with the mounting screw location (Figure 9.8).

Vertical Positioning System Recommendations

Z System End Stop. When extended to the top vertical position, the Z system is designed so that the end effector mount hits the bottom of the Z platform to provide the up direction travel end stop. On the prototype, the striking surface of the end effector mount is just far enough down such that the bottom platform seal "rolls over" the bottom edge of the Z guide tube (Figure 9.9). This problem can be prevented on future units either by pushing the bottom Z platform slightly higher in its bore, or by adjusting the endmount dimensions slightly to make the endmount contact the platform before the seal can roll off the tube.

New Z Guide Tube Groove Location. The manufacture and assembly of several vertical system components can be improved by moving the location of the Z guide tube groove 90° from its present location (Figure 9.10). By moving the groove 90°, the bearing adjustment screws can be moved into better position for drilling and tapping the hole (part rotation from the other drilled and tapped holes is no longer required), and for making the bearing screw torque adjustment (the platform ledge is no longer in the way). The change requires that the top mounting holes on the Z guide be rotated so that the tube can mount to the theta motor mount with the groove in the proper position. The spotface

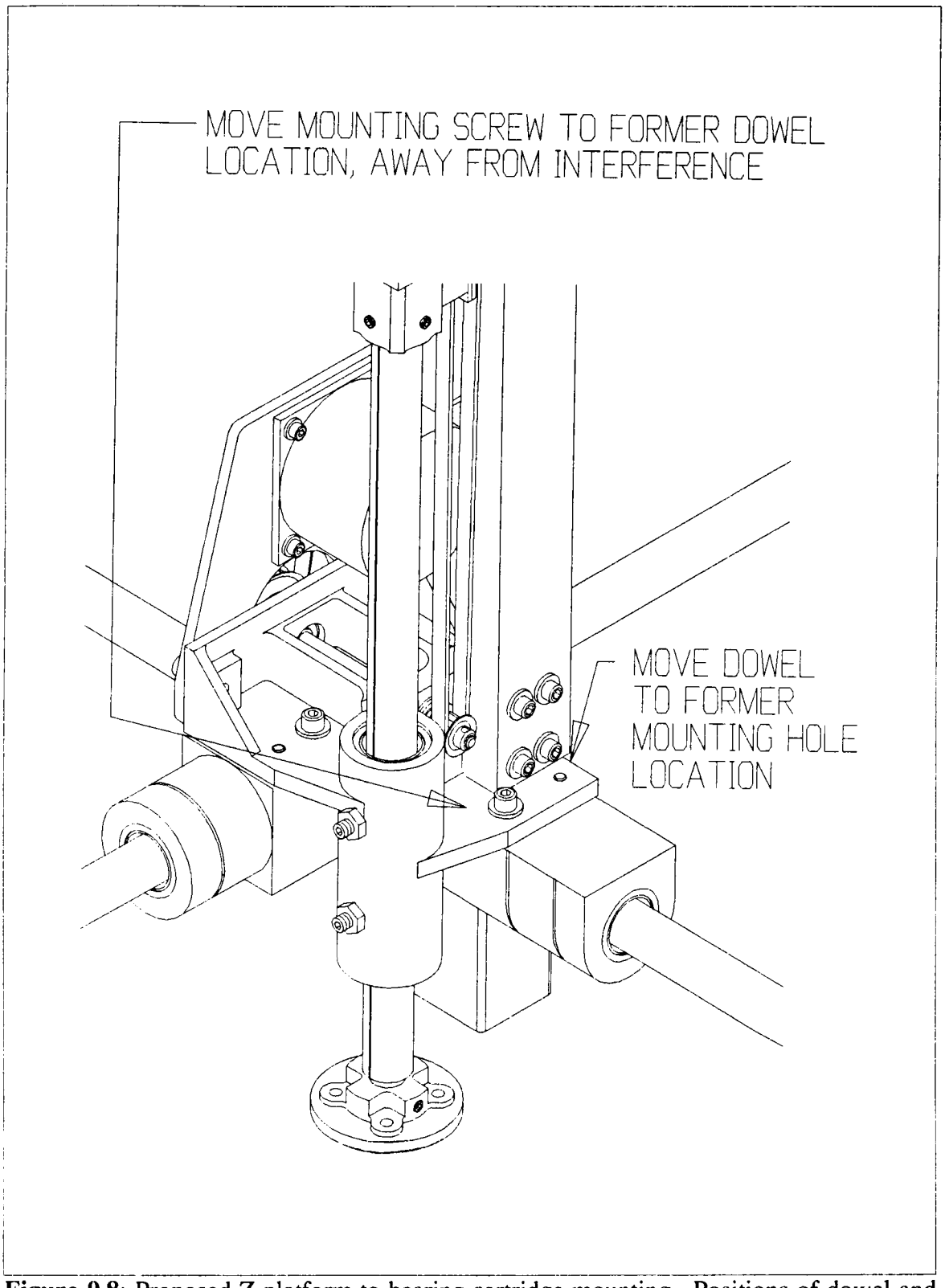


Figure 9.8: Proposed Z platform to bearing cartridge mounting. Positions of dowel and screw are swapped to eliminate interference.

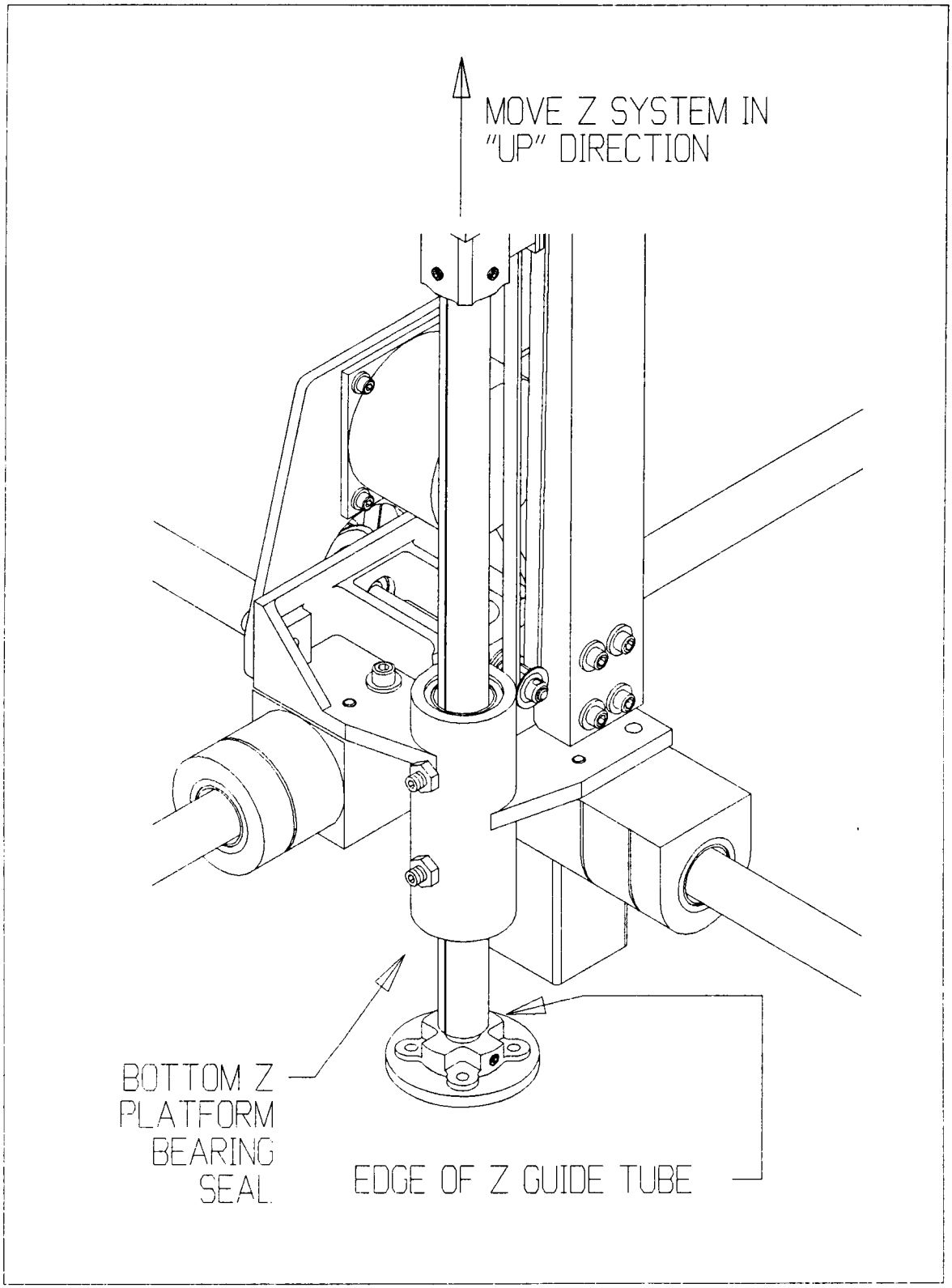


Figure 9.9: Z system end stop problem. When Z guide tube is raised to its highest position the Z platform's lower seal "lips" over the edge of the tube.

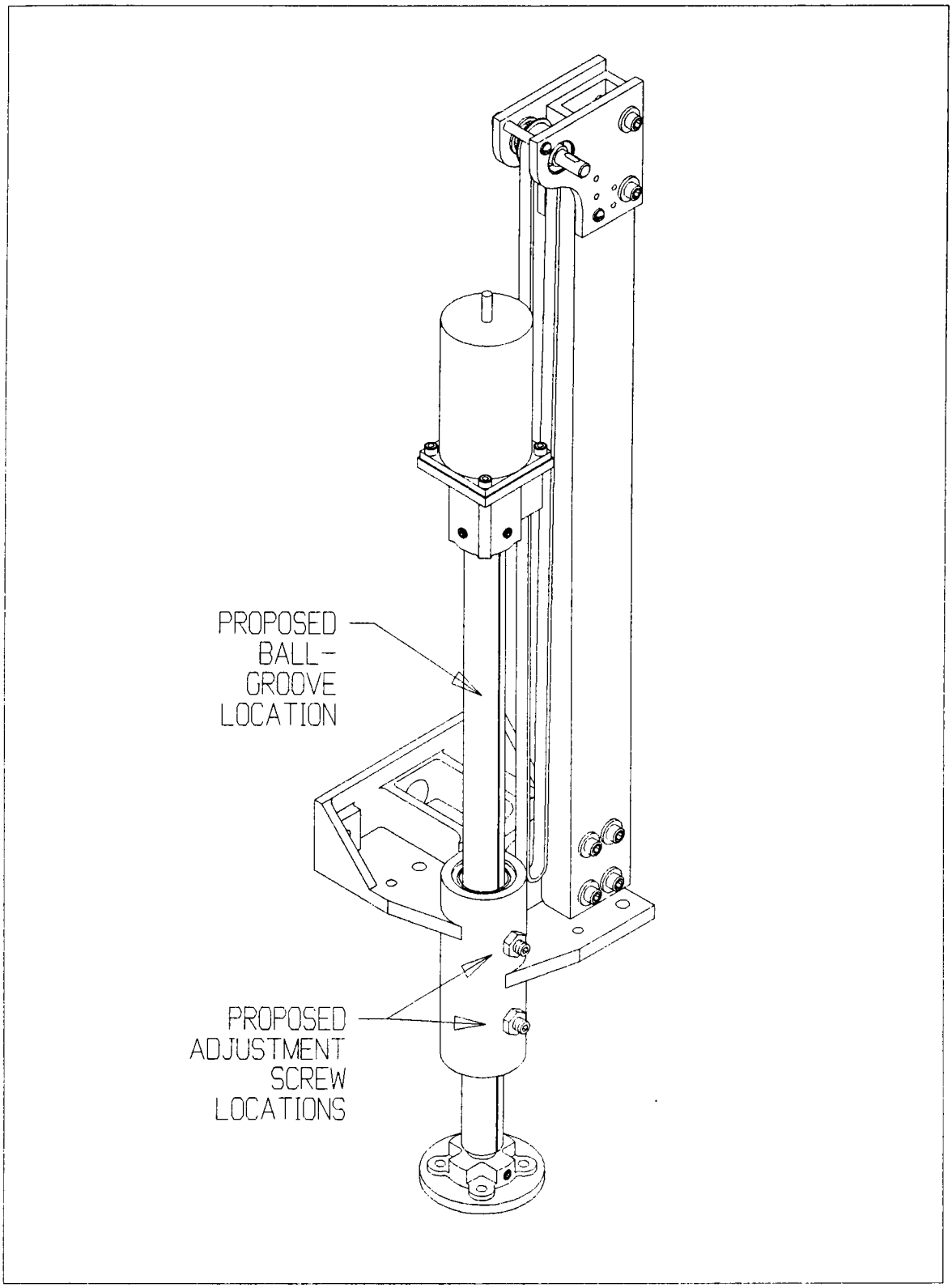


Figure 9.10: Proposed Z guide tube groove location. New location provides for easier manufacture and assembly.

diameter for the Z platform adjustment screw hole should be increased over the current value to provide additional wrench or socket clearance.

Z Platform Pattern Modification. The drilling operation in the Z platform for the Z drive shaft ball bearings can be improved if the hole can be drilled all the way through from one direction. A "scalloped" section is needed in the Z platform casting to provide the needed clearance so that the bit can drill through both walls (Figure 9.11). The needed "scallop" can be cut into the platform pattern rather easily with a ball end mill.

Mast Attachment to Z Platform. The upper pair of the mast to Z platform attachment screws can be raised on the Z platform wall to provide better support (Figure 9.11).

Wire Support Changes. A 90° bend in the wire hanger used to support the theta motor wire will help to hold the wire in place more effectively without using tape. The roll pin in the hanger bracket should be replaced with a small screw to facilitate assembly, since the roll pin insertion was difficult, and the force needed to insert the roll pin on the Z mast can damage the Z assembly.

Safety

Prior to use by customers, the UT Robot will need additional user protection features to prevent potential operator hazards.

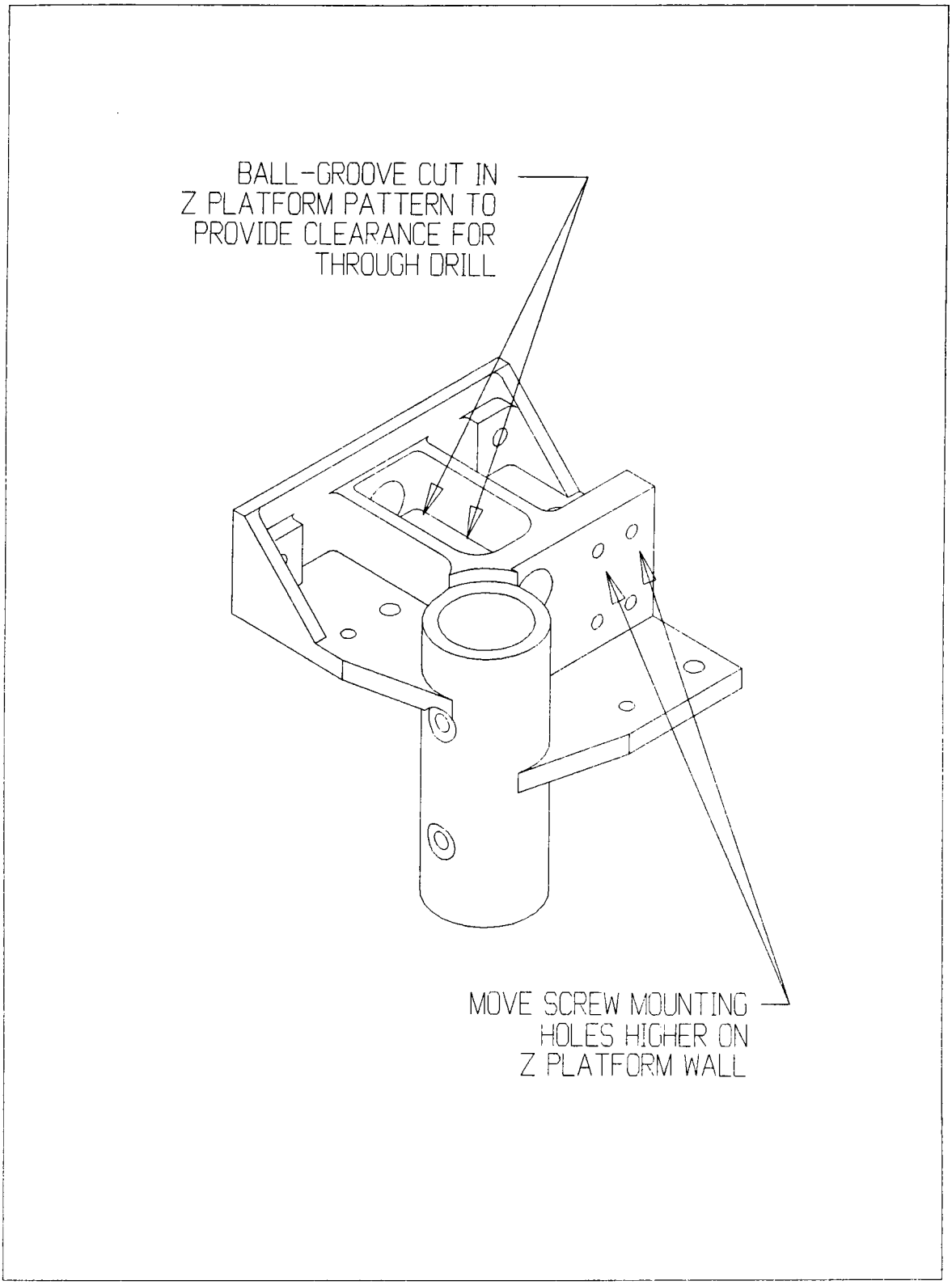


Figure 9.11: Proposed changes to Z platform. "Scallop" cut facilitates manufacturing. New mast mounting hole location also requires corresponding change to the Z mast.

Guarding. The movement of the horizontal system along the guide shafts represents a potential hazard to operators near the robot's work area. A simple guard can be installed to shield the moving slider and belts from any outside interference. The guard member could be bent from sheet aluminum and mounted to frame members under the guide shafts.

Emergency Stop. An emergency stop switch will be necessary to allow an operator to stop the robot if an error or accident should occur during the robot's operation. A bright red push button is typically used for such applications, and is wired to disconnect the power from the robot and the end effector tool. Several buttons may be required around the robot, depending on the robot's size.

Position Verification System. A position verification system similar to the proposed "grid" system discussed earlier should be implemented on the UT Robot before using the robot in an application where positioning failures may be expensive or hazardous. While it may be feasible to use a "non-verified" robot to load inexpensive parts into a box, it is not advisable to use the unverified system to manipulate cutting tools or to move radioactive samples.

Z Arm Lock. The Z arm lock needs to be installed before using the UT Robot in applications where the end effector or carried parts can be damaged if the Z arm falls to its bottom position during a power failure.

Operating Procedure Recommendations

Z Guide Tube. The inner diameter of the Z guide tube should be cleaned with a pipe cleaner or similar tool before assembling the theta system. The tube cleaning is needed to avoid possible contamination of the radial bearings used in the theta system. A cleaning instruction note has been added to the Z guide tube drawing.

Theta Transmission Tube. The theta transmission tube needs to have a straightness requirement and inspection along its length to prevent it from contacting the inner diameter of the Z guide tube. A straightness requirement note has been added to the theta transmission tube drawing.

Stepper Motor Verification. It is recommended that the torque-speed performance for all stepper motors used on the UT Robot be verified on the stepper motor tester located in one of the Mechanical and Aerospace Engineering development labs. The tester, developed as an M.S. thesis by Chris Moscone [Moscone, 1991], can be used to verify the torque-speed characteristics of the motors.

Frame. The accuracy of the horizontal positioning system is established by the corner supports and guide tubes. Thus, the frame mounting holes used to secure the corner supports to the frame should have adequate clearance so that the robot can "adjust itself" and maintain its alignment.

Future Considerations

Casting Options

As discussed in the previous chapter, the castings used on the UT Robot can be manufactured using either loose patterns or mounted tooling. Some cost savings may be realized by using mounted tooling. Since additional tooling expenses are required to mount the tooling, a careful assessment of projected part needs and production timing must be made.

If mounted patterns are considered, the corner support should be the first part considered, since four corners are needed per robot, the corner pattern does not currently have a holder, and the cost estimates indicate that the corner provides the largest possible savings over the other cast parts.

Additional Configuration Options

Bearing Cartridge Option. The bearing cartridge is designed to provide a mount for the vertical positioning system and to hold the four linear bearings used to move along the horizontal control shafts. Since the UT Robot is designed to accommodate three shaft sizes, the bearing cartridge must be able to hold the linear bearings used with the largest shaft. However, if the smallest shaft is used, the bearing cartridge is tremendously oversized versus its functional requirements, and adds substantial weight to the horizontal system. For a very light weight application, it may be desirable to consider a smaller

bearing cartridge design to use with the small shaft option. So long as the Z Platform mounting features (dowel and screw positions) are maintained, the smaller cartridge would not affect the mounting or performance of any other part of the robot system.

Small Translational Only Robot. One additional robot option for a light-load application needing no rotation could be to use a smaller Z tube and bearing set (0.75" nominal diameter). Any additional production costs would be negligible by using the same Z platform casting for either the regular or smaller shaft diameter size. Only a tool change during machining would be needed to make the parts for each particular version. for additional savings, the grooved tube could be replaced with a grooved shaft. Minus the rotational motor and using lower cost (smaller) linear bearings and shafts for the vertical system, this configuration might make an effective "low-end" version of the robot.

LIST OF REFERENCES

LIST OF REFERENCES

Fuqua Jr., John B., *UT Robot Design Project*, Unpublished M.S. Project in Industrial Engineering, The University of Tennessee, Knoxville, TN, April 1991.

Garrett, Lawrence Mancil (1989), *The Design and Prototyping of A Four-Degree-Of-Freedom, Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, May 1989.

Granger, Mark L. (1988), *The Design and Prototyping of The Horizontal Positioning Mechanism Used In A Low-Cost, High-Speed, Cartesian-Motion Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, June 1988.

Ireson, W. G., and Coombs, C. F., *Handbook of Reliability Engineering and Management*, McGraw-Hill Book Company, NY, 1980.

Johnson, William Steven (1990), *Motion Control Software Package for the U.T. Robot*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, December 1990.

Lee, Larry (1989), "Robots: New Hope For Industry?", *Knoxville News-Sentinel*, July 31, 1989, page B1.

Moscone, Chrisopher G. (1991), *The Design of a Stepper Motor Torque Characterization System*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, May 1991.

Speckhart, Frank H., and Wilson, Clement C., (1991), "Product Development in the University Environment", *Proceedings of the Design Productivity International Conference (Volume One)*, Honolulu, HI, February 1991.

Stack, Bill (1990), "A Generic Robot Takes Shape", *Industry Week*, May 21, 1990.

Walker, David A. (1990), *Creating Reliability In The Design Process: An Evaluation Approach, Design Tool, And Example Application*, M.S. Thesis in Mechanical Engineering, The University of Tennessee, Knoxville, TN, August 1990.

Walker, David A., Kennedy, Michael E., and Wilson, Clement C., (1991), "Creating Reliability During The Design Process", *Proceedings of the Design Productivity International Conference (Volume Two)*, Honolulu, HI, February 1991.

Yeo, Siak Thong (1988), *The Use of Embedded Microcontrollers in the Design of a Low-Cost Industrial Robot*, M.S. Thesis in Electrical Engineering, The University of Tennessee, Knoxville, TN, June 1988.

APPENDICES

APPENDIX A

UT Robot Software Specifications

UT PRODUCTION ROBOT -- MOTION CONTROL REQUIREMENTS
Preliminary -- 06/26/89 -- Revision 1.10
(Reformatted from original computer file - 4/23/91)

Section I: General Requirements

A) General Performance and I/O:

1) The motion control software shall be capable of controlling a minimum of four stepper motors simultaneously (X,Y,Z, and Theta).

2) The motion control software shall be capable of providing a minimum of __ external signal outputs to other devices and controls. (For example, the software should be capable of signalling a clamping device to close/open, and a belt feed system to start/stop.)

3) The motion control software shall be capable of performing a programmed motion sequence "on command", either from an "internal" trigger (such as by a program "call" or by pressing the "return" key on the computer keyboard) or from an "external" trigger (such as by a photocell or pushbutton switch).

4) The motion control software shall be capable of accepting inputs from a minimum of four (4) "robot calibration" sensors (such as photocells or switches).

5) The option control software shall be designed to receive/send the required input/output signals (as described above) using standard PC parallel port devices. Parallel port pin allocation shall be modular: Port #1 shall contain motor actuation and calibration signals (signals required for all robot applications), while Port #2 shall be used for other external I/O signals (application-specific signals, such as external sensors or belt on/off signals).

6) The motion control software shall be capable of altering its motion program (i.e. "make choices") based on either external or internal inputs. For example, the program should be capable of executing different point to point procedures, depending on the status of a photocell array (could be used in a robot system designed to detect and move different-sized doors automatically).

7) The motion control software shall be designed in a modular form, so that various enhanced features, such as new user interfaces, can be added easily to the "base" motor control software.

8) The motion control software shall incorporate appropriate message, status, and instructional messages as is necessary for safe and efficent robot operation.

B) Hardware:

1) The motion control software shall be developed to operate on an IBM-PC or equivalent Intel computer (and higher). The computer will be equipped with at least 256 K memory, and at least one parallel port. A second parallel port will be optional for applications requiring external sensors or outputs. A math co-processor will NOT be provided unless the software cannot be designed without one.

2) The program should be capable of being started from either a diskette drive or a fixed disk.

3) The motor control output signals shall interface through the parallel port directly to a "standard" stepper motor driver, specifically IMS Model IB463 and equivalents.

Section II: Motion Programming Control Requirements

A) Motion Types :

The motion control program shall be capable of performing the following types of motion:

1) Point-to-Point Sequence: Control motors to move robot from one point to another.

2) Controlled Path: Control motors to move robot along a specifically defined path composed of straight lines and arcs.

3) External Control: Control motors to move robot in response to a keyboard or similar input. (This mode could be used, for example, to "teach" the robot new point-to-point or path positions for a new program).

4) Hybrid: Control motors using a combination of External Control, Point-to-Point, and Controlled Path motion modes. (Example: Hybrid mode could be used to establish a reference position using External Control, then to execute a point-to-point or controlled path program from the reference points.)

5) Calibration: Control motors to move robot to the robot's calibration points, as signalled from photocells or microswitchs mounted on the robot. The calibration sequence shall be started only upon operator's command.

6) Calibration Check: Control motors to move robot to the robot's calibration points, to verify that the actual robot position is the same as that computed by the motor control software. This routine must be capable of being invoked by other motion modes (for example, performing an occasional calibration check within an automatic point-to-point program). If a calibration error is detected, the program shall terminate all motion and display error and warning messages.

B) Motion Data Sources:

The control software shall be capable of accepting position and motion data from a variety of sources, including:

1) External data files : read point-to-point, path, and related data from an external ASCII file or similar source (data file format to be defined).

2) Internal subroutines : program required motions (points and paths) as part of the control code.

3) Keyboard (or Similar) input : accept motion requests from the keyboard (e.g. pressing the arrow keys) or similar device (such as a special motion control box).

4) External programs : receive a "call" from another program. In this mode, the "calling" program provides the relevant motion data (in a format to be defined), while the motion control software executes the desired motion.

5) Robot position data : capable of saving data points corresponding to the robot's position when directed to do so. Primarily for use in "teach" mode, used in conjunction with keyboard input.

6) SmartCam output files : perform operations as directed by a SmartCam output data file for milling machines. (future)

7) Scanner : reproduce a path read from a digital scanning device connected to the computer. (future)

Robot Motion Parameter Data:

A) X Direction:
* Degrees Per Motor Step
* Motor Pulley Diameter
* Reduction Pulley Diameter
* Belt Pulley Diameter
* Travel Limits (Length)
* Coordinate Position of Recalibration Sensor

B) Y Direction:
* Degrees Per Motor Step
* Motor Pulley Diameter
* Reduction Pulley Diameter
* Belt Pulley Diameter
* Travel Limits (Length)
* Coordinate Position of Calibration Sensor

C) Z Direction:
* Degrees Per Motor Step
* Motor Pulley Diameter
* Travel Limits (Length)
* Coordinate Position of Calibration Sensor

D) Theta Direction:
* Degrees Per Motor Step
* Travel Limits (Angle) - for cases when wires or hoses are attached to end effector
* Coordinate Position of Calibration Sensor

Robot Positioning Control:

* Position:
  + Absolute Coordinates
  + Relative Coordinates (translational and/or rotational)

* Velocity:
  + Desired Velocity
  + Maximum Velocity Limit

* Acceleration:
  + Desired Acceleration/Deceleration
  + Ramp Type (Square, Trapezoidal, Parabolic, etc.)
  + Maximum Acceleration Limit

Other Robot Data:

* Payload Weight
* Robot Component Weights
* System Torque/Weight/Speed Data and Equations
* Motor Torque/Speed Characteristics
  + Factor of Safety
  + Motor Current

APPENDIX B

Reduction Ratio Chart

REDUCTION RATIO CHART

Purpose of Chart :

The purpose of this chart is to enable the designer to:

A) determine the reduction ratio of the drive system, given the motor and intermediate drive pulleys;

B) select motor and intermediate drive pulleys, given the desired robot reduction ratio.

How To Use This Chart :

A) To determine the reduction ratio, given the motor and intermediate drive pulleys:

1) Find the given intermediate drive pulley along the top row of the chart.

2) Find the given motor pulley along down the left column of the chart.

3) Move down the column for the given intermediate drive pulley and right along the along the row for the given motor pulley. At the intersection, read the reduction ratio.

B) To select motor and intermediate drive pulleys, given reduction ratio:

1) Find desired reduction ratio in the body of the table. There likely are several alternatives available.

2) Go up the column of the chart to find the required intermediate drive pulley.

3) Go left along the row of the chart to find the required motor pulley.

TIMING BELT PULLEY REDUCTION RATIOS BELT PITCH = 0.200 IN

$$\text{REDUCTION RATIO} = \frac{\text{INTERMEDIATE (REDUCTION) PULLEY PD}}{\text{MOTOR PULLEY PD}}$$

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		0.637	0.700	0.764	0.828	0.891	0.955	1.019	1.082	1.146	1.210	1.273	1.337	1.401	1.464	1.528	1.592
10	0.637	1.000	1.100	1.200	1.300	1.400	1.500	1.600	1.700	1.800	1.900	2.000	2.100	2.200	2.300	2.400	2.500
11	0.700	0.909	1.000	1.091	1.182	1.273	1.364	1.455	1.545	1.636	1.727	1.818	1.909	2.000	2.091	2.182	2.273
12	0.764	0.833	0.917	1.000	1.083	1.167	1.250	1.333	1.417	1.500	1.583	1.667	1.750	1.833	1.917	2.000	2.083
13	0.828	0.769	0.846	0.923	1.000	1.077	1.154	1.231	1.308	1.385	1.462	1.538	1.615	1.692	1.769	1.846	1.923
14	0.891	0.714	0.786	0.857	0.929	1.000	1.071	1.143	1.214	1.286	1.357	1.429	1.500	1.571	1.643	1.714	1.786
15	0.955	0.667	0.733	0.800	0.867	0.933	1.000	1.067	1.133	1.200	1.267	1.333	1.400	1.467	1.533	1.600	1.667
16	1.019	0.625	0.688	0.750	0.813	0.875	0.938	1.000	1.063	1.125	1.188	1.250	1.313	1.375	1.438	1.500	1.563
17	1.082	0.588	0.647	0.706	0.765	0.824	0.882	0.941	1.000	1.059	1.118	1.176	1.235	1.294	1.353	1.412	1.471
18	1.146	0.556	0.611	0.667	0.722	0.778	0.833	0.889	0.944	1.000	1.056	1.111	1.167	1.222	1.278	1.333	1.389
19	1.210	0.526	0.579	0.632	0.684	0.737	0.789	0.842	0.895	0.947	1.000	1.053	1.105	1.158	1.211	1.263	1.316
20	1.273	0.500	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.050	1.100	1.150	1.200	1.250
21	1.337	0.476	0.524	0.571	0.619	0.667	0.714	0.762	0.810	0.857	0.905	0.952	1.000	1.048	1.095	1.143	1.190
22	1.401	0.455	0.500	0.545	0.591	0.636	0.682	0.727	0.773	0.818	0.864	0.909	0.955	1.000	1.045	1.091	1.136
23	1.464	0.435	0.478	0.522	0.565	0.609	0.652	0.696	0.739	0.783	0.826	0.870	0.913	0.957	1.000	1.043	1.087
24	1.528	0.417	0.458	0.500	0.542	0.583	0.625	0.667	0.708	0.750	0.792	0.833	0.875	0.917	0.958	1.000	1.042
25	1.592	0.400	0.440	0.480	0.520	0.560	0.600	0.640	0.680	0.720	0.760	0.800	0.840	0.880	0.920	0.960	1.000
26	1.655	0.385	0.423	0.462	0.500	0.538	0.577	0.615	0.654	0.692	0.731	0.769	0.808	0.846	0.885	0.923	0.962
27	1.719	0.370	0.407	0.444	0.481	0.519	0.556	0.593	0.630	0.667	0.704	0.741	0.778	0.815	0.852	0.889	0.926
28	1.783	0.357	0.393	0.429	0.464	0.500	0.536	0.571	0.607	0.643	0.679	0.714	0.750	0.786	0.821	0.857	0.893
29	1.846	0.345	0.379	0.414	0.448	0.483	0.517	0.552	0.586	0.621	0.655	0.690	0.724	0.759	0.793	0.828	0.862
30	1.910	0.333	0.367	0.400	0.433	0.467	0.500	0.533	0.567	0.600	0.633	0.667	0.700	0.733	0.767	0.800	0.833
32	2.037	0.313	0.344	0.375	0.406	0.438	0.469	0.500	0.531	0.563	0.594	0.625	0.656	0.688	0.719	0.750	0.781
36	2.292	0.278	0.306	0.333	0.361	0.389	0.417	0.444	0.472	0.500	0.528	0.556	0.583	0.611	0.639	0.667	0.694
40	2.546	0.250	0.275	0.300	0.325	0.350	0.375	0.400	0.425	0.450	0.475	0.500	0.525	0.550	0.575	0.600	0.625
42	2.674	0.238	0.262	0.286	0.310	0.333	0.357	0.381	0.405	0.429	0.452	0.476	0.500	0.524	0.548	0.571	0.595
44	2.801	0.227	0.250	0.273	0.295	0.318	0.341	0.364	0.386	0.409	0.432	0.455	0.477	0.500	0.523	0.545	0.568
45	2.865	0.222	0.244	0.267	0.289	0.311	0.333	0.356	0.378	0.400	0.422	0.444	0.467	0.489	0.511	0.533	0.556
48	3.056	0.208	0.229	0.250	0.271	0.292	0.313	0.333	0.354	0.375	0.396	0.417	0.438	0.458	0.479	0.500	0.521
50	3.183	0.200	0.220	0.240	0.260	0.280	0.300	0.320	0.340	0.360	0.380	0.400	0.420	0.440	0.460	0.480	0.500
60	3.820	0.167	0.183	0.200	0.217	0.233	0.250	0.267	0.283	0.300	0.317	0.333	0.350	0.367	0.383	0.400	0.417
72	4.584	0.139	0.153	0.167	0.181	0.194	0.208	0.222	0.236	0.250	0.264	0.278	0.292	0.306	0.319	0.333	0.347

TIMING BELT PULLEY REDUCTION RATIOS BELT PITCH = 0.2 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	2.600	2.700	2.800	2.900	3.000	3.200	3.600	4.000	4.200	4.400	4.500	4.800	5.000	6.000	7.200
11	0.700	2.364	2.455	2.545	2.636	2.727	2.909	3.273	3.636	3.818	4.000	4.091	4.364	4.545	5.455	6.545
12	0.764	2.167	2.250	2.333	2.417	2.500	2.667	3.000	3.333	3.500	3.667	3.750	4.000	4.167	5.000	6.000
13	0.828	2.000	2.077	2.154	2.231	2.308	2.462	2.769	3.077	3.231	3.385	3.462	3.692	3.846	4.615	5.538
14	0.891	1.857	1.929	2.000	2.071	2.143	2.286	2.571	2.857	3.000	3.143	3.214	3.429	3.571	4.286	5.143
15	0.955	1.733	1.800	1.867	1.933	2.000	2.133	2.400	2.667	2.800	2.933	3.000	3.200	3.333	4.000	4.800
16	1.019	1.625	1.688	1.750	1.813	1.875	2.000	2.250	2.500	2.625	2.750	2.813	3.000	3.125	3.750	4.500
17	1.082	1.529	1.588	1.647	1.706	1.765	1.882	2.118	2.353	2.471	2.588	2.647	2.824	2.941	3.529	4.235
18	1.146	1.444	1.500	1.556	1.611	1.667	1.778	2.000	2.222	2.333	2.444	2.500	2.667	2.778	3.333	4.000
19	1.210	1.368	1.421	1.474	1.526	1.579	1.684	1.895	2.105	2.211	2.316	2.368	2.526	2.632	3.158	3.789
20	1.273	1.300	1.350	1.400	1.450	1.500	1.600	1.800	2.000	2.100	2.200	2.250	2.400	2.500	3.000	3.600
21	1.337	1.238	1.286	1.333	1.381	1.429	1.524	1.714	1.905	2.000	2.095	2.143	2.286	2.381	2.857	3.429
22	1.401	1.182	1.227	1.273	1.318	1.364	1.455	1.636	1.818	1.909	2.000	2.045	2.182	2.273	2.727	3.273
23	1.464	1.130	1.174	1.217	1.261	1.304	1.391	1.565	1.739	1.826	1.913	1.957	2.087	2.174	2.609	3.130
24	1.528	1.083	1.125	1.167	1.208	1.250	1.333	1.500	1.667	1.750	1.833	1.875	2.000	2.083	2.500	3.000
25	1.592	1.040	1.080	1.120	1.160	1.200	1.280	1.440	1.600	1.680	1.760	1.800	1.920	2.000	2.400	2.880
26	1.655	1.000	1.038	1.077	1.115	1.154	1.231	1.385	1.538	1.615	1.692	1.731	1.846	1.923	2.308	2.769
27	1.719	0.963	1.000	1.037	1.074	1.111	1.185	1.333	1.481	1.556	1.630	1.667	1.778	1.852	2.222	2.667
28	1.783	0.929	0.964	1.000	1.036	1.071	1.143	1.286	1.429	1.500	1.571	1.607	1.714	1.786	2.143	2.571
29	1.846	0.897	0.931	0.966	1.000	1.034	1.103	1.241	1.379	1.448	1.517	1.552	1.655	1.724	2.069	2.483
30	1.910	0.867	0.900	0.933	0.967	1.000	1.067	1.200	1.333	1.400	1.467	1.500	1.600	1.667	2.000	2.400
32	2.037	0.813	0.844	0.875	0.906	0.938	1.000	1.125	1.250	1.313	1.375	1.406	1.500	1.563	1.875	2.250
36	2.292	0.722	0.750	0.778	0.806	0.833	0.889	1.000	1.111	1.167	1.222	1.250	1.333	1.389	1.667	2.000
40	2.546	0.650	0.675	0.700	0.725	0.750	0.800	0.900	1.000	1.050	1.100	1.125	1.200	1.250	1.500	1.800
42	2.674	0.619	0.643	0.667	0.690	0.714	0.762	0.857	0.952	1.000	1.048	1.071	1.143	1.190	1.429	1.714
44	2.801	0.591	0.614	0.636	0.659	0.682	0.727	0.818	0.909	0.955	1.000	1.023	1.091	1.136	1.364	1.636
45	2.865	0.578	0.600	0.622	0.644	0.667	0.711	0.800	0.889	0.933	0.978	1.000	1.067	1.111	1.333	1.600
48	3.056	0.542	0.563	0.583	0.604	0.625	0.667	0.750	0.833	0.875	0.917	0.938	1.000	1.042	1.250	1.500
50	3.183	0.520	0.540	0.560	0.580	0.600	0.640	0.720	0.800	0.840	0.880	0.900	0.960	1.000	1.200	1.440
60	3.820	0.433	0.450	0.467	0.483	0.500	0.533	0.600	0.667	0.700	0.733	0.750	0.800	0.833	1.000	1.200
72	4.584	0.361	0.375	0.389	0.403	0.417	0.444	0.500	0.556	0.583	0.611	0.625	0.667	0.694	0.833	1.000

APPENDIX C

Horizontal System Resolution Selection Charts

HORIZONTAL SYSTEM RESOLUTION SELECTION CHARTS

Purpose of Charts :

The purpose of these charts is to enable the designer to:

A) determine the step resolution (in/step) or resolution "index" (steps/in) of the horizontal system, given the motor and intermediate drive pulleys;

B) select motor and intermediate drive pulleys, given a step resolution or "index".

How To Use These Charts :

A) To determine the step resolution (or resolution index), given the motor and intermediate drive pulleys:

1) Locate the "Step Resolution" (or "Resolution Index") chart.

2) Find the given intermediate drive pulley along the top row of the chart.

3) Find the given motor pulley along down the left column of the chart.

4) Move down the column for the given intermediate drive pulley and right along the along the row for the given motor pulley. At the intersection, read the step resolution (or resolution index).

B) To select motor and intermediate drive pulleys, given step resolution (or resolution index):

1) Locate the "Step Resolution" (or "Resolution Index") chart.

2) Find desired resolution (or index) in the table body. There likely are several alternatives available.

3) Go up the column of the chart to find the intermediate drive pulley.

4) Go left along the row of the chart to find the motor pulley.

STEP RESOLUTION - HORIZONTAL SYSTEM BELT PITCH = 0.200 IN

DRIVE PULLEY - # OF TEETH 15 /REVOLUTION
PITCH DIAMETER 0.955 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: 0.001 INCHES/STEP

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	15.00	13.64	12.50	11.54	10.71	10.00	9.38	8.82	8.33	7.89	7.50	7.14	6.82	6.52	6.25	6.00
11	0.700	16.50	15.00	13.75	12.69	11.79	11.00	10.31	9.71	9.17	8.68	8.25	7.86	7.50	7.17	6.88	6.60
12	0.764	18.00	16.36	15.00	13.85	12.86	12.00	11.25	10.59	10.00	9.47	9.00	8.57	8.18	7.83	7.50	7.20
13	0.828	19.50	17.73	16.25	15.00	13.93	13.00	12.19	11.47	10.83	10.26	9.75	9.29	8.86	8.48	8.13	7.80
14	0.891	21.00	19.09	17.50	16.15	15.00	14.00	13.13	12.35	11.67	11.05	10.50	10.00	9.55	9.13	8.75	8.40
15	0.955	22.50	20.45	18.75	17.31	16.07	15.00	14.06	13.24	12.50	11.84	11.25	10.71	10.23	9.78	9.38	9.00
16	1.019	24.00	21.82	20.00	18.46	17.14	16.00	15.00	14.12	13.33	12.63	12.00	11.43	10.91	10.43	10.00	9.60
17	1.082	25.50	23.18	21.25	19.62	18.21	17.00	15.94	15.00	14.17	13.42	12.75	12.14	11.59	11.09	10.63	10.20
18	1.146	27.00	24.55	22.50	20.77	19.29	18.00	16.88	15.88	15.00	14.21	13.50	12.86	12.27	11.74	11.25	10.80
19	1.210	28.50	25.91	23.75	21.92	20.36	19.00	17.81	16.76	15.83	15.00	14.25	13.57	12.95	12.39	11.88	11.40
20	1.273	30.00	27.27	25.00	23.08	21.43	20.00	18.75	17.65	16.67	15.79	15.00	14.29	13.64	13.04	12.50	12.00
21	1.337	31.50	28.64	26.25	24.23	22.50	21.00	19.69	18.53	17.50	16.58	15.75	15.00	14.32	13.70	13.13	12.60
22	1.401	33.00	30.00	27.50	25.38	23.57	22.00	20.63	19.41	18.33	17.37	16.50	15.71	15.00	14.35	13.75	13.20
23	1.464	34.50	31.36	28.75	26.54	24.64	23.00	21.56	20.29	19.17	18.16	17.25	16.43	15.68	15.00	14.38	13.80
24	1.528	36.00	32.73	30.00	27.69	25.71	24.00	22.50	21.18	20.00	18.95	18.00	17.14	16.36	15.65	15.00	14.40
25	1.592	37.50	34.09	31.25	28.85	26.79	25.00	23.44	22.06	20.83	19.74	18.75	17.86	17.05	16.30	15.63	15.00
26	1.655	39.00	35.45	32.50	30.00	27.86	26.00	24.38	22.94	21.67	20.53	19.50	18.57	17.73	16.96	16.25	15.60
27	1.719	40.50	36.82	33.75	31.15	28.93	27.00	25.31	23.82	22.50	21.32	20.25	19.29	18.41	17.61	16.88	16.20
28	1.783	42.00	38.18	35.00	32.31	30.00	28.00	26.25	24.71	23.33	22.11	21.00	20.00	19.09	18.26	17.50	16.80
29	1.846	43.50	39.55	36.25	33.46	31.07	29.00	27.19	25.59	24.17	22.89	21.75	20.71	19.77	18.91	18.13	17.40
30	1.910	45.00	40.91	37.50	34.62	32.14	30.00	28.13	26.47	25.00	23.68	22.50	21.43	20.45	19.57	18.75	18.00
32	2.037	48.00	43.64	40.00	36.92	34.29	32.00	30.00	28.24	26.67	25.26	24.00	22.86	21.82	20.87	20.00	19.20
36	2.292	54.00	49.09	45.00	41.54	38.57	36.00	33.75	31.76	30.00	28.42	27.00	25.71	24.55	23.48	22.50	21.60
40	2.546	60.00	54.55	50.00	46.15	42.86	40.00	37.50	35.29	33.33	31.58	30.00	28.57	27.27	26.09	25.00	24.00
42	2.674	63.00	57.27	52.50	48.46	45.00	42.00	39.38	37.06	35.00	33.16	31.50	30.00	28.64	27.39	26.25	25.20
44	2.801	66.00	60.00	55.00	50.77	47.14	44.00	41.25	38.82	36.67	34.74	33.00	31.43	30.00	28.70	27.50	26.40
45	2.865	67.50	61.36	56.25	51.92	48.21	45.00	42.19	39.71	37.50	35.53	33.75	32.14	30.68	29.35	28.13	27.00
48	3.056	72.00	65.45	60.00	55.38	51.43	48.00	45.00	42.35	40.00	37.89	36.00	34.29	32.73	31.30	30.00	28.80
50	3.183	75.00	68.18	62.50	57.69	53.57	50.00	46.88	44.12	41.67	39.47	37.50	35.71	34.09	32.61	31.25	30.00
60	3.820	90.00	81.82	75.00	69.23	64.29	60.00	56.25	52.94	50.00	47.37	45.00	42.86	40.91	39.13	37.50	36.00
72	4.584	108.00	98.18	90.00	83.08	77.14	72.00	67.50	63.53	60.00	56.84	54.00	51.43	49.09	46.96	45.00	43.20

STEP RESOLUTION - HORIZONTAL SYSTEM BELT PITCH = 0.2 IN

DRIVE PULLEY - # OF TEETH 15 /REVOLUTION
PITCH DIAMETER 0.955 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: 0.001 INCHES/STEP

MOTOR PULLEY
:
V

INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	5.77	5.56	5.36	5.17	5.00	4.69	4.17	3.75	3.57	3.41	3.33	3.13	3.00	2.50	2.08
11	0.700	6.35	6.11	5.89	5.69	5.50	5.16	4.58	4.13	3.93	3.75	3.67	3.44	3.30	2.75	2.29
12	0.764	6.92	6.67	6.43	6.21	6.00	5.63	5.00	4.50	4.29	4.09	4.00	3.75	3.60	3.00	2.50
13	0.828	7.50	7.22	6.96	6.72	6.50	6.09	5.42	4.88	4.64	4.43	4.33	4.06	3.90	3.25	2.71
14	0.891	8.08	7.78	7.50	7.24	7.00	6.56	5.83	5.25	5.00	4.77	4.67	4.38	4.20	3.50	2.92
15	0.955	8.65	8.33	8.04	7.76	7.50	7.03	6.25	5.63	5.36	5.11	5.00	4.69	4.50	3.75	3.13
16	1.019	9.23	8.89	8.57	8.28	8.00	7.50	6.67	6.00	5.71	5.45	5.33	5.00	4.80	4.00	3.33
17	1.082	9.81	9.44	9.11	8.79	8.50	7.97	7.08	6.38	6.07	5.80	5.67	5.31	5.10	4.25	3.54
18	1.146	10.38	10.00	9.64	9.31	9.00	8.44	7.50	6.75	6.43	6.14	6.00	5.63	5.40	4.50	3.75
19	1.210	10.96	10.56	10.18	9.83	9.50	8.91	7.92	7.13	6.79	6.48	6.33	5.94	5.70	4.75	3.96
20	1.273	11.54	11.11	10.71	10.34	10.00	9.38	8.33	7.50	7.14	6.82	6.67	6.25	6.00	5.00	4.17
21	1.337	12.12	11.67	11.25	10.86	10.50	9.84	8.75	7.88	7.50	7.16	7.00	6.56	6.30	5.25	4.38
22	1.401	12.69	12.22	11.79	11.38	11.00	10.31	9.17	8.25	7.86	7.50	7.33	6.88	6.60	5.50	4.58
23	1.464	13.27	12.78	12.32	11.90	11.50	10.78	9.58	8.63	8.21	7.84	7.67	7.19	6.90	5.75	4.79
24	1.528	13.85	13.33	12.86	12.41	12.00	11.25	10.00	9.00	8.57	8.18	8.00	7.50	7.20	6.00	5.00
25	1.592	14.42	13.89	13.39	12.93	12.50	11.72	10.42	9.38	8.93	8.52	8.33	7.81	7.50	6.25	5.21
26	1.655	15.00	14.44	13.93	13.45	13.00	12.19	10.83	9.75	9.29	8.86	8.67	8.13	7.80	6.50	5.42
27	1.719	15.58	15.00	14.46	13.97	13.50	12.66	11.25	10.13	9.64	9.20	9.00	8.44	8.10	6.75	5.63
28	1.783	16.15	15.56	15.00	14.48	14.00	13.13	11.67	10.50	10.00	9.55	9.33	8.75	8.40	7.00	5.83
29	1.846	16.73	16.11	15.54	15.00	14.50	13.59	12.08	10.88	10.36	9.89	9.67	9.06	8.70	7.25	6.04
30	1.910	17.31	16.67	16.07	15.52	15.00	14.06	12.50	11.25	10.71	10.23	10.00	9.38	9.00	7.50	6.25
32	2.037	18.46	17.78	17.14	16.55	16.00	15.00	13.33	12.00	11.43	10.91	10.67	10.00	9.60	8.00	6.67
36	2.292	20.77	20.00	19.29	18.62	18.00	16.88	15.00	13.50	12.86	12.27	12.00	11.25	10.80	9.00	7.50
40	2.546	23.08	22.22	21.43	20.69	20.00	18.75	16.67	15.00	14.29	13.64	13.33	12.50	12.00	10.00	8.33
42	2.674	24.23	23.33	22.50	21.72	21.00	19.69	17.50	15.75	15.00	14.32	14.00	13.13	12.60	10.50	8.75
44	2.801	25.38	24.44	23.57	22.76	22.00	20.63	18.33	16.50	15.71	15.00	14.67	13.75	13.20	11.00	9.17
45	2.865	25.96	25.00	24.11	23.28	22.50	21.09	18.75	16.88	16.07	15.34	15.00	14.06	13.50	11.25	9.38
48	3.056	27.69	26.67	25.71	24.83	24.00	22.50	20.00	18.00	17.14	16.36	16.00	15.00	14.40	12.00	10.00
50	3.183	28.85	27.78	26.79	25.86	25.00	23.44	20.83	18.75	17.86	17.05	16.67	15.63	15.00	12.50	10.42
60	3.820	34.62	33.33	32.14	31.03	30.00	28.13	25.00	22.50	21.43	20.45	20.00	18.75	18.00	15.00	12.50
72	4.584	41.54	40.00	38.57	37.24	36.00	33.75	30.00	27.00	25.71	24.55	24.00	22.50	21.60	18.00	15.00

RESOLUTION INDEX - HORIZONTAL

BELT PITCH = 0.200 IN

DRIVE PULLEY - # OF TEETH 15 /REVOLUTION

PITCH DIAMETER 0.955 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: # STEPS / INCH

MOTOR PULLEY
:
v

INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	66.67	73.33	80.00	86.67	93.33	100.00	106.67	113.33	120.00	126.67	133.33	140.00	146.67	153.33	160.00	166.67
11	0.700	60.61	66.67	72.73	78.79	84.85	90.91	96.97	103.03	109.09	115.15	121.21	127.27	133.33	139.39	145.45	151.52
12	0.764	55.56	61.11	66.67	72.22	77.78	83.33	88.89	94.44	100.00	105.56	111.11	116.67	122.22	127.78	133.33	138.89
13	0.828	51.28	56.41	61.54	66.67	71.79	76.92	82.05	87.18	92.31	97.44	102.56	107.69	112.82	117.95	123.08	128.21
14	0.891	47.62	52.38	57.14	61.90	66.67	71.43	76.19	80.95	85.71	90.48	95.24	100.00	104.76	109.52	114.29	119.05
15	0.955	44.44	48.89	53.33	57.78	62.22	66.67	71.11	75.56	80.00	84.44	88.89	93.33	97.78	102.22	106.67	111.11
16	1.019	41.67	45.83	50.00	54.17	58.33	62.50	66.67	70.83	75.00	79.17	83.33	87.50	91.67	95.83	100.00	104.17
17	1.082	39.22	43.14	47.06	50.98	54.90	58.82	62.75	66.67	70.59	74.51	78.43	82.35	86.27	90.20	94.12	98.04
18	1.146	37.04	40.74	44.44	48.15	51.85	55.56	59.26	62.96	66.67	70.37	74.07	77.78	81.48	85.19	88.89	92.59
19	1.210	35.09	38.60	42.11	45.61	49.12	52.63	56.14	59.65	63.16	66.67	70.18	73.68	77.19	80.70	84.21	87.72
20	1.273	33.33	36.67	40.00	43.33	46.67	50.00	53.33	56.67	60.00	63.33	66.67	70.00	73.33	76.67	80.00	83.33
21	1.337	31.75	34.92	38.10	41.27	44.44	47.62	50.79	53.97	57.14	60.32	63.49	66.67	69.84	73.02	76.19	79.37
22	1.401	30.30	33.33	36.36	39.39	42.42	45.45	48.48	51.52	54.55	57.58	60.61	63.64	66.67	69.70	72.73	75.76
23	1.464	28.99	31.88	34.78	37.68	40.58	43.48	46.38	49.28	52.17	55.07	57.97	60.87	63.77	66.67	69.57	72.46
24	1.528	27.78	30.56	33.33	36.11	38.89	41.67	44.44	47.22	50.00	52.78	55.56	58.33	61.11	63.89	66.67	69.44
25	1.592	26.67	29.33	32.00	34.67	37.33	40.00	42.67	45.33	48.00	50.67	53.33	56.00	58.67	61.33	64.00	66.67
26	1.655	25.64	28.21	30.77	33.33	35.90	38.46	41.03	43.59	46.15	48.72	51.28	53.85	56.41	58.97	61.54	64.10
27	1.719	24.69	27.16	29.63	32.10	34.57	37.04	39.51	41.98	44.44	46.91	49.38	51.85	54.32	56.79	59.26	61.73
28	1.783	23.81	26.19	28.57	30.95	33.33	35.71	38.10	40.48	42.86	45.24	47.62	50.00	52.38	54.76	57.14	59.52
29	1.846	22.99	25.29	27.59	29.89	32.18	34.48	36.78	39.08	41.38	43.68	45.98	48.28	50.57	52.87	55.17	57.47
30	1.910	22.22	24.44	26.67	28.89	31.11	33.33	35.56	37.78	40.00	42.22	44.44	46.67	48.89	51.11	53.33	55.56
32	2.037	20.83	22.92	25.00	27.08	29.17	31.25	33.33	35.42	37.50	39.58	41.67	43.75	45.83	47.92	50.00	52.08
36	2.292	18.52	20.37	22.22	24.07	25.93	27.78	29.63	31.48	33.33	35.19	37.04	38.89	40.74	42.59	44.44	46.30
40	2.546	16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67	33.33	35.00	36.67	38.33	40.00	41.67
42	2.674	15.87	17.46	19.05	20.63	22.22	23.81	25.40	26.98	28.57	30.16	31.75	33.33	34.92	36.51	38.10	39.68
44	2.801	15.15	16.67	18.18	19.70	21.21	22.73	24.24	25.76	27.27	28.79	30.30	31.82	33.33	34.85	36.36	37.88
45	2.865	14.81	16.30	17.78	19.26	20.74	22.22	23.70	25.19	26.67	28.15	29.63	31.11	32.59	34.07	35.56	37.04
48	3.056	13.89	15.28	16.67	18.06	19.44	20.83	22.22	23.61	25.00	26.39	27.78	29.17	30.56	31.94	33.33	34.72
50	3.183	13.33	14.67	16.00	17.33	18.67	20.00	21.33	22.67	24.00	25.33	26.67	28.00	29.33	30.67	32.00	33.33
60	3.820	11.11	12.22	13.33	14.44	15.56	16.67	17.78	18.89	20.00	21.11	22.22	23.33	24.44	25.56	26.67	27.78
72	4.584	9.26	10.19	11.11	12.04	12.96	13.89	14.81	15.74	16.67	17.59	18.52	19.44	20.37	21.30	22.22	23.15

RESOLUTION INDEX - HORIZONTAL BELT PITCH = 0.2 IN

DRIVE PULLEY - # OF TEETH 15 /REVOLUTION
PITCH DIAMETER 0.955 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: # STEPS / INCH

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	173.33	180.00	186.67	193.33	200.00	213.33	240.00	266.67	280.00	293.33	300.00	320.00	333.33	400.00	480.00
11	0.700	157.58	163.64	169.70	175.76	181.82	193.94	218.18	242.42	254.55	266.67	272.73	290.91	303.03	363.64	436.36
12	0.764	144.44	150.00	155.56	161.11	166.67	177.78	200.00	222.22	233.33	244.44	250.00	266.67	277.78	333.33	400.00
13	0.828	133.33	138.46	143.59	148.72	153.85	164.10	184.62	205.13	215.38	225.64	230.77	246.15	256.41	307.69	369.23
14	0.891	123.81	128.57	133.33	138.10	142.86	152.38	171.43	190.48	200.00	209.52	214.29	228.57	238.10	285.71	342.86
15	0.955	115.56	120.00	124.44	128.89	133.33	142.22	160.00	177.78	186.67	195.56	200.00	213.33	222.22	266.67	320.00
16	1.019	108.33	112.50	116.67	120.83	125.00	133.33	150.00	166.67	175.00	183.33	187.50	200.00	208.33	250.00	300.00
17	1.082	101.96	105.88	109.80	113.73	117.65	125.49	141.18	156.86	164.71	172.55	176.47	188.24	196.08	235.29	282.35
18	1.146	96.30	100.00	103.70	107.41	111.11	118.52	133.33	148.15	155.56	162.96	166.67	177.78	185.19	222.22	266.67
19	1.210	91.23	94.74	98.25	101.75	105.26	112.28	126.32	140.35	147.37	154.39	157.89	168.42	175.44	210.53	252.63
20	1.273	86.67	90.00	93.33	96.67	100.00	106.67	120.00	133.33	140.00	146.67	150.00	160.00	166.67	200.00	240.00
21	1.337	82.54	85.71	88.89	92.06	95.24	101.59	114.29	126.98	133.33	139.68	142.86	152.38	158.73	190.48	228.57
22	1.401	78.79	81.82	84.85	87.88	90.91	96.97	109.09	121.21	127.27	133.33	136.36	145.45	151.52	181.82	218.18
23	1.464	75.36	78.26	81.16	84.06	86.96	92.75	104.35	115.94	121.74	127.54	130.43	139.13	144.93	173.91	208.70
24	1.528	72.22	75.00	77.78	80.56	83.33	88.89	100.00	111.11	116.67	122.22	125.00	133.33	138.89	166.67	200.00
25	1.592	69.33	72.00	74.67	77.33	80.00	85.33	96.00	106.67	112.00	117.33	120.00	128.00	133.33	160.00	192.00
26	1.655	66.67	69.23	71.79	74.36	76.92	82.05	92.31	102.56	107.69	112.82	115.38	123.08	128.21	153.85	184.62
27	1.719	64.20	66.67	69.14	71.60	74.07	79.01	88.89	98.77	103.70	108.64	111.11	118.52	123.46	148.15	177.78
28	1.783	61.90	64.29	66.67	69.05	71.43	76.19	85.71	95.24	100.00	104.76	107.14	114.29	119.05	142.86	171.43
29	1.846	59.77	62.07	64.37	66.67	68.97	73.56	82.76	91.95	96.55	101.15	103.45	110.34	114.94	137.93	165.52
30	1.910	57.78	60.00	62.22	64.44	66.67	71.11	80.00	88.89	93.33	97.78	100.00	106.67	111.11	133.33	160.00
32	2.037	54.17	56.25	58.33	60.42	62.50	66.67	75.00	83.33	87.50	91.67	93.75	100.00	104.17	125.00	150.00
36	2.292	48.15	50.00	51.85	53.70	55.56	59.26	66.67	74.07	77.78	81.48	83.33	88.89	92.59	111.11	133.33
40	2.546	43.33	45.00	46.67	48.33	50.00	53.33	60.00	66.67	70.00	73.33	75.00	80.00	83.33	100.00	120.00
42	2.674	41.27	42.86	44.44	46.03	47.62	50.79	57.14	63.49	66.67	69.84	71.43	76.19	79.37	95.24	114.29
44	2.801	39.39	40.91	42.42	43.94	45.45	48.48	54.55	60.61	63.64	66.67	68.18	72.73	75.76	90.91	109.09
45	2.865	38.52	40.00	41.48	42.96	44.44	47.41	53.33	59.26	62.22	65.19	66.67	71.11	74.07	88.89	106.67
48	3.056	36.11	37.50	38.89	40.28	41.67	44.44	50.00	55.56	58.33	61.11	62.50	66.67	69.44	83.33	100.00
50	3.183	34.67	36.00	37.33	38.67	40.00	42.67	48.00	53.33	56.00	58.67	60.00	64.00	66.67	80.00	96.00
60	3.820	28.89	30.00	31.11	32.22	33.33	35.56	40.00	44.44	46.67	48.89	50.00	53.33	55.56	66.67	80.00
72	4.584	24.07	25.00	25.93	26.85	27.78	29.63	33.33	37.04	38.89	40.74	41.67	44.44	46.30	55.56	66.67

APPENDIX D

Horizontal Reduction System Belt Length Charts

HORIZONTAL REDUCTION SYSTEM BELT LENGTH CHARTS

Purpose of Charts :

The purpose of these charts is to enable the designer to determine the correct size horizontal system reduction timing belt for a given pulley combination.

How To Use These Charts :

To determine the correct horizontal system reduction timing belt, given the motor and intermediate drive pulleys:

1) Find the minimum required length for the reduction belt:

   a) Locate the "Minimum Length" chart.

   b) Find the given intermediate drive pulley along the top row of the chart.

   c) Find the given motor pulley along down the left column of the chart.

   d) Move down the column for the given intermediate drive pulley and right along the along the row for the given motor pulley. At the intersection, read the minimum required belt length.

2) Find the maximum required length for the reduction belt by repeating the procedure in Step 1, but use the "Maximum Length" chart.

3) Select a belt, using a vendor catalog, of a length that is between the minimum and maximum length values located above.

   HINT: If both the intermediate drive pulley and motor pulley have flanges on them, select a belt length that is closer to the maximum value.

TIMING BELT LENGTH REQUIREMENTS

BELT PITCH = 0.200 IN

XY - HORIZONTAL MINIMUM LENGTH

CENTER-TO-CENTER SPACING = 6.35 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	14.70	14.80	14.90	15.00	15.10	15.20	15.31	15.41	15.51	15.61	15.72	15.82	15.92	16.03	16.13	16.24
11	0.700	14.80	14.90	15.00	15.10	15.20	15.30	15.40	15.51	15.61	15.71	15.81	15.92	16.02	16.12	16.23	16.33
12	0.764	14.90	15.00	15.10	15.20	15.30	15.40	15.50	15.60	15.71	15.81	15.91	16.01	16.12	16.22	16.32	16.43
13	0.828	15.00	15.10	15.20	15.30	15.40	15.50	15.60	15.70	15.80	15.91	16.01	16.11	16.21	16.32	16.42	16.52
14	0.891	15.10	15.20	15.30	15.40	15.50	15.60	15.70	15.80	15.90	16.00	16.11	16.21	16.31	16.41	16.52	16.62
15	0.955	15.20	15.30	15.40	15.50	15.60	15.70	15.80	15.90	16.00	16.10	16.20	16.31	16.41	16.51	16.61	16.72
16	1.019	15.31	15.40	15.50	15.60	15.70	15.80	15.90	16.00	16.10	16.20	16.30	16.40	16.51	16.61	16.71	16.81
17	1.082	15.41	15.51	15.60	15.70	15.80	15.90	16.00	16.10	16.20	16.30	16.40	16.50	16.61	16.71	16.81	16.91
18	1.146	15.51	15.61	15.71	15.80	15.90	16.00	16.10	16.20	16.30	16.40	16.50	16.60	16.71	16.81	16.91	17.01
19	1.210	15.61	15.71	15.81	15.91	16.00	16.10	16.20	16.30	16.40	16.50	16.60	16.70	16.80	16.91	17.01	17.11
20	1.273	15.72	15.81	15.91	16.01	16.11	16.20	16.30	16.40	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.20
21	1.337	15.82	15.92	16.01	16.11	16.21	16.31	16.40	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.20	17.30
22	1.401	15.92	16.02	16.12	16.21	16.31	16.41	16.51	16.60	16.70	16.80	16.90	17.00	17.10	17.20	17.30	17.40
23	1.464	16.03	16.12	16.22	16.32	16.41	16.51	16.61	16.71	16.80	16.90	17.00	17.10	17.20	17.30	17.40	17.50
24	1.528	16.13	16.23	16.32	16.42	16.52	16.61	16.71	16.81	16.91	17.00	17.10	17.20	17.30	17.40	17.50	17.60
25	1.592	16.24	16.33	16.43	16.52	16.62	16.72	16.81	16.91	17.01	17.11	17.20	17.30	17.40	17.50	17.60	17.70
26	1.655	16.34	16.44	16.53	16.63	16.72	16.82	16.92	17.01	17.11	17.21	17.31	17.40	17.50	17.60	17.70	17.80
27	1.719	16.45	16.54	16.64	16.73	16.83	16.92	17.02	17.12	17.21	17.31	17.41	17.51	17.60	17.70	17.80	17.90
28	1.783	16.55	16.65	16.74	16.84	16.93	17.03	17.12	17.22	17.32	17.41	17.51	17.61	17.71	17.80	17.90	18.00
29	1.846	16.66	16.75	16.85	16.94	17.04	17.13	17.23	17.32	17.42	17.52	17.61	17.71	17.81	17.91	18.00	18.10
30	1.910	16.76	16.86	16.95	17.05	17.14	17.24	17.33	17.43	17.52	17.62	17.72	17.81	17.91	18.01	18.11	18.20
32	2.037	16.98	17.07	17.16	17.26	17.35	17.45	17.54	17.64	17.73	17.83	17.92	18.02	18.12	18.21	18.31	18.41
36	2.292	17.41	17.50	17.59	17.68	17.78	17.87	17.96	18.06	18.15	18.25	18.34	18.44	18.53	18.63	18.72	18.82
40	2.546	17.84	17.93	18.03	18.12	18.21	18.30	18.39	18.48	18.58	18.67	18.76	18.86	18.95	19.05	19.14	19.24
42	2.674	18.06	18.15	18.24	18.33	18.43	18.52	18.61	18.70	18.79	18.88	18.98	19.07	19.16	19.26	19.35	19.45
44	2.801	18.28	18.37	18.46	18.55	18.64	18.73	18.83	18.92	19.01	19.10	19.19	19.28	19.38	19.47	19.56	19.66
45	2.865	18.40	18.48	18.57	18.66	18.75	18.84	18.93	19.03	19.12	19.21	19.30	19.39	19.48	19.58	19.67	19.76
48	3.056	18.73	18.82	18.91	19.00	19.08	19.17	19.26	19.35	19.44	19.53	19.63	19.72	19.81	19.90	19.99	20.08
50	3.183	18.96	19.04	19.13	19.22	19.31	19.40	19.48	19.57	19.66	19.75	19.84	19.93	20.03	20.12	20.21	20.30
60	3.820	20.10	20.19	20.27	20.35	20.44	20.52	20.61	20.70	20.78	20.87	20.96	21.04	21.13	21.22	21.31	21.40
72	4.584	21.52	21.60	21.68	21.76	21.84	21.92	22.00	22.09	22.17	22.25	22.33	22.42	22.50	22.59	22.67	22.75

TIMING BELT LENGTH REQUIREMENTS BELT PITCH = 0.200 IN

XY - HORIZONTAL MINIMUM LENGTH

CENTER-TO-CENTER SPACING = 6.35 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26 1.655	27 1.719	28 1.783	29 1.846	30 1.910	32 2.037	36 2.292	40 2.546	42 2.674	44 2.801	45 2.865	48 3.056	50 3.183	60 3.820	72 4.584
10	0.637	16.34	16.45	16.55	16.66	16.76	16.98	17.41	17.84	18.06	18.28	18.40	18.73	18.96	20.10	21.52
11	0.700	16.44	16.54	16.65	16.75	16.86	17.07	17.50	17.93	18.15	18.37	18.48	18.82	19.04	20.19	21.60
12	0.764	16.53	16.64	16.74	16.85	16.95	17.16	17.59	18.03	18.24	18.46	18.57	18.91	19.13	20.27	21.68
13	0.828	16.63	16.73	16.84	16.94	17.05	17.26	17.68	18.12	18.33	18.55	18.66	19.00	19.22	20.35	21.76
14	0.891	16.72	16.83	16.93	17.04	17.14	17.35	17.78	18.21	18.43	18.64	18.75	19.08	19.31	20.44	21.84
15	0.955	16.82	16.92	17.03	17.13	17.24	17.45	17.87	18.30	18.52	18.73	18.84	19.17	19.40	20.52	21.92
16	1.019	16.92	17.02	17.12	17.23	17.33	17.54	17.96	18.39	18.61	18.83	18.93	19.26	19.48	20.61	22.00
17	1.082	17.01	17.12	17.22	17.32	17.43	17.64	18.06	18.48	18.70	18.92	19.03	19.35	19.57	20.70	22.09
18	1.146	17.11	17.21	17.32	17.42	17.52	17.73	18.15	18.58	18.79	19.01	19.12	19.44	19.66	20.78	22.17
19	1.210	17.21	17.31	17.41	17.52	17.62	17.83	18.25	18.67	18.88	19.10	19.21	19.53	19.75	20.87	22.25
20	1.273	17.31	17.41	17.51	17.61	17.72	17.92	18.34	18.76	18.98	19.19	19.30	19.63	19.84	20.96	22.33
21	1.337	17.40	17.51	17.61	17.71	17.81	18.02	18.44	18.86	19.07	19.28	19.39	19.72	19.93	21.04	22.42
22	1.401	17.50	17.60	17.71	17.81	17.91	18.12	18.53	18.95	19.16	19.38	19.48	19.81	20.03	21.13	22.50
23	1.464	17.60	17.70	17.80	17.91	18.01	18.21	18.63	19.05	19.26	19.47	19.58	19.90	20.12	21.22	22.59
24	1.528	17.70	17.80	17.90	18.00	18.11	18.31	18.72	19.14	19.35	19.56	19.67	19.99	20.21	21.31	22.67
25	1.592	17.80	17.90	18.00	18.10	18.20	18.41	18.82	19.24	19.45	19.66	19.76	20.08	20.30	21.40	22.75
26	1.655	17.90	18.00	18.10	18.20	18.30	18.51	18.92	19.33	19.54	19.75	19.86	20.18	20.39	21.48	22.84
27	1.719	18.00	18.10	18.20	18.30	18.40	18.60	19.01	19.43	19.64	19.85	19.95	20.27	20.48	21.57	22.92
28	1.783	18.10	18.20	18.30	18.40	18.50	18.70	19.11	19.52	19.73	19.94	20.05	20.36	20.58	21.66	23.01
29	1.846	18.20	18.30	18.40	18.50	18.60	18.80	19.21	19.62	19.83	20.04	20.14	20.46	20.67	21.75	23.10
30	1.910	18.30	18.40	18.50	18.60	18.70	18.90	19.31	19.72	19.92	20.13	20.24	20.55	20.76	21.84	23.18
32	2.037	18.51	18.60	18.70	18.80	18.90	19.10	19.50	19.91	20.12	20.32	20.43	20.74	20.95	22.03	23.36
36	2.292	18.92	19.01	19.11	19.21	19.31	19.50	19.90	20.30	20.51	20.71	20.81	21.12	21.33	22.39	23.71
40	2.546	19.33	19.43	19.52	19.62	19.72	19.91	20.30	20.70	20.90	21.10	21.20	21.51	21.72	22.76	24.06
42	2.674	19.54	19.64	19.73	19.83	19.92	20.12	20.51	20.90	21.10	21.30	21.40	21.71	21.91	22.95	24.24
44	2.801	19.75	19.85	19.94	20.04	20.13	20.32	20.71	21.10	21.30	21.50	21.60	21.90	22.11	23.14	24.43
45	2.865	19.86	19.95	20.05	20.14	20.24	20.43	20.81	21.20	21.40	21.60	21.70	22.00	22.20	23.24	24.52
48	3.056	20.18	20.27	20.36	20.46	20.55	20.74	21.12	21.51	21.71	21.90	22.00	22.30	22.50	23.52	24.79
50	3.183	20.39	20.48	20.58	20.67	20.76	20.95	21.33	21.72	21.91	22.11	22.20	22.50	22.70	23.72	24.98
60	3.820	21.48	21.57	21.66	21.75	21.84	22.03	22.39	22.76	22.95	23.14	23.24	23.52	23.72	24.70	25.92
72	4.584	22.84	22.92	23.01	23.10	23.18	23.36	23.71	24.06	24.24	24.43	24.52	24.79	24.98	25.92	27.10

TIMING BELT LENGTH REQUIREMENTS

BELT PITCH = 0.200 IN

XY - HORIZONTAL MAXIMUM LENGTH

CENTER-TO-CENTER SPACING = 6.80 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	15.60	15.70	15.80	15.90	16.00	16.10	16.21	16.31	16.41	16.51	16.61	16.72	16.82	16.93	17.03	17.13
11	0.700	15.70	15.80	15.90	16.00	16.10	16.20	16.30	16.41	16.51	16.61	16.71	16.81	16.92	17.02	17.13	17.23
12	0.764	15.80	15.90	16.00	16.10	16.20	16.30	16.40	16.50	16.61	16.71	16.81	16.91	17.01	17.12	17.22	17.33
13	0.828	15.90	16.00	16.10	16.20	16.30	16.40	16.50	16.60	16.70	16.81	16.91	17.01	17.11	17.21	17.32	17.42
14	0.891	16.00	16.10	16.20	16.30	16.40	16.50	16.60	16.70	16.80	16.90	17.01	17.11	17.21	17.31	17.41	17.52
15	0.955	16.10	16.20	16.30	16.40	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.21	17.31	17.41	17.51	17.61
16	1.019	16.21	16.30	16.40	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.20	17.30	17.41	17.51	17.61	17.71
17	1.082	16.31	16.41	16.50	16.60	16.70	16.80	16.90	17.00	17.10	17.20	17.30	17.40	17.50	17.61	17.71	17.81
18	1.146	16.41	16.51	16.61	16.70	16.80	16.90	17.00	17.10	17.20	17.30	17.40	17.50	17.60	17.70	17.81	17.91
19	1.210	16.51	16.61	16.71	16.81	16.90	17.00	17.10	17.20	17.30	17.40	17.50	17.60	17.70	17.80	17.90	18.01
20	1.273	16.61	16.71	16.81	16.91	17.01	17.10	17.20	17.30	17.40	17.50	17.60	17.70	17.80	17.90	18.00	18.10
21	1.337	16.72	16.81	16.91	17.01	17.11	17.21	17.30	17.40	17.50	17.60	17.70	17.80	17.90	18.00	18.10	18.20
22	1.401	16.82	16.92	17.01	17.11	17.21	17.31	17.41	17.50	17.60	17.70	17.80	17.90	18.00	18.10	18.20	18.30
23	1.464	16.93	17.02	17.12	17.21	17.31	17.41	17.51	17.61	17.70	17.80	17.90	18.00	18.10	18.20	18.30	18.40
24	1.528	17.03	17.13	17.22	17.32	17.41	17.51	17.61	17.71	17.81	17.90	18.00	18.10	18.20	18.30	18.40	18.50
25	1.592	17.13	17.23	17.33	17.42	17.52	17.61	17.71	17.81	17.91	18.01	18.10	18.20	18.30	18.40	18.50	18.60
26	1.655	17.24	17.33	17.43	17.53	17.62	17.72	17.81	17.91	18.01	18.11	18.21	18.30	18.40	18.50	18.60	18.70
27	1.719	17.34	17.44	17.53	17.63	17.73	17.82	17.92	18.01	18.11	18.21	18.31	18.41	18.50	18.60	18.70	18.80
28	1.783	17.45	17.54	17.64	17.73	17.83	17.93	18.02	18.12	18.21	18.31	18.41	18.51	18.61	18.70	18.80	18.90
29	1.846	17.55	17.65	17.74	17.84	17.93	18.03	18.13	18.22	18.32	18.41	18.51	18.61	18.71	18.81	18.90	19.00
30	1.910	17.66	17.75	17.85	17.94	18.04	18.13	18.23	18.33	18.42	18.52	18.61	18.71	18.81	18.91	19.01	19.10
32	2.037	17.87	17.97	18.06	18.15	18.25	18.34	18.44	18.53	18.63	18.73	18.82	18.92	19.01	19.11	19.21	19.31
36	2.292	18.30	18.39	18.49	18.58	18.67	18.77	18.86	18.95	19.05	19.14	19.24	19.33	19.43	19.53	19.62	19.72
40	2.546	18.73	18.83	18.92	19.01	19.10	19.19	19.29	19.38	19.47	19.57	19.66	19.75	19.85	19.94	20.04	20.13
42	2.674	18.95	19.04	19.13	19.23	19.32	19.41	19.50	19.59	19.69	19.78	19.87	19.97	20.06	20.15	20.25	20.34
44	2.801	19.17	19.26	19.35	19.44	19.53	19.63	19.72	19.81	19.90	19.99	20.09	20.18	20.27	20.37	20.46	20.55
45	2.865	19.28	19.37	19.46	19.55	19.64	19.73	19.83	19.92	20.01	20.10	20.19	20.29	20.38	20.47	20.57	20.66
48	3.056	19.62	19.70	19.79	19.88	19.97	20.06	20.15	20.24	20.33	20.43	20.52	20.61	20.70	20.79	20.89	20.98
50	3.183	19.84	19.93	20.02	20.10	20.19	20.28	20.37	20.46	20.55	20.64	20.73	20.83	20.92	21.01	21.10	21.19
60	3.820	20.97	21.06	21.14	21.23	21.32	21.40	21.49	21.58	21.66	21.75	21.84	21.93	22.02	22.10	22.19	22.28
72	4.584	22.38	22.46	22.54	22.62	22.70	22.79	22.87	22.95	23.04	23.12	23.20	23.29	23.37	23.46	23.54	23.63

TIMING BELT LENGTH REQUIREMENTS BELT PITCH = 0.200 IN

XY - HORIZONTAL MAXIMUM LENGTH

CENTER-TO-CENTER SPACING = 6.8 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ----->

# TEETH		26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
P DIA.		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	17.24	17.34	17.45	17.55	17.66	17.87	18.30	18.73	18.95	19.17	19.28	19.62	19.84	20.97	22.38
11	0.700	17.33	17.44	17.54	17.65	17.75	17.97	18.39	18.83	19.04	19.26	19.37	19.70	19.93	21.06	22.46
12	0.764	17.43	17.53	17.64	17.74	17.85	18.06	18.49	18.92	19.13	19.35	19.46	19.79	20.02	21.14	22.54
13	0.828	17.53	17.63	17.73	17.84	17.94	18.15	18.58	19.01	19.23	19.44	19.55	19.88	20.10	21.23	22.62
14	0.891	17.62	17.73	17.83	17.93	18.04	18.25	18.67	19.10	19.32	19.53	19.64	19.97	20.19	21.32	22.70
15	0.955	17.72	17.82	17.93	18.03	18.13	18.34	18.77	19.19	19.41	19.63	19.73	20.06	20.28	21.40	22.79
16	1.019	17.81	17.92	18.02	18.13	18.23	18.44	18.86	19.29	19.50	19.72	19.83	20.15	20.37	21.49	22.87
17	1.082	17.91	18.01	18.12	18.22	18.33	18.53	18.95	19.38	19.59	19.81	19.92	20.24	20.46	21.58	22.95
18	1.146	18.01	18.11	18.21	18.32	18.42	18.63	19.05	19.47	19.69	19.90	20.01	20.33	20.55	21.66	23.04
19	1.210	18.11	18.21	18.31	18.41	18.52	18.73	19.14	19.57	19.78	19.99	20.10	20.43	20.64	21.75	23.12
20	1.273	18.21	18.31	18.41	18.51	18.61	18.82	19.24	19.66	19.87	20.09	20.19	20.52	20.73	21.84	23.20
21	1.337	18.30	18.41	18.51	18.61	18.71	18.92	19.33	19.75	19.97	20.18	20.29	20.61	20.83	21.93	23.29
22	1.401	18.40	18.50	18.61	18.71	18.81	19.01	19.43	19.85	20.06	20.27	20.38	20.70	20.92	22.02	23.37
23	1.464	18.50	18.60	18.70	18.81	18.91	19.11	19.53	19.94	20.15	20.37	20.47	20.79	21.01	22.10	23.46
24	1.528	18.60	18.70	18.80	18.90	19.01	19.21	19.62	20.04	20.25	20.46	20.57	20.89	21.10	22.19	23.54
25	1.592	18.70	18.80	18.90	19.00	19.10	19.31	19.72	20.13	20.34	20.55	20.66	20.98	21.19	22.28	23.63
26	1.655	18.80	18.90	19.00	19.10	19.20	19.41	19.81	20.23	20.44	20.65	20.75	21.07	21.29	22.37	23.72
27	1.719	18.90	19.00	19.10	19.20	19.30	19.50	19.91	20.33	20.53	20.74	20.85	21.17	21.38	22.46	23.80
28	1.783	19.00	19.10	19.20	19.30	19.40	19.60	20.01	20.42	20.63	20.84	20.94	21.26	21.47	22.55	23.89
29	1.846	19.10	19.20	19.30	19.40	19.50	19.70	20.11	20.52	20.73	20.93	21.04	21.35	21.57	22.64	23.98
30	1.910	19.20	19.30	19.40	19.50	19.60	19.80	20.21	20.61	20.82	21.03	21.13	21.45	21.66	22.73	24.06
32	2.037	19.41	19.50	19.60	19.70	19.80	20.00	20.40	20.81	21.01	21.22	21.33	21.64	21.85	22.92	24.24
36	2.292	19.81	19.91	20.01	20.11	20.21	20.40	20.80	21.20	21.41	21.61	21.71	22.02	22.23	23.29	24.59
40	2.546	20.23	20.33	20.42	20.52	20.61	20.81	21.20	21.60	21.80	22.00	22.10	22.41	22.61	23.66	24.95
42	2.674	20.44	20.53	20.63	20.73	20.82	21.01	21.41	21.80	22.00	22.20	22.30	22.61	22.81	23.85	25.13
44	2.801	20.65	20.74	20.84	20.93	21.03	21.22	21.61	22.00	22.20	22.40	22.50	22.80	23.01	24.04	25.32
45	2.865	20.75	20.85	20.94	21.04	21.13	21.33	21.71	22.10	22.30	22.50	22.60	22.90	23.10	24.13	25.41
48	3.056	21.07	21.17	21.26	21.35	21.45	21.64	22.02	22.41	22.61	22.80	22.90	23.20	23.40	24.42	25.69
50	3.183	21.29	21.38	21.47	21.57	21.66	21.85	22.23	22.61	22.81	23.01	23.10	23.40	23.60	24.61	25.87
60	3.820	22.37	22.46	22.55	22.64	22.73	22.92	23.29	23.66	23.85	24.04	24.13	24.42	24.61	25.60	26.82
72	4.584	23.72	23.80	23.89	23.98	24.06	24.24	24.59	24.95	25.13	25.32	25.41	25.69	25.87	26.82	28.00

APPENDIX E

Vertical System Resolution Selection Charts

VERTICAL SYSTEM RESOLUTION SELECTION CHARTS

Purpose of Charts :

The purpose of these charts is to enable the designer to:

A) determine the step resolution (in/step) or resolution "index" (steps/in) of the vertical system, given the motor and intermediate drive pulleys;

B) select motor and intermediate drive pulleys, given a vertical step resolution or "index".

How To Use These Charts :

A) To determine the vertical step resolution (or resolution index), given the motor and intermediate drive pulleys:

1) Locate the "Step Resolution" (or "Resolution Index") chart.

2) Find the given intermediate drive pulley along the top row of the chart.

3) Find the given motor pulley along down the left column of the chart.

4) Move down the column for the given intermediate drive pulley and right along the along the row for the given motor pulley. At the intersection, read the step resolution (or resolution index).

B) To select motor and intermediate drive pulleys, given step resolution (or resolution index):

1) Locate the "Step Resolution" (or "Resolution Index") chart.

2) Find desired resolution (or index) in the table body. There likely are several alternatives available.

3) Go up the column of the chart to find the intermediate drive pulley.

4) Go left along the row of the chart to find the motor pulley.

STEP RESOLUTION - VERTICAL BELT PITCH = 0.200 IN

DRIVE PULLEY - # OF TEETH 10 /REVOLUTION
PITCH DIAMETER 0.637 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: 0.001 INCHES/STEP

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		0.637	0.700	0.764	0.828	0.891	0.955	1.019	1.082	1.146	1.210	1.273	1.337	1.401	1.464	1.528	1.592
10	0.637	10.00	9.09	8.33	7.69	7.14	6.67	6.25	5.88	5.56	5.26	5.00	4.76	4.55	4.35	4.17	4.00
11	0.700	11.00	10.00	9.17	8.46	7.86	7.33	6.88	6.47	6.11	5.79	5.50	5.24	5.00	4.78	4.58	4.40
12	0.764	12.00	10.91	10.00	9.23	8.57	8.00	7.50	7.06	6.67	6.32	6.00	5.71	5.45	5.22	5.00	4.80
13	0.828	13.00	11.82	10.83	10.00	9.29	8.67	8.13	7.65	7.22	6.84	6.50	6.19	5.91	5.65	5.42	5.20
14	0.891	14.00	12.73	11.67	10.77	10.00	9.33	8.75	8.24	7.78	7.37	7.00	6.67	6.36	6.09	5.83	5.60
15	0.955	15.00	13.64	12.50	11.54	10.71	10.00	9.38	8.82	8.33	7.89	7.50	7.14	6.82	6.52	6.25	6.00
16	1.019	16.00	14.55	13.33	12.31	11.43	10.67	10.00	9.41	8.89	8.42	8.00	7.62	7.27	6.96	6.67	6.40
17	1.082	17.00	15.45	14.17	13.08	12.14	11.33	10.63	10.00	9.44	8.95	8.50	8.10	7.73	7.39	7.08	6.80
18	1.146	18.00	16.36	15.00	13.85	12.86	12.00	11.25	10.59	10.00	9.47	9.00	8.57	8.18	7.83	7.50	7.20
19	1.210	19.00	17.27	15.83	14.62	13.57	12.67	11.88	11.18	10.56	10.00	9.50	9.05	8.64	8.26	7.92	7.60
20	1.273	20.00	18.18	16.67	15.38	14.29	13.33	12.50	11.76	11.11	10.53	10.00	9.52	9.09	8.70	8.33	8.00
21	1.337	21.00	19.09	17.50	16.15	15.00	14.00	13.13	12.35	11.67	11.05	10.50	10.00	9.55	9.13	8.75	8.40
22	1.401	22.00	20.00	18.33	16.92	15.71	14.67	13.75	12.94	12.22	11.58	11.00	10.48	10.00	9.57	9.17	8.80
23	1.464	23.00	20.91	19.17	17.69	16.43	15.33	14.38	13.53	12.78	12.11	11.50	10.95	10.45	10.00	9.58	9.20
24	1.528	24.00	21.82	20.00	18.46	17.14	16.00	15.00	14.12	13.33	12.63	12.00	11.43	10.91	10.43	10.00	9.60
25	1.592	25.00	22.73	20.83	19.23	17.86	16.67	15.63	14.71	13.89	13.16	12.50	11.90	11.36	10.87	10.42	10.00
26	1.655	26.00	23.64	21.67	20.00	18.57	17.33	16.25	15.29	14.44	13.68	13.00	12.38	11.82	11.30	10.83	10.40
27	1.719	27.00	24.55	22.50	20.77	19.29	18.00	16.88	15.88	15.00	14.21	13.50	12.86	12.27	11.74	11.25	10.80
28	1.783	28.00	25.45	23.33	21.54	20.00	18.67	17.50	16.47	15.56	14.74	14.00	13.33	12.73	12.17	11.67	11.20
29	1.846	29.00	26.36	24.17	22.31	20.71	19.33	18.13	17.06	16.11	15.26	14.50	13.81	13.18	12.61	12.08	11.60
30	1.910	30.00	27.27	25.00	23.08	21.43	20.00	18.75	17.65	16.67	15.79	15.00	14.29	13.64	13.04	12.50	12.00
32	2.037	32.00	29.09	26.67	24.62	22.86	21.33	20.00	18.82	17.78	16.84	16.00	15.24	14.55	13.91	13.33	12.80
36	2.292	36.00	32.73	30.00	27.69	25.71	24.00	22.50	21.18	20.00	18.95	18.00	17.14	16.36	15.65	15.00	14.40
40	2.546	40.00	36.36	33.33	30.77	28.57	26.67	25.00	23.53	22.22	21.05	20.00	19.05	18.18	17.39	16.67	16.00
42	2.674	42.00	38.18	35.00	32.31	30.00	28.00	26.25	24.71	23.33	22.11	21.00	20.00	19.09	18.26	17.50	16.80
44	2.801	44.00	40.00	36.67	33.85	31.43	29.33	27.50	25.88	24.44	23.16	22.00	20.95	20.00	19.13	18.33	17.60
45	2.865	45.00	40.91	37.50	34.62	32.14	30.00	28.13	26.47	25.00	23.68	22.50	21.43	20.45	19.57	18.75	18.00
48	3.056	48.00	43.64	40.00	36.92	34.29	32.00	30.00	28.24	26.67	25.26	24.00	22.86	21.82	20.87	20.00	19.20
50	3.183	50.00	45.45	41.67	38.46	35.71	33.33	31.25	29.41	27.78	26.32	25.00	23.81	22.73	21.74	20.83	20.00
60	3.820	60.00	54.55	50.00	46.15	42.86	40.00	37.50	35.29	33.33	31.58	30.00	28.57	27.27	26.09	25.00	24.00
72	4.584	72.00	65.45	60.00	55.38	51.43	48.00	45.00	42.35	40.00	37.89	36.00	34.29	32.73	31.30	30.00	28.80

STEP RESOLUTION - VERTICAL

BELT PITCH = 0.2 IN

DRIVE PULLEY - # OF TEETH 10 /REVOLUTION

PITCH DIAMETER 0.637 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: 0.001 INCHES/STEP

MOTOR PULLEY
:
V

INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26 1.655	27 1.719	28 1.783	29 1.846	30 1.910	32 2.037	36 2.292	40 2.546	42 2.674	44 2.801	45 2.865	48 3.056	50 3.183	60 3.820	72 4.584
10	0.637	3.85	3.70	3.57	3.45	3.33	3.13	2.78	2.50	2.38	2.27	2.22	2.08	2.00	1.67	1.39
11	0.700	4.23	4.07	3.93	3.79	3.67	3.44	3.06	2.75	2.62	2.50	2.44	2.29	2.20	1.83	1.53
12	0.764	4.62	4.44	4.29	4.14	4.00	3.75	3.33	3.00	2.86	2.73	2.67	2.50	2.40	2.00	1.67
13	0.828	5.00	4.81	4.64	4.48	4.33	4.06	3.61	3.25	3.10	2.95	2.89	2.71	2.60	2.17	1.81
14	0.891	5.38	5.19	5.00	4.83	4.67	4.38	3.89	3.50	3.33	3.18	3.11	2.92	2.80	2.33	1.94
15	0.955	5.77	5.56	5.36	5.17	5.00	4.69	4.17	3.75	3.57	3.41	3.33	3.13	3.00	2.50	2.08
16	1.019	6.15	5.93	5.71	5.52	5.33	5.00	4.44	4.00	3.81	3.64	3.56	3.33	3.20	2.67	2.22
17	1.082	6.54	6.30	6.07	5.86	5.67	5.31	4.72	4.25	4.05	3.86	3.78	3.54	3.40	2.83	2.36
18	1.146	6.92	6.67	6.43	6.21	6.00	5.63	5.00	4.50	4.29	4.09	4.00	3.75	3.60	3.00	2.50
19	1.210	7.31	7.04	6.79	6.55	6.33	5.94	5.28	4.75	4.52	4.32	4.22	3.96	3.80	3.17	2.64
20	1.273	7.69	7.41	7.14	6.90	6.67	6.25	5.56	5.00	4.76	4.55	4.44	4.17	4.00	3.33	2.78
21	1.337	8.08	7.78	7.50	7.24	7.00	6.56	5.83	5.25	5.00	4.77	4.67	4.38	4.20	3.50	2.92
22	1.401	8.46	8.15	7.86	7.59	7.33	6.88	6.11	5.50	5.24	5.00	4.89	4.58	4.40	3.67	3.06
23	1.464	8.85	8.52	8.21	7.93	7.67	7.19	6.39	5.75	5.48	5.23	5.11	4.79	4.60	3.83	3.19
24	1.528	9.23	8.89	8.57	8.28	8.00	7.50	6.67	6.00	5.71	5.45	5.33	5.00	4.80	4.00	3.33
25	1.592	9.62	9.26	8.93	8.62	8.33	7.81	6.94	6.25	5.95	5.68	5.56	5.21	5.00	4.17	3.47
26	1.655	10.00	9.63	9.29	8.97	8.67	8.13	7.22	6.50	6.19	5.91	5.78	5.42	5.20	4.33	3.61
27	1.719	10.38	10.00	9.64	9.31	9.00	8.44	7.50	6.75	6.43	6.14	6.00	5.63	5.40	4.50	3.75
28	1.783	10.77	10.37	10.00	9.66	9.33	8.75	7.78	7.00	6.67	6.36	6.22	5.83	5.60	4.67	3.89
29	1.846	11.15	10.74	10.36	10.00	9.67	9.06	8.06	7.25	6.90	6.59	6.44	6.04	5.80	4.83	4.03
30	1.910	11.54	11.11	10.71	10.34	10.00	9.38	8.33	7.50	7.14	6.82	6.67	6.25	6.00	5.00	4.17
32	2.037	12.31	11.85	11.43	11.03	10.67	10.00	8.89	8.00	7.62	7.27	7.11	6.67	6.40	5.33	4.44
36	2.292	13.85	13.33	12.86	12.41	12.00	11.25	10.00	9.00	8.57	8.18	8.00	7.50	7.20	6.00	5.00
40	2.546	15.38	14.81	14.29	13.79	13.33	12.50	11.11	10.00	9.52	9.09	8.89	8.33	8.00	6.67	5.56
42	2.674	16.15	15.56	15.00	14.48	14.00	13.13	11.67	10.50	10.00	9.55	9.33	8.75	8.40	7.00	5.83
44	2.801	16.92	16.30	15.71	15.17	14.67	13.75	12.22	11.00	10.48	10.00	9.78	9.17	8.80	7.33	6.11
45	2.865	17.31	16.67	16.07	15.52	15.00	14.06	12.50	11.25	10.71	10.23	10.00	9.38	9.00	7.50	6.25
48	3.056	18.46	17.78	17.14	16.55	16.00	15.00	13.33	12.00	11.43	10.91	10.67	10.00	9.60	8.00	6.67
50	3.183	19.23	18.52	17.86	17.24	16.67	15.63	13.89	12.50	11.90	11.36	11.11	10.42	10.00	8.33	6.94
60	3.820	23.08	22.22	21.43	20.69	20.00	18.75	16.67	15.00	14.29	13.64	13.33	12.50	12.00	10.00	8.33
72	4.584	27.69	26.67	25.71	24.83	24.00	22.50	20.00	18.00	17.14	16.36	16.00	15.00	14.40	12.00	10.00

RESOLUTION INDEX - VERTICAL

BELT PITCH = 0.200 IN

DRIVE PULLEY - # OF TEETH 10 /REVOLUTION
PITCH DIAMETER 0.637 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: # STEPS / INCH

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	100.00	110.00	120.00	130.00	140.00	150.00	160.00	170.00	180.00	190.00	200.00	210.00	220.00	230.00	240.00	250.00
11	0.700	90.91	100.00	109.09	118.18	127.27	136.36	145.45	154.55	163.64	172.73	181.82	190.91	200.00	209.09	218.18	227.27
12	0.764	83.33	91.67	100.00	108.33	116.67	125.00	133.33	141.67	150.00	158.33	166.67	175.00	183.33	191.67	200.00	208.33
13	0.828	76.92	84.62	92.31	100.00	107.69	115.38	123.08	130.77	138.46	146.15	153.85	161.54	169.23	176.92	184.62	192.31
14	0.891	71.43	78.57	85.71	92.86	100.00	107.14	114.29	121.43	128.57	135.71	142.86	150.00	157.14	164.29	171.43	178.57
15	0.955	66.67	73.33	80.00	86.67	93.33	100.00	106.67	113.33	120.00	126.67	133.33	140.00	146.67	153.33	160.00	166.67
16	1.019	62.50	68.75	75.00	81.25	87.50	93.75	100.00	106.25	112.50	118.75	125.00	131.25	137.50	143.75	150.00	156.25
17	1.082	58.82	64.71	70.59	76.47	82.35	88.24	94.12	100.00	105.88	111.76	117.65	123.53	129.41	135.29	141.18	147.06
18	1.146	55.56	61.11	66.67	72.22	77.78	83.33	88.89	94.44	100.00	105.56	111.11	116.67	122.22	127.78	133.33	138.89
19	1.210	52.63	57.89	63.16	68.42	73.68	78.95	84.21	89.47	94.74	100.00	105.26	110.53	115.79	121.05	126.32	131.58
20	1.273	50.00	55.00	60.00	65.00	70.00	75.00	80.00	85.00	90.00	95.00	100.00	105.00	110.00	115.00	120.00	125.00
21	1.337	47.62	52.38	57.14	61.90	66.67	71.43	76.19	80.95	85.71	90.48	95.24	100.00	104.76	109.52	114.29	119.05
22	1.401	45.45	50.00	54.55	59.09	63.64	68.18	72.73	77.27	81.82	86.36	90.91	95.45	100.00	104.55	109.09	113.64
23	1.464	43.48	47.83	52.17	56.52	60.87	65.22	69.57	73.91	78.26	82.61	86.96	91.30	95.65	100.00	104.35	108.70
24	1.528	41.67	45.83	50.00	54.17	58.33	62.50	66.67	70.83	75.00	79.17	83.33	87.50	91.67	95.83	100.00	104.17
25	1.592	40.00	44.00	48.00	52.00	56.00	60.00	64.00	68.00	72.00	76.00	80.00	84.00	88.00	92.00	96.00	100.00
26	1.655	38.46	42.31	46.15	50.00	53.85	57.69	61.54	65.38	69.23	73.08	76.92	80.77	84.62	88.46	92.31	96.15
27	1.719	37.04	40.74	44.44	48.15	51.85	55.56	59.26	62.96	66.67	70.37	74.07	77.78	81.48	85.19	88.89	92.59
28	1.783	35.71	39.29	42.86	46.43	50.00	53.57	57.14	60.71	64.29	67.86	71.43	75.00	78.57	82.14	85.71	89.29
29	1.846	34.48	37.93	41.38	44.83	48.28	51.72	55.17	58.62	62.07	65.52	68.97	72.41	75.86	79.31	82.76	86.21
30	1.910	33.33	36.67	40.00	43.33	46.67	50.00	53.33	56.67	60.00	63.33	66.67	70.00	73.33	76.67	80.00	83.33
32	2.037	31.25	34.38	37.50	40.63	43.75	46.88	50.00	53.13	56.25	59.38	62.50	65.63	68.75	71.88	75.00	78.13
36	2.292	27.78	30.56	33.33	36.11	38.89	41.67	44.44	47.22	50.00	52.78	55.56	58.33	61.11	63.89	66.67	69.44
40	2.546	25.00	27.50	30.00	32.50	35.00	37.50	40.00	42.50	45.00	47.50	50.00	52.50	55.00	57.50	60.00	62.50
42	2.674	23.81	26.19	28.57	30.95	33.33	35.71	38.10	40.48	42.86	45.24	47.62	50.00	52.38	54.76	57.14	59.52
44	2.801	22.73	25.00	27.27	29.55	31.82	34.09	36.36	38.64	40.91	43.18	45.45	47.73	50.00	52.27	54.55	56.82
45	2.865	22.22	24.44	26.67	28.89	31.11	33.33	35.56	37.78	40.00	42.22	44.44	46.67	48.89	51.11	53.33	55.56
48	3.056	20.83	22.92	25.00	27.08	29.17	31.25	33.33	35.42	37.50	39.58	41.67	43.75	45.83	47.92	50.00	52.08
50	3.183	20.00	22.00	24.00	26.00	28.00	30.00	32.00	34.00	36.00	38.00	40.00	42.00	44.00	46.00	48.00	50.00
60	3.820	16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67	33.33	35.00	36.67	38.33	40.00	41.67
72	4.584	13.89	15.28	16.67	18.06	19.44	20.83	22.22	23.61	25.00	26.39	27.78	29.17	30.56	31.94	33.33	34.72

RESOLUTION INDEX - VERTICAL BELT PITCH = 0.2 IN

DRIVE PULLEY - # OF TEETH 10 /REVOLUTION
PITCH DIAMETER 0.637 IN

STEP MOTOR - DEGREES/STEP 1.8 DEGREES/STEP

NOTE: !!!!!!! RESOLUTION VALUES ARE IN: # STEPS / INCH

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH		26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
P DIA.		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	260.00	270.00	280.00	290.00	300.00	320.00	360.00	400.00	420.00	440.00	450.00	480.00	500.00	600.00	720.00
11	0.700	236.36	245.45	254.55	263.64	272.73	290.91	327.27	363.64	381.82	400.00	409.09	436.36	454.55	545.45	654.55
12	0.764	216.67	225.00	233.33	241.67	250.00	266.67	300.00	333.33	350.00	366.67	375.00	400.00	416.67	500.00	600.00
13	0.828	200.00	207.69	215.38	223.08	230.77	246.15	276.92	307.69	323.08	338.46	346.15	369.23	384.62	461.54	553.85
14	0.891	185.71	192.86	200.00	207.14	214.29	228.57	257.14	285.71	300.00	314.29	321.43	342.86	357.14	428.57	514.29
15	0.955	173.33	180.00	186.67	193.33	200.00	213.33	240.00	266.67	280.00	293.33	300.00	320.00	333.33	400.00	480.00
16	1.019	162.50	168.75	175.00	181.25	187.50	200.00	225.00	250.00	262.50	275.00	281.25	300.00	312.50	375.00	450.00
17	1.082	152.94	158.82	164.71	170.59	176.47	188.24	211.76	235.29	247.06	258.82	264.71	282.35	294.12	352.94	423.53
18	1.146	144.44	150.00	155.56	161.11	166.67	177.78	200.00	222.22	233.33	244.44	250.00	266.67	277.78	333.33	400.00
19	1.210	136.84	142.11	147.37	152.63	157.89	168.42	189.47	210.53	221.05	231.58	236.84	252.63	263.16	315.79	378.95
20	1.273	130.00	135.00	140.00	145.00	150.00	160.00	180.00	200.00	210.00	220.00	225.00	240.00	250.00	300.00	360.00
21	1.337	123.81	128.57	133.33	138.10	142.86	152.38	171.43	190.48	200.00	209.52	214.29	228.57	238.10	285.71	342.86
22	1.401	118.18	122.73	127.27	131.82	136.36	145.45	163.64	181.82	190.91	200.00	204.55	218.18	227.27	272.73	327.27
23	1.464	113.04	117.39	121.74	126.09	130.43	139.13	156.52	173.91	182.61	191.30	195.65	208.70	217.39	260.87	313.04
24	1.528	108.33	112.50	116.67	120.83	125.00	133.33	150.00	166.67	175.00	183.33	187.50	200.00	208.33	250.00	300.00
25	1.592	104.00	108.00	112.00	116.00	120.00	128.00	144.00	160.00	168.00	176.00	180.00	192.00	200.00	240.00	288.00
26	1.655	100.00	103.85	107.69	111.54	115.38	123.08	138.46	153.85	161.54	169.23	173.08	184.62	192.31	230.77	276.92
27	1.719	96.30	100.00	103.70	107.41	111.11	118.52	133.33	148.15	155.56	162.96	166.67	177.78	185.19	222.22	266.67
28	1.783	92.86	96.43	100.00	103.57	107.14	114.29	128.57	142.86	150.00	157.14	160.71	171.43	178.57	214.29	257.14
29	1.846	89.66	93.10	96.55	100.00	103.45	110.34	124.14	137.93	144.83	151.72	155.17	165.52	172.41	206.90	248.28
30	1.910	86.67	90.00	93.33	96.67	100.00	106.67	120.00	133.33	140.00	146.67	150.00	160.00	166.67	200.00	240.00
32	2.037	81.25	84.38	87.50	90.63	93.75	100.00	112.50	125.00	131.25	137.50	140.63	150.00	156.25	187.50	225.00
36	2.292	72.22	75.00	77.78	80.56	83.33	88.89	100.00	111.11	116.67	122.22	125.00	133.33	138.89	166.67	200.00
40	2.546	65.00	67.50	70.00	72.50	75.00	80.00	90.00	100.00	105.00	110.00	112.50	120.00	125.00	150.00	180.00
42	2.674	61.90	64.29	66.67	69.05	71.43	76.19	85.71	95.24	100.00	104.76	107.14	114.29	119.05	142.86	171.43
44	2.801	59.09	61.36	63.64	65.91	68.18	72.73	81.82	90.91	95.45	100.00	102.27	109.09	113.64	136.36	163.64
45	2.865	57.78	60.00	62.22	64.44	66.67	71.11	80.00	88.89	93.33	97.78	100.00	106.67	111.11	133.33	160.00
48	3.056	54.17	56.25	58.33	60.42	62.50	66.67	75.00	83.33	87.50	91.67	93.75	100.00	104.17	125.00	150.00
50	3.183	52.00	54.00	56.00	58.00	60.00	64.00	72.00	80.00	84.00	88.00	90.00	96.00	100.00	120.00	144.00
60	3.820	43.33	45.00	46.67	48.33	50.00	53.33	60.00	66.67	70.00	73.33	75.00	80.00	83.33	100.00	120.00
72	4.584	36.11	37.50	38.89	40.28	41.67	44.44	50.00	55.56	58.33	61.11	62.50	66.67	69.44	83.33	100.00

APPENDIX F

Vertical Reduction System Belt Length Charts

VERTICAL REDUCTION SYSTEM BELT LENGTH CHARTS

Purpose of Charts :

The purpose of these charts is to enable the designer to determine the correct size vertical system reduction timing belt for a given pulley combination.

How To Use These Charts :

To determine the correct vertical system reduction timing belt, given the motor and intermediate drive pulleys:

1) Find the minimum required length for the reduction belt:

   a) Locate the "Minimum Length" chart.

   b) Find the given intermediate drive pulley along the top row of the chart.

   c) Find the given motor pulley along down the left column of the chart.

   d) Move down the column for the given intermediate drive pulley and right along the along the row for the given motor pulley. At the intersection, read the minimum required belt length.

2) Find the maximum required length for the reduction belt by repeating the procedure in Step 1, but use the "Maximum Length" chart.

3) Select a belt, using a vendor catalog, of a length that is between the minimum and maximum length values located above.

   HINT: If both the intermediate drive pulley and motor pulley have flanges on them, select a belt length that is closer to the maximum value.

REDUCTION TIMING BELT LENGTH REQUIREMENTS BELT PITCH = 0.200 IN

Z - VERTICAL MINIMUM LENGTH

CENTER-TO-CENTER SPACING = 3.90 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	9.80	9.90	10.00	10.10	10.20	10.31	10.41	10.51	10.62	10.72	10.83	10.93	11.04	11.14	11.25	11.36
11	0.700	9.90	10.00	10.10	10.20	10.30	10.40	10.51	10.61	10.71	10.82	10.92	11.03	11.13	11.24	11.34	11.45
12	0.764	10.00	10.10	10.20	10.30	10.40	10.50	10.60	10.71	10.81	10.91	11.02	11.12	11.23	11.33	11.44	11.54
13	0.828	10.10	10.20	10.30	10.40	10.50	10.60	10.70	10.80	10.91	11.01	11.11	11.22	11.32	11.43	11.53	11.64
14	0.891	10.20	10.30	10.40	10.50	10.60	10.70	10.80	10.90	11.00	11.11	11.21	11.31	11.42	11.52	11.63	11.73
15	0.955	10.31	10.40	10.50	10.60	10.70	10.80	10.90	11.00	11.10	11.20	11.31	11.41	11.51	11.62	11.72	11.83
16	1.019	10.41	10.51	10.60	10.70	10.80	10.90	11.00	11.10	11.20	11.30	11.40	11.51	11.61	11.71	11.82	11.92
17	1.082	10.51	10.61	10.71	10.80	10.90	11.00	11.10	11.20	11.30	11.40	11.50	11.60	11.71	11.81	11.91	12.02
18	1.146	10.62	10.71	10.81	10.91	11.00	11.10	11.20	11.30	11.40	11.50	11.60	11.70	11.80	11.91	12.01	12.11
19	1.210	10.72	10.82	10.91	11.01	11.11	11.20	11.30	11.40	11.50	11.60	11.70	11.80	11.90	12.00	12.11	12.21
20	1.273	10.83	10.92	11.02	11.11	11.21	11.31	11.40	11.50	11.60	11.70	11.80	11.90	12.00	12.10	12.20	12.31
21	1.337	10.93	11.03	11.12	11.22	11.31	11.41	11.51	11.60	11.70	11.80	11.90	12.00	12.10	12.20	12.30	12.40
22	1.401	11.04	11.13	11.23	11.32	11.42	11.51	11.61	11.71	11.80	11.90	12.00	12.10	12.20	12.30	12.40	12.50
23	1.464	11.14	11.24	11.33	11.43	11.52	11.62	11.71	11.81	11.91	12.00	12.10	12.20	12.30	12.40	12.50	12.60
24	1.528	11.25	11.34	11.44	11.53	11.63	11.72	11.82	11.91	12.01	12.11	12.20	12.30	12.40	12.50	12.60	12.70
25	1.592	11.36	11.45	11.54	11.64	11.73	11.83	11.92	12.02	12.11	12.21	12.31	12.40	12.50	12.60	12.70	12.80
26	1.655	11.47	11.56	11.65	11.74	11.84	11.93	12.03	12.12	12.22	12.31	12.41	12.51	12.60	12.70	12.80	12.90
27	1.719	11.58	11.67	11.76	11.85	11.94	12.04	12.13	12.23	12.32	12.42	12.51	12.61	12.71	12.80	12.90	13.00
28	1.783	11.68	11.78	11.87	11.96	12.05	12.14	12.24	12.33	12.43	12.52	12.62	12.71	12.81	12.91	13.00	13.10
29	1.846	11.79	11.88	11.98	12.07	12.16	12.25	12.34	12.44	12.53	12.63	12.72	12.82	12.91	13.01	13.11	13.20
30	1.910	11.90	11.99	12.08	12.18	12.27	12.36	12.45	12.54	12.64	12.73	12.83	12.92	13.02	13.11	13.21	13.31
32	2.037	12.13	12.21	12.30	12.39	12.48	12.58	12.67	12.76	12.85	12.94	13.04	13.13	13.23	13.32	13.42	13.51
36	2.292	12.58	12.66	12.75	12.84	12.93	13.01	13.10	13.19	13.28	13.38	13.47	13.56	13.65	13.74	13.84	13.93
40	2.546	13.04	13.12	13.20	13.29	13.38	13.46	13.55	13.64	13.73	13.81	13.90	13.99	14.08	14.18	14.27	14.36
42	2.674	13.27	13.35	13.44	13.52	13.60	13.69	13.78	13.86	13.95	14.04	14.13	14.21	14.30	14.39	14.48	14.58
44	2.801	13.50	13.58	13.67	13.75	13.84	13.92	14.00	14.09	14.18	14.26	14.35	14.44	14.53	14.61	14.70	14.79
45	2.865	13.62	13.70	13.78	13.87	13.95	14.04	14.12	14.20	14.29	14.38	14.46	14.55	14.64	14.73	14.81	14.90
48	3.056	13.98	14.06	14.14	14.22	14.30	14.38	14.47	14.55	14.64	14.72	14.80	14.89	14.98	15.06	15.15	15.24
50	3.183	14.22	14.30	14.38	14.46	14.54	14.62	14.70	14.78	14.87	14.95	15.04	15.12	15.20	15.29	15.38	15.46
60	3.820	15.46	15.53	15.61	15.68	15.76	15.83	15.91	15.99	16.06	16.14	16.22	16.30	16.38	16.46	16.54	16.62
72	4.584	17.02	17.09	17.16	17.22	17.29	17.36	17.43	17.50	17.57	17.64	17.71	17.79	17.86	17.93	18.01	18.08

REDUCTION TIMING BELT LENGTH REQUIREMENTS BELT PITCH = 0.200 IN

2 - VERTICAL MINIMUM LENGTH

CENTER-TO-CENTER SPACING = 3.9 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26	27	28	29	30	32	36	40	42	44	45	48	50	60	72
		1.655	1.719	1.783	1.846	1.910	2.037	2.292	2.546	2.674	2.801	2.865	3.056	3.183	3.820	4.584
10	0.637	11.47	11.58	11.68	11.79	11.90	12.13	12.58	13.04	13.27	13.50	13.62	13.98	14.22	15.46	17.02
11	0.700	11.56	11.67	11.78	11.88	11.99	12.21	12.66	13.12	13.35	13.58	13.70	14.06	14.30	15.53	17.09
12	0.764	11.65	11.76	11.87	11.98	12.08	12.30	12.75	13.20	13.44	13.67	13.78	14.14	14.38	15.61	17.16
13	0.828	11.74	11.85	11.96	12.07	12.18	12.39	12.84	13.29	13.52	13.75	13.87	14.22	14.46	15.68	17.22
14	0.891	11.84	11.94	12.05	12.16	12.27	12.48	12.93	13.38	13.60	13.84	13.95	14.30	14.54	15.76	17.29
15	0.955	11.93	12.04	12.14	12.25	12.36	12.58	13.01	13.46	13.69	13.92	14.04	14.38	14.62	15.83	17.36
16	1.019	12.03	12.13	12.24	12.34	12.45	12.67	13.10	13.55	13.78	14.00	14.12	14.47	14.70	15.91	17.43
17	1.082	12.12	12.23	12.33	12.44	12.54	12.76	13.19	13.64	13.86	14.09	14.20	14.55	14.78	15.99	17.50
18	1.146	12.22	12.32	12.43	12.53	12.64	12.85	13.28	13.73	13.95	14.18	14.29	14.64	14.87	16.06	17.57
19	1.210	12.31	12.42	12.52	12.63	12.73	12.94	13.38	13.81	14.04	14.26	14.38	14.72	14.95	16.14	17.64
20	1.273	12.41	12.51	12.62	12.72	12.83	13.04	13.47	13.90	14.13	14.35	14.46	14.80	15.04	16.22	17.71
21	1.337	12.51	12.61	12.71	12.82	12.92	13.13	13.56	13.99	14.21	14.44	14.55	14.89	15.12	16.30	17.79
22	1.401	12.60	12.71	12.81	12.91	13.02	13.23	13.65	14.08	14.30	14.53	14.64	14.98	15.20	16.38	17.86
23	1.464	12.70	12.80	12.91	13.01	13.11	13.32	13.74	14.18	14.39	14.61	14.73	15.06	15.29	16.46	17.93
24	1.528	12.80	12.90	13.00	13.11	13.21	13.42	13.84	14.27	14.48	14.70	14.81	15.15	15.38	16.54	18.01
25	1.592	12.90	13.00	13.10	13.20	13.31	13.51	13.93	14.36	14.58	14.79	14.90	15.24	15.46	16.62	18.08
26	1.655	13.00	13.10	13.20	13.30	13.40	13.61	14.03	14.45	14.67	14.88	14.99	15.33	15.55	16.70	18.16
27	1.719	13.10	13.20	13.30	13.40	13.50	13.71	14.12	14.54	14.76	14.98	15.08	15.41	15.64	16.78	18.23
28	1.783	13.20	13.30	13.40	13.50	13.60	13.80	14.22	14.64	14.85	15.07	15.18	15.50	15.73	16.87	18.31
29	1.846	13.30	13.40	13.50	13.60	13.70	13.90	14.31	14.73	14.94	15.16	15.27	15.59	15.81	16.95	18.39
30	1.910	13.40	13.50	13.60	13.70	13.80	14.00	14.41	14.83	15.04	15.25	15.36	15.68	15.90	17.04	18.46
32	2.037	13.61	13.71	13.80	13.90	14.00	14.20	14.60	15.02	15.23	15.44	15.54	15.87	16.08	17.20	18.62
36	2.292	14.03	14.12	14.22	14.31	14.41	14.60	15.00	15.40	15.61	15.82	15.92	16.24	16.45	17.55	18.94
40	2.546	14.45	14.54	14.64	14.73	14.83	15.02	15.40	15.80	16.00	16.20	16.31	16.62	16.83	17.90	19.27
42	2.674	14.67	14.76	14.85	14.94	15.04	15.23	15.61	16.00	16.20	16.40	16.50	16.81	17.02	18.08	19.44
44	2.801	14.88	14.98	15.07	15.16	15.25	15.44	15.82	16.20	16.40	16.60	16.70	17.00	17.21	18.27	19.60
45	2.865	14.99	15.08	15.18	15.27	15.36	15.54	15.92	16.31	16.50	16.70	16.80	17.10	17.31	18.36	19.69
48	3.056	15.33	15.41	15.50	15.59	15.68	15.87	16.24	16.62	16.81	17.00	17.10	17.40	17.60	18.64	19.95
50	3.183	15.55	15.64	15.73	15.81	15.90	16.08	16.45	16.83	17.02	17.21	17.31	17.60	17.80	18.83	20.13
60	3.820	16.70	16.78	16.87	16.95	17.04	17.20	17.55	17.90	18.08	18.27	18.36	18.64	18.83	19.80	21.04
72	4.584	18.16	18.23	18.31	18.39	18.46	18.62	18.94	19.27	19.44	19.60	19.69	19.95	20.13	21.04	22.20

TIMING BELT LENGTH REQUIREMENTS BELT PITCH = 0.200 IN

Z - VERTICAL MAXIMUM LENGTH

CENTER-TO-CENTER SPACING = 4.50 IN

MOTOR PULLEY
:
V INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	10 0.637	11 0.700	12 0.764	13 0.828	14 0.891	15 0.955	16 1.019	17 1.082	18 1.146	19 1.210	20 1.273	21 1.337	22 1.401	23 1.464	24 1.528	25 1.592
10	0.637	11.00	11.10	11.20	11.30	11.40	11.51	11.61	11.71	11.81	11.92	12.02	12.13	12.23	12.34	12.44	12.55
11	0.700	11.10	11.20	11.30	11.40	11.50	11.60	11.71	11.81	11.91	12.01	12.12	12.22	12.33	12.43	12.54	12.64
12	0.764	11.20	11.30	11.40	11.50	11.60	11.70	11.80	11.91	12.01	12.11	12.21	12.32	12.42	12.53	12.63	12.74
13	0.828	11.30	11.40	11.50	11.60	11.70	11.80	11.90	12.00	12.11	12.21	12.31	12.41	12.52	12.62	12.73	12.83
14	0.891	11.40	11.50	11.60	11.70	11.80	11.90	12.00	12.10	12.20	12.31	12.41	12.51	12.61	12.72	12.82	12.93
15	0.955	11.51	11.60	11.70	11.80	11.90	12.00	12.10	12.20	12.30	12.40	12.51	12.61	12.71	12.81	12.92	13.02
16	1.019	11.61	11.71	11.80	11.90	12.00	12.10	12.20	12.30	12.40	12.50	12.60	12.71	12.81	12.91	13.01	13.12
17	1.082	11.71	11.81	11.91	12.00	12.10	12.20	12.30	12.40	12.50	12.60	12.70	12.80	12.91	13.01	13.11	13.21
18	1.146	11.81	11.91	12.01	12.11	12.20	12.30	12.40	12.50	12.60	12.70	12.80	12.90	13.00	13.11	13.21	13.31
19	1.210	11.92	12.01	12.11	12.21	12.31	12.40	12.50	12.60	12.70	12.80	12.90	13.00	13.10	13.20	13.31	13.41
20	1.273	12.02	12.12	12.21	12.31	12.41	12.51	12.60	12.70	12.80	12.90	13.00	13.10	13.20	13.30	13.40	13.51
21	1.337	12.13	12.22	12.32	12.41	12.51	12.61	12.71	12.80	12.90	13.00	13.10	13.20	13.30	13.40	13.50	13.60
22	1.401	12.23	12.33	12.42	12.52	12.61	12.71	12.81	12.91	13.00	13.10	13.20	13.30	13.40	13.50	13.60	13.70
23	1.464	12.34	12.43	12.53	12.62	12.72	12.81	12.91	13.01	13.11	13.20	13.30	13.40	13.50	13.60	13.70	13.80
24	1.528	12.44	12.54	12.63	12.73	12.82	12.92	13.01	13.11	13.21	13.31	13.40	13.50	13.60	13.70	13.80	13.90
25	1.592	12.55	12.64	12.74	12.83	12.93	13.02	13.12	13.21	13.31	13.41	13.51	13.60	13.70	13.80	13.90	14.00
26	1.655	12.66	12.75	12.84	12.94	13.03	13.13	13.22	13.32	13.41	13.51	13.61	13.71	13.80	13.90	14.00	14.10
27	1.719	12.77	12.86	12.95	13.04	13.14	13.23	13.33	13.42	13.52	13.61	13.71	13.81	13.91	14.00	14.10	14.20
28	1.783	12.87	12.97	13.06	13.15	13.24	13.34	13.43	13.53	13.62	13.72	13.81	13.91	14.01	14.11	14.20	14.30
29	1.846	12.98	13.07	13.17	13.26	13.35	13.44	13.54	13.63	13.73	13.82	13.92	14.01	14.11	14.21	14.31	14.40
30	1.910	13.09	13.18	13.27	13.37	13.46	13.55	13.64	13.74	13.83	13.93	14.02	14.12	14.21	14.31	14.41	14.51
32	2.037	13.31	13.40	13.49	13.58	13.67	13.77	13.86	13.95	14.04	14.14	14.23	14.33	14.42	14.52	14.61	14.71
36	2.292	13.75	13.84	13.93	14.02	14.11	14.20	14.29	14.38	14.47	14.57	14.66	14.75	14.84	14.94	15.03	15.13
40	2.546	14.20	14.29	14.38	14.46	14.55	14.64	14.73	14.82	14.91	15.00	15.09	15.18	15.27	15.37	15.46	15.55
42	2.674	14.43	14.52	14.60	14.69	14.78	14.86	14.95	15.04	15.13	15.22	15.31	15.40	15.49	15.58	15.67	15.77
44	2.801	14.66	14.75	14.83	14.92	15.00	15.09	15.18	15.26	15.35	15.44	15.53	15.62	15.71	15.80	15.89	15.98
45	2.865	14.78	14.86	14.95	15.03	15.12	15.20	15.29	15.38	15.46	15.55	15.64	15.73	15.82	15.91	16.00	16.09
48	3.056	15.13	15.21	15.29	15.38	15.46	15.55	15.63	15.72	15.80	15.89	15.98	16.06	16.15	16.24	16.33	16.42
50	3.183	15.36	15.44	15.53	15.61	15.69	15.78	15.86	15.95	16.03	16.12	16.20	16.29	16.38	16.46	16.55	16.64
60	3.820	16.57	16.65	16.72	16.80	16.88	16.96	17.04	17.12	17.20	17.28	17.36	17.44	17.53	17.61	17.69	17.78
72	4.584	18.08	18.15	18.22	18.30	18.37	18.44	18.52	18.59	18.66	18.74	18.82	18.89	18.97	19.05	19.12	19.20

TIMING BELT LENGTH REQUIREMENTS — BELT PITCH = 0.200 IN

2 - VERTICAL — MAXIMUM LENGTH

CENTER-TO-CENTER SPACING = 4.5 IN

MOTOR PULLEY
:
V — INTERMEDIATE DRIVE PULLEY ---->

# TEETH	P DIA.	26 1.655	27 1.719	28 1.783	29 1.846	30 1.910	32 2.037	36 2.292	40 2.546	42 2.674	44 2.801	45 2.865	48 3.056	50 3.183	60 3.820	72 4.584
10	0.637	12.66	12.77	12.87	12.98	13.09	13.31	13.75	14.20	14.43	14.66	14.78	15.13	15.36	16.57	18.08
11	0.700	12.75	12.86	12.97	13.07	13.18	13.40	13.84	14.29	14.52	14.75	14.86	15.21	15.44	16.65	18.15
12	0.764	12.84	12.95	13.06	13.17	13.27	13.49	13.93	14.38	14.60	14.83	14.95	15.29	15.53	16.72	18.22
13	0.828	12.94	13.04	13.15	13.26	13.37	13.58	14.02	14.46	14.69	14.92	15.03	15.38	15.61	16.80	18.30
14	0.891	13.03	13.14	13.24	13.35	13.46	13.67	14.11	14.55	14.78	15.00	15.12	15.46	15.69	16.88	18.37
15	0.955	13.13	13.23	13.34	13.44	13.55	13.77	14.20	14.64	14.86	15.09	15.20	15.55	15.78	16.96	18.44
16	1.019	13.22	13.33	13.43	13.54	13.64	13.86	14.29	14.73	14.95	15.18	15.29	15.63	15.86	17.04	18.52
17	1.082	13.32	13.42	13.53	13.63	13.74	13.95	14.38	14.82	15.04	15.26	15.38	15.72	15.95	17.12	18.59
18	1.146	13.41	13.52	13.62	13.73	13.83	14.04	14.47	14.91	15.13	15.35	15.46	15.80	16.03	17.20	18.66
19	1.210	13.51	13.61	13.72	13.82	13.93	14.14	14.57	15.00	15.22	15.44	15.55	15.89	16.12	17.28	18.74
20	1.273	13.61	13.71	13.81	13.92	14.02	14.23	14.66	15.09	15.31	15.53	15.64	15.98	16.20	17.36	18.82
21	1.337	13.71	13.81	13.91	14.01	14.12	14.33	14.75	15.18	15.40	15.62	15.73	16.06	16.29	17.44	18.89
22	1.401	13.80	13.91	14.01	14.11	14.21	14.42	14.84	15.27	15.49	15.71	15.82	16.15	16.38	17.53	18.97
23	1.464	13.90	14.00	14.11	14.21	14.31	14.52	14.94	15.37	15.58	15.80	15.91	16.24	16.46	17.61	19.05
24	1.528	14.00	14.10	14.20	14.31	14.41	14.61	15.03	15.46	15.67	15.89	16.00	16.33	16.55	17.69	19.12
25	1.592	14.10	14.20	14.30	14.40	14.51	14.71	15.13	15.55	15.77	15.98	16.09	16.42	16.64	17.78	19.20
26	1.655	14.20	14.30	14.40	14.50	14.60	14.81	15.22	15.64	15.86	16.07	16.18	16.51	16.73	17.86	19.28
27	1.719	14.30	14.40	14.50	14.60	14.70	14.91	15.32	15.74	15.95	16.17	16.27	16.60	16.82	17.95	19.36
28	1.783	14.40	14.50	14.60	14.70	14.80	15.00	15.41	15.83	16.04	16.26	16.37	16.69	16.91	18.03	19.44
29	1.846	14.50	14.60	14.70	14.80	14.90	15.10	15.51	15.93	16.14	16.35	16.46	16.78	17.00	18.12	19.52
30	1.910	14.60	14.70	14.80	14.90	15.00	15.20	15.61	16.02	16.23	16.44	16.55	16.87	17.09	18.20	19.60
32	2.037	14.81	14.91	15.00	15.10	15.20	15.40	15.80	16.21	16.42	16.63	16.74	17.06	17.27	18.38	19.76
36	2.292	15.22	15.32	15.41	15.51	15.61	15.80	16.20	16.60	16.81	17.01	17.12	17.43	17.64	18.73	20.09
40	2.546	15.64	15.74	15.83	15.93	16.02	16.21	16.60	17.00	17.20	17.40	17.51	17.81	18.02	19.09	20.43
42	2.674	15.86	15.95	16.04	16.14	16.23	16.42	16.81	17.20	17.40	17.60	17.70	18.01	18.21	19.27	20.60
44	2.801	16.07	16.17	16.26	16.35	16.44	16.63	17.01	17.40	17.60	17.80	17.90	18.20	18.41	19.46	20.78
45	2.865	16.18	16.27	16.37	16.46	16.55	16.74	17.12	17.51	17.70	17.90	18.00	18.30	18.51	19.55	20.86
48	3.056	16.51	16.60	16.69	16.78	16.87	17.06	17.43	17.81	18.01	18.20	18.30	18.60	18.80	19.83	21.13
50	3.183	16.73	16.82	16.91	17.00	17.09	17.27	17.64	18.02	18.21	18.41	18.51	18.80	19.00	20.02	21.31
60	3.820	17.86	17.95	18.03	18.12	18.20	18.38	18.73	19.09	19.27	19.46	19.55	19.83	20.02	21.00	22.23
72	4.584	19.28	19.36	19.44	19.52	19.60	19.76	20.09	20.43	20.60	20.78	20.86	21.13	21.31	22.23	23.40

APPENDIX G

Robot Horizontal Components Sizing Chart

ROBOT HORIZONTAL COMPONENTS SIZING CHART

Purpose of Chart :

The purpose of this chart is to enable the designer to determine the correct sizes for certain horizontal system components, given the desired horizontal travel and shaft diameter.

How To Use This Chart :

To determine the correct lengths for guide shafts, control shaft, frame member length and XY drive belt length, given the travel and shaft diameter:

1) Find the row on the chart that lists the desired shaft diameter and travel specification:

   a) Read the travel suffix for the desired row; this suffix is the value used in the guide shaft and control shaft drawings.

   b) Read the "On-Axis Outside Shaft Length" for the desired row; this value is the guide shaft length required to achieve the desired travel.

   c) Read the "On-Axis Inside Shaft Length" for the desired row; this value is the control shaft length required to span across the work area.

   d) Read the "On-Axis Frame Member Length" for the desired row; this value is the horizontal frame member length required for the frame.

   e) Read the "On-Axis Frame Suffix" for the desired row; this value is the part number suffix used on the horizontal frame member drawings.

   f) Read the "XY Drive Belt" for the desired row; this value is length of timing belt needed (per side) to make the XY drive belt.

ROBOT HORIZONTAL WORK AREA AND COMPONENT SIZE MATRIX

DIMENSIONS IN INCHES

X-Y SYSTEM TRAVEL AND COMPONENT SIZES

TRAVEL SUFFIX -XXX	SHAFT DIA.	ON-AXIS NOMINAL TRAVEL	X-AXIS SHAFT SPACING	ON-AXIS OUTSIDE SHAFT LENGTH	ON-AXIS INSIDE SHAFT LENGTH	TOTAL SHAFT LENGTH REQ'D PER AXIS	ON-AXIS FRAME MEMBER LENGTH	ON-AXIS FRAME SUFFIX #	"ACTUAL" AXIS TRAVEL	"XY" DRIVE BELT
-240	0.75	24.000	36.750	30.250	33.750	94.250	39.000	-392	24.000	69.3
-300	0.75	30.000	42.750	36.250	39.750	112.250	45.000	-452	30.000	81.3
-360	0.75	36.000	48.750	42.250	45.750	130.250	51.000	-512	36.000	93.3
-240	1.00	24.000	38.500	32.000	35.500	99.500	40.750	-410	24.062	72.8
-300	1.00	30.000	44.500	38.000	41.500	117.500	46.750	-470	30.062	84.8
-360	1.00	36.000	50.500	44.000	47.500	135.500	52.750	-530	36.062	96.8
-420	1.00	42.000	56.500	50.000	53.500	153.500	58.750	-590	42.062	108.8
-240	1.25	24.000	39.750	33.250	36.750	103.250	42.000	-422	24.062	75.3
-300	1.25	30.000	45.750	39.250	42.750	121.250	48.000	-482	30.062	87.3
-360	1.25	36.000	51.750	45.250	48.750	139.250	54.000	-542	36.062	99.3
-420	1.25	42.000	57.750	51.250	54.750	157.250	60.000	-602	42.062	111.3

APPENDIX H

Parts Cost Summary Sheets - Prototype

PARTS COST SUMMARY SHEETS - PROTOTYPE

Purpose of Charts:

The purpose of these charts is to enable the designer to evaluate the various cost components incurred to make parts used to build the prototype UT Robot.

How To Use These Charts :

To determine the cost components (categories) of parts manufactured to build the UT Robot prototype:

1) Locate the sheet(s) corresponding to the desired part(s) to be analyzed.

2) The cost assumptions used in the analysis are presented at the top of each sheet.

3) The costs to manufacture the part are divided into three major categories:

   a) Material costs are those incurred to purchase raw materials; these include extra ordering costs or volume discounts.

   b) Processing costs are those incurred to transform the incoming materials into the finished part. Major items in this category are set-up and machining time. Two types of processing can be performed: manual and/or automated.

   c) Tooling costs are those incurred to purchase any tooling needed to complete the manufacturing of the part. An "amortized" cost is presented: the costs are a percentage assessment to each part based on the expected life of the tool.

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................      MEK001-DDD
PART NAME ................................ Corner Support (m,l)

Quantity Required / Robot        (# pieces)                  4

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $42.35
   Order Charge Assessment       ($/part)             $0.00
   Volume Discount, Total        ($/part)             $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $42.35


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)             $0.00
   Unit Setup, Total ............($/part)            $80.00
   Machining, Total .............($/part)           $130.00

   Manual Operations, Total .....($/part)           $210.00
   Automated Operations, Total ..($/part)             $0.00
                                                  ----------
PROCESSING SUBTOTAL ......................          $210.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $1.00
   Disposables ..................($/part)             $5.00
   Casting Pattern Allowance ....($/part)            $10.18
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $16.18

                                                  ==========
PART COST, TOTAL (unit) ..................          $268.53
                                                  ==========
PART COST, TOTAL (per robot) .............        $1,074.10
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................    MEK011, MEK012
PART NAME ................................ XY Plates,LH&RH (m)

Quantity Required / Robot        (# pieces)                   4

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~


MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $3.60
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $3.60


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)             $30.00
   Machining, Total ..............($/part)             $40.00

   Manual Operations, Total .....($/part)              $70.00
   Automated Operations, Total ..($/part)               $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................            $70.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.80
   Disposables ..................($/part)              $2.00
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $2.80

                                                  ===============
PART COST, TOTAL (unit) ..................            $76.40
                                                  ===============
PART COST, TOTAL (per robot) .............           $305.60
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK016
PART NAME ................................     Z Plate (m)

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $3.69
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $3.69


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)             $40.00
   Machining, Total ..............($/part)             $40.00

   Manual Operations, Total .....($/part)              $80.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $80.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.80
   Disposables ..................($/part)              $2.00
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $2.80

                                                  ===============
PART COST, TOTAL (unit) ..................             $86.49
                                                  ===============
PART COST, TOTAL (per robot) .............             $86.49
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................      MEK021-DDD
PART NAME ................................     Slider (m,l)

Quantity Required / Robot        (# pieces)                    4
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $23.15
   Order Charge Assessment       ($/part)               $0.00
   Volume Discount, Total        ($/part)               $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $23.15


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)               $0.00
   Unit Setup, Total .............($/part)              $30.00
   Machining, Total ..............($/part)              $74.00

   Manual Operations, Total .....($/part)             $104.00
   Automated Operations, Total ..($/part)               $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................            $104.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)               $2.30
   Disposables ..................($/part)               $5.00
   Casting Pattern Allowance ....($/part)               $9.28
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............              $16.58

                                                  ===============
PART COST, TOTAL (unit) ..................             $143.73
                                                  ===============
PART COST, TOTAL (per robot) .............             $574.91
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK042, 043
PART NAME		Belt Clip Parts
Quantity Required / Robot	(# pieces)	10
MATERIAL COSTS:		
Material Cost, Gross per Part	($/part)	$0.27
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$0.27
PROCESSING COSTS:		
Initial Setup Cost Assessment.	($/part)	$0.50
Unit Setup, Total	($/part)	$1.00
Machining, Total	($/part)	$1.20
Manual Operations, Total	($/part)	$0.00
Automated Operations, Total ..	($/part)	$2.70
PROCESSING SUBTOTAL		$2.70
TOOLING COSTS:		
Tool Allowance, Total.....	($/part)	$0.60
Disposables	($/part)	$0.10
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$0.70
PART COST, TOTAL (unit)		$3.67
PART COST, TOTAL (per robot)		$36.70

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK046
PART NAME ................................   Reduct Shaft, XY

Quantity Required / Robot        (# pieces)                  8

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $1.92
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $1.92


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total ............($/part)              $2.00
   Machining, Total .............($/part)              $4.00

   Manual Operations, Total .....($/part)              $6.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $1.20
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.70

                                                  ===============
PART COST, TOTAL (unit) ..................             $9.62
                                                  ===============
PART COST, TOTAL (per robot) .............            $76.96
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK047
PART NAME	Reduct Shaft, Z
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:	
Material Cost, Gross per Part ($/part)	$4.00
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$4.00
PROCESSING COSTS:	
Initial Setup Cost Assessment.($/part)	$0.00
Unit Setup, Total .....($/part)	$2.00
Machining, Total .....($/part)	$6.00
Manual Operations, Total .....($/part)	$8.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$8.00
TOOLING COSTS:	
Tool Allowance, Total.....($/part)	$1.40
Disposables .....($/part)	$0.50
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$1.90
PART COST, TOTAL (unit)	$13.90
PART COST, TOTAL (per robot)	$13.90

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................       MEK048
PART NAME ................................    Idler Shaft, Z

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $2.08
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                   ----------
MATERIAL SUBTOTAL ........................             $2.08


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)              $2.00
   Machining, Total ..............($/part)              $4.00

   Manual Operations, Total .....($/part)              $6.00
   Automated Operations, Total ..($/part)              $0.00
                                                   ----------
PROCESSING SUBTOTAL ......................             $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $1.20
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                   ----------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.70

                                                   ==========
PART COST, TOTAL (unit) ..................             $9.78
                                                   ==========
PART COST, TOTAL (per robot) .............             $9.78
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK051-DDD
PART NAME	Brg. Cartr'ge (m,l)
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$80.35
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$80.35

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$60.00
Unit Setup, Total .....($/part)	$20.00
Machining, Total .....($/part)	$240.00
Manual Operations, Total .....($/part)	$320.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$320.00

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$3.80
Disposables .....($/part)	$5.00
Casting Pattern Allowance ....($/part)	$42.93
TOOLING ALLOWANCE SUBTOTAL	$51.73
PART COST, TOTAL (unit)	$452.08
PART COST, TOTAL (per robot)	$452.08

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................        MEK063
PART NAME ................................    Motor, Rot Sys.

Quantity Required / Robot        (# pieces)                  1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $102.00
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................           $102.00


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total ............($/part)              $2.00
   Machining, Total .............($/part)              $4.00

   Manual Operations, Total .....($/part)              $6.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $2.00
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $2.50

                                                  ===============
PART COST, TOTAL (unit) ..................           $110.50
                                                  ===============
PART COST, TOTAL (per robot) .............           $110.50
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK064
PART NAME ................................  Motor, Tran. Sys.

Quantity Required / Robot        (# pieces)                5

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)          $98.50
   Order Charge Assessment       ($/part)           $0.00
   Volume Discount, Total        ($/part)           $0.00
                                                ---------------
MATERIAL SUBTOTAL ........................          $98.50


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)           $0.00
   Unit Setup, Total ............($/part)           $2.00
   Machining, Total .............($/part)           $4.00

   Manual Operations, Total .....($/part)           $6.00
   Automated Operations, Total ..($/part)           $0.00
                                                ---------------
PROCESSING SUBTOTAL ......................          $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)           $2.00
   Disposables ..................($/part)           $0.50
   Casting Pattern Allowance ....($/part)           $0.00
                                                ---------------
TOOLING ALLOWANCE SUBTOTAL ...............          $2.50

                                                ===============
PART COST, TOTAL (unit) ..................        $107.00
                                                ===============
PART COST, TOTAL (per robot) .............        $535.00
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK071-DDD
PART NAME	Z Platform (m,l)
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:	
Material Cost, Gross per Part ($/part)	$61.20
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$61.20
PROCESSING COSTS:	
Initial Setup Cost Assessment.($/part)	$80.00
Unit Setup, Total .....($/part)	$20.00
Machining, Total .....($/part)	$160.00
Manual Operations, Total .....($/part)	$260.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$260.00
TOOLING COSTS:	
Tool Allowance, Total.....($/part)	$3.80
Disposables .....($/part)	$5.00
Casting Pattern Allowance ....($/part)	$66.84
TOOLING ALLOWANCE SUBTOTAL	$75.64
PART COST, TOTAL (unit)	$396.84
PART COST, TOTAL (per robot)	$396.84

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK081
PART NAME	T. Mtr. Mnt (m,l)
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:	
Material Cost, Gross per Part ($/part)	$8.70
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$8.70
PROCESSING COSTS:	
Initial Setup Cost Assessment.($/part)	$10.00
Unit Setup, Total .....($/part)	$6.00
Machining, Total .....($/part)	$60.00
Manual Operations, Total .....($/part)	$76.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$76.00
TOOLING COSTS:	
Tool Allowance, Total.....($/part)	$1.00
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$13.73
TOOLING ALLOWANCE SUBTOTAL	$16.73
PART COST, TOTAL (unit)	$101.43
PART COST, TOTAL (per robot)	$101.43

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................        MEK091
PART NAME ................................     Plate, Mast

Quantity Required / Robot        (# pieces)                  2

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $0.95
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $0.95


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $2.50
   Unit Setup, Total ............($/part)              $1.00
   Machining, Total .............($/part)              $1.20

   Manual Operations, Total .....($/part)              $0.00
   Automated Operations, Total ..($/part)              $4.70
                                                  ---------------
PROCESSING SUBTOTAL ......................             $4.70


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.50
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.00

                                                  ===============
PART COST, TOTAL (unit) ..................             $6.65
                                                  ===============
PART COST, TOTAL (per robot) .............            $13.29
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK093
PART NAME		Mast, Z-Axis
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:		
Material Cost, Gross per Part	($/part)	$8.52
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$8.52
PROCESSING COSTS:		
Initial Setup Cost Assessment.	($/part)	$3.00
Unit Setup, Total	($/part)	$1.00
Machining, Total	($/part)	$1.20
Manual Operations, Total	($/part)	$0.00
Automated Operations, Total ..	($/part)	$5.20
PROCESSING SUBTOTAL		$5.20
TOOLING COSTS:		
Tool Allowance, Total.....	($/part)	$0.50
Disposables	($/part)	$1.00
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$1.50
PART COST, TOTAL (unit)		$15.22
PART COST, TOTAL (per robot)		$15.22

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................      MEK095,096
PART NAME ................................   Brackets, Frame

Quantity Required / Robot        (# pieces)                2
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)             $0.20
   Order Charge Assessment       ($/part)             $0.00
   Volume Discount, Total        ($/part)             $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................            $0.20


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)             $2.00
   Unit Setup, Total ............($/part)             $2.00
   Machining, Total .............($/part)             $8.00

   Manual Operations, Total .....($/part)            $12.00
   Automated Operations, Total ..($/part)             $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................           $12.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $0.50
   Disposables ..................($/part)             $0.50
   Casting Pattern Allowance ....($/part)             $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............            $1.00

                                                  ===============
PART COST, TOTAL (unit) ..................           $13.20
                                                  ===============
PART COST, TOTAL (per robot) .............           $26.40
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................        MEK097
PART NAME ................................    Bracket, Z Mast

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $0.41
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $0.41


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total ............($/part)              $4.00
   Machining, Total .............($/part)              $8.00

   Manual Operations, Total .....($/part)             $12.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................            $12.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.50
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.00

                                                  ===============
PART COST, TOTAL (unit) ..................             $13.41
                                                  ===============
PART COST, TOTAL (per robot) .............             $13.41
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------

Travel "X","Y","Z":	42.0	42.0	24.0
Shaft Dia. (in) :	1.00		

------- Cost Assumptions --------

Set-up, Manual:	$20.00 /hr
Set-up, Auto :	$10.00 /hr
Manual Machine:	$20.00 /hr
Auto Machine :	$6.00 /hr
Amortize over:	10 robots
Batch Size :	1 robots

PART NUMBER	MEK098
PART NAME	Rod, Hanger
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:	
Material Cost, Gross per Part ($/part)	$0.60
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$0.60
PROCESSING COSTS:	
Initial Setup Cost Assessment.($/part)	$0.00
Unit Setup, Total .....($/part)	$0.00
Machining, Total .....($/part)	$2.00
Manual Operations, Total .....($/part)	$2.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$2.00
TOOLING COSTS:	
Tool Allowance, Total.....($/part)	$0.25
Disposables .....($/part)	$0.50
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$0.75
PART COST, TOTAL (unit)	$3.35
PART COST, TOTAL (per robot)	$3.35

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................        MEK099
PART NAME ................................  Rod, Frame Support

Quantity Required / Robot        (# pieces)                1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $1.76
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $1.76


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $0.00
   Unit Setup, Total ............($/part)            $0.00
   Machining, Total .............($/part)           $10.00

   Manual Operations, Total .....($/part)           $10.00
   Automated Operations, Total ..($/part)            $0.00
                                                  ----------
PROCESSING SUBTOTAL ......................          $10.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)            $0.00
   Disposables ..................($/part)            $0.50
   Casting Pattern Allowance ....($/part)            $0.00
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $0.50

                                                  ==========
PART COST, TOTAL (unit) ..................          $12.26
                                                  ==========
PART COST, TOTAL (per robot) .............          $12.26
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK201
PART NAME ................................  Converter, M-Tube

Quantity Required / Robot        (# pieces)                  1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $0.38
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $0.38


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $6.00
   Unit Setup, Total ............($/part)             $20.00
   Machining, Total .............($/part)             $20.00

   Manual Operations, Total .....($/part)             $46.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $46.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.50
   Disposables ..................($/part)              $2.00
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $2.50

                                                  ===============
PART COST, TOTAL (unit) ..................             $48.88
                                                  ===============
PART COST, TOTAL (per robot) .............             $48.88
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK211-ZZZ
PART NAME		Tube, Guide, Z-Axis
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$76.88
Order Charge Assessment	($/part)	$20.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$96.88

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$6.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$40.00
Manual Operations, Total	($/part)	$46.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$46.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$2.50
Disposables	($/part)	$2.00
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$4.50
PART COST, TOTAL (unit)		$147.38
PART COST, TOTAL (per robot)		$147.38

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................      MEK216-ZZZ
PART NAME ................................ Tube, Theta Trans

Quantity Required / Robot        (# pieces)                1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $8.82
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                ---------------
MATERIAL SUBTOTAL .........................          $8.82


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $6.00
   Unit Setup, Total .............($/part)            $0.00
   Machining, Total ..............($/part)           $30.00

   Manual Operations, Total .....($/part)           $36.00
   Automated Operations, Total ..($/part)            $0.00
                                                ---------------
PROCESSING SUBTOTAL .......................         $36.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)            $0.50
   Disposables ..................($/part)            $1.00
   Casting Pattern Allowance ....($/part)            $0.00
                                                ---------------
TOOLING ALLOWANCE SUBTOTAL ................          $1.50

                                                ===============
PART COST, TOTAL (unit) ...................         $46.32
                                                ===============
PART COST, TOTAL (per robot) ..............         $46.32
```

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK231
PART NAME	End. Eff. Mnt (m,l)
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$7.85
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$7.85

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$0.00
Unit Setup, Total .....($/part)	$12.00
Machining, Total .....($/part)	$40.00
Manual Operations, Total .....($/part)	$52.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$52.00

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$0.50
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$7.43
TOOLING ALLOWANCE SUBTOTAL	$9.93
PART COST, TOTAL (unit)	$69.78
PART COST, TOTAL (per robot)	$69.78

PARTS MANUFACTURING COST ASSESSMENT
Prototype

---------- Robot Configuration --------

Travel "X","Y","Z":	42.0	42.0	24.0
Shaft Dia. (in) :	1.00		

------- Cost Assumptions --------

Set-up, Manual:	$20.00 /hr
Set-up, Auto :	$10.00 /hr
Manual Machine:	$20.00 /hr
Auto Machine :	$6.00 /hr
Amortize over:	10 robots
Batch Size :	1 robots

PART NUMBER	MEK301,02,03,04
PART NAME	Mbrs, Frame, Horiz
Quantity Required / Robot (# pieces)	8

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$1.68
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$1.68

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$0.00
Unit Setup, Total .....($/part)	$0.00
Machining, Total .....($/part)	$16.00
Manual Operations, Total .....($/part)	$16.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$16.00

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$0.50
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$2.50
PART COST, TOTAL (unit)	$20.18
PART COST, TOTAL (per robot)	$161.44

```
PARTS MANUFACTURING COST ASSESSMENT
   Prototype
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK306
PART NAME ................................   Mbr, Frame, Vert

Quantity Required / Robot        (# pieces)                4
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $7.92
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................           $7.92


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $0.00
   Unit Setup, Total .............($/part)            $0.00
   Machining, Total ..............($/part)           $20.00

   Manual Operations, Total .....($/part)           $20.00
   Automated Operations, Total ..($/part)            $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................          $20.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)            $0.50
   Disposables ..................($/part)            $2.00
   Casting Pattern Allowance ....($/part)            $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............           $2.50

                                                  ===============
PART COST, TOTAL (unit) ..................          $30.42
                                                  ===============
PART COST, TOTAL (per robot) .............         $121.68
```

APPENDIX I

Parts Cost Summary Sheets - Projected Production

PARTS COST SUMMARY SHEETS - PROJECTED PRODUCTION

Purpose of Charts:

The purpose of these charts is to enable the designer to evaluate the various estimated cost components that would be incurred to make parts for a production UT Robot.

How To Use These Charts :

To determine the estimated cost components (categories) of parts manufactured to build a production UT Robot:

1) Locate the sheet(s) corresponding to the desired part(s) to be analyzed.

2) The cost assumptions used in the analysis are presented at the top of each sheet.

3) The costs to manufacture the part are divided into three major categories:

   a) Material costs are those incurred to purchase raw materials; these include extra ordering costs or volume discounts.

   b) Processing costs are those incurred to transform the incoming materials into the finished part. Major items in this category are set-up and machining time. Two types of processing can be performed: manual and/or automated.

   c) Tooling costs are those incurred to purchase any tooling needed to complete the manufacturing of the part. An "amortized" cost is presented: the costs are a percentage assessment to each part based on the expected life of the tool.

```
PARTS MANUFACTURING COST ASSESSMENT
   Loose Patterns, Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................      MEK001-DDD
PART NAME ................................ Corner Support (m,l)

Quantity Required / Robot        (# pieces)                  4

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $48.40
   Order Charge Assessment       ($/part)             $0.00
   Volume Discount, Total        ($/part)             $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $48.40


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)             $2.00
   Unit Setup, Total .............($/part)             $0.00
   Machining, Total ..............($/part)            $18.60

   Manual Operations, Total .....($/part)             $0.00
   Automated Operations, Total ..($/part)            $20.60
                                                  ----------
PROCESSING SUBTOTAL ......................           $20.60


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $1.00
   Disposables ..................($/part)             $5.00
   Casting Pattern Allowance ....($/part)            $10.18
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $16.18

                                                  ==========
PART COST, TOTAL (unit) ..................           $85.18
                                                  ==========
PART COST, TOTAL (per robot) .............          $340.70
```

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK011, MEK012
PART NAME	XY Plates,LH&RH (m)
Quantity Required / Robot (# pieces)	4

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$3.60
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$3.60

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$0.75
Unit Setup, Total .....($/part)	$0.00
Machining, Total .....($/part)	$3.00
Manual Operations, Total .....($/part)	$0.00
Automated Operations, Total ..($/part)	$3.75
PROCESSING SUBTOTAL	$3.75

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$0.80
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$2.80
PART COST, TOTAL (unit)	$10.15
PART COST, TOTAL (per robot)	$40.60

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK016
PART NAME		Z Plate (m)
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$3.69
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$3.69

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$3.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$3.00
Manual Operations, Total	($/part)	$0.00
Automated Operations, Total ..	($/part)	$6.00
PROCESSING SUBTOTAL		$6.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$0.80
Disposables	($/part)	$2.00
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$2.80
PART COST, TOTAL (unit)		$12.49
PART COST, TOTAL (per robot)		$12.49

PARTS MANUFACTURING COST ASSESSMENT
Loose Patterns, Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK021-DDD
PART NAME		Slider (m,l)
Quantity Required / Robot	(# pieces)	4

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$26.70
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$26.70

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$2.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$12.00
Manual Operations, Total	($/part)	$0.00
Automated Operations, Total ..	($/part)	$14.00
PROCESSING SUBTOTAL		$14.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$2.30
Disposables	($/part)	$5.00
Casting Pattern Allowance	($/part)	$9.28
TOOLING ALLOWANCE SUBTOTAL		$16.58
PART COST, TOTAL (unit)		$57.28
PART COST, TOTAL (per robot)		$229.11

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................    MEK042, 043
PART NAME ................................  Belt Clip Parts

Quantity Required / Robot        (# pieces)              10

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)          $0.27
   Order Charge Assessment       ($/part)          $0.00
   Volume Discount, Total        ($/part)          $0.00
                                                 ---------------
MATERIAL SUBTOTAL ........................         $0.27


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)          $0.50
   Unit Setup, Total ............($/part)          $1.00
   Machining, Total .............($/part)          $1.20

   Manual Operations, Total .....($/part)          $0.00
   Automated Operations, Total ..($/part)          $2.70
                                                 ---------------
PROCESSING SUBTOTAL ......................         $2.70


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)          $0.60
   Disposables ..................($/part)          $0.10
   Casting Pattern Allowance ....($/part)          $0.00
                                                 ---------------
TOOLING ALLOWANCE SUBTOTAL ...............         $0.70

                                                 ===============
PART COST, TOTAL (unit) ..................         $3.67
                                                 ===============
PART COST, TOTAL (per robot) .............        $36.70
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK046
PART NAME ................................    Reduct Shaft, XY

Quantity Required / Robot        (# pieces)                  8

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $1.92
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $1.92


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total ............($/part)              $2.00
   Machining, Total .............($/part)              $4.00

   Manual Operations, Total .....($/part)              $6.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $1.20
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.70

                                                  ===============
PART COST, TOTAL (unit) ..................             $9.62
                                                  ===============
PART COST, TOTAL (per robot) .............            $76.96
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK047
PART NAME ................................    Reduct Shaft, Z

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $4.00
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $4.00


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)              $2.00
   Machining, Total ..............($/part)              $6.00

   Manual Operations, Total .....($/part)              $8.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $8.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $1.40
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.90

                                                  ===============
PART COST, TOTAL (unit) ..................            $13.90
                                                  ===============
PART COST, TOTAL (per robot) .............            $13.90
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:      10 robots
   Batch Size    :       1 robots


PART NUMBER ..............................        MEK048
PART NAME ................................    Idler Shaft, Z

Quantity Required / Robot        (# pieces)                  1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $2.08
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $2.08


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)              $2.00
   Machining, Total ..............($/part)              $4.00

   Manual Operations, Total .....($/part)              $6.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................             $6.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $1.20
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $1.70

                                                  ===============
PART COST, TOTAL (unit) ..................             $9.78
                                                  ===============
PART COST, TOTAL (per robot) .............             $9.78
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Loose Patterns, Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................      MEK051-DDD
PART NAME ................................ Brg. Cartr'ge (m,l)

Quantity Required / Robot        (# pieces)                1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)          $58.30
   Order Charge Assessment       ($/part)           $0.00
   Volume Discount, Total        ($/part)           $0.00
                                                 ----------
MATERIAL SUBTOTAL ........................         $58.30


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)          $20.00
   Unit Setup, Total .............($/part)          $15.00
   Machining, Total ..............($/part)          $29.00

   Manual Operations, Total .....($/part)          $30.00
   Automated Operations, Total ..($/part)          $34.00
                                                 ----------
PROCESSING SUBTOTAL ......................         $64.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)           $3.80
   Disposables ..................($/part)           $5.00
   Casting Pattern Allowance ....($/part)          $42.93
                                                 ----------
TOOLING ALLOWANCE SUBTOTAL ...............         $51.73

                                                 ==========
PART COST, TOTAL (unit) ..................        $174.03
                                                 ==========
PART COST, TOTAL (per robot) .............        $174.03
```

PARTS MANUFACTURING COST ASSESSMENT
Production

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK063
PART NAME		Motor, Rot Sys.
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:		
Material Cost, Gross per Part	($/part)	$167.00
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$167.00
PROCESSING COSTS:		
Initial Setup Cost Assessment.	($/part)	$0.00
Unit Setup, Total	($/part)	$2.00
Machining, Total	($/part)	$4.00
Manual Operations, Total	($/part)	$6.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$6.00
TOOLING COSTS:		
Tool Allowance, Total.....	($/part)	$2.00
Disposables	($/part)	$0.50
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$2.50
PART COST, TOTAL (unit)		$175.50
PART COST, TOTAL (per robot)		$175.50

PARTS MANUFACTURING COST ASSESSMENT
Production

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK064
PART NAME		Motor, Tran. Sys.
Quantity Required / Robot	(# pieces)	5

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$130.00
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	($18.20)
MATERIAL SUBTOTAL		$111.80

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$0.00
Unit Setup, Total	($/part)	$2.00
Machining, Total	($/part)	$4.00
Manual Operations, Total	($/part)	$6.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$6.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$2.00
Disposables	($/part)	$0.50
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$2.50
PART COST, TOTAL (unit)		$120.30
PART COST, TOTAL (per robot)		$601.50

```
PARTS MANUFACTURING COST ASSESSMENT
   Loose Patterns, Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................      MEK071-DDD
PART NAME ................................   Z Platform (m,l)

Quantity Required / Robot        (# pieces)                  1

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $57.25
   Order Charge Assessment       ($/part)             $0.00
   Volume Discount, Total        ($/part)             $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $57.25


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $30.00
   Unit Setup, Total ............($/part)            $15.00
   Machining, Total .............($/part)            $35.00

   Manual Operations, Total .....($/part)            $30.00
   Automated Operations, Total ..($/part)            $50.00
                                                  ----------
PROCESSING SUBTOTAL ......................           $80.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $3.80
   Disposables ..................($/part)             $5.00
   Casting Pattern Allowance ....($/part)            $66.84
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $75.64

                                                  ==========
PART COST, TOTAL (unit) ..................          $212.89
                                                  ==========
PART COST, TOTAL (per robot) .............          $212.89
```

PARTS MANUFACTURING COST ASSESSMENT
Loose Patterns, Auto Manf #1

---------- Robot Configuration --------

Travel "X","Y","Z":	42.0	42.0	24.0
Shaft Dia. (in) :	1.00		

------- Cost Assumptions --------

Set-up, Manual:	$20.00 /hr
Set-up, Auto :	$10.00 /hr
Manual Machine:	$20.00 /hr
Auto Machine :	$6.00 /hr
Amortize over:	10 robots
Batch Size :	1 robots

PART NUMBER	MEK081
PART NAME	T. Mtr. Mnt (m,l)
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$11.15
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$11.15

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$1.00
Unit Setup, Total .....($/part)	$5.00
Machining, Total .....($/part)	$4.80
Manual Operations, Total .....($/part)	$0.00
Automated Operations, Total ..($/part)	$10.80
PROCESSING SUBTOTAL	$10.80

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$1.00
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$13.73
TOOLING ALLOWANCE SUBTOTAL	$16.73
PART COST, TOTAL (unit)	$38.68
PART COST, TOTAL (per robot)	$38.68

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK091
PART NAME	Plate, Mast
Quantity Required / Robot (# pieces)	2

MATERIAL COSTS:	
Material Cost, Gross per Part ($/part)	$0.95
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$0.95
PROCESSING COSTS:	
Initial Setup Cost Assessment.($/part)	$2.50
Unit Setup, Total .....($/part)	$1.00
Machining, Total .....($/part)	$1.20
Manual Operations, Total .....($/part)	$0.00
Automated Operations, Total ..($/part)	$4.70
PROCESSING SUBTOTAL	$4.70
TOOLING COSTS:	
Tool Allowance, Total.....($/part)	$0.50
Disposables .....($/part)	$0.50
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$1.00
PART COST, TOTAL (unit)	$6.65
PART COST, TOTAL (per robot)	$13.29

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK093
PART NAME ................................    Mast, Z-Axis

Quantity Required / Robot        (# pieces)                1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $8.52
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $8.52


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $3.00
   Unit Setup, Total .............($/part)            $1.00
   Machining, Total ..............($/part)            $1.20

   Manual Operations, Total .....($/part)            $0.00
   Automated Operations, Total ..($/part)            $5.20
                                                  ----------
PROCESSING SUBTOTAL ......................           $5.20


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)            $0.50
   Disposables ..................($/part)            $1.00
   Casting Pattern Allowance ....($/part)            $0.00
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $1.50

                                                  ==========
PART COST, TOTAL (unit) ..................          $15.22
                                                  ==========
PART COST, TOTAL (per robot) .............          $15.22
```

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK095,096
PART NAME		Brackets, Frame
Quantity Required / Robot	(# pieces)	2

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$0.20
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$0.20

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$2.00
Unit Setup, Total	($/part)	$2.00
Machining, Total	($/part)	$8.00
Manual Operations, Total	($/part)	$12.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$12.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$0.50
Disposables	($/part)	$0.50
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$1.00
PART COST, TOTAL (unit)		$13.20
PART COST, TOTAL (per robot)		$26.40

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................      MEK097
PART NAME ................................   Bracket, Z Mast

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $0.41
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $0.41


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $0.00
   Unit Setup, Total .............($/part)            $4.00
   Machining, Total ..............($/part)            $8.00

   Manual Operations, Total .....($/part)           $12.00
   Automated Operations, Total ..($/part)            $0.00
                                                  ----------
PROCESSING SUBTOTAL ......................          $12.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)            $0.50
   Disposables ..................($/part)            $0.50
   Casting Pattern Allowance ....($/part)            $0.00
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $1.00

                                                  ==========
PART COST, TOTAL (unit) ..................          $13.41
                                                  ==========
PART COST, TOTAL (per robot) .............          $13.41
```

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)   :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK098
PART NAME ................................     Rod, Hanger

Quantity Required / Robot        (# pieces)                  1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $0.60
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                   ----------
MATERIAL SUBTOTAL ........................             $0.60


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total .............($/part)              $0.00
   Machining, Total ..............($/part)              $2.00

   Manual Operations, Total .....($/part)              $2.00
   Automated Operations, Total ..($/part)              $0.00
                                                   ----------
PROCESSING SUBTOTAL ......................             $2.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.25
   Disposables ..................($/part)              $0.50
   Casting Pattern Allowance ....($/part)              $0.00
                                                   ----------
TOOLING ALLOWANCE SUBTOTAL ...............             $0.75

                                                   ==========
PART COST, TOTAL (unit) ..................             $3.35
                                                   ==========
PART COST, TOTAL (per robot) .............             $3.35
```

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK099
PART NAME		Rod, Frame Support
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$1.76
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$1.76

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$0.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$10.00
Manual Operations, Total	($/part)	$10.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$10.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$0.00
Disposables	($/part)	$0.50
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$0.50
PART COST, TOTAL (unit)		$12.26
PART COST, TOTAL (per robot)		$12.26

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................        MEK201
PART NAME ................................  Converter, M-Tube

Quantity Required / Robot        (# pieces)                1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)            $0.38
   Order Charge Assessment       ($/part)            $0.00
   Volume Discount, Total        ($/part)            $0.00
                                                  ----------
MATERIAL SUBTOTAL ........................           $0.38


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)            $6.00
   Unit Setup, Total .............($/part)           $20.00
   Machining, Total ..............($/part)           $20.00

   Manual Operations, Total .....($/part)            $46.00
   Automated Operations, Total ..($/part)             $0.00
                                                  ----------
PROCESSING SUBTOTAL ......................           $46.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)             $0.50
   Disposables ..................($/part)             $2.00
   Casting Pattern Allowance ....($/part)             $0.00
                                                  ----------
TOOLING ALLOWANCE SUBTOTAL ...............           $2.50

                                                  ==========
PART COST, TOTAL (unit) ..................           $48.88
                                                  ==========
PART COST, TOTAL (per robot) .............           $48.88
```

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK211-ZZZ
PART NAME	Tube, Guide, Z-Axis
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$76.88
Order Charge Assessment ($/part)	$20.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$96.88

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$6.00
Unit Setup, Total .....($/part)	$0.00
Machining, Total .....($/part)	$40.00
Manual Operations, Total .....($/part)	$46.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$46.00

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$2.50
Disposables .....($/part)	$2.00
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$4.50
PART COST, TOTAL (unit)	$147.38
PART COST, TOTAL (per robot)	$147.38

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER	MEK216-ZZZ
PART NAME	Tube, Theta Trans
Quantity Required / Robot (# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part ($/part)	$8.82
Order Charge Assessment ($/part)	$0.00
Volume Discount, Total ($/part)	$0.00
MATERIAL SUBTOTAL	$8.82

PROCESSING COSTS:

Initial Setup Cost Assessment.($/part)	$6.00
Unit Setup, Total .....($/part)	$0.00
Machining, Total .....($/part)	$30.00
Manual Operations, Total .....($/part)	$36.00
Automated Operations, Total ..($/part)	$0.00
PROCESSING SUBTOTAL	$36.00

TOOLING COSTS:

Tool Allowance, Total.....($/part)	$0.50
Disposables .....($/part)	$1.00
Casting Pattern Allowance ....($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL	$1.50
PART COST, TOTAL (unit)	$46.32
PART COST, TOTAL (per robot)	$46.32

PARTS MANUFACTURING COST ASSESSMENT
Loose Patterns, Auto Manf #1

---------- Robot Configuration --------

Travel "X","Y","Z":	42.0	42.0	24.0
Shaft Dia. (in) :	1.00		

------- Cost Assumptions --------

Set-up, Manual:	$20.00 /hr
Set-up, Auto :	$10.00 /hr
Manual Machine:	$20.00 /hr
Auto Machine :	$6.00 /hr
Amortize over:	10 robots
Batch Size :	1 robots

PART NUMBER		MEK231
PART NAME		End. Eff. Mnt (m,l)
Quantity Required / Robot	(# pieces)	1

MATERIAL COSTS:

Material Cost, Gross per Part	($/part)	$7.85
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$7.85

PROCESSING COSTS:

Initial Setup Cost Assessment.	($/part)	$3.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$6.00
Manual Operations, Total	($/part)	$0.00
Automated Operations, Total ..	($/part)	$9.00
PROCESSING SUBTOTAL		$9.00

TOOLING COSTS:

Tool Allowance, Total.....	($/part)	$0.50
Disposables	($/part)	$2.00
Casting Pattern Allowance	($/part)	$7.43
TOOLING ALLOWANCE SUBTOTAL		$9.93
PART COST, TOTAL (unit)		$26.78
PART COST, TOTAL (per robot)		$26.78

```
PARTS MANUFACTURING COST ASSESSMENT
   Auto Manf #1
---------- Robot Configuration --------
Travel "X","Y","Z":  42.0   42.0   24.0
Shaft Dia. (in)    :  1.00

------- Cost Assumptions --------
   Set-up, Manual: $20.00 /hr
   Set-up, Auto  : $10.00 /hr
   Manual Machine: $20.00 /hr
   Auto Machine  :  $6.00 /hr
   Amortize over:       10 robots
   Batch Size    :        1 robots


PART NUMBER ..............................  MEK301,02,03,04
PART NAME ................................  Mbrs, Frame, Horiz

Quantity Required / Robot        (# pieces)                  8
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~~~~~

MATERIAL COSTS:
---------------
   Material Cost, Gross per Part ($/part)              $1.68
   Order Charge Assessment       ($/part)              $0.00
   Volume Discount, Total        ($/part)              $0.00
                                                  ---------------
MATERIAL SUBTOTAL ........................             $1.68


PROCESSING COSTS:
-----------------
   Initial Setup Cost Assessment.($/part)              $0.00
   Unit Setup, Total ............($/part)              $0.00
   Machining, Total .............($/part)             $16.00

   Manual Operations, Total .....($/part)             $16.00
   Automated Operations, Total ..($/part)              $0.00
                                                  ---------------
PROCESSING SUBTOTAL ......................            $16.00


TOOLING COSTS:
--------------
   Tool Allowance, Total.........($/part)              $0.50
   Disposables ..................($/part)              $2.00
   Casting Pattern Allowance ....($/part)              $0.00
                                                  ---------------
TOOLING ALLOWANCE SUBTOTAL ...............             $2.50

                                                  ===============
PART COST, TOTAL (unit) ..................            $20.18
                                                  ===============
PART COST, TOTAL (per robot) .............           $161.44
```

PARTS MANUFACTURING COST ASSESSMENT
Auto Manf #1

---------- Robot Configuration --------
Travel "X","Y","Z": 42.0 42.0 24.0
Shaft Dia. (in) : 1.00

------- Cost Assumptions --------
Set-up, Manual: $20.00 /hr
Set-up, Auto : $10.00 /hr
Manual Machine: $20.00 /hr
Auto Machine : $6.00 /hr
Amortize over: 10 robots
Batch Size : 1 robots

PART NUMBER		MEK306
PART NAME		Mbr, Frame, Vert
Quantity Required / Robot	(# pieces)	4
MATERIAL COSTS:		
Material Cost, Gross per Part	($/part)	$7.92
Order Charge Assessment	($/part)	$0.00
Volume Discount, Total	($/part)	$0.00
MATERIAL SUBTOTAL		$7.92
PROCESSING COSTS:		
Initial Setup Cost Assessment.	($/part)	$0.00
Unit Setup, Total	($/part)	$0.00
Machining, Total	($/part)	$20.00
Manual Operations, Total	($/part)	$20.00
Automated Operations, Total ..	($/part)	$0.00
PROCESSING SUBTOTAL		$20.00
TOOLING COSTS:		
Tool Allowance, Total.....	($/part)	$0.50
Disposables	($/part)	$2.00
Casting Pattern Allowance	($/part)	$0.00
TOOLING ALLOWANCE SUBTOTAL		$2.50
PART COST, TOTAL (unit)		$30.42
PART COST, TOTAL (per robot)		$121.68

APPENDIX J

Horizontal System Theoretical Performance Charts

HORIZONTAL SYSTEM THEORETICAL PERFORMANCE CHARTS

Purpose of Charts:

The purpose of these charts is to enable the designer to estimate the performance of the UT Robot's horizontal positioning system.

How To Use These Charts :

Determine various aspects of the estimated dynamic performance for the horizontal positioning system.

Charts are provided for:

a) Required Motor Speed versus Reduction Ratio and Horizontal Linear Velocity;

b) Available (Horizontal) Driving Force (at the bearing cartridge) versus Reduction Ratio and Horizontal Linear Velocity;

c) Inertia Ratio (Load/Motor) versus Reduction Ratio and "Carry" Weight;

d) Inertia Ratio Indication Chart based on Motor Guidelines versus Reduction and "Carry" Weight;

e) Theoretical Maximum Acceleration for a Given Reduction Ratio versus Linear Velocity and "Carry Weight":

i) for a Reduction Ratio of 1:1
ii) for a Reduction Ratio of 2:1
iii) for a Reduction Ratio of 3:1

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

INERTIA RATIO (Jload / Jmotor) FOR GIVEN REDUCTION AND LOAD WEIGHT

"Base" Weight : 45 lb

REDUCTION RATIO	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.25	748.48	764.34	780.20	796.06	811.92	827.77	843.63	859.49	875.35	891.21	907.07	922.93	938.79	954.65	970.51	986.36
0.50	187.15	191.12	195.08	199.05	203.01	206.98	210.94	214.91	218.87	222.84	226.80	230.76	234.73	238.69	242.66	246.62
0.75	83.20	84.97	86.73	88.49	90.25	92.01	93.78	95.54	97.30	99.06	100.82	102.59	104.35	106.11	107.87	109.63
1.00	46.82	47.81	48.80	49.79	50.79	51.78	52.77	53.76	54.75	55.74	56.73	57.72	58.71	59.71	60.70	61.69
1.25	29.98	30.62	31.25	31.88	32.52	33.15	33.79	34.42	35.06	35.69	36.32	36.96	37.59	38.23	38.86	39.50
1.50	20.83	21.27	21.71	22.15	22.60	23.04	23.48	23.92	24.36	24.80	25.24	25.68	26.12	26.56	27.00	27.44
1.75	15.32	15.64	15.96	16.29	16.61	16.94	17.26	17.58	17.91	18.23	18.55	18.88	19.20	19.53	19.85	20.17
2.00	11.74	11.99	12.23	12.48	12.73	12.98	13.22	13.47	13.72	13.97	14.22	14.46	14.71	14.96	15.21	15.45
2.25	9.28	9.48	9.68	9.87	10.07	10.26	10.46	10.65	10.85	11.05	11.24	11.44	11.63	11.83	12.02	12.22
2.50	7.53	7.69	7.85	8.00	8.16	8.32	8.48	8.64	8.80	8.96	9.11	9.27	9.43	9.59	9.75	9.91
2.75	6.23	6.36	6.49	6.62	6.75	6.88	7.02	7.15	7.28	7.41	7.54	7.67	7.80	7.93	8.06	8.19
3.00	5.24	5.35	5.46	5.57	5.68	5.79	5.90	6.01	6.12	6.23	6.34	6.45	6.56	6.67	6.78	6.89
3.25	4.47	4.57	4.66	4.75	4.85	4.94	5.04	5.13	5.22	5.32	5.41	5.50	5.60	5.69	5.79	5.88
3.50	3.86	3.94	4.02	4.10	4.19	4.27	4.35	4.43	4.51	4.59	4.67	4.75	4.83	4.91	4.99	5.08
3.75	3.37	3.44	3.51	3.58	3.65	3.72	3.79	3.86	3.93	4.00	4.07	4.15	4.22	4.29	4.36	4.43
4.00	2.97	3.03	3.09	3.15	3.21	3.28	3.34	3.40	3.46	3.52	3.59	3.65	3.71	3.77	3.83	3.90

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

AVAILABLE DRIVING FORCE (lb at load point) FOR GIVEN REDUCTION AND SPEED

REDUCTION RATIO	Desired Linear Velocity (in/sec)															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.25	1.64	1.63	1.62	1.61	1.61	1.60	1.59	1.58	1.57	1.56	1.56	1.55	1.54	1.53	1.52	1.51
0.50	3.28	3.25	3.21	3.18	3.14	3.11	3.08	3.04	3.01	2.97	2.94	2.91	2.87	2.84	2.80	2.77
0.75	4.92	4.84	4.77	4.69	4.61	4.54	4.46	4.38	4.31	4.23	4.15	4.08	4.00	3.92	3.85	3.77
1.00	6.56	6.43	6.29	6.15	6.02	5.88	5.74	5.61	5.47	5.33	5.20	5.06	4.92	4.79	4.65	4.51
1.25	8.20	7.99	7.78	7.56	7.35	7.14	6.92	6.71	6.49	6.28	6.07	5.85	5.64	5.43	5.21	5.00
1.50	9.84	9.54	9.23	8.92	8.61	8.31	8.00	7.69	7.38	7.08	6.77	6.46	6.15	5.84	5.54	5.23
1.75	11.48	11.07	10.65	10.23	9.81	9.39	8.97	8.55	8.13	7.72	7.30	6.88	6.46	6.04	5.62	5.20
2.00	13.13	12.58	12.03	11.48	10.94	10.39	9.84	9.30	8.75	8.20	7.66	7.11	6.56	6.02	5.47	4.92
2.25	14.77	14.07	13.38	12.69	12.00	11.30	10.61	9.92	9.23	8.54	7.84	7.15	6.46	5.77	5.08	4.38
2.50	16.41	15.55	14.70	13.84	12.99	12.13	11.28	10.42	9.57	8.72	7.86	7.01	6.15	5.30	4.44	3.59
2.75	18.05	17.01	15.98	14.95	13.91	12.88	11.84	10.81	9.78	8.74	7.71	6.67	5.64	4.61	3.57	2.54
3.00	19.69	18.46	17.23	16.00	14.77	13.54	12.30	11.07	9.84	8.61	7.38	6.15	4.92	3.69	2.46	1.23
3.25	21.33	19.88	18.44	17.00	15.55	14.11	12.66	11.22	9.78	8.33	6.89	5.44	4.00	2.55	1.11	0.00
3.50	22.97	21.29	19.62	17.94	16.27	14.59	12.92	11.25	9.57	7.90	6.22	4.55	2.87	1.20	0.00	0.00
3.75	24.61	22.69	20.76	18.84	16.92	15.00	13.07	11.15	9.23	7.31	5.38	3.46	1.54	0.00	0.00	0.00
4.00	26.25	24.06	21.88	19.69	17.50	15.31	13.13	10.94	8.75	6.56	4.38	2.19	0.00	0.00	0.00	0.00

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

REQUIRED MOTOR SPEED (rev/sec) FOR GIVEN REDUCTION AND LINEAR VELOCITY

REDUCTION RATIO	Desired Linear Velocity (in/sec)															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.25	0.00	0.21	0.42	0.63	0.83	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13
0.50	0.00	0.42	0.83	1.25	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25
0.75	0.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75	9.38
1.00	0.00	0.83	1.67	2.50	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	10.00	10.83	11.67	12.50
1.25	0.00	1.04	2.08	3.13	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	12.50	13.54	14.58	15.63
1.50	0.00	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	15.00	16.25	17.50	18.75
1.75	0.00	1.46	2.92	4.38	5.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	17.50	18.96	20.42	21.88
2.00	0.00	1.67	3.33	5.00	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	20.00	21.67	23.33	25.00
2.25	0.00	1.88	3.75	5.63	7.50	9.38	11.25	13.13	15.00	16.88	18.75	20.63	22.50	24.38	26.25	28.13
2.50	0.00	2.08	4.17	6.25	8.33	10.42	12.50	14.58	16.67	18.75	20.83	22.92	25.00	27.08	29.17	31.25
2.75	0.00	2.29	4.58	6.88	9.17	11.46	13.75	16.04	18.33	20.63	22.92	25.21	27.50	29.79	32.08	34.38
3.00	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
3.25	0.00	2.71	5.42	8.13	10.83	13.54	16.25	18.96	21.67	24.38	27.08	29.79	32.50	35.21	37.92	NA
3.50	0.00	2.92	5.83	8.75	11.67	14.58	17.50	20.42	23.33	26.25	29.17	32.08	35.00	37.92	NA	NA
3.75	0.00	3.13	6.25	9.38	12.50	15.63	18.75	21.88	25.00	28.13	31.25	34.38	37.50	NA	NA	NA
4.00	0.00	3.33	6.67	10.00	13.33	16.67	20.00	23.33	26.67	30.00	33.33	36.67	40.00	NA	NA	NA

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

INERTIA RATIO (Jload / Jmotor) FOR GIVEN REDUCTION AND LOAD WEIGHT

Inertia Ratio Criteria: MIN = 0.10 - = Ratio too low
MAX = 10.00 + = Ratio too high

REDUCTION RATIO	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.25	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.75	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1.00	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1.25	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1.50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1.75	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.00	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.25	OK	OK	OK	OK	+	+	+	+	+	+	+	+	+	+	+	+
2.50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.75	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.00	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.25	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.75	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
4.00	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's) FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 45 lb
Reduction Ratio : 1 :1

"Carry" Weight (lb) = End Effector Weight + Load Weight

Linear Velocity (in/sec)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.00	0.28	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.22	0.22	0.22
2.50	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21
5.00	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.21	0.21
7.50	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.20
10.00	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.20
12.50	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19
15.00	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19
17.50	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.19
20.00	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18
22.50	0.23	0.23	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18
25.00	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17
27.50	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17
30.00	0.21	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.16
32.50	0.21	0.20	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16
35.00	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15
37.50	0.20	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's) FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 45 lb
Reduction Ratio : 2 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.00	0.53	0.52	0.51	0.51	0.50	0.49	0.48	0.47	0.46	0.46	0.45	0.44	0.43	0.43	0.42	0.41
2.50	0.51	0.50	0.49	0.48	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.42	0.41	0.40	0.40
5.00	0.49	0.48	0.47	0.46	0.45	0.45	0.44	0.43	0.42	0.42	0.41	0.40	0.40	0.39	0.39	0.38
7.50	0.47	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.40	0.40	0.39	0.39	0.38	0.37	0.37	0.36
10.00	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36	0.35	0.34
12.50	0.42	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33
15.00	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.32	0.32	0.31
17.50	0.38	0.37	0.36	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.29
20.00	0.36	0.35	0.34	0.34	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.28
22.50	0.33	0.33	0.32	0.32	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.28	0.27	0.27	0.26	0.26
25.00	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24
27.50	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22
30.00	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21
32.50	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19
35.00	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.17
37.50	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16

HORIZONTAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 15 (@ 0.2 pitch)
Desired Velocity Increment ..... 2.5 (in/sec)
Desired Weight Increment ..... 1 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's) FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 45 lb
Reduction Ratio : 3 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.00	0.73	0.72	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.58
2.50	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.55	0.54
5.00	0.64	0.63	0.61	0.60	0.59	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.53	0.52	0.51	0.50
7.50	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.53	0.52	0.51	0.50	0.50	0.49	0.48	0.47	0.47
10.00	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.49	0.48	0.47	0.46	0.46	0.45	0.44	0.44	0.43
12.50	0.50	0.49	0.48	0.48	0.47	0.46	0.45	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40	0.40
15.00	0.45	0.45	0.44	0.43	0.42	0.42	0.41	0.40	0.40	0.39	0.39	0.38	0.38	0.37	0.36	0.36
17.50	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.36	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.32
20.00	0.36	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.30	0.29	0.29
22.50	0.32	0.31	0.31	0.30	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.25
25.00	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22
27.50	0.23	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18
30.00	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.14
32.50	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11
35.00	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07
37.50	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

APPENDIX K

Vertical System Theoretical Performance Charts

VERTICAL SYSTEM THEORETICAL PERFORMANCE CHARTS

Purpose of Charts:

The purpose of these charts is to enable the designer to estimate the performance of the UT Robot's vertical positioning system.

How To Use These Charts :

Determine various aspects of the estimated dynamic performance for the vertical positioning system.

Charts are provided for:

a) Required Motor Speed versus Reduction Ratio and Vertical Linear Velocity;

b) Available (Vertical) Driving Force (at the payload, exclusive of gravity) versus Reduction Ratio and Vertical Linear Velocity;

c) Inertia Ratio (Load/Motor) versus Reduction Ratio and "Carry" Weight;

d) Inertia Ratio Indication Chart based on Motor Guidelines versus Reduction and "Carry" Weight;

e) Theoretical Maximum Acceleration (in the "UP" direction) for a given Reduction Ratio versus Linear Velocity and "Carry Weight":
   i) for a Reduction Ratio of 1:1
   ii) for a Reduction Ratio of 2:1
   iii) for a Reduction Ratio of 3:1

f) Theoretical Maximum Acceleration (in the "DOWN" direction) for a given Reduction Ratio versus Linear Velocity and "Carry Weight":
   i) for a Reduction Ratio of 1:1
   ii) for a Reduction Ratio of 2:1
   iii) for a Reduction Ratio of 3:1

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

REQUIRED MOTOR SPEED (rev/sec) FOR GIVEN REDUCTION AND LINEAR VELOCITY

REDUCTION RATIO	Desired Linear Velocity (in/sec)															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.25	0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75	1.88
0.50	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75
0.75	0.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75	4.13	4.50	4.88	5.25	5.63
1.00	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50
1.25	0.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75	9.38
1.50	0.00	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50	8.25	9.00	9.75	10.50	11.25
1.75	0.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75	9.63	10.50	11.38	12.25	13.13
2.00	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
2.25	0.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25	12.38	13.50	14.63	15.75	16.88
2.50	0.00	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	15.00	16.25	17.50	18.75
2.75	0.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75	15.13	16.50	17.88	19.25	20.63
3.00	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00	19.50	21.00	22.50
3.25	0.00	1.63	3.25	4.88	6.50	8.13	9.75	11.38	13.00	14.63	16.25	17.88	19.50	21.13	22.75	24.38
3.50	0.00	1.75	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.75	17.50	19.25	21.00	22.75	24.50	26.25
3.75	0.00	1.88	3.75	5.63	7.50	9.38	11.25	13.13	15.00	16.88	18.75	20.63	22.50	24.38	26.25	28.13
4.00	0.00	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

AVAILABLE DRIVING FORCE (lb at load point) FOR GIVEN REDUCTION AND SPEED

REDUCTION RATIO	Desired Linear Velocity (in/sec)															
	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
0.25	1.64	1.64	1.63	1.63	1.62	1.61	1.61	1.60	1.60	1.59	1.59	1.58	1.58	1.57	1.57	1.56
0.50	3.28	3.26	3.24	3.22	3.20	3.18	3.16	3.14	3.12	3.10	3.08	3.06	3.04	3.01	2.99	2.97
0.75	4.92	4.88	4.83	4.78	4.74	4.69	4.65	4.60	4.55	4.51	4.46	4.41	4.37	4.32	4.28	4.23
1.00	6.56	6.48	6.40	6.32	6.23	6.15	6.07	5.99	5.91	5.82	5.74	5.66	5.58	5.50	5.41	5.33
1.25	8.20	8.07	7.95	7.82	7.69	7.56	7.43	7.31	7.18	7.05	6.92	6.79	6.67	6.54	6.41	6.28
1.50	9.84	9.66	9.47	9.29	9.11	8.92	8.74	8.55	8.37	8.18	8.00	7.81	7.63	7.44	7.26	7.08
1.75	11.48	11.23	10.98	10.73	10.48	10.23	9.98	9.73	9.47	9.22	8.97	8.72	8.47	8.22	7.97	7.72
2.00	13.13	12.80	12.47	12.14	11.81	11.48	11.16	10.83	10.50	10.17	9.84	9.52	9.19	8.86	8.53	8.20
2.25	14.77	14.35	13.94	13.52	13.10	12.69	12.27	11.86	11.44	11.03	10.61	10.20	9.78	9.37	8.95	8.54
2.50	16.41	15.89	15.38	14.87	14.36	13.84	13.33	12.82	12.30	11.79	11.28	10.77	10.25	9.74	9.23	8.72
2.75	18.05	17.43	16.81	16.19	15.57	14.95	14.32	13.70	13.08	12.46	11.84	11.22	10.60	9.98	9.36	8.74
3.00	19.69	18.95	18.21	17.47	16.73	16.00	15.26	14.52	13.78	13.04	12.30	11.57	10.83	10.09	9.35	8.61
3.25	21.33	20.46	19.60	18.73	17.86	17.00	16.13	15.26	14.40	13.53	12.66	11.80	10.93	10.06	9.20	8.33
3.50	22.97	21.96	20.96	19.95	18.95	17.94	16.94	15.93	14.93	13.92	12.92	11.92	10.91	9.91	8.90	7.90
3.75	24.61	23.46	22.30	21.15	20.00	18.84	17.69	16.53	15.38	14.23	13.07	11.92	10.77	9.61	8.46	7.31
4.00	26.25	24.94	23.63	22.31	21.00	19.69	18.38	17.06	15.75	14.44	13.13	11.81	10.50	9.19	7.88	6.56

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

INERTIA RATIO (Jload / Jmotor) FOR GIVEN REDUCTION AND LOAD WEIGHT

"Base" Weight : 9.5 lb

REDUCTION RATIO	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.25	101.79	119.41	137.03	154.65	172.27	189.89	207.51	225.13	242.75	260.38	278.00	295.62	313.24	330.86	348.48	366.10
0.50	25.48	29.88	34.29	38.69	43.10	47.51	51.91	56.32	60.72	65.13	69.53	73.94	78.34	82.75	87.15	91.56
0.75	11.35	13.31	15.26	17.22	19.18	21.14	23.10	25.05	27.01	28.97	30.93	32.89	34.84	36.80	38.76	40.72
1.00	6.40	7.50	8.61	9.71	10.81	11.91	13.01	14.11	15.21	16.31	17.42	18.52	19.62	20.72	21.82	22.92
1.25	4.11	4.82	5.52	6.23	6.93	7.64	8.34	9.05	9.75	10.46	11.16	11.87	12.57	13.28	13.98	14.69
1.50	2.87	3.36	3.85	4.34	4.82	5.32	5.81	6.30	6.79	7.27	7.76	8.25	8.74	9.23	9.72	10.21
1.75	2.12	2.48	2.84	3.20	3.56	3.92	4.28	4.64	5.00	5.36	5.72	6.08	6.44	6.79	7.15	7.51
2.00	1.63	1.91	2.18	2.46	2.73	3.01	3.29	3.56	3.84	4.11	4.39	4.66	4.94	5.21	5.49	5.76
2.25	1.30	1.52	1.73	1.95	2.17	2.39	2.60	2.82	3.04	3.26	3.48	3.69	3.91	4.13	4.35	4.56
2.50	1.06	1.24	1.41	1.59	1.77	1.94	2.12	2.29	2.47	2.65	2.82	3.00	3.18	3.35	3.53	3.70
2.75	0.88	1.03	1.18	1.32	1.47	1.61	1.76	1.90	2.05	2.19	2.34	2.49	2.63	2.78	2.92	3.07
3.00	0.75	0.87	0.99	1.12	1.24	1.36	1.48	1.61	1.73	1.85	1.97	2.10	2.22	2.34	2.46	2.59
3.25	0.65	0.75	0.85	0.96	1.06	1.17	1.27	1.38	1.48	1.58	1.69	1.79	1.90	2.00	2.11	2.21
3.50	0.56	0.65	0.74	0.83	0.92	1.01	1.10	1.19	1.28	1.37	1.46	1.55	1.64	1.73	1.82	1.91
3.75	0.50	0.57	0.65	0.73	0.81	0.89	0.97	1.04	1.12	1.20	1.28	1.36	1.44	1.51	1.59	1.67
4.00	0.44	0.51	0.58	0.65	0.72	0.79	0.85	0.92	0.99	1.06	1.13	1.20	1.27	1.34	1.40	1.47

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

INERTIA RATIO (Jload / Jmotor) FOR GIVEN REDUCTION AND LOAD WEIGHT

Inertia Ratio Criteria: MIN = 0.10 - = Ratio too low
MAX = 10.00 + = Ratio too high

"Carry" Weight (lb) = End Effector Weight + Load Weight

REDUCTION RATIO	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.25	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.50	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.75	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1.00	OK	OK	OK	OK	+	+	+	+	+	+	+	+	+	+	+	+
1.25	OK	OK	OK	OK	OK	OK	OK	OK	OK	+	+	+	+	+	+	+
1.50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	+
1.75	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.00	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.25	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.75	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.00	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.25	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.50	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
3.75	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
4.00	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "UP") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 1 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	0.66	0.44	0.28	0.15	0.04	-0.05	-0.12	-0.19	-0.24	-0.29	-0.33	-0.37	-0.40	-0.43	-0.46	-0.48
1.00	0.64	0.43	0.27	0.14	0.03	-0.06	-0.13	-0.19	-0.25	-0.30	-0.34	-0.37	-0.41	-0.44	-0.47	-0.49
2.00	0.63	0.42	0.26	0.13	0.02	-0.06	-0.14	-0.20	-0.25	-0.30	-0.34	-0.38	-0.41	-0.44	-0.47	-0.49
3.00	0.61	0.40	0.24	0.12	0.01	-0.07	-0.15	-0.21	-0.26	-0.31	-0.35	-0.39	-0.42	-0.45	-0.48	-0.50
4.00	0.60	0.39	0.23	0.11	0.00	-0.08	-0.15	-0.22	-0.27	-0.32	-0.36	-0.39	-0.42	-0.45	-0.48	-0.50
5.00	0.58	0.38	0.22	0.10	-0.01	-0.09	-0.16	-0.22	-0.28	-0.32	-0.36	-0.40	-0.43	-0.46	-0.49	-0.51
6.00	0.57	0.36	0.21	0.08	-0.02	-0.10	-0.17	-0.23	-0.28	-0.33	-0.37	-0.40	-0.44	-0.46	-0.49	-0.51
7.00	0.55	0.35	0.20	0.07	-0.03	-0.11	-0.18	-0.24	-0.29	-0.33	-0.37	-0.41	-0.44	-0.47	-0.49	-0.52
8.00	0.54	0.34	0.19	0.06	-0.04	-0.12	-0.19	-0.25	-0.30	-0.34	-0.38	-0.42	-0.45	-0.47	-0.50	-0.52
9.00	0.52	0.32	0.17	0.05	-0.04	-0.13	-0.19	-0.25	-0.30	-0.35	-0.39	-0.42	-0.45	-0.48	-0.50	-0.53
10.00	0.51	0.31	0.16	0.04	-0.05	-0.13	-0.20	-0.26	-0.31	-0.35	-0.39	-0.43	-0.46	-0.49	-0.51	-0.53
11.00	0.49	0.30	0.15	0.03	-0.06	-0.14	-0.21	-0.27	-0.32	-0.36	-0.40	-0.43	-0.46	-0.49	-0.51	-0.54
12.00	0.47	0.28	0.14	0.02	-0.07	-0.15	-0.22	-0.28	-0.32	-0.37	-0.41	-0.44	-0.47	-0.50	-0.52	-0.54
13.00	0.46	0.27	0.13	0.01	-0.08	-0.16	-0.23	-0.28	-0.33	-0.37	-0.41	-0.44	-0.47	-0.50	-0.52	-0.55
14.00	0.44	0.26	0.11	0.00	-0.09	-0.17	-0.23	-0.29	-0.34	-0.38	-0.42	-0.45	-0.48	-0.51	-0.53	-0.55
15.00	0.43	0.24	0.10	-0.01	-0.10	-0.18	-0.24	-0.30	-0.35	-0.39	-0.42	-0.46	-0.49	-0.51	-0.53	-0.56

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "UP") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 2 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	1.32	1.10	0.92	0.77	0.64	0.53	0.43	0.34	0.27	0.20	0.14	0.08	0.03	-0.01	-0.06	-0.09
1.00	1.28	1.06	0.89	0.74	0.61	0.50	0.40	0.32	0.24	0.18	0.12	0.06	0.01	-0.03	-0.07	-0.11
2.00	1.24	1.02	0.85	0.70	0.58	0.47	0.38	0.29	0.22	0.15	0.10	0.04	-0.01	-0.05	-0.09	-0.13
3.00	1.19	0.99	0.81	0.67	0.55	0.44	0.35	0.27	0.20	0.13	0.07	0.02	-0.03	-0.07	-0.11	-0.14
4.00	1.15	0.95	0.78	0.64	0.52	0.41	0.32	0.24	0.17	0.11	0.05	0.00	-0.04	-0.09	-0.13	-0.16
5.00	1.11	0.91	0.74	0.61	0.49	0.39	0.30	0.22	0.15	0.09	0.03	-0.02	-0.06	-0.10	-0.14	-0.18
6.00	1.06	0.87	0.71	0.57	0.46	0.36	0.27	0.19	0.13	0.07	0.01	-0.04	-0.08	-0.12	-0.16	-0.19
7.00	1.02	0.83	0.67	0.54	0.43	0.33	0.24	0.17	0.10	0.04	-0.01	-0.06	-0.10	-0.14	-0.18	-0.21
8.00	0.98	0.79	0.64	0.51	0.40	0.30	0.22	0.14	0.08	0.02	-0.03	-0.08	-0.12	-0.16	-0.20	-0.23
9.00	0.94	0.75	0.60	0.47	0.37	0.27	0.19	0.12	0.06	-0.00	-0.05	-0.10	-0.14	-0.18	-0.21	-0.24
10.00	0.89	0.71	0.57	0.44	0.34	0.24	0.16	0.09	0.03	-0.02	-0.07	-0.12	-0.16	-0.20	-0.23	-0.26
11.00	0.85	0.67	0.53	0.41	0.31	0.22	0.14	0.07	0.01	-0.05	-0.09	-0.14	-0.18	-0.21	-0.25	-0.28
12.00	0.81	0.64	0.50	0.38	0.28	0.19	0.11	0.04	-0.01	-0.07	-0.12	-0.16	-0.20	-0.23	-0.26	-0.29
13.00	0.76	0.60	0.46	0.34	0.25	0.16	0.09	0.02	-0.04	-0.09	-0.14	-0.18	-0.22	-0.25	-0.28	-0.31
14.00	0.72	0.56	0.42	0.31	0.21	0.13	0.06	-0.00	-0.06	-0.11	-0.16	-0.20	-0.24	-0.27	-0.30	-0.33
15.00	0.68	0.52	0.39	0.28	0.18	0.10	0.03	-0.03	-0.08	-0.13	-0.18	-0.22	-0.25	-0.29	-0.32	-0.35

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "UP") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 3 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	1.46	1.30	1.16	1.03	0.92	0.82	0.73	0.65	0.58	0.51	0.45	0.39	0.34	0.29	0.24	0.20
1.00	1.40	1.24	1.10	0.98	0.87	0.78	0.69	0.61	0.54	0.47	0.41	0.36	0.30	0.26	0.21	0.17
2.00	1.33	1.18	1.05	0.93	0.82	0.73	0.64	0.57	0.50	0.43	0.37	0.32	0.27	0.22	0.18	0.14
3.00	1.27	1.12	0.99	0.87	0.77	0.68	0.60	0.52	0.45	0.39	0.34	0.28	0.23	0.19	0.15	0.11
4.00	1.20	1.06	0.93	0.82	0.72	0.63	0.55	0.48	0.41	0.35	0.30	0.25	0.20	0.15	0.11	0.08
5.00	1.14	1.00	0.88	0.77	0.67	0.58	0.51	0.44	0.37	0.31	0.26	0.21	0.16	0.12	0.08	0.04
6.00	1.07	0.94	0.82	0.71	0.62	0.54	0.46	0.39	0.33	0.27	0.22	0.17	0.13	0.09	0.05	0.01
7.00	1.01	0.88	0.76	0.66	0.57	0.49	0.42	0.35	0.29	0.23	0.18	0.14	0.09	0.05	0.02	-0.02
8.00	0.94	0.82	0.70	0.61	0.52	0.44	0.37	0.31	0.25	0.19	0.14	0.10	0.06	0.02	-0.02	-0.05
9.00	0.88	0.76	0.65	0.55	0.47	0.39	0.32	0.26	0.21	0.15	0.11	0.06	0.02	-0.01	-0.05	-0.08
10.00	0.81	0.69	0.59	0.50	0.42	0.34	0.28	0.22	0.16	0.11	0.07	0.03	-0.01	-0.05	-0.08	-0.11
11.00	0.75	0.63	0.53	0.45	0.37	0.30	0.23	0.17	0.12	0.07	0.03	-0.01	-0.05	-0.08	-0.12	-0.15
12.00	0.68	0.57	0.48	0.39	0.32	0.25	0.19	0.13	0.08	0.03	-0.01	-0.05	-0.08	-0.12	-0.15	-0.18
13.00	0.62	0.51	0.42	0.34	0.27	0.20	0.14	0.09	0.04	-0.01	-0.05	-0.08	-0.12	-0.15	-0.18	-0.21
14.00	0.55	0.45	0.36	0.29	0.22	0.15	0.10	0.04	-0.00	-0.04	-0.08	-0.12	-0.15	-0.18	-0.21	-0.24
15.00	0.49	0.39	0.31	0.23	0.16	0.10	0.05	0.00	-0.04	-0.08	-0.12	-0.16	-0.19	-0.22	-0.25	-0.27

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "DOWN") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 8 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	1.78	1.68	1.60	1.54	1.49	1.45	1.41	1.38	1.36	1.34	1.32	1.30	1.28	1.27	1.25	1.24
1.00	1.77	1.67	1.59	1.53	1.48	1.44	1.41	1.38	1.35	1.33	1.31	1.29	1.28	1.26	1.25	1.24
2.00	1.75	1.65	1.58	1.52	1.47	1.43	1.40	1.37	1.34	1.32	1.30	1.29	1.27	1.26	1.24	1.23
3.00	1.74	1.64	1.57	1.51	1.46	1.42	1.39	1.36	1.34	1.32	1.30	1.28	1.27	1.25	1.24	1.23
4.00	1.72	1.63	1.56	1.50	1.45	1.41	1.38	1.35	1.33	1.31	1.29	1.27	1.26	1.25	1.23	1.22
5.00	1.71	1.61	1.54	1.49	1.44	1.41	1.37	1.35	1.32	1.30	1.28	1.27	1.25	1.24	1.23	1.22
6.00	1.69	1.60	1.53	1.48	1.43	1.40	1.37	1.34	1.32	1.30	1.28	1.26	1.25	1.24	1.22	1.21
7.00	1.68	1.59	1.52	1.47	1.42	1.39	1.36	1.33	1.31	1.29	1.27	1.26	1.24	1.23	1.22	1.21
8.00	1.66	1.58	1.51	1.46	1.41	1.38	1.35	1.32	1.30	1.28	1.27	1.25	1.24	1.23	1.21	1.21
9.00	1.64	1.56	1.50	1.45	1.41	1.37	1.34	1.32	1.30	1.28	1.26	1.25	1.23	1.22	1.21	1.20
10.00	1.63	1.55	1.49	1.44	1.40	1.36	1.33	1.31	1.29	1.27	1.25	1.24	1.23	1.22	1.21	1.20
11.00	1.61	1.54	1.47	1.43	1.39	1.35	1.33	1.30	1.28	1.26	1.25	1.23	1.22	1.21	1.20	1.19
12.00	1.60	1.52	1.46	1.41	1.38	1.34	1.32	1.29	1.27	1.26	1.24	1.23	1.22	1.20	1.20	1.19
13.00	1.58	1.51	1.45	1.40	1.37	1.34	1.31	1.29	1.27	1.25	1.24	1.22	1.21	1.20	1.19	1.18
14.00	1.57	1.50	1.44	1.39	1.36	1.33	1.30	1.28	1.26	1.24	1.23	1.22	1.20	1.19	1.19	1.18
15.00	1.55	1.48	1.43	1.38	1.35	1.32	1.29	1.27	1.25	1.24	1.22	1.21	1.20	1.19	1.18	1.17

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "DOWN") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 2 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	1.99	1.93	1.87	1.82	1.77	1.73	1.70	1.67	1.64	1.61	1.58	1.56	1.54	1.52	1.50	1.48
1.00	1.93	1.86	1.81	1.77	1.72	1.69	1.65	1.62	1.59	1.57	1.55	1.52	1.50	1.49	1.47	1.45
2.00	1.86	1.80	1.76	1.71	1.67	1.64	1.61	1.58	1.55	1.53	1.51	1.49	1.47	1.45	1.44	1.42
3.00	1.80	1.74	1.70	1.66	1.62	1.59	1.56	1.53	1.51	1.49	1.47	1.45	1.43	1.42	1.40	1.39
4.00	1.73	1.68	1.64	1.60	1.57	1.54	1.52	1.49	1.47	1.45	1.43	1.41	1.40	1.38	1.37	1.36
5.00	1.67	1.62	1.58	1.55	1.52	1.49	1.47	1.45	1.43	1.41	1.39	1.38	1.36	1.35	1.34	1.33
6.00	1.60	1.56	1.53	1.50	1.47	1.45	1.42	1.40	1.39	1.37	1.35	1.34	1.33	1.32	1.30	1.29
7.00	1.54	1.50	1.47	1.44	1.42	1.40	1.38	1.36	1.34	1.33	1.32	1.30	1.29	1.28	1.27	1.26
8.00	1.47	1.44	1.41	1.39	1.37	1.35	1.33	1.32	1.30	1.29	1.28	1.27	1.26	1.25	1.24	1.23
9.00	1.41	1.38	1.36	1.34	1.32	1.30	1.29	1.27	1.26	1.25	1.24	1.23	1.22	1.21	1.21	1.20
10.00	1.34	1.32	1.30	1.28	1.27	1.25	1.24	1.23	1.22	1.21	1.20	1.19	1.19	1.18	1.17	1.17
11.00	1.28	1.26	1.24	1.23	1.22	1.21	1.20	1.19	1.18	1.17	1.16	1.16	1.15	1.15	1.14	1.14
12.00	1.21	1.20	1.19	1.18	1.17	1.16	1.15	1.14	1.14	1.13	1.13	1.12	1.12	1.11	1.11	1.10
13.00	1.15	1.14	1.13	1.12	1.12	1.11	1.10	1.10	1.10	1.09	1.09	1.08	1.08	1.08	1.08	1.07
14.00	1.08	1.08	1.07	1.07	1.07	1.06	1.06	1.06	1.05	1.05	1.05	1.05	1.05	1.04	1.04	1.04
15.00	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01

VERTICAL SYSTEM MOTOR-LOAD-SPEED-INERTIA DATA

Motor Capability: (assumed linear)
Tstatic = 105 in*oz
Max Speed= 40 RPS
Jmotor = 0.23 lb*in^2

Number of Teeth, Drive Pulley ..... 10 (@ 0.2 pitch)
Desired Velocity Increment ..... 1 (in/sec)
Desired Weight Increment ..... 2.5 (lb)

THEORETICAL MAXIMUM ACCELERATION (g's - "DOWN") FOR SPECIFIED REDUCTION RATIO

"Base" Weight : 9.5 lb
Reduction Ratio : 3 :1

Linear Velocity (in/sec)	"Carry" Weight (lb) = End Effector Weight + Load Weight															
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50
0.00	2.11	2.01	1.92	1.85	1.79	1.73	1.69	1.64	1.61	1.57	1.55	1.52	1.49	1.47	1.45	1.43
1.00	2.07	1.97	1.89	1.82	1.76	1.70	1.66	1.62	1.58	1.55	1.52	1.50	1.48	1.45	1.44	1.42
2.00	2.03	1.93	1.85	1.78	1.73	1.68	1.63	1.59	1.56	1.53	1.50	1.48	1.46	1.44	1.42	1.40
3.00	1.98	1.89	1.81	1.75	1.69	1.65	1.61	1.57	1.54	1.51	1.48	1.46	1.44	1.42	1.40	1.38
4.00	1.94	1.85	1.78	1.72	1.66	1.62	1.58	1.54	1.51	1.49	1.46	1.44	1.42	1.40	1.38	1.37
5.00	1.90	1.81	1.74	1.68	1.63	1.59	1.55	1.52	1.49	1.46	1.44	1.42	1.40	1.38	1.37	1.35
6.00	1.86	1.77	1.71	1.65	1.60	1.56	1.53	1.49	1.47	1.44	1.42	1.40	1.38	1.36	1.35	1.33
7.00	1.81	1.74	1.67	1.62	1.57	1.53	1.50	1.47	1.44	1.42	1.40	1.38	1.36	1.35	1.33	1.32
8.00	1.77	1.70	1.64	1.59	1.54	1.51	1.47	1.45	1.42	1.40	1.38	1.36	1.34	1.33	1.31	1.30
9.00	1.73	1.66	1.60	1.55	1.51	1.48	1.45	1.42	1.40	1.38	1.36	1.34	1.32	1.31	1.30	1.28
10.00	1.68	1.62	1.57	1.52	1.48	1.45	1.42	1.40	1.37	1.35	1.33	1.32	1.30	1.29	1.28	1.27
11.00	1.64	1.58	1.53	1.49	1.45	1.42	1.39	1.37	1.35	1.33	1.31	1.30	1.28	1.27	1.26	1.25
12.00	1.60	1.54	1.49	1.46	1.42	1.39	1.37	1.35	1.33	1.31	1.29	1.28	1.27	1.25	1.24	1.23
13.00	1.55	1.50	1.46	1.42	1.39	1.36	1.34	1.32	1.30	1.29	1.27	1.26	1.25	1.24	1.23	1.22
14.00	1.51	1.46	1.42	1.39	1.36	1.34	1.32	1.30	1.28	1.26	1.25	1.24	1.23	1.22	1.21	1.20
15.00	1.47	1.42	1.39	1.36	1.33	1.31	1.29	1.27	1.26	1.24	1.23	1.22	1.21	1.20	1.19	1.18

APPENDIX L

Linear Bearing and Shaft Ordering Cost Charts

LINEAR BEARING AND SHAFT ORDERING COST CHARTS

Purpose of Charts :

The purpose of these charts is to help the designer order the proper number (and amount) of linear bearings and shafting, and to estimate the purchase cost for these items.

How To Use These Charts :

To determine the estimated cost and order quantity (categories) for linear bearings, shafting and seals to build a production UT Robot:

1) Locate the sheet corresponding to the desired robot size ("travel") configuration. The travel specifications are located near the top of the sheet.

2) The required shaft lengths are presented directly below the travel data.

3) The quantity and costs to purchase the required parts are listed:

   a) Series "A" bearing: used in sliders and bearing cartridge;

   b) "Super-16" bearing: used in the Z platform;

   c) Bearing Seals: used at all bearing locations;

   d) "Locking" screws: Model BGS-4 adjustment screw, used with the "Super" bearing;

   e) Shafting order total (in): total length of guide and control shafts. Used to compute cost. HINT: order shafts cut to desired lengths.

   f) Tube: used as the Z guide tube;

   g) Set-up charges, volume discount: per vendor cost schedule;

   h) Order total cost.

UT ROBOT - SHAFTING,LINEAR BEARING CALCULATIONS AND ORDER SHEET

04/24/91

ROBOT TRAVEL PARAMETERS :

NUMBER ROBOTS REQUIRED : 1

X and Y SHAFT DIAMETER : 0.75 in

X DIRECTION TRAVEL : 24.00 in
Y DIRECTION TRAVEL : 24.00 in
Z DIRECTION TRAVEL : 12.00 in

SHAFTING INFORMATION (find from dimensional data) :

X GUIDE SHAFT LENGTH : 30.25 in
Y "MIDDLE" SHAFT LENGTH : 33.75 in

Y GUIDE SHAFT LENGTH : 30.25 in
X "MIDDLE" SHAFT LENGTH : 33.75 in

Z TUBE LENGTH : 19.00 in

REQUIRED PARTS ORDER AND COSTS :

THOMSON P/N	PART / MATERIAL	#/ROBOT	# REQ'D	$ / UNIT	$ TOTAL
A-122026	Series "A" Brg	8	8	$16.43	$131.44
SUPER-16	"Super-16" Bearing	2	2	$26.45	$52.90
S-750	Bearing Seal	14	14	$2.89	$40.46
BGS-4	"Locking" Screws	2	2	$3.25	$6.50
			Component SUBTOTAL..		$231.30
	Case 60 Shaft	188.50	188.50	$0.53	$99.91
	Case 60 BG Tube	19.00	19.00	$2.48	$47.07
	Set-Up Chrg, Shaft				$20.00
	Set-Up Chrg, Tube				$20.00
	SHAFTING VOLUME DISCOUNT....				$0.00
			Shafting SUBTOTAL...		$186.98
	ORDER TOTAL				$418.28

UT ROBOT - SHAFTING,LINEAR BEARING CALCULATIONS AND ORDER SHEET

04/24/91

ROBOT TRAVEL PARAMETERS :

NUMBER ROBOTS REQUIRED : 1

X and Y SHAFT DIAMETER : 1.00 in

X DIRECTION TRAVEL : 24.00 in
Y DIRECTION TRAVEL : 24.00 in
Z DIRECTION TRAVEL : 12.00 in

SHAFTING INFORMATION (find from dimensional data) :

X GUIDE SHAFT LENGTH : 32.00 in
Y "MIDDLE" SHAFT LENGTH : 35.50 in

Y GUIDE SHAFT LENGTH : 32.00 in
X "MIDDLE" SHAFT LENGTH : 35.50 in

Z TUBE LENGTH : 19.00 in

REQUIRED PARTS ORDER AND COSTS :

THOMSON P/N	PART / MATERIAL	#/ROBOT	# REQ'D	$ / UNIT	$ TOTAL
A-162536	Series "A" Brg	8	8	$29.30	$234.40
SUPER-16	"Super-16" Bearing	2	2	$26.45	$52.90
S-1000	Bearing Seal	14	14	$3.63	$50.82
BGS-4	"Locking" Screws	2	2	$3.25	$6.50
			Component SUBTOTAL..		$344.62
	Case 60 Shaft	199.00	199.00	$0.73	$145.27
	Case 60 BG Tube	19.00	19.00	$2.48	$47.07
	Set-Up Chrg, Shaft				$20.00
	Set-Up Chrg, Tube				$20.00
	SHAFTING VOLUME DISCOUNT....				$0.00
			Shafting SUBTOTAL...		$232.34
	ORDER TOTAL				$576.96

UT ROBOT - SHAFTING,LINEAR BEARING CALCULATIONS AND ORDER SHEET

04/24/91

ROBOT TRAVEL PARAMETERS :

NUMBER ROBOTS REQUIRED : 1

X and Y SHAFT DIAMETER : 1.00 in

X DIRECTION TRAVEL : 36.00 in
Y DIRECTION TRAVEL : 36.00 in
Z DIRECTION TRAVEL : 18.00 in

SHAFTING INFORMATION (find from dimensional data) :

X GUIDE SHAFT LENGTH : 44.00 in
Y "MIDDLE" SHAFT LENGTH : 47.50 in

Y GUIDE SHAFT LENGTH : 44.00 in
X "MIDDLE" SHAFT LENGTH : 47.50 in

Z TUBE LENGTH : 25.00 in

REQUIRED PARTS ORDER AND COSTS :

THOMSON P/N	PART / MATERIAL	#/ROBOT	# REQ'D	$ / UNIT	$ TOTAL
A-162536	Series "A" Brg	8	8	$29.30	$234.40
SUPER-16	"Super-16" Bearing	2	2	$26.45	$52.90
S-1000	Bearing Seal	14	14	$3.63	$50.82
BGS-4	"Locking" Screws	2	2	$3.25	$6.50
			Component SUBTOTAL..		$344.62
	Case 60 Shaft	271.00	271.00	$0.73	$197.83
	Case 60 BG Tube	25.00	25.00	$2.48	$61.93
	Set-Up Chrg, Shaft				$20.00
	Set-Up Chrg, Tube				$20.00
	SHAFTING VOLUME DISCOUNT....				($14.99)
			Shafting SUBTOTAL...		$284.78
	ORDER TOTAL				$629.40

UT ROBOT - SHAFTING,LINEAR BEARING CALCULATIONS AND ORDER SHEET

04/24/91

ROBOT TRAVEL PARAMETERS :

NUMBER ROBOTS REQUIRED : 1

X and Y SHAFT DIAMETER : 1.00 in

X DIRECTION TRAVEL : 42.00 in
Y DIRECTION TRAVEL : 42.00 in
Z DIRECTION TRAVEL : 24.00 in

SHAFTING INFORMATION (find from dimensional data) :

X GUIDE SHAFT LENGTH : 50.00 in
Y "MIDDLE" SHAFT LENGTH : 53.50 in

Y GUIDE SHAFT LENGTH : 50.00 in
X "MIDDLE" SHAFT LENGTH : 53.50 in

Z TUBE LENGTH : 31.00 in

REQUIRED PARTS ORDER AND COSTS :

THOMSON P/N	PART / MATERIAL	#/ROBOT	# REQ'D	$ / UNIT	$ TOTAL
A-162536	Series "A" Brg	8	8	$29.30	$234.40
SUPER-16	"Super-16" Bearing	2	2	$26.45	$52.90
S-1000	Bearing Seal	14	14	$3.63	$50.82
BGS-4	"Locking" Screws	2	2	$3.25	$6.50
			Component SUBTOTAL..		$344.62
	Case 60 Shaft	307.00	307.00	$0.73	$224.11
	Case 60 BG Tube	31.00	31.00	$2.48	$76.80
	Set-Up Chrg, Shaft				$20.00
	Set-Up Chrg, Tube				$20.00
	SHAFTING VOLUME DISCOUNT....				($17.05)
			Shafting SUBTOTAL...		$323.86
	ORDER TOTAL				$668.48

UT ROBOT - SHAFTING,LINEAR BEARING CALCULATIONS AND ORDER SHEET

04/24/91

ROBOT TRAVEL PARAMETERS :

NUMBER ROBOTS REQUIRED : 1

X and Y SHAFT DIAMETER : 1.25 in

X DIRECTION TRAVEL : 42.00 in
Y DIRECTION TRAVEL : 42.00 in
Z DIRECTION TRAVEL : 24.00 in

SHAFTING INFORMATION (find from dimensional data) :

X GUIDE SHAFT LENGTH : 51.25 in
Y "MIDDLE" SHAFT LENGTH : 54.75 in

Y GUIDE SHAFT LENGTH : 51.25 in
X "MIDDLE" SHAFT LENGTH : 54.75 in

Z TUBE LENGTH : 31.00 in

REQUIRED PARTS ORDER AND COSTS :

THOMSON P/N	PART / MATERIAL	#/ROBOT	# REQ'D	$ / UNIT	$ TOTAL
A-203242	Series "A" Brg	8	8	$50.02	$400.16
SUPER-16	"Super-16" Bearing	2	2	$26.45	$52.90
S-1250	Bearing Seal	14	14	$6.26	$87.64
BGS-4	"Locking" Screws	2	2	$3.25	$6.50
			Component SUBTOTAL..		$547.20
	Case 60 Shaft	314.50	314.50	$0.94	$295.63
	Case 60 BG Tube	31.00	31.00	$2.48	$76.80
	Set-Up Chrg, Shaft				$20.00
	Set-Up Chrg, Tube				$20.00
	SHAFTING VOLUME DISCOUNT....				($20.62)
			Shafting SUBTOTAL...		$391.81
	ORDER TOTAL				$939.01

APPENDIX M

UT Robot Parts Assembly Listing

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
FRAME ASSEMBLY - ASY300-XXX,YYY,ZZZ						
2	MEK301-XXX	Member, Horiz., X Top	UT M/S	---	ASY300-RRR	5
2	MEK302-YYY	Member, Horiz., Y Top	UT M/S	---	ASY300-RRR	5
2	MEK303-XXX	Member, Horiz., X Bottom	UT M/S	---	ASY300-RRR	5
2	MEK304-YYY	Member, Horiz., Y Bottom	UT M/S	---	ASY300-RRR	5
4	MEK306-ZZZ	Frame Member, Vertical ("Z")	UT M/S	---	ASY300-RRR	5
32	VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581	ASY300-RRR	5
32	VEN487	Washer, Flat, for 0.312 ID	McMASTER-CARR	98019A185	ASY300-RRR	5
ROBOT COMPLETE ASSEMBLY - ASY501-XXX,YYY,ZZZ,DDD						
1	ASY506-RRR	Assembly, Robot Mechanical	UT ASS'Y	---	ASY501-ZZZ	1
1	ASY601	Assembly, Robot Electrical	UT ASS'Y	---	ASY501-ZZZ	1
ROBOT MECHANICAL ASSEMBLY - ASY506-XXX,YYY,ZZZ,DDD						
1	ASY511-RRR	Assembly, XY Drive	UT ASS'Y	---	ASY506-RRR	2
1	ASY581-ZZZ	Assembly, Z Drive	UT ASS'Y	---	ASY506-RRR	2
3	VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581	ASY506-RRR	2
3	VEN487	Washer, Flat, for 0.312 ID	McMASTER-CARR	98019A185	ASY506-RRR	2
1	KIT631	Kit, Wiring Mechanical Support	UT ASS'Y	---	ASY506-RRR	2
X-Y DRIVE ASSEMBLY - ASY511-XXX,YYY,DDD						
1	ASY516-RRR	Assembly, XY Motion	UT ASS'Y	---	ASY511-RRR	3
2	ASY531	Assembly, XY Motor (LH)	UT ASS'Y	---	ASY511-RRR	3
2	ASY532	Assembly, XY Motor (RH)	UT ASS'Y	---	ASY511-RRR	3
1	KIT611-XXX	Kit, X Reduction Drive	UT ASS'Y	---	ASY511-RRR	3
1	KIT611-YYY	Kit, Y Reduction Drive	UT ASS'Y	---	ASY511-RRR	3
2	VEN843-XXX	Belt, Timing, for X Drive	STOCK DRIVE	6R3-C037	ASY511-RRR	3
2	VEN843-YYY	Belt, Timing, for Y Drive	STOCK DRIVE	6R3-C037	ASY511-RRR	3
4	ASY540	Assembly, Belt Attachment	UT ASS'Y	---	ASY511-RRR	3

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
8	VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581	ASY511-RRR	3
2	VEN487	Washer, Flat, for 0.312 ID	McMASTER-CARR	98019A185	ASY511-RRR	3
X-Y MOTION ASSEMBLY - ASY516-XXX,YYY,DDD						
4	MEK001-DDD	Support, Corner	UT FMC	---	ASY516-RRR	4
4	ASY521-DDD	Assembly, Slider	UT ASS'Y	---	ASY516-RRR	4
1	ASY541-DDD	Assembly, Cartridge, X-Y	UT ASS'Y	---	ASY516-RRR	4
2	VEN406-XXX	Shaft, X Guide	THOMSON		ASY516-RRR	4
1	VEN407-XXX	Shaft, X Control	THOMSON		ASY516-RRR	4
2	VEN406-YYY	Shaft, Y Guide	THOMSON		ASY516-RRR	4
1	VEN407-YYY	Shaft, Y Control	THOMSON		ASY516-RRR	4
1	ASY300-RRR	Assembly, Frame	UT ASS'Y	---	ASY516-RRR	4
8	VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581	ASY516-RRR	4
8	VEN491	Nut, Hexagonal, 0.312-24 UNF	KNOX BOLT	---	ASY516-RRR	4
SLIDER ASSEMBLY - ASY521-DDD						
1	MEK021-DDD	Housing, Slider	UT FMC	---	ASY521-DDD	5
1	VEN401-DDD	Bearing, Linear, x.xx Tube Dia.	THOMSON	A162XXX	ASY521-DDD	5
2	VEN402-DDD	Seal, Linear Brg, x.xx Tube Dia.	THOMSON	S-XXXX	ASY521-DDD	5
XY REDUCTION SHAFT ASSEMBLY - ASY526						
1	MEK046	Shaft, XY Reduction	UT M/S	---	ASY526	5
1	VEN801	Pulley, Timing Belt, 0.955 PD	STOCK DRIVE	6A3-15DF03712	ASY526	5
Z REDUCTION SHAFT ASSEMBLY - ASY527						
1	MEK047	Shaft, Z Reduction	UT M/S	---	ASY527	5
1	VEN801	Pulley, Timing Belt, 0.955 PD	STOCK DRIVE	6A3-15DF03712	ASY527	5

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
XY MOTOR ASSEMBLY (LH) - ASY531						
1	MEK011	Plate, Motor Mounting (LH)	UT FMC	---	ASY531	4
1	MEK064	Motor, Stepper, Translation, #1	UT FMC	---	ASY531	4
4	VEN448-050	SHCS 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242	ASY531	4
4	VEN484	Washer, 0.190 nom D (0.438 OD)	KNOX BOLT	N/A	ASY531	4
XY MOTOR ASSEMBLY (RH) - ASY532						
1	MEK012	Plate, Motor Mounting (RH)	UT FMC	---	ASY532	4
1	MEK064	Motor, Stepper, Translation, #1	UT FMC	---	ASY532	4
4	VEN448-050	SHCS 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242	ASY532	4
4	VEN484	Washer, 0.190 nom D (0.438 OD)	KNOX BOLT	N/A	ASY532	4
Z MOTOR ASSEMBLY - ASY536						
1	MEK016	Plate, Motor Mounting, Z Platform	UT FMC	---	ASY536	4
1	MEK064	Motor, Stepper, Translation, #1	UT M/S	---	ASY536	4
4	VEN448-050	SHCS 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242	ASY536	4
4	VEN484	Washer, 0.190 nom D (0.438 OD)	KNOX BOLT	N/A	ASY536	4
THETA MOTOR ASSEMBLY - ASY538						
1	MEK063	Motor, Step, Rotation Sys, S23-3	UT M/S	---	ASY538	5
1	VEN498-050	Pin, Roll, 3/32 Dia., 0.50 lng	McMASTER-CARR	92383A204	ASY538	5
BELT ATTACHMENT ASSEMBLY - ASY540						
1	MEK042	Attachment, Belt, Fixed	UT FMC	---	ASY540	4
1	MEK043	Attachment, Belt, Adjustable	UT FMC	---	ASY540	4
4	VEN466-050	SHCS 0.138(#6)-32 UNC, 0.50 lng	McMASTER-CARR	91251A148	ASY540	4

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
4	VEN482	Washer, 0.138 nom D (0.312 OD)	KNOX BOLT	N/A	ASY540	4
X-Y CARTRIDGE ASSEMBLY - ASY541-DDD						
1	MEK051-DDD	Cartridge, Bearing, Right Angle	UT FMC	---	ASY541-DDD	5
4	VEN401-DDD	Bearing, Linear, X.XX Tube Dia.	THOMSON	A162XXX	ASY541-DDD	5
4	VEN402-DDD	Seal, Linear Brg, X.XX Tube Dia.	THOMSON	S-XXXX	ASY541-DDD	5
2	VEN496-075	Pin, Dowel, 0.250 dia.,0.750 lng	McMASTER-CARR	90145A540	ASY541-DDD	5
THETA MOTION ASSEMBLY - ASY551-ZZZ						
1	MEK201	Converter, Motor-Tube	UT M/S	---	ASY551-ZZZ	5
1	MEK211-ZZZ	Tube, Guide, Z-Axis	UT M/S	---	ASY551-ZZZ	5
1	MEK216-ZZZ	Tube, Theta Transmission	UT M/S	---	ASY551-ZZZ	5
1	MEK231	Mount, End Effector	UT FMC	---	ASY551-ZZZ	5
2	VEN422	Bearing, Radial, 0.625/0.875	NBS	SR10282Z(A3)	ASY551-ZZZ	5
2	VEN493-038	S Scr, Hlf-Dg, 0.250 UNF, 0.375L	KNOX BOLT	N/A	ASY551-ZZZ	5
1	VEN498-050	Pin, Roll, 3/32 Dia., 0.50 lng	McMASTER-CARR	92383A204	ASY551-ZZZ	5
AR	VEN427-ttt	Shims, 0.625 ID, 0.yyy thk.	SUPERIOR WSHR	N/A	ASY551-ZZZ	5
Z-THETA MOTION ASSEMBLY - ASY561-ZZZ						
1	ASY551-ZZZ	Assembly, Theta Motion	UT ASS'Y	---	ASY561-ZZZ	4
1	ASY571	Assembly, Z Platform	UT ASS'Y	---	ASY561-ZZZ	4
1	ASY591-ZZZ	Assembly, Z Mast	UT ASS'Y	---	ASY561-ZZZ	4
1	MEK081	Motor Mount, Theta	UT FMC	---	ASY561-ZZZ	4
1	ASY538	Assembly, Theta Motor	UT ASS'Y	---	ASY561-ZZZ	4
2	VEN493-038	S Scr, Hlf-Dg, 0.250 UNF, 0.375L	KNOX BOLT	N/A	ASY561-ZZZ	4
4	VEN450-175	SHCS, 0.250-28 UNF, 1.75 lng	KNOX BOLT	N/A	ASY561-ZZZ	4
4	VEN486	Washer, Flat, for 0.250 Dia.	KNOX BOLT	N/A	ASY561-ZZZ	4
4	VEN448-050	SHCS, 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242	ASY561-ZZZ	4

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
Z-PLATFORM ASSEMBLY - ASY571						
1	MEK071	Platform, Z-Theta	UT FMC	---	ASY571	5
2	VEN403-100	Brg, Linear, "SUPER", 1.00 T Dia	THOMSON	SUPER-16	ASY571	5
2	VEN402-100	Seal, Linear Brg, 1.00 Tube Dia.	THOMSON	S-1000	ASY571	5
2	VEN404-100	As'sy, Screw, Adjusting	THOMSON	BGS-4	ASY571	5
Z-THETA DRIVE SYSTEM - ASY581-ZZZ						
1	ASY561-ZZZ	Assembly, Z Motion	UT ASS'Y	---	ASY581-ZZZ	3
1	ASY536	Assembly, Z Motor	UT ASS'Y	---	ASY581-ZZZ	3
1	ASY540	Assembly, Belt Attachment	UT ASS'Y	---	ASY581-ZZZ	3
2	VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581	ASY581-ZZZ	3
2	VEN487	Washer, Flat, for 0.312 ID	McMASTER-CARR	98019A185	ASY581-ZZZ	3
1	KIT621	Kit, Z Reduction Drive	UT ASS'Y	---	ASY581-ZZZ	3
Z MAST ASSEMBLY - ASY591-ZZZ						
2	MEK091	Plate, Mounting, Mast	UT FMC	---	ASY591-ZZZ	5
1	MEK093-ZZZ	Mast, Z-Axis	UT FMC	---	ASY591-ZZZ	5
1	VEN832	Pulley, Tmg Blt, Hubless, 0.955PD	STOCK DRIVE	6A3-15H3710	ASY591-ZZZ	5
2	VEN421	Brg, Radial, Flanged, 0.375 Bore	NBS	FR6-2RS	ASY591-ZZZ	5
2	VEN426-031	Spacer, 0.375 Brg IR, 0.031 thk.	McMASTER-CARR	3088A431	ASY591-ZZZ	5
2	VEN426-125	Spacer, 0.375 Brg IR, 0.125 thk.	McMASTER-CARR	3088A511	ASY591-ZZZ	5
1	VEN497	Spacer, 0.250 Dia., 1.00 lng	McMASTER-CARR	90309A133	ASY591-ZZZ	5
2	VEN494-175	Scr, Rnd Hd, 0.138 UNC, 1.75 lng	KNOX BOLT	N/A	ASY591-ZZZ	5
2	VEN450-175	SHCS, 0.250-28 UNF, 1.75 lng	KNOX BOLT	N/A	ASY591-ZZZ	5
2	VEN495	Nut, 0.138 UNC	KNOX BOLT	N/A	ASY591-ZZZ	5
2	VEN490	Nut, 0.250 UNF	KNOX BOLT	N/A	ASY591-ZZZ	5
2	VEN482	Washer, Flat, for 0.138 Dia.	KNOX BOLT	N/A	ASY591-ZZZ	5
2	VEN486	Washer, Flat, for 0.250 Dia.	KNOX BOLT	N/A	ASY591-ZZZ	5
1	VEN840-LLL	Belt, Timing, Continuous L.LL in	STOCK DRIVE	-CHART-	ASY591-ZZZ	5

UT ROBOT ASSEMBLY - SUBSYSTEMS PARTS LISTS

REQ'D QTY	P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N	REL TO AS'SY P/N	AS'SY LEVEL
X-Y DRIVE COMPONENTS KIT - KIT611						
4	ASY526	Assembly, XY Reduction Shaft	UT ASS'Y	---	KIT611	4
8	VEN421	Brg, Radial, Flanged, 0.375 Bore	NBS	FR6-2RS	KIT611	4
2	VEN428	Collar, Shaft, 0.375 bore	McMASTER-CARR	6166K23	KIT611	4
4	VEN426-094	Spacer, 0.375 Brg IR, 0.094 thk.	McMASTER-CARR	3088A482	KIT611	4
4	VEN426-125	Spacer, 0.375 Brg IR, 0.125 thk.	McMASTER-CARR	3088A511	KIT611	4
2	CHART	Pulley, Motor	STOCK DRIVE	---	KIT611	4
2	CHART	Pulley, XY Reduction	STOCK DRIVE	---	KIT611	4
2	CHART	Belt, Timing, XY Reduction	STOCK DRIVE	---	KIT611	4
2	CHART	Spacer Set, XY Reduction	McMASTER-CARR	---	KIT611	4
Z DRIVE COMPONENT KIT - KIT621						
1	ASY527	Assembly, Z Reduction Shaft	UT ASS'Y	---	KIT621	4
2	VEN421	Brg, Radial, Flanged, 0.375 Bore	NBS	FR6-2RS	KIT621	4
1	VEN426-031	Spacer, 0.375 Brg IR, 0.031 thk.	McMASTER-CARR	3088A431	KIT621	4
1	VEN426-125	Spacer, 0.375 Brg IR, 0.125 thk.	McMASTER-CARR	3088A511	KIT621	4
1	CHART	Pulley, Motor	STOCK DRIVE	---	KIT621	4
1	CHART	Pulley, Z Reduction	STOCK DRIVE	---	KIT621	4
1	CHART	Belt, Timing, Z Reduction	STOCK DRIVE	---	KIT621	4
1	CHART	Spacer Set, Z Reduction	McMASTER-CARR	---	KIT621	4
WIRING MECHANICAL SUPPORT KIT - KIT631						
1	MEK095	Bracket, Frame Rod, Base	UT M/S	---	KIT631	3
1	MEK096	Bracket, Frame Rod, Intermediate	UT M/S	---	KIT631	3
1	MEK097	Bracket, Hanger Z Mast	UT M/S	---	KIT631	3
1	MEK098	Rod, Hanger, Z Mast	UT M/S	---	KIT631	3
1	MEK099	Rod, Wire Support, Frame Mounted	UT M/S	---	KIT631	3
6	VEN448-050	SHCS 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242	KIT631	3
1	VEN498-050	Pin, Roll, 3/32 Dia., 0.50 lng	McMASTER-CARR	92383A204	KIT631	3

APPENDIX N

UT Robot Part Number Listing

UT ROBOT - MASTER PARTS LIST

P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N
	ASSEMBLY PART NUMBERS		
ASY300-RRR	Assembly, Frame	UT ASS'Y	---
ASY506-RRR	Assembly, Robot Mechanical	UT ASS'Y	---
ASY511-RRR	Assembly, XY Drive	UT ASS'Y	---
ASY516-RRR	Assembly, XY Motion	UT ASS'Y	---
ASY521-DDD	Assembly, Slider	UT ASS'Y	---
ASY526	Assembly, XY Reduction Shaft	UT ASS'Y	---
ASY527	Assembly, Z Reduction Shaft	UT ASS'Y	---
ASY531	Assembly, XY Motor (LH)	UT ASS'Y	---
ASY532	Assembly, XY Motor (RH)	UT ASS'Y	---
ASY536	Assembly, Z Motor	UT ASS'Y	---
ASY538	Assembly, Theta Motor	UT ASS'Y	---
ASY540	Assembly, Belt Attachment	UT ASS'Y	---
ASY540	Assembly, Belt Attachment	UT ASS'Y	---
ASY541-DDD	Assembly, Cartridge, X-Y	UT ASS'Y	---
ASY551-ZZZ	Assembly, Theta Motion	UT ASS'Y	---
ASY561-ZZZ	Assembly, Z Motion	UT ASS'Y	---
ASY571	Assembly, Z Platform	UT ASS'Y	---
ASY581-ZZZ	Assembly, Z Drive	UT ASS'Y	---
ASY591-ZZZ	Assembly, Z Mast	UT ASS'Y	---
ASY601	Assembly, Robot Electrical	UT ASS'Y	---
	DRIVE KIT PART NUMBERS		
KIT611-XXX	Kit, X Reduction Drive	UT ASS'Y	---
KIT611-YYY	Kit, Y Reduction Drive	UT ASS'Y	---
KIT621	Kit, Z Reduction Drive	UT ASS'Y	---
KIT631	Kit, Wiring Mechanical Support	UT ASS'Y	---
	MANUFACTURED PART NUMBERS		
MEK001-DDD	Support, Corner	UT FMC	---
MEK011	Plate, Motor Mounting (LH)	UT FMC	---
MEK012	Plate, Motor Mounting (RH)	UT FMC	---
MEK016	Plate, Motor Mounting, Z Platform	UT FMC	---
MEK021-DDD	Housing, Slider	UT FMC	---
MEK042	Attachment, Belt, Fixed	UT FMC	---
MEK043	Attachment, Belt, Adjustable	UT FMC	---

UT ROBOT - MASTER PARTS LIST

P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N
MEK046	Shaft, XY Reduction	UT M/S	---
MEK047	Shaft, Z Reduction	UT M/S	---
MEK051-DDD	Cartridge, Bearing, Right Angle	UT FMC	---
MEK063	Motor, Step, Rotation Sys, S23-3	UT M/S	---
MEK064	Motor, Stepper, Translation, #1	UT M/S	---
MEK071	Platform, Z-Theta	UT FMC	---
MEK081	Motor Mount, Theta	UT FMC	---
MEK091	Plate, Mounting, Mast	UT FMC	---
MEK093-ZZZ	Mast, Z-Axis	UT FMC	---
MEK095	Bracket, Frame Rod, Base	UT M/S	---
MEK096	Bracket, Frame Rod, Intermediate	UT M/S	---
MEK097	Bracket, Hanger Z Mast	UT M/S	---
MEK098	Rod, Hanger, Z Mast	UT M/S	---
MEK099	Rod, Wire Support, Frame Mounted	UT M/S	---
MEK101	Pattern, Cstg, Corner Block		
MEK110	Pattern, Cstg, XY Slider Housing		
MEK115	Pattern Holder, Slider		
MEK131	Pattern, Cstg, Endmount		
MEK151	Pattern, Cstg, Bearing Cartridge		
MEK161	Pat'rn Support, Part, Brg Crtrdge		
MEK171	Pattern, Cstg, Z-Platform		
MEK176	Pattern Holder, Z-Platform		
MEK181	Pattern, Cstg, Theta Motor Mount		
MEK201	Converter, Motor-Tube	UT M/S	---
MEK211-ZZZ	Tube, Guide, Z-Axis	UT M/S	---
MEK216-ZZZ	Tube, Theta Transmission	UT M/S	---
MEK231	Mount, End Effector	UT FMC	---
MEK301-XXX	Member, Horiz., X Top	UT M/S	---
MEK302-YYY	Member, Horiz., Y Top	UT M/S	---
MEK303-XXX	Member, Horiz., X Bottom	UT M/S	---
MEK304-YYY	Member, Horiz., Y Bottom	UT M/S	---
MEK306-ZZZ	Frame Member, Vertical ("Z")	UT M/S	---
	UT ROBOT PART NUMBERS FOR VENDOR PARTS		
VEN401-DDD	Bearing, Linear, x.xx Tube Dia.	THOMSON	A162XXX
VEN402-DDD	Seal, Linear Brg, x.xx Tube Dia.	THOMSON	S-XXXX
VEN403-100	Brg, Linear, "SUPER", 1.00 T Dia	THOMSON	SUPER-16
VEN404-100	As'sy, Screw, Adjusting	THOMSON	BGS-4
VEN406-XXX	Shaft, X Guide	THOMSON	

UT ROBOT - MASTER PARTS LIST

P/N	PART NAME, DESCRIPTION	VENDOR	VENDOR P/N
VEN407-XXX	Shaft, X Control	THOMSON	
VEN421	Brg, Radial, Flanged, 0.375 Bore	NBS	FR6-2RS
VEN422	Bearing, Radial, 0.625/0.875	NBS	SR1028ZZ(A3)
VEN426-031	Spacer, 0.375 Brg IR, 0.031 thk.	McMASTER-CARR	3088A431
VEN426-094	Spacer, 0.375 Brg IR, 0.094 thk.	McMASTER-CARR	3088A482
VEN426-125	Spacer, 0.375 Brg IR, 0.125 thk.	McMASTER-CARR	3088A511
VEN427-ttt	Shims, 0.625 ID, 0.yyy thk.	SUPERIOR WSHR	N/A
VEN428	Collar, Shaft, 0.375 bore	McMASTER-CARR	6166K23
VEN448-050	SHCS 0.190-32 UNF, 0.50 lng	McMASTER-CARR	91252A242
VEN450-175	SHCS, 0.250-28 UNF, 1.75 lng	KNOX BOLT	N/A
VEN450-175	SHCS, 0.250-28 UNF, 1.75 lng	KNOX BOLT	N/A
VEN451-075	SHCS, 0.312-24 UNF, 0.75 long	McMASTER-CARR	91252A581
VEN466-050	SHCS 0.138(#6)-32 UNC, 0.50 lng	McMASTER-CARR	91251A148
VEN482	Washer, Flat, for 0.138 Dia.	KNOX BOLT	N/A
VEN484	Washer, 0.190 nom D (0.438 OD)	KNOX BOLT	N/A
VEN486	Washer, Flat, for 0.250 Dia.	KNOX BOLT	N/A
VEN487	Washer, Flat, for 0.312 ID	McMASTER-CARR	98019A185
VEN490	Nut, 0.250 UNF	KNOX BOLT	N/A
VEN491	Nut, Hexagonal, 0.312-24 UNF	KNOX BOLT	---
VEN493-038	S Scr, Hlf-Dg, 0.250 UNF, 0.375L	KNOX BOLT	N/A
VEN494-175	Scr, Rnd Hd, 0.138 UNC, 1.75 lng	KNOX BOLT	N/A
VEN495	Nut, 0.138 UNC	KNOX BOLT	N/A
VEN496-075	Pin, Dowel, 0.250 dia.,0.750 lng	McMASTER-CARR	90145A540
VEN497	Spacer, 0.250 Dia., 1.00 lng	McMASTER-CARR	90309A133
VEN498-050	Pin, Roll, 3/32 Dia., 0.50 lng	McMASTER-CARR	92383A204
VEN801	Pulley, Timing Belt, 0.955 PD	STOCK DRIVE	6A3-15DF0371
VEN832	Pulley, Tmg Blt, Hubless, 0.955PD	STOCK DRIVE	6A3-15H3710
VEN840-LLL	Belt, Timing, Continuous L.LL in	STOCK DRIVE	N/A
VEN843-XXX	Belt, Timing, for X Drive	STOCK DRIVE	6R3-C037
VEN843-YYY	Belt, Timing, for Y Drive	STOCK DRIVE	6R3-C037

APPENDIX O

UT Robot Assembly Instructions

ASSEMBLY INSTRUCTIONS
for

ASY300-RRR : Frame Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Identify all items and lay them out on the floor similar to that shown on the assembly drawing.
2	Make sure that the holes in the horizontal members match the threaded holes on the vertical member. If they do not, then rotate the vertical members or switch positions of horizontal members until the holes align at all connections. Hints: A) Holes on the vertical members face "outside" of the enclosed area. B) If holes on the vertical member do not align with the horizontal members, try reversing the ends of the vertical member. C) Do not mix the bottom horizontal ("base") members with the top ("mount") members.
3	After sliding the washer (Item 7) onto the cap screw (Item 6), insert the screw through one of the horizontal members and screw into the corresponding threaded hole in the vertical member (Item 5). Screw should be snug, but do not over tighten. some looseness is helpful for adjusting the frame as it is constructed.
4	Repeat previous step 31 additional times to secure the frame assembly.
5	Tighten screws securely.

ASSEMBLY INSTRUCTIONS
for

ASY506-RRR : Robot Mechanical Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Align mounting holes on the Z drive assembly (Item 2) to the corresponding holes and dowel pins on the horizontal drive system (Item 1). (Reference drawing sheet 2, Z Platform Attachment).
2	When aligned, push Z drive system down gently to engage the dowel pins on the horizontal system mount. Secure the Z drive system platform to the horizontal system with three cap screws (Item 3) and washers (Item 4).
3	Attach the mast wire support portion of the wiring support kit (Item 5) to the Z drive system's mast using the screws provided in the kit. IMPORTANT: Secure the bracket to the mast BEFORE securing the rod to the bracket. Then insert the rod into the bracket so that the rod extends over the top of the mast, then secure with the roll pin provided in the kit.
4	Attach the frame wire support portion of the wiring support kit to the frame. If not previously drilled, mounting holes may have to be drilled and tapped into the frame members. IMPORTANT: The two brackets must be aligned vertically. Make sure that the bracket locations are aligned before drilling. The bracket with the through hole is to be installed on the top frame member to permit installation of the support rod. The blind hole is to be installed on the bottom frame member hole with the hole facing up. Insert the frame support rod through the holes in the frame brackets.

ASSEMBLY INSTRUCTIONS
for

ASY511-RRR : XY Drive Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Note the orientation of XY motion system (Item 1) with respect to the diagram on sheet 3. Locate the "home" corner, which is where the coordinate origin is located. HINT: Use the orientation of the bearing cartridge, at the intersection of the shafts crossing the work area, to determine the "home" corner position.
2	Using the drawing on sheet 3, "Drive System Layout", locate and mark the pulley sets that are to be installed at each corner.
3	Refer to drawing KIT611. Install the idler set assemblies as required around the robot: a) Install the two flanged bearings into the hole in the horizontal system's corner support. b) Install the 0.094 spacer onto the XY drive shaft. Insert shaft from the "inside" part of the corner through the two bearings. c) Put the two 0.125 spacers onto the shaft, then install the shaft collar. Rotate the shaft collar so that the set screw will go into the groove on the drive shaft. Push the drive pulley and the collar towards each other together to remove any looseness. Tighten the set screw on the collar.
4	Refer to drawing KIT611. Install the drive set assemblies as required around the robot:

CAUTION: If the X and Y reductions are different, be sure to distinguish between the X drive pulley locations and the Y drive pulleys.

a) Install the two flanged bearings into the hole in the horizontal system's corner support.

b) Install the 0.094 spacer onto the XY drive shaft. Insert shaft from the "inside" part of the corner through the two bearings.

c) Put the reduction pulley spacers onto the shaft, then the reduction pulley. Be sure that the pulley is installed flange first. Rotate the pulley so that one of the pulley's set screws will go into the groove on the drive shaft. Push the pulleys towards each other together to remove any looseness. Tighten the set screw on the reduction pulley.

5 Install the drive belts on all four sides. Reference sheet 2, "drive belt attachment view".

a) Engage the screw threads from the belt clip assembly (Item 8) into the corresponding threaded hole underneath the slider housing. Do not tighten, but merely engage a sufficient amount so the clip assembly will not fall off.

b) Stretch a belt of sufficient length from underneath the slider around the drive and idler pulleys and back around to the slider. Make sure that the belt is oriented so that teeth engage the teeth on the pulleys (teeth "inside" the loop). Cut the belt to length just so that the ends cannot touch when pulled together.

c) Insert each belt end into the belt clip assembly. It is usually easier to insert the belt end for the non-moving part of the clip first. When the belt is inserted such that the belt teeth engage the teeth on the belt attachment, push the clip against the slider to hold the belt in the clip. Hand-tighten the belt attachment screws.

d) Using a screwdriver or similar object, push the moving part of the belt attachment towards the center of the slider to tighten the belt. When the desired belt tension is attained, tighten the belt attachment screws.

If the belt is still too loose when the adjustable clip is adjusted all the way, the belt is either too long or the belt is not engaging the attachment teeth properly. The belt should be shortened slightly or the belt ends must be re-fed to assure that the belt is inserted properly.

The tightening procedure requires some dexterity and practice. When done properly, however, the belt attachment is very secure.

6 Install the motor assemblies (Items 2 and 3). Note the orientation of the assemblies on the "assembled" view, sheet 1. Motors are mounted at the corner faces where the drive pulleys are located. X direction motors are mounted with the horizontal orientation, while the Y motors are mounted vertically (Sheet 3).

a) Locate the mounting holes on the corner support used to support the motor. Make sure that the motor assembly part number and mounting orientation match those on the drawing. Line up the motor mounting plate with the appropriate holes and secure using two screws and washers (Items 9 and 10). Do not tighten.

b) Install the drive pulley on the motor shaft, flange end first. Align one of the pulley's set screws so that it will go down into the groove on the motor shaft when it is tightened. Tighten the set screws.

c) With the motor plate mounting screws loose, pivot the motor so that the reduction timing belt (provided in KIT611) can be installed over the motor pulley and the reduction pulley. Install the belt "teeth in" so that the belt teeth engage the pulley teeth.

d) With the reduction belt installed, rotate the motor plate to tighten the belt. When adjusted, tighten the mounting screws.

ASSEMBLY INSTRUCTIONS
for

ASY516-RRR : XY Motion Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Note the orientation of the parts with respect to the diagram on sheet 1. In particular, note the orientation of the slider assemblies (Item 2).
2	Using the drawing on sheet 1, "Component Layout" as a guide, install a slider (Item 2) onto one of the "Y" direction guide shafts (Item 6). IMPORTANT: Note the orientation of the slider on the "Y" guide shaft. This will be referred to as the "right-side-up" position.
3	Install each end of the guide shaft (the one with the slider on it) into the hole on the corner support (Item 1). Be sure that the remaining hole on the corners and the hole on the face of the slider all face the same direction. Install the "X" guide shafts (Item 4) into the other corner support holes, and support the shaft with a wood block.
4	Slide the "Y" axis control shaft (Item 7) through the LOWER bore of the bearing cartridge (Item 3). Put each end of the shaft into the slider's mounting hole, and orient the slider so that it is "upside-down"; that is, the through hole in the slider should be lower than the control shaft.
5	Adjust the position of the partially assembled control shaft and sliders so that the slider holes line up with the two "X" guide shafts (Item 4). When adjusted, slide the sliders onto the "X" guide shafts.

6 Install the "X" axis control shaft (Item 5) through the UPPER bore of the bearing cartridge (Item 3). Then insert the end of the shaft into the slider that was installed in Step 2.

7 Repeat steps 1 and 2 with the other "Y" guide shaft, remaining slider, and final two corner supports.

8 Bring the sub-assembly from Step 7 near the two overhanging guide shafts, with the mounting holes facing toward the shafts. Move the slider along the guide shaft so that the slider is aligned with the control shaft (Item 5). When aligned, insert the guide tubes into the corner support and the control tube into the slider.

ASSEMBLY INSTRUCTIONS
for

ASY521-DDD : XY Slider Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Install the linear bearing (Item 2) into the slider housing (Item 1). Center the bearing in the housing.
2	Install the press-fit seals (Item 3) into each end of the slider housing. Install the seals with the seal lip to the inside (see drawing).

ASSEMBLY INSTRUCTIONS
for

ASY526 : XY Reduction Shaft Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Put the timing belt pulley (Item 2) onto the shaft (Item 1). Be sure to install the pulley on the "spot drill" end of the shaft with the hub trailing.
2	Rotate the pulley so that one of the pulley's set screws will go into the shaft's spot drill when tightened. Tighten the pulley set screws onto the shaft.

ASSEMBLY INSTRUCTIONS
for

ASY527 : Z Reduction Shaft Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Put the timing belt pulley (Item 2) onto the smaller diameter part of the shaft (Item 1). Be sure to install the pulley with the hub trailing.
2	Rotate the pulley so that the pulley's set screw will go into the shaft's spot drill when tightened. Tighten the pulley set screw onto the shaft.

ASSEMBLY INSTRUCTIONS
for

ASY531 : XY Motor Assembly (LH)
ASY532 : XY Motor Assembly (RH)
ASY536 : Z Motor Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Put the motor (Item 2) onto the milled out area of the motor plate (Item 1). Rotate the motor so that: a) the motor mounting holes align with the threaded holes in the plate; b) the power cable is oriented "away" from the plate.
2	Put four washers (Item 4) onto four cap screws (Item 3), insert the screw through the motor mounting holes and screw them into the holes in the motor plate. tighten securely.

ASSEMBLY INSTRUCTIONS
for

ASY538 : Theta Motor Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Put the roll pin (Item 2) through the hole in the motor shaft (Item 1). Center the pin in the hole.

ASSEMBLY INSTRUCTIONS
for

ASY540 : Belt Attachment Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Put the adjustable part of the attachment (Item 2) on top of the fixed part of the attachment (Item 1). Line up the holes on the fixed part with the slots on the adjustable part.
2	Place a washer (Item 4) over a screw (Item 3) and insert the screw through the hole and slot. Repeat for all four screws. Place loose assembly carefully on a small tray or other surface until ready for use.

ASSEMBLY INSTRUCTIONS
for

ASY541-DDD : XY Cartridge

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Install the linear bearings (Item 2) into the cartridge housing (Item 1). Insert two bearings into each bore. Push them in all the way until they hit a stop.
2	Install the press-fit seals (Item 3) into each end of the slider housing. Install the seals with the seal lip to the inside (see drawing).
3	Install the dowel pins (Item 4) into the bearing cartridge. It may be necessary to tap them down lightly with a hammer.

ASSEMBLY INSTRUCTIONS
for

ASY551-ZZZ : Theta Motion Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Insert the theta-tube converter (Item 1) into the theta transmission tube (Item 3). Move and rotate the tube until the radial hole in the tube aligns with the corresponding hole in the converter. Secure by inserting the roll pin (Item 2) through the holes.
2	Install bearings (Item 4) into each end of the Z guide tube (Item 5). Push them in all the way until they hit a stop.
3	Insert the theta tube down through the top of the Z guide tube all the way until the theta converter rests inside the bearing. NOTE: The top of the Z guide tube can be recognized by the two radial holes near the top of the tube. Make sure that the converter rests securely on the top bearing. Take care not to ram the theta transmission tube into the bottom bearing.
4	Place six 0.010 thick shims (Item 8) on the end effector mount (Item 6). Put end effector mount onto theta transmission shaft and insert until end effector mount rests inside the bearing and the shims are tightly squeezed between the bearing and the mount. Rotate tube or mount until the radial holes on the mount and tube are aligned.
5	Insert the two dog-point screws (Item 7) into the mount and screw in until the point engages the hole in the theta transmission shaft. If the screw point cannot engaged, remove one shim and try again. Repeat until

6 Hold the Z guide tube. Try to press the end effector in and out of the tube. If assembly is loose, disassemble, add shims, and reassemble. Repeat as necessary until no looseness is felt.

ASSEMBLY INSTRUCTIONS
for

ASY561-ZZZ : Z Motion Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Insert the theta motion assembly (Item 1) up through the bottom of the Z platform assembly (Item 2). Rotate the motion assembly until the axial groove in the tube is aligned with the two adjustment screws on the side of the Z platform's bore.
2	Place the theta motor mount (Item 4) onto the top of the theta motion assembly as it sticks out the top of the Z platform. Rotate the motor assembly on the tube until the mounting holes line up. Insert the two dog-point screws (Item 6) into the mount and screw in until the screw securely engage the holes in the theta motion assembly's tube.
3	Mount the theta motor (Item 5) onto the theta motor mount. Align the roll pin on the motor shaft with the groove at the top of the theta motion assembly. Push down firmly until the motor face rests ont eh top of the theta motor mount. Rotate the motor so that the mounting holes align and the power cable extends "away" from the platform. Secure with four screws (Item 9).
4	Attach the Z mast (Item 3) to the Z platform with the four long screws (Item 7) and washers (Item 8).

ASSEMBLY INSTRUCTIONS
for

ASY571-DDD : Z Platform Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Install the linear "Super" bearings (Item 2) into the Z-Theta platform casting (Item 1). Insert two bearings into the bore.
	IMPORTANT: Align one of the "tracks" on the bearing with the adjustment screw hole during installation. The adjustment screws must engage one of these tracks on both bearings.
2	Install the press-fit seals (Item 3) into each end of the slider housing. Install the seals with the seal lip to the inside (see drawing).
3	Install the adjustment screws (Item 4) into the side of the Z platform.
	WARNING: Do NOT tighten.

ASSEMBLY INSTRUCTIONS
for

ASY581-RRR : Z-Theta Drive Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Using the views on sheet 3 as a guide, install the Z reduction assembly (Item 6) on the Z motion assembly (Item 1):
	a) Install the two flanged bearings into the holes on both ends of the Z motion assembly, flange side "out".
	b) Install a 0.031 AND a 0.125 spacer onto the Z drive shaft. Insert shaft through from the "mast" end of the assembly through to the opposite end.
	c) Put the Z reduction spacers onto the shaft, then install the reduction pulley. Rotate the pulley so that the pulley's set screw will go into the groove on the drive shaft. Push the drive pulley and the collar towards each other together to remove any looseness. Tighten the set screw on the pulley.
2	Install the Z motor assembly (Item 2).
	a) Locate the mounting holes on the Z platform that are used to support the motor. Line up the motor mounting plate with the appropriate holes and secure using two screws and washers (Items 4 and 5). Do not tighten.
	b) Install the drive pulley on the motor shaft, flange end first. Align one of the pulley's set screws so that it will go down into the groove on the motor shaft when it is tightened. Tighten the set screws.
	c) With the motor plate mounting screws loose, pivot the motor so that the reduction timing belt (provided in KIT631) can be installed

over the motor pulley and the reduction pulley. Install the belt "teeth in" so that the belt teeth engage the pulley teeth.

d) With the reduction belt installed, rotate the motor plate to tighten the belt. When adjusted, tighten the mounting screws.

3 Install the Z drive belt:

a) Remove the mast height adjustment screw at the top of the mast so that the mat plates can be adjusted. If necessary, loosen the two socket head cap screws as well.

b) Pivot the mast down far enough to wrap the Z drive belt around the drive pulley near the bottom of the Z mast. Make sure that the belt teeth are meshed with the pulley.

c) Tighten the Z drive belt by rotating the Z mast top. The mast adjustment screw can be inserted through any one of the five sets of adjustment holes. Each adjustment hole provides a different belt tension. Select the one closest to the desired tension. Make sure that a washer is still on the adjustment screw, and insert through the plates and mast. Put a washer on the end, and secure with the nut.

ASSEMBLY INSTRUCTIONS
for

ASY591-ZZZ : Z Mast Assembly

(instructions refer to assembly drawings)

STEP	INSTRUCTION
1	Assemble the "bearing and pulley" sub-assembly (exploded view, sheet 1):

a) Put the hubless pulley (Item 3) onto the mast idler shaft (Item 7). Align one of the set screws on the pulley so that the screw will go into the hole at the center of the shaft. Tighten the set screws.

b) Put one each of 0.031 (Item 5) and 0.125 (Item 6) spacers on both sides of the hubless pulley.

c) Put the two flanged bearings (Item 4) on either side of the idler shaft, flange side "in".

2 Position the mast plates (Item 2) on the outer race of the bearings assembled in step 1. Press plates lightly against bearing flanges to hold bearing assembly together.

IMPORTANT: Make sure that the mast plates are oriented the same way on both sides.

3 Place the Z drive belt over the hubless pulley. Orient the belt so that the belt teeth mesh with the timing belt pulley teeth.

4 Position the long spacer (Item 14) between the mast plates and align with the small hole at the corner of the mast plate. Insert the long screw (Item 8) through a washer (Item 10), the mast plates and the long spacer. Place a washer (Item 10) over the end of the screw and secure with the nut (Item 11). Do not over tighten.

5 Slide the Z mast (Item 1) between the mast plates. Before inserting, orient the mast so the small holes in the mast are closest to the belt and pulley. Secure the plates to the mast by inserting two screws (Item 9) with washers (Item 12). Insert the screws through the holes in the mast plates and mast, slide a washer (Item 12) onto the end of the screw, and secure with a nut (Item 13). Hand tighten only.

6 Rotate the mast plates to any convenient position so that the long adjustment screw (Item 8) can be inserted through any one of the five sets of adjustment holes. Place a washer (Item 10) on the screw, and insert through the plates and mast. Put a washer on the end, and secure with a nut (Item 11).

APPENDIX P

"A" Size Part and Assembly Drawings

"A" SIZE PART AND ASSEMBLY DRAWINGS

Contents :

This Appendix contains the "A" size drawings used in the manufacture and assembly of the UT Robot.

Organization :

The drawings are displayed in part number numerical order. For a part number listing, consult Appendix M or Appendix N.

Other Drawings :

"C" and "D" size drawings are contained "In Pocket".

Drawing Use Note :

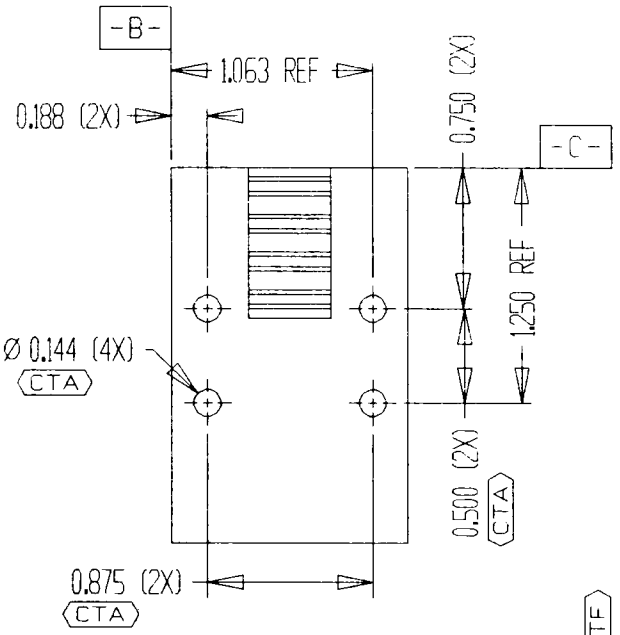
The drawings in this Appendix are the property of Michael E. Kennedy and the University of Tennessee Superior Engineering Design Program. Use of these materials to produce parts without the expressed written consent of the property owners is prohibited.

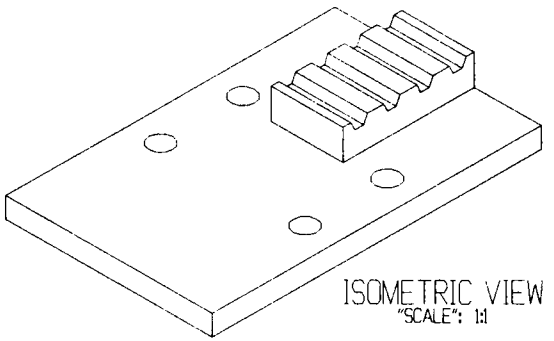
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY540	1	MECHANICAL	MEK	14 MAR 91			

P/N MEK042

"A" SIZE TEMPLATE

0 .25" REAL SIZE

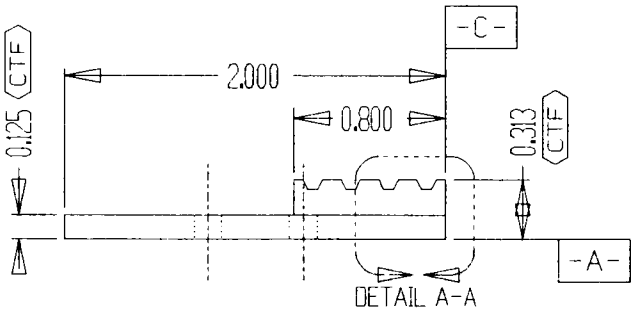




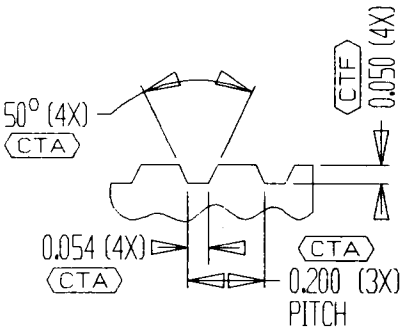
ISOMETRIC VIEW
"SCALE": 1:1

NOTES:

1. TOLERANCES FOR TOOTH DETAIL DIMENSIONS ARE NON-CUMULATIVE.
2. TOOTH DETAIL TOLERANCES ARE TO BE ±0.001.



DETAIL A-A



DETAIL A-A 1 2
"SCALE": 2:1
TOOTH DETAIL VIEW

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

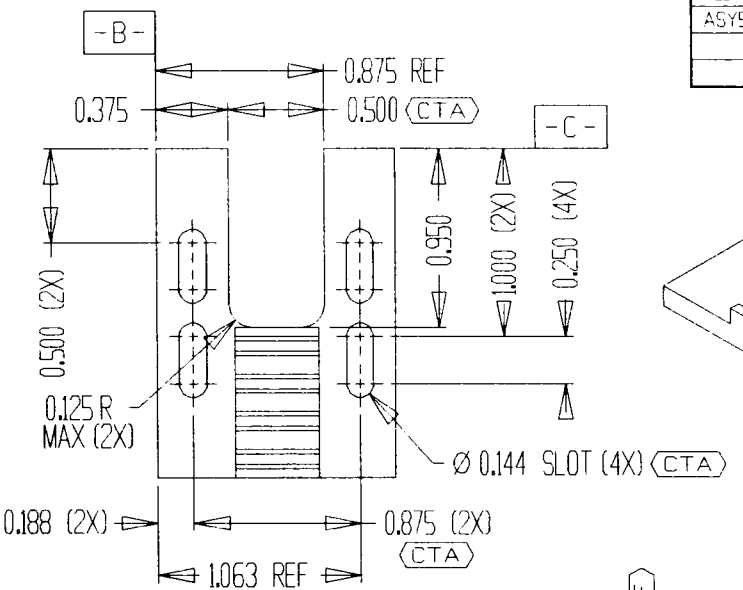
SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK042		UT
MATERIAL T6061 Aluminum	TOLERANCES UNLESS NOTED		TITLE ATTACHMENT, BELT, FIXED		
	LINEAR +/-	0.005			
	ANGLES +/-	1°			
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	18 JAN 91
	EDGE/ CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	25 JAN 91
IBMCAD FILE CLIPFIXD.R2	EDGE/ CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	14 MAR 91

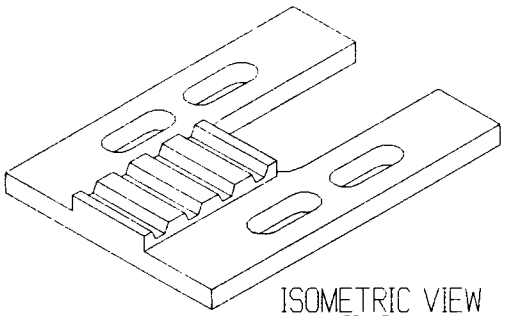
MEK042

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY540	1	MECHANICAL	MEK	14 MAR 91			

P/N MEK043

"A" SIZE TEMPLATE 0 .25" REAL SIZE

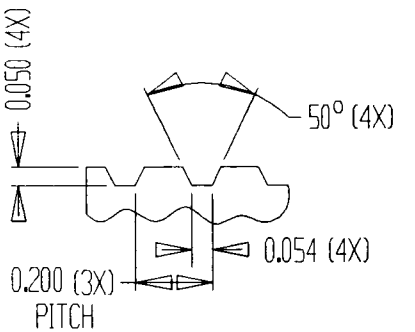




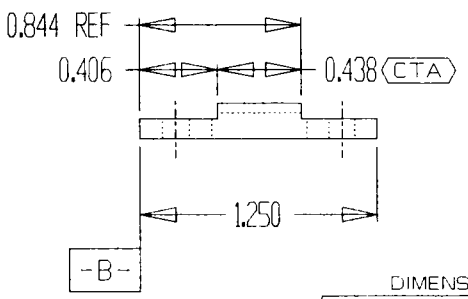
ISOMETRIC VIEW
"SCALE": 1:1

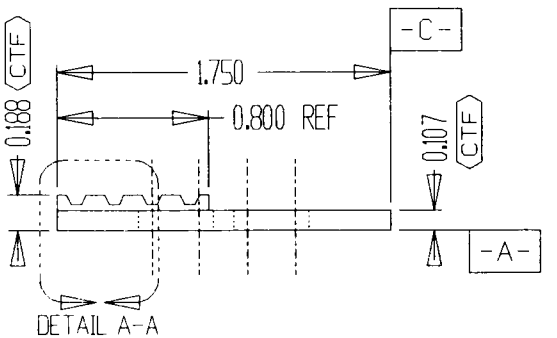
NOTES:

1. TOLERANCES FOR TOOTH DETAIL DIMENSIONS ARE NON-CUMULATIVE.
2. TOOTH DETAIL TOLERANCES ARE TO BE ±0.001.



DETAIL A-A 1 2
SCALE: 2:1
TOOTH DETAIL VIEW





DETAIL A-A

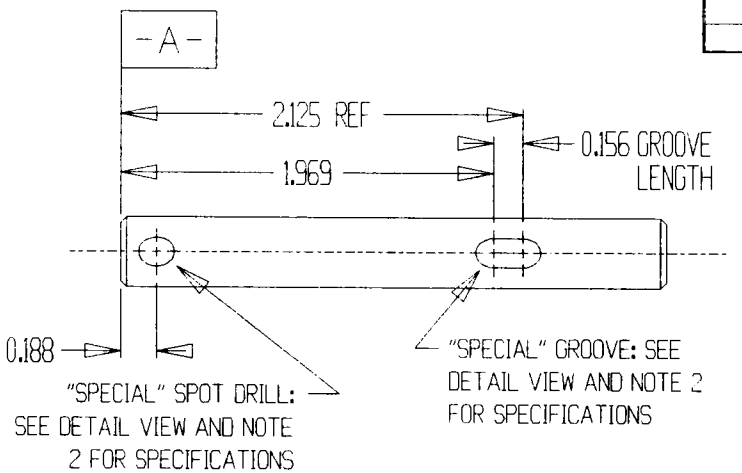
DIMENSIONAL 'KEY' CODES:

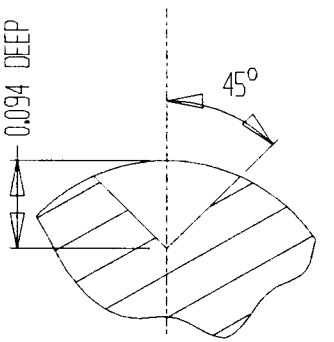
SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

MEK043

SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK043		UT
MATERIAL T6061 Aluminum	TOLERANCES UNLESS NOTED		TITLE ATTACHMENT, BELT, ADJUSTABLE		
	LINEAR +/-	0.020			
	ANGLES +/-	0.020			
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	19 JAN 91
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	25 JAN 91
IBMCAD FILE CLIPMOVE.R2	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	14 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK046
ASY526	1	MECHANICAL	MEK	06 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE





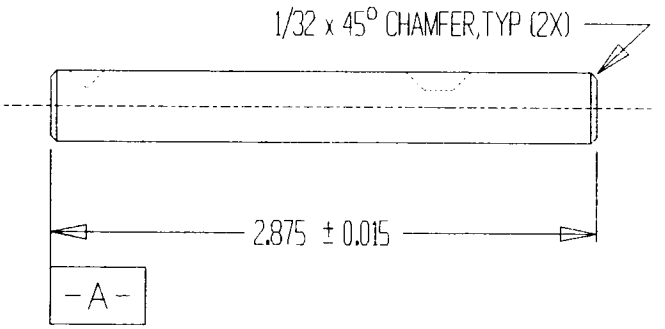
GROOVE DETAIL [2]
"SCALE": 5/1
"SHAFT SECTION" VIEW

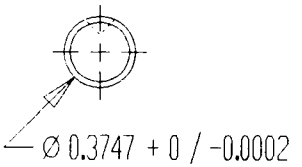
NOTES:

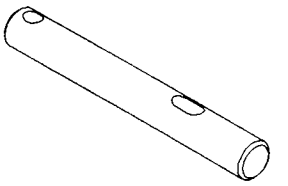
1 SUGGESTED VENDOR FOR SHAFT STOCK:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

USE SUFFICIENT LENGTH OF STOCK DRIVE P/N 7X1-12xxx SHAFT.

[2] USE A MODIFIED 0.198 (#9) OR LARGER DRILL FOR THE SPECIFIED GROOVE. MODIFY DRILL BIT ANGLE FROM 30° TO 45°, +5°/0°. GROOVE DEPTH IS 0.094 DEEP, AS MEASURED FROM FIRST TIP CONTACT WITH SHAFT.







ISOMETRIC VIEW
"SCALE": 1/2
"HORIZONTAL" VIEW

SCALE 1:1	DIMENSIONS IN INCHES			PART # MEK046			UT
MATERIAL #303 STAINLESS STEEL	TOLERANCES UNLESS NOTED			TITLE SHAFT, XY REDUCTION			
	LINEAR +/-		0.002				
	ANGLES +/-		1°				
OTHER NOTES	RADII UNLESS NOTED		0.020	DESIGNER	MEK	18 DEC 90	
	EDGE/ CORNER BREAKS	OUTSIDE MAX	0.020	CHECKED	MEK	06 MAR 91	
IBMCAD FILE XYSSSHFT.R2		INSIDE MAX	0.020	APPROVED	MEK	06 MAR 91	

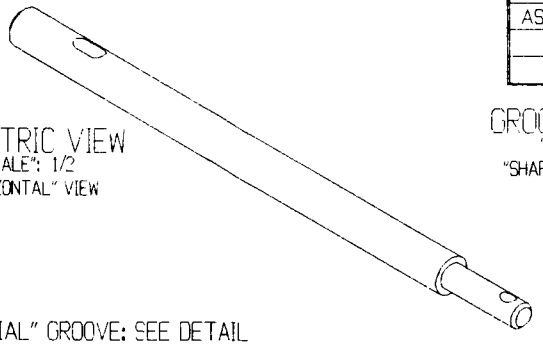
MEK046

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY527	1	MECHANICAL	MEK	06 MAR 91			

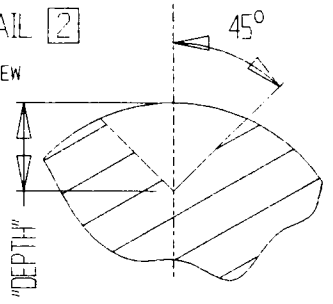
P/N MEK047

"A" SIZE TEMPLATE 0 .25" REAL SIZE

ISOMETRIC VIEW
"SCALE": 1/2
"HORIZONTAL" VIEW



GROOVE DETAIL [2]
"SCALE": 5/1
"SHAFT SECTION" VIEW

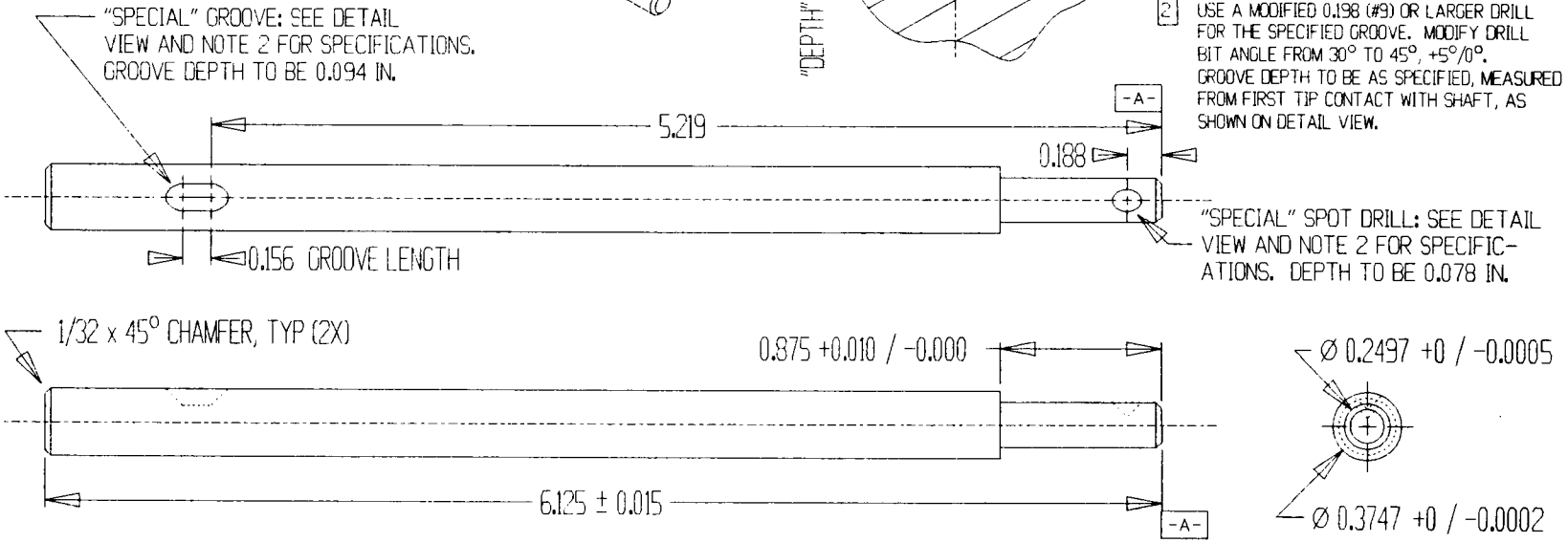


NOTES:

1 SUGGESTED VENDOR FOR SHAFT STOCK:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

USE SUFFICIENT LENGTH OF STOCK DRIVE P/N 7X1-12xxx SHAFT.

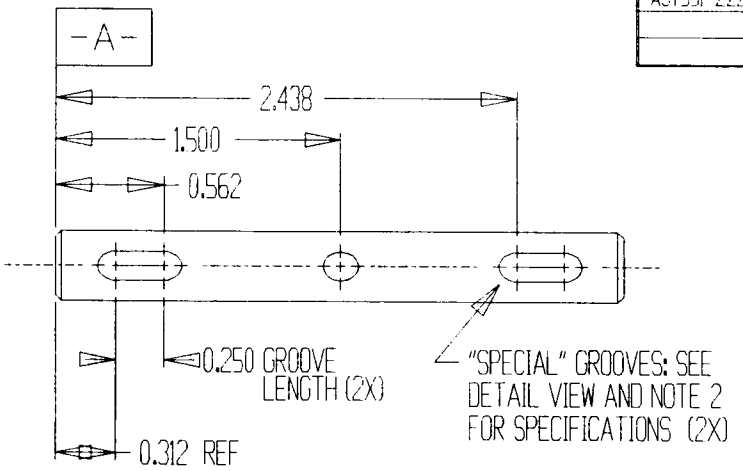
[2] USE A MODIFIED 0.198 (#9) OR LARGER DRILL FOR THE SPECIFIED GROOVE. MODIFY DRILL BIT ANGLE FROM 30° TO 45°, +5°/0°. GROOVE DEPTH TO BE AS SPECIFIED, MEASURED FROM FIRST TIP CONTACT WITH SHAFT, AS SHOWN ON DETAIL VIEW.

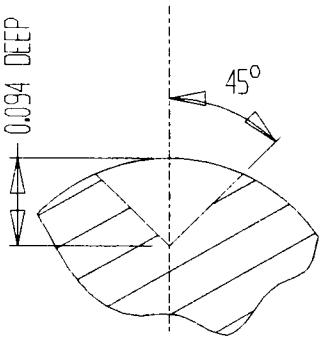


SCALE 1:1		DIMENSIONS IN INCHES			PART # MEK047		UT
MATERIAL #303 STAINLESS STEEL		TOLERANCES UNLESS NOTED					
		LINEAR +/-		0.002	TITLE SHAFT, Z REDUCTION		
		ANGLES +/-		1°			
OTHER NOTES		RADII UNLESS NOTED		0.020	DESIGNER	MEK	18 DEC 90
		EDGE/ CORNER BREAKS	OUTSIDE MAX	0.020	CHECKED	MEK	06 MAR 91
IBMCAD FILE ZSSSHAFT.R2			INSIDE MAX	0.020	APPROVED	MEK	06 MAR 91

MEK047

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK048
ASY591-ZZZ	1	MECHANICAL	MEK	14 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE





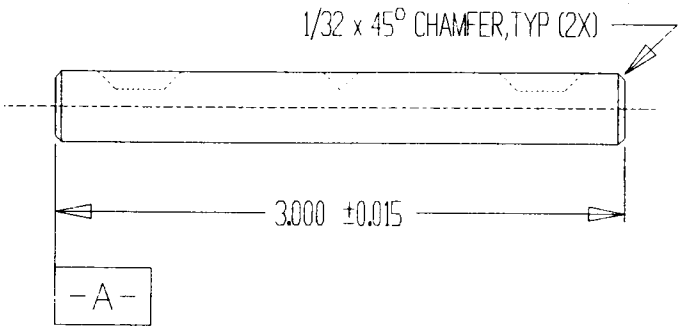
GROOVE DETAIL [2]
"SCALE": 5/1
"SHAFT SECTION" VIEW

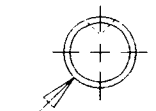
NOTES:

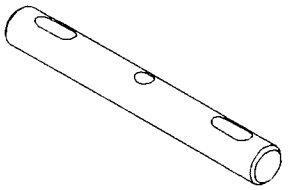
1 SUGGESTED VENDOR FOR SHAFT STOCK:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

USE SUFFICIENT LENGTH OF STOCK DRIVE P/N 7X1-12xxx SHAFT.

[2] USE A MODIFIED 0.198 (#9) OR LARGER DRILL FOR THE SPECIFIED GROOVE. MODIFY DRILL BIT ANGLE FROM 30° TO 45°, +5°/0°. GROOVE DEPTH IS 0.094 DEEP, AS MEASURED FROM FIRST TIP CONTACT WITH SHAFT.





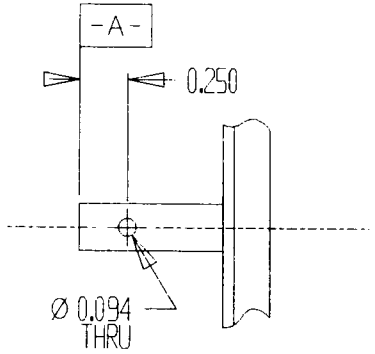


ISOMETRIC VIEW
"SCALE": 1/2
"HORIZONTAL" VIEW

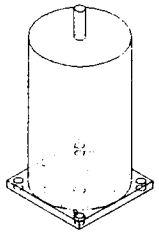
SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK048			UT
MATERIAL #303 STAINLESS STEEL	TOLERANCES UNLESS NOTED		TITLE SHAFT, Z MAST IDLER			
	LINEAR +/-	0.002				
	ANGLES +/-	1°				
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	18 DEC 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	14 MAR 91	
IBMCAD FILE MASTSHFT.P2	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	14 MAR 91	

MEK048

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK063
ASY538	1	MECHANICAL	MEK	03 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



DETAIL A-A
SCALE: 1:1
"SHAFT HOLE" DETAIL VIEW



ISOMETRIC VIEW
"SCALE": 1/5
"SHAFT END DOWN" VIEW

NOTES:

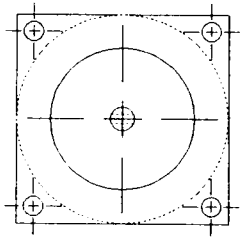
1 THIS DRAWING DENOTES SHAFT MODIFICATIONS FOR A VENDOR-SUPPLIED MOTOR. ACCEPTABLE VENDOR P/N'S ARE:

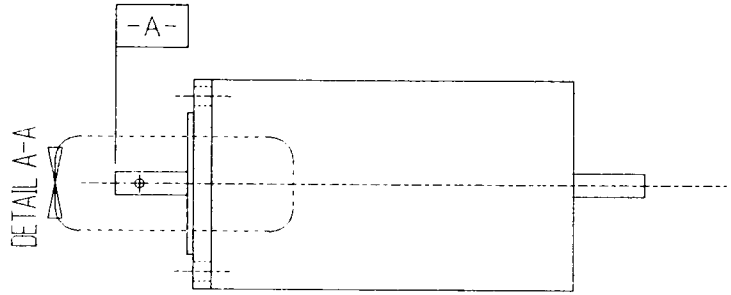
VEN413 - ANAHEIM AUTOMATION #23D306D

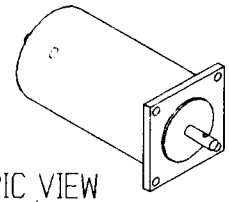
USE OF ANY MOTOR P/N'S OTHER THAN THAT SPECIFIED AS APPROVED REQUIRES ENGINEERING APPROVAL.

2 MOTORS CAN BE SUSCEPTABLE TO DAMAGE DURING MACHINING OPERATIONS. EXERCISE THE FOLLOWING PRECAUTIONS:

* ALWAYS PROVIDE EXTERNAL SUPPORT FOR THE MOTOR SHAFT DURING ANY MACHINING OPERATION.
* PROTECT MOTOR SHAFT BEARINGS FROM MACHINING CHIPS AND OTHER DEBRIS BY WRAPPING MOTOR BODY SECURELY IN PLASTIC BEFORE BEGINNING ANY MACHINING OPERATION.







ISOMETRIC VIEW
"SCALE": 1/5
"SHAFT HORIZONTAL" VIEW

SCALE 1/2	DIMENSIONS IN INCHES			PART # MEK063	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE MOTOR, STEPPER,	
	ANGLES +/-		N/A	ROTATION SYSTEM, "SIZE 3"	
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK 19 DEC 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK 03 MAR 91
IBMCAD FILE MTRROT3.R2		INSIDE MAX	N/A	APPROVED	MEK 03 MAR 91

MEK063

REL FOR ASM	QTY
ASY531	1
ASY532	1
ASY536	1

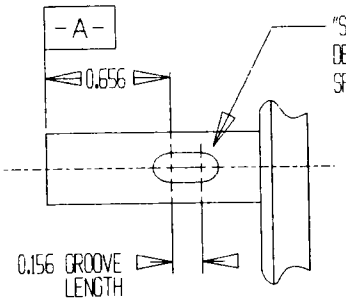
TECHNICAL APPROVALS		
MECHANICAL	MEK	12 MAR 91

INIT	DATE	EC #

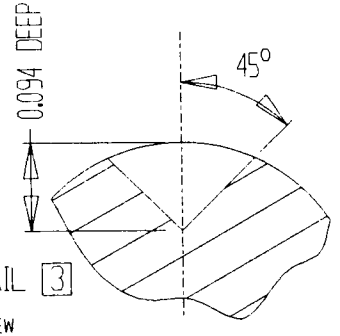
P/N MEK064

"A" SIZE TEMPLATE

0 .25" REAL SIZE



DETAIL A-A
SCALE: 1:1
"GROOVE LOCATION" VIEW



GROOVE DETAIL [3]
"SCALE": 5/1
"SHAFT SECTION" VIEW

NOTES:

[1] THIS DRAWING DENOTES SHAFT MODIFICATIONS FOR A VENDOR-SUPPLIED MOTOR. ACCEPTABLE VENDOR P/NS ARE:

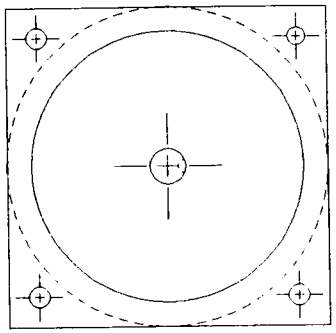
VEN414 – ANAHEIM AUTOMATION #34D106S

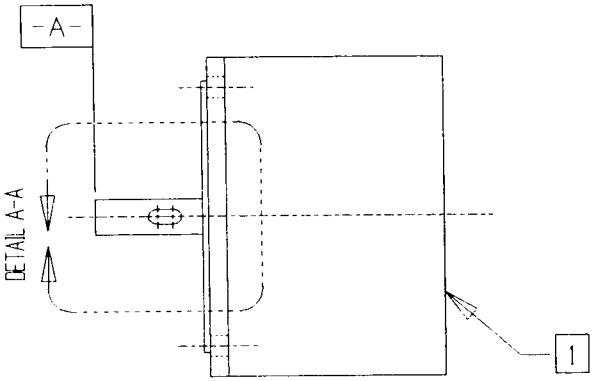
USE OF ANY MOTOR P/NS OTHER THAN THAT SPECIFIED AS APPROVED REQUIRES ENGINEERING APPROVAL.

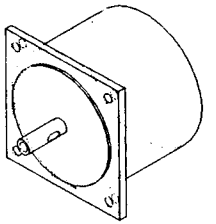
2 MOTORS CAN BE SUSCEPTABLE TO DAMAGE DURING MACHINING OPERATIONS. EXERCISE THE FOLLOWING PRECAUTIONS:

* ALWAYS PROVIDE EXTERNAL SUPPORT FOR THE MOTOR SHAFT DURING ANY MACHINING OPERATION.
* PROTECT MOTOR SHAFT BEARINGS FROM MACHINING CHIPS AND OTHER DEBRIS BY WRAPPING MOTOR BODY SECURELY IN PLASTIC BEFORE BEGINNING ANY MACHINING OPERATION.

[3] USE A MODIFIED 0.198 (#9) OR LARGER DRILL FOR THE SPECIFIED GROOVE. MODIFY DRILL BIT ANGLE FROM 30° TO 45°, +5°/ -0°. GROOVE DEPTH IS 0.094 IN., AS MEASURED FROM FIRST CONTACT WITH THE SHAFT.







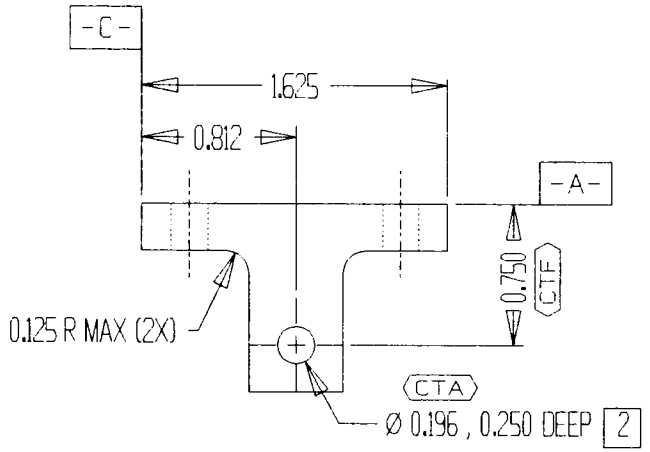
ISOMETRIC VIEW
"SCALE": 1/5
"SHAFT FRONT LEFT" VIEW

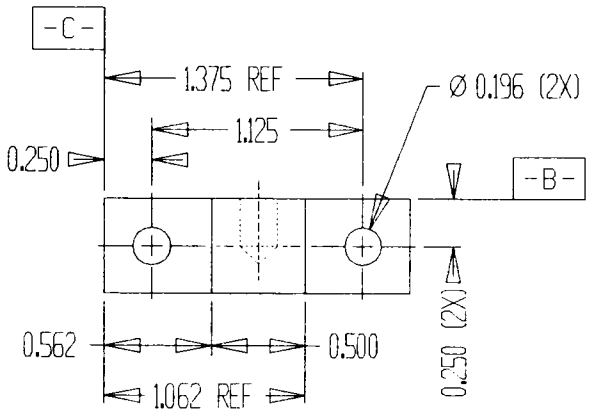
SCALE	1/2	DIMENSIONS IN	INCHES
MATERIAL	N/A	TOLERANCES UNLESS NOTED	
		LINEAR +/-	0.001
		ANGLES +/-	1°
OTHER NOTES		RADII UNLESS NOTED	0.020
		EDGE/CORNER BREAKS OUTSIDE MAX	0.020
IBMCAD FILE	MTRXYZ1.R2	EDGE/CORNER BREAKS INSIDE MAX	0.020

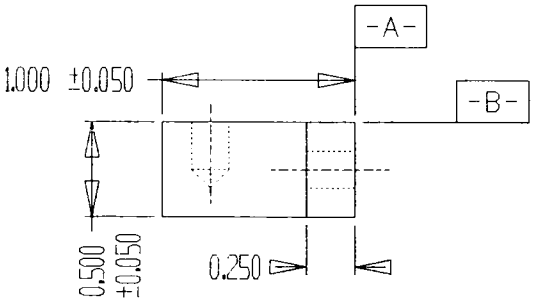
PART #	MEK064	UT
TITLE	MOTOR, STEPPER, TRANSLATION SYS., "SIZE 1"	
DESIGNER	MEK	19 DEC 90
CHECKED	MEK	12 MAR 91
APPROVED	MEK	12 MAR 91

MEK064

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK095
KIT631	1	MECHANICAL	MEK	30 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



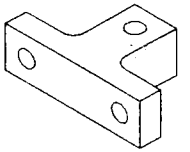




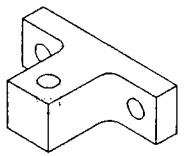
NOTES:

1 MAY BE CUT AND MACHINED FROM 0.50 IN x 1.00 IN BAR STOCK.

2 ADDITIONAL 0.093 IN PERMITTED FOR DRILL TIP.



ISOMETRIC VIEW
"SCALE": 1/2
"FRAME ATTACHMENT ORIENTATION"



ISOMETRIC VIEW
"SCALE": 1/2

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

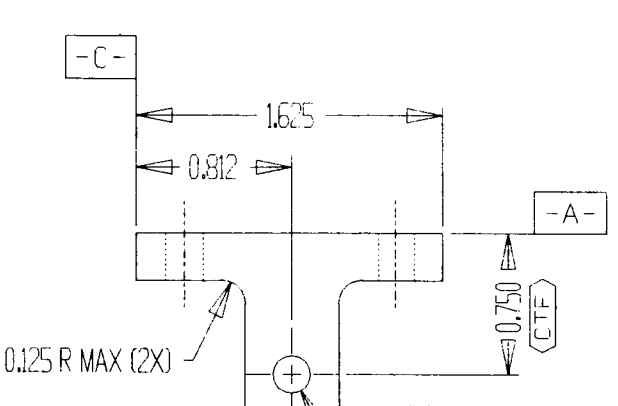
SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK095		UT
MATERIAL T6061 Alumnum OR SIMILAR	TOLERANCES UNLESS NOTED		TITLE BRACKET, FRAME ROD, BASE SUPPORT		
	LINEAR +/-	0.005			
	ANGLES +/-	1°			
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	19 FEB 91
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	19 FEB 91
IBMCAD FILE FBRAKET1.R2	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	30 MAR 91

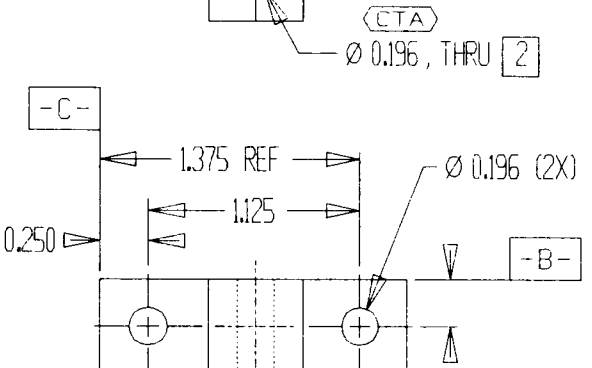
MEK095

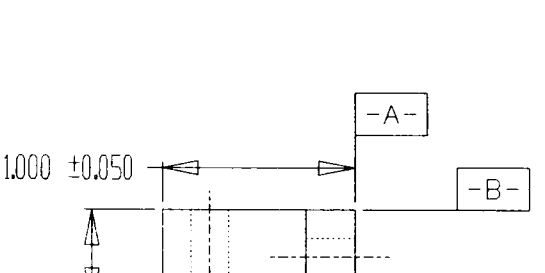
PEL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
KIT631	1	MECHANICAL	MEK	30 MAR 91			

P/N MEK096

"A" SIZE TEMPLATE 0 .25" REAL SIZE

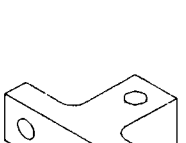




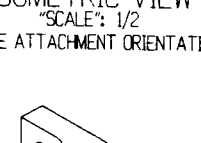


NOTES:

1 MAY BE CUT AND MACHINED FROM 0.50 IN x 1.00 IN BAR STOCK.



ISOMETRIC VIEW
"SCALE": 1/2
"FRAME ATTACHMENT ORIENTATION"



ISOMETRIC VIEW
"SCALE": 1/2
"FRAME ATTACHMENT ORIENTATION"

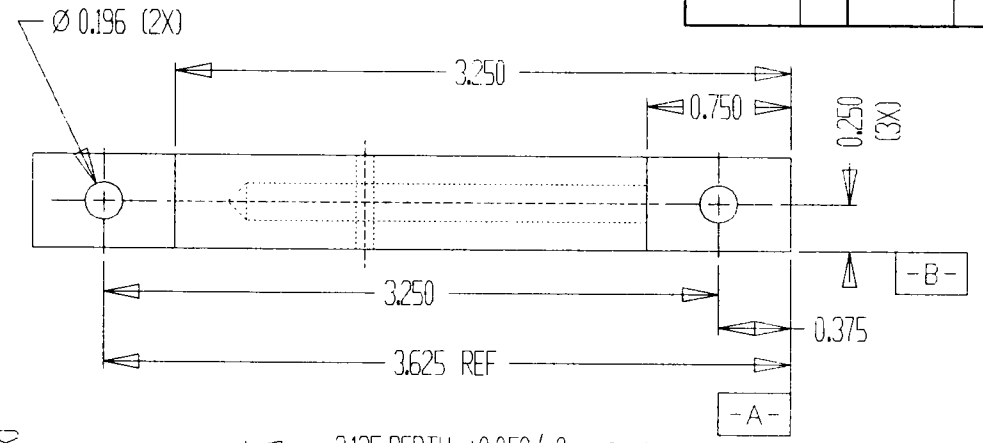
DIMENSIONAL 'KEY' CODES:

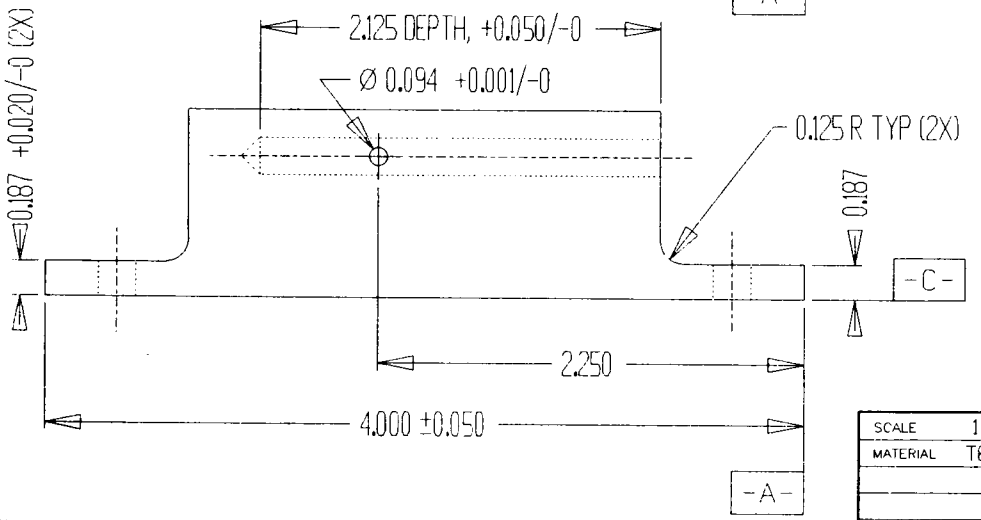
SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

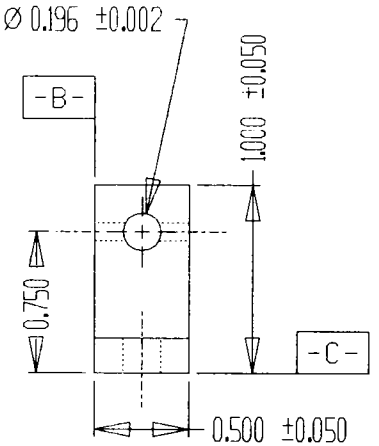
SCALE 1:1	DIMENSIONS IN INCHES			PART # MEK096	UT
MATERIAL T6061 Aluminum OR SIMILAR	TOLERANCES UNLESS NOTED			TITLE BRACKET, FRAME ROD, INTERMEDIATE SUPPORT	
	LINEAR +/-		0.005		
	ANGLES +/-		1°		
OTHER NOTES	RADII UNLESS NOTED		0.020	DESIGNER	MEK 19 FEB 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	0.020	CHECKED	MEK 19 FEB 91
IBMCAD FILE FBRAKET2.R2		INSIDE MAX	0.020	APPROVED	MEK 30 MAR 91

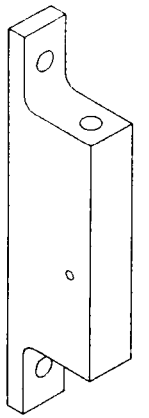
MEK096

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK097
KIT631	1	MECHANICAL	MEK	30 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE









ISOMETRIC VIEW
"SCALE": 1/2

NOTES:

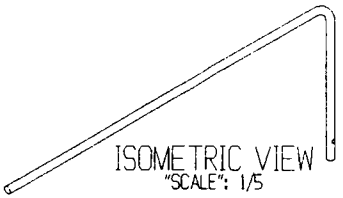
1 MAY BE CUT AND MACHINED FROM 0.50 IN x 1.00 IN BAR STOCK.

2 ADDITIONAL 0.125 IN PERMITTED FOR DRILL TIP.

SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK097	UT
MATERIAL T6061 Aluminum OR SIMILAR	TOLERANCES UNLESS NOTED		TITLE BRACKET, HANGER Z MAST	
	LINEAR +/-	0.005		
	ANGLES +/-	1°		
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER MEK 19 FEB 91	
	EDGE/ CORNER BREAKS OUTSIDE MAX	0.020	CHECKED MEK 25 FEB 91	
IBMCAD FILE WBRACKET.R3	EDGE/ CORNER BREAKS INSIDE MAX	0.020	APPROVED MEK 30 MAR 91	

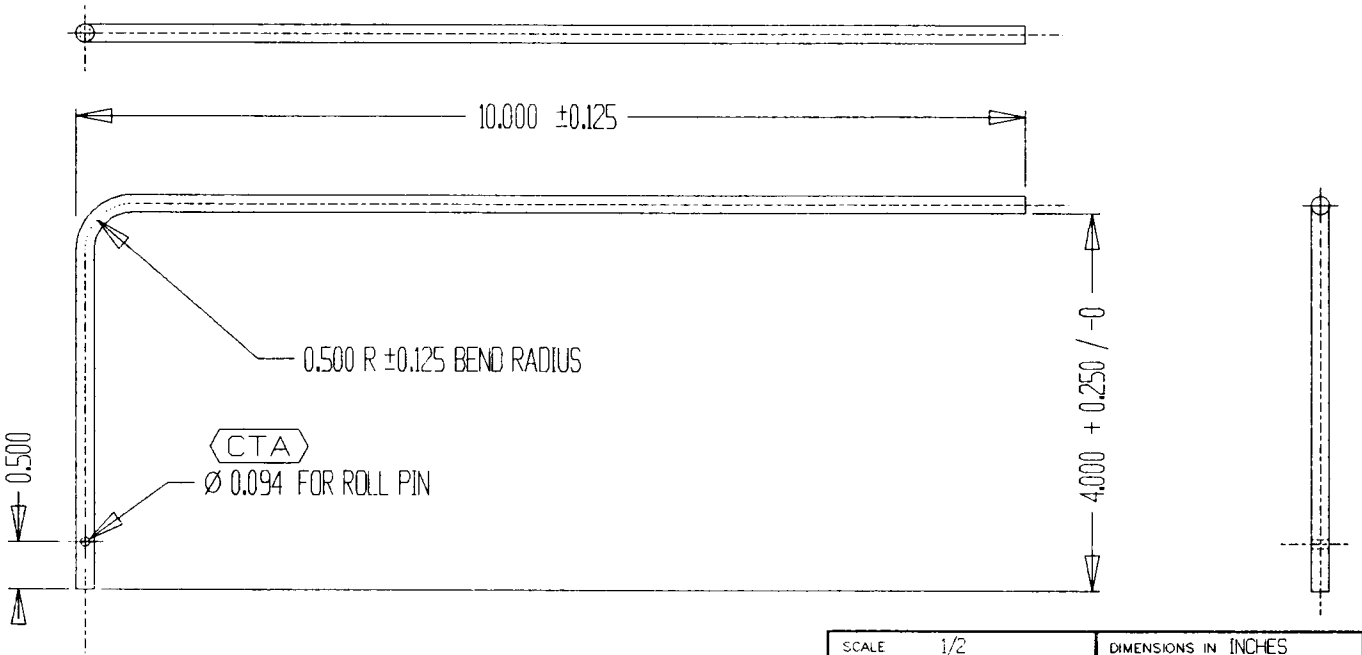
MEK097

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK098
KITE31	1	MECHANICAL	MEK	30 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



NOTES:

1 CUT AND BEND FROM Ø0.188 SOFT STEEL "WIRE" STOCK.



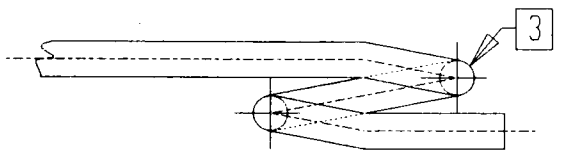
DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
(CTA)	"CRITICAL TO ASSEMBLY" DIMENSION
(CTF)	"CRITICAL TO FUNCTION" DIMENSION
(CTM)	"CRITICAL TO MANUFACTURE" DIMENSION

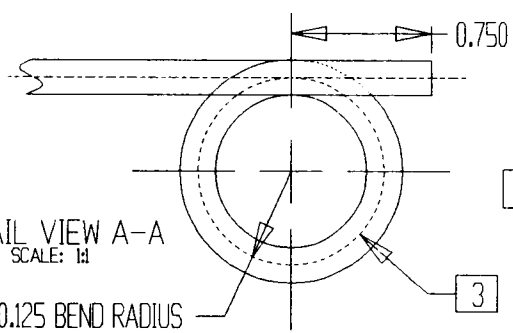
SCALE 1/2	DIMENSIONS IN INCHES		PART # MEK098			UT
MATERIAL SEE NOTE 1	TOLERANCES UNLESS NOTED		TITLE ROD, HANGER, Z MAST			
	LINEAR +/-	0.005				
	ANGLES +/-	1°				
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	01 FEB 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	30 MAR 91	
IBMCAD FILE HANGROD.R2	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	30 MAR 91	

MEK098

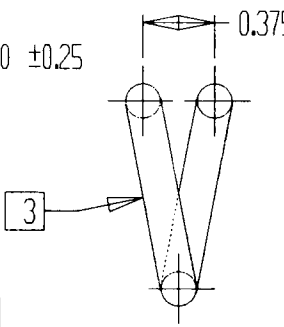
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N MEK099-LLL
KIT631	1	MECHANICAL	MEK	30 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



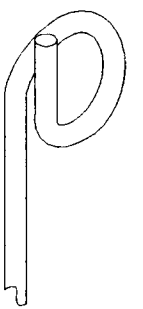
VIEW B-B
SCALE: 1:1



DETAIL VIEW A-A
SCALE: 1:1



VIEW C-C
SCALE: 1:1



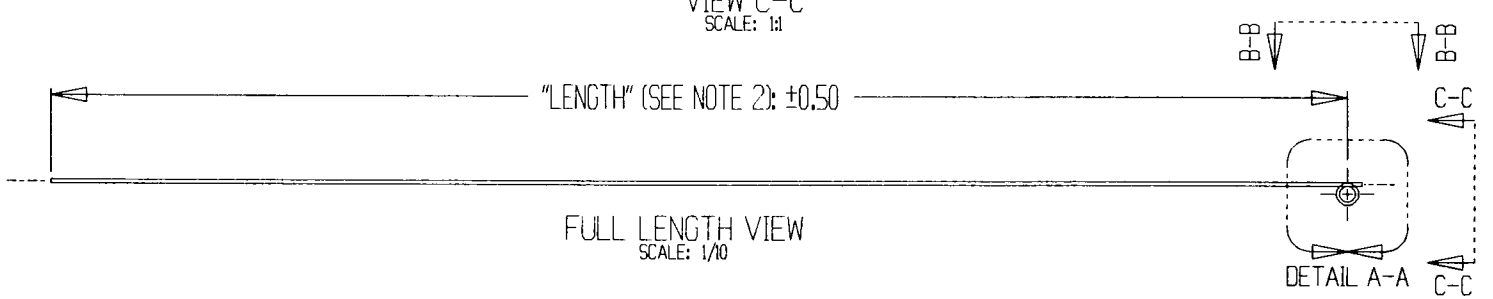
ISOMETRIC VIEW
"SCALE": 1/2
CLOSE-UP VIEW OF LOOP

NOTES:

1 CUT AND BEND FROM Ø0.188 SOFT STEEL "WIRE" STOCK.

2 BASIC PART LENGTH IS DETERMINED FROM P/N SUFFIX. NOTED LENGTH IS P/N SUFFIX DIVIDED BY TEN (10). FOR EXAMPLE, P/N SUFFIX -680 CALLS FOR A 68.0 DIMENSION LENGTH.

3 LOOP MAY BE WOUND IN EITHER A RIGHT-HAND OR A LEFT-HAND DIRECTION.



FULL LENGTH VIEW
SCALE: 1/10

DETAIL A-A

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

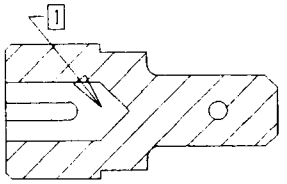
SCALE 1/2	DIMENSIONS IN INCHES		PART # MEK099-LLL		UT
MATERIAL SEE NOTE 1	TOLERANCES UNLESS NOTED		TITLE ROD, WIRE SUPPORT, FRAME MOUNTED		
	LINEAR +/-	0.005			
	ANGLES +/-	1°			
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	19 FEB 91
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	19 FEB 91
IBMCAD FILE FRAMEROD.R2	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	30 MAR 91

MEK099-LLL

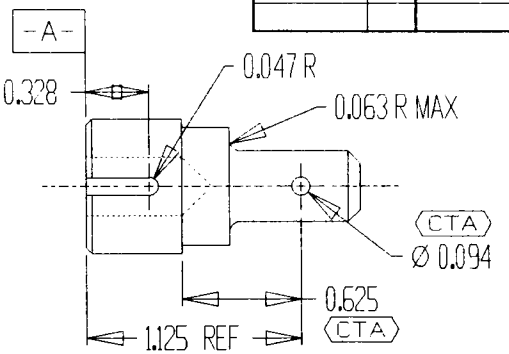
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY551-ZZZ	1	MECHANICAL	MEK	03 MAR 91			

P/N MEK201

"A" SIZE TEMPLATE 0 — 25" REAL SIZE

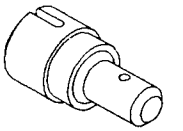


SECTION VIEW A-A
SCALE: 2:1

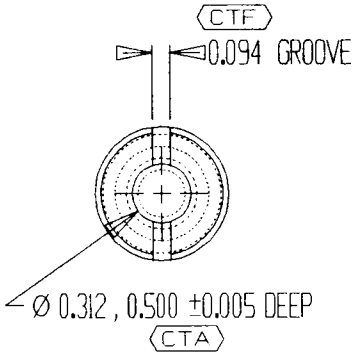


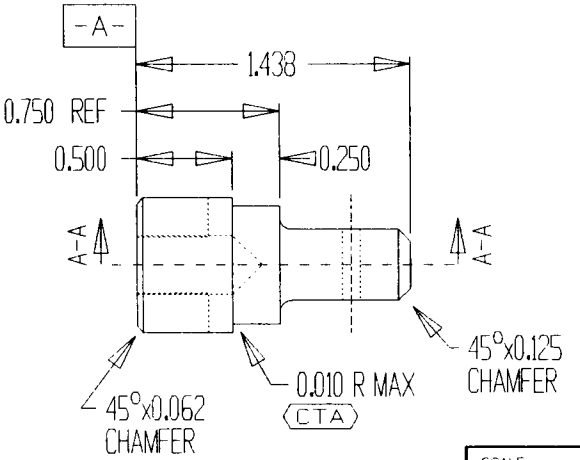
NOTES :

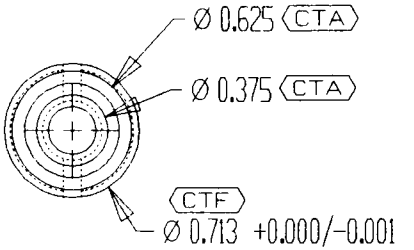
1. UP TO 0.312 ADDITIONAL DEPTH PERMITTED FOR DRILL TIP.
2. MATERIAL IS O-1 OIL HARDENING DRILL ROD, 0.750 OUTER DIAMETER. AFTER MACHINING, HARDEN BY OIL QUENCH AND TEMPER TO A HARDNESS OF Rc 40-45 (OPTIONAL).

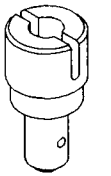


ISOMETRIC VIEW
"SCALE": 1/2
"HORIZONTAL ORIENTATION"









ISOMETRIC VIEW
"SCALE": 1/2
"VERTICAL ORIENTATION"

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

MEK201

SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK201		UT
MATERIAL O-1 DRILL ROD 2	TOLERANCES UNLESS NOTED		TITLE CONVERTER, MOTOR-TUBE		
	LINEAR +/-	0.005			
	ANGLES +/-	1°			
OTHER NOTES	RADII UNLESS NOTED	0.020	DESIGNER	MEK	20 AUG 90
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020	CHECKED	MEK	03 MAR 91
IBMCAD FILE CONVMTR .R4	EDGE/CORNER BREAKS INSIDE MAX	0.020	APPROVED	MEK	03 MAR 91

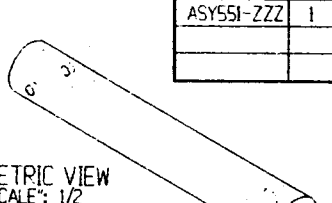
P/N SUFFIX CHART : [1]

P/N SUFFIX	"NOMINAL" LENGTH	ACTUAL LENGTH "L"
-120	12.000	19.375
-150	15.000	22.375
-175	17.500	24.875
-200	20.000	27.375
-240	24.000	31.375

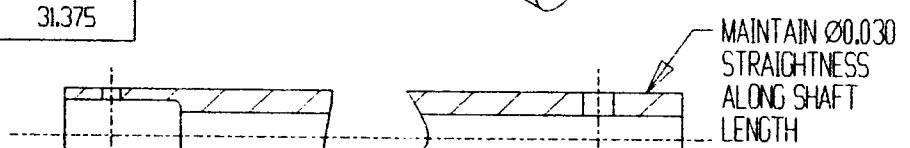
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY551-ZZZ	1	MECHANICAL	MEK	03 MAR 91			

P/N MEK216-ZZZ

"A" SIZE TEMPLATE 0 25" REAL SIZE



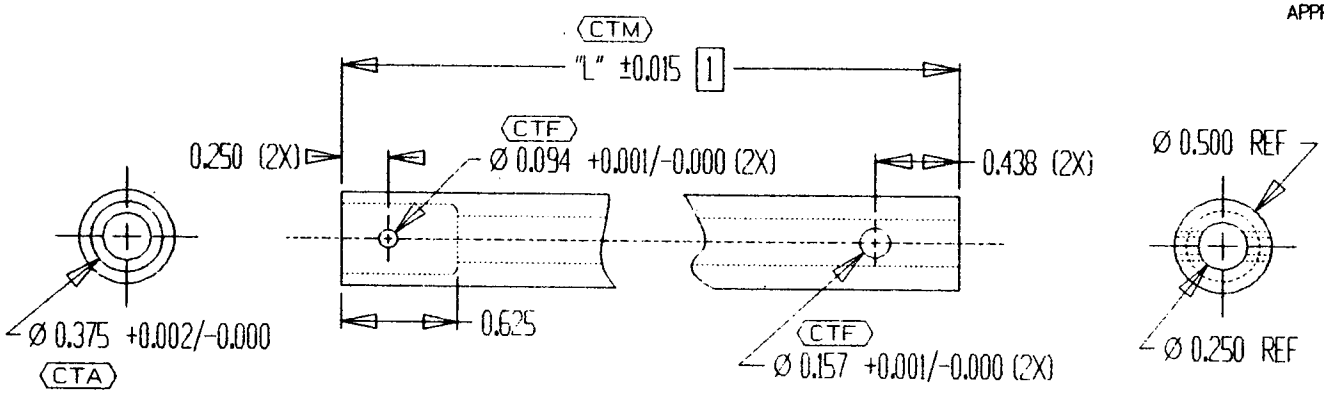
ISOMETRIC VIEW
"SCALE": 1/2
"HORIZONTAL ORIENTATION"



NOTES :

[1] TUBE NOMINAL LENGTH IS DESIGNATED BY THE PART SUFFIX, AND INDICATES THE SPECIFIED "Z" TRAVEL FOR THE ROBOT ASSEMBLY. ACTUAL TUBE LENGTH IS DETERMINED FROM THE NOMINAL LENGTH. SEE P/N SUFFIX CHART.

[2] TUBE IS T6061 ALUMINUM, 0.500 OUTER DIAMETER, 0.125 WALL.
SUGGESTED VENDOR:
LOFTIS
CHATTANOOGA, TN
ALTERNATE MATERIAL AND VENDOR MAY BE PERMITTED, BUT SPECIFIC ENGINEERING APPROVAL IS REQUIRED.





ISOMETRIC VIEW
"SCALE": 1/2
"VERTICAL ORIENTATION"

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
CTA	"CRITICAL TO ASSEMBLY" DIMENSION
CTF	"CRITICAL TO FUNCTION" DIMENSION
CTM	"CRITICAL TO MANUFACTURE" DIMENSION

MEK216-ZZZ

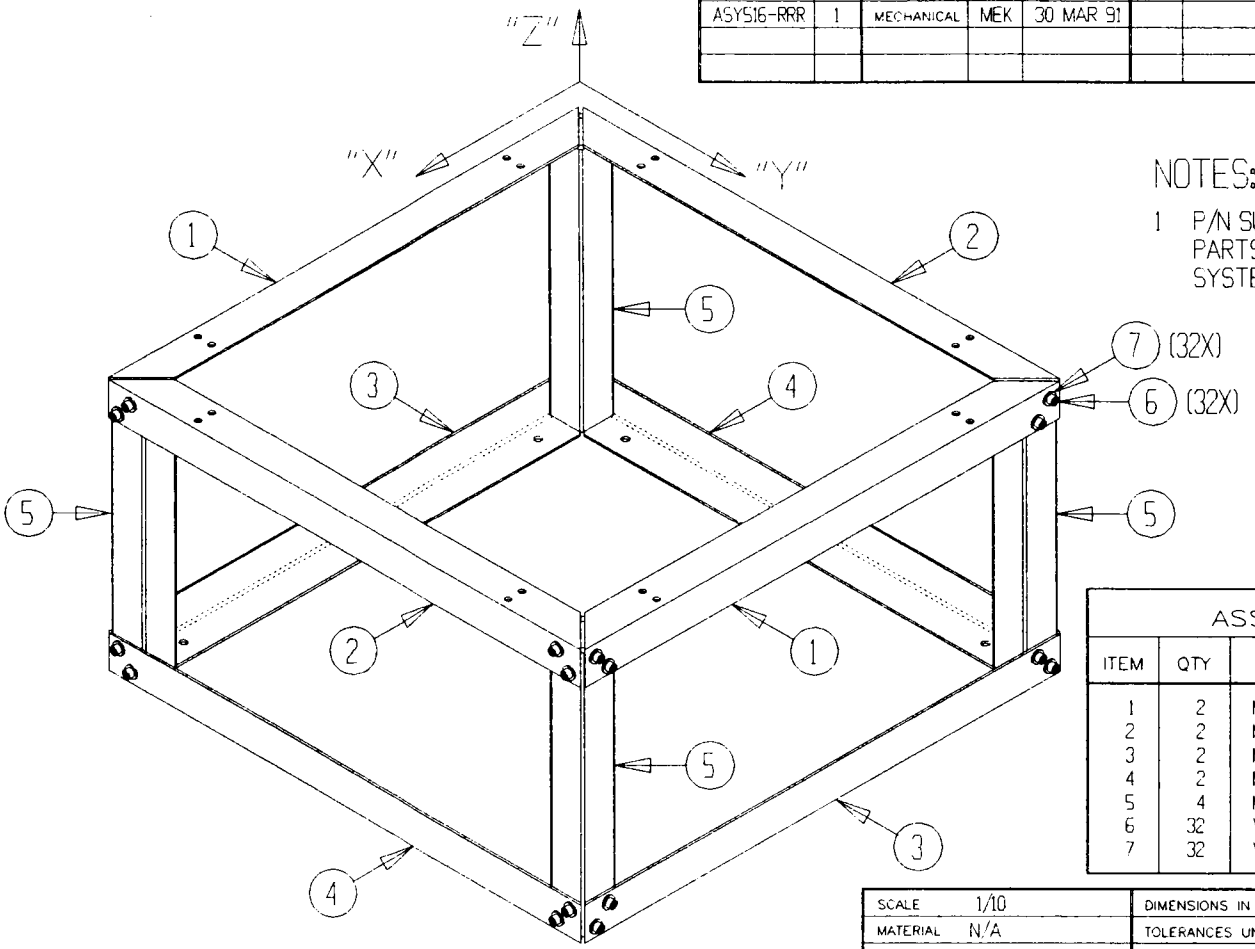
SCALE 1:1	DIMENSIONS IN INCHES		PART # MEK216-ZZZ [1]		UT
MATERIAL SEE NOTE 2	TOLERANCES UNLESS NOTED		TITLE TUBE, THETA TRANSMISSION		
	LINEAR +/-	0.005	DESIGNER	MEK	07 JUL 90
	ANGLES +/-	1°	CHECKED	MEK	03 MAR 91
OTHER NOTES	RADII UNLESS NOTED	0.020	APPROVED	MEK	03 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	0.020			
IBMCAD FILE TTUBE .R2	EDGE/CORNER BREAKS INSIDE MAX	0.020			

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY516-RRR	1	MECHANICAL	MEK	30 MAR 91			

P/N ASY300-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 2



ASSEMBLED VIEW
"SCALE": 1/10

NOTES:

1 P/N SUFFIXES -XXX, -YYY, -ZZZ IN THE PARTS LIST ARE DETERMINED FROM ROBOT SYSTEM TRAVEL SPECIFICATIONS.

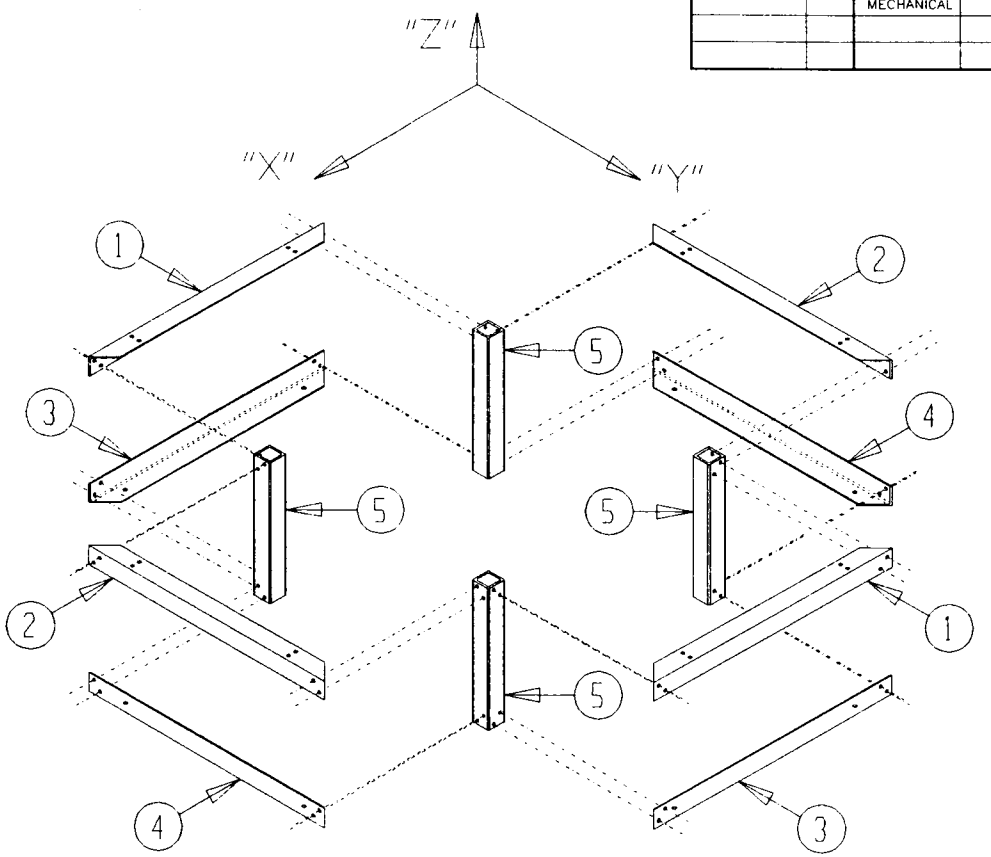
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	2	MEK301-XXX	MEMBER, MOUNT, "X" DIRECTION
2	2	MEK302-YYY	MEMBER, MOUNT, "Y" DIRECTION
3	2	MEK303-XXX	MEMBER, BASE, "X" DIRECTION
4	2	MEK304-YYY	MEMBER, BASE, "Y" DIRECTION
5	4	MEK306-ZZZ	MEMBER, VERTICAL "Z"
6	32	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
7	32	VEN487	WASHER, FOR 0.312 SCREW

SCALE 1/10	DIMENSIONS IN INCHES		PART # ASY300-RRR	UT		
MATERIAL N/A	TOLERANCES UNLESS NOTED					
	LINEAR +/-	N/A	TITLE ASSEMBLY, FRAME			
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	27 MAR 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	27 MAR 91	
IBMCAD FILE FRAMEASY.P4	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	30 MAR 91	

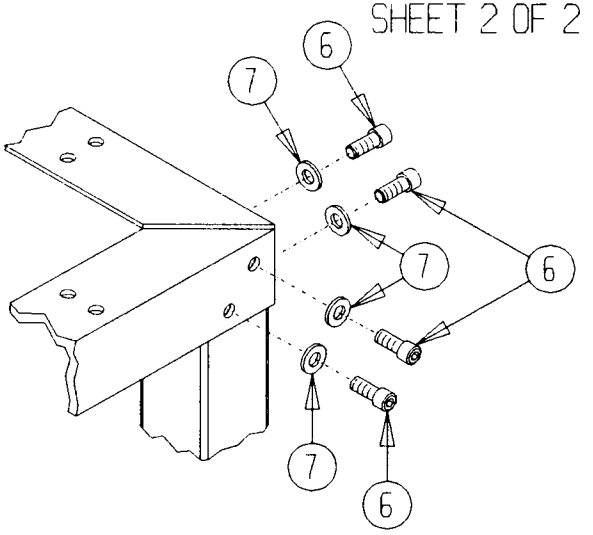
ASY300-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY300-RRR
		MECHANICAL						"A" SIZE TEMPLATE 0 .25" REAL SIZE



EXPLODED VIEW
"SCALE": 1/20
FASTENERS NOT SHOWN

SHEET 2 OF 2



FASTENER DETAIL VIEW
"SCALE": 1/5
ARRANGEMENT USED AT ALL CONNECTIONS

ASY300-RRR

SCALE 1/10	DIMENSIONS IN INCHES			PART # ASY300-RRR			UT
MATERIAL N/A	TOLERANCES UNLESS NOTED						
	LINEAR +/-		N/A	TITLE ASSEMBLY, FRAME			
	ANGLES +/-		N/A				
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	27 MAR 91	
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	27 MAR 91	
IBMCAD FILE FRAMEASY.R4		INSIDE MAX	N/A	APPROVED	MEK	30 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY521-DDD	1	MECHANICAL	MEK	04 MAR 91			
ASY541-DDD	4						

P/N VEN401-DDD

"A" SIZE TEMPLATE 0 .25" REAL SIZE

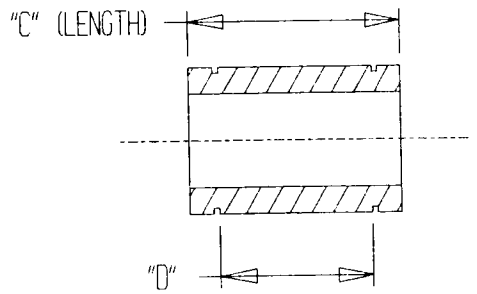
P/N SUFFIX CHART : [1]

P/N SUFFIX	SHAFT Ø	VENDOR P/N	"A"	"B"	"C"	"D"
-075	0.750	A-122026	0.7500	1.2500	1.625	1.062
-100	1.000	A-162536	1.0000	1.5625	2.250	1.625
-125	1.250	A-203242	1.2500	2.0000	2.625	1.875

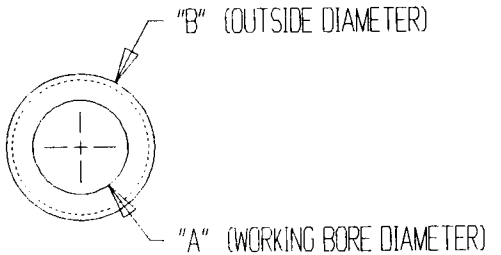
NOTES:

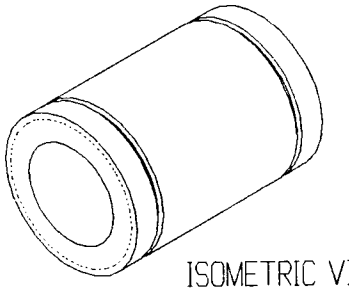
[1] VENDOR PART NUMBER AND RELEVANT REFERENCE DIMENSIONS ARE DETERMINED FROM P/N SUFFIX CHART. PART DIMENSIONS PROVIDED IN THIS CHART ARE FOR REFERENCE ONLY.

2 SPECIFIED VENDOR: THOMSON INDUSTRIES, INC. PORT WASHINGTON, NY
USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.



(DISTANCE BETWEEN RETAINING RINGS)





ISOMETRIC VIEW
"SCALE": 1/2
"-100 VERSION"

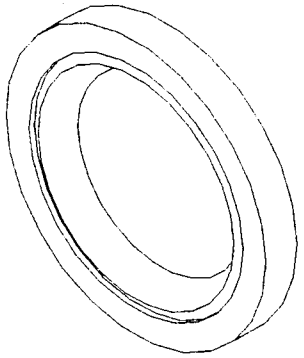
SCALE 1/2	DIMENSIONS IN INCHES			PART # VEN401-DDD	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE LINEAR BEARING, BALL,	
	ANGLES +/-		N/A	"A" SERIES PRECISION	
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	18 OCT 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	04 MAR 91
IBMCAD FILE LINBRG .R3		INSIDE MAX	N/A	APPROVED	MEK	04 MAR 91

VEN401-DDD

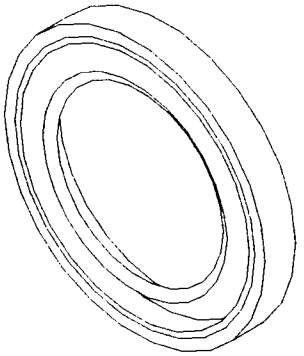
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY521-DDD	2	MECHANICAL	MEK	05 MAR 91			
ASY541-DDD	4						
ASY571	2						

P/N VEN402-DDD

"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW #1
"SCALE": 1:1
"FRONT SIDE VIEW - 1" NOM DIA."

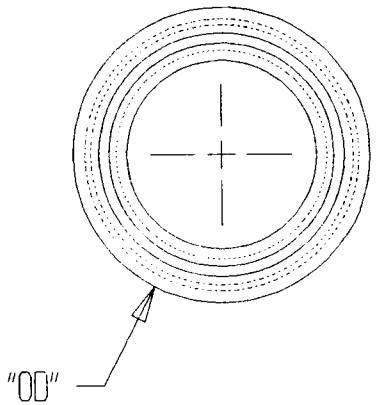


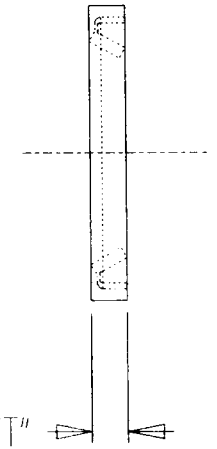
ISOMETRIC VIEW #2
"SCALE": 1:1
"REAR SIDE VIEW - 1" NOM DIA."

NOTES:

1. VENDOR PART NUMBER AND RELEVANT REFERENCE DIMENSIONS ARE DETERMINED FROM P/N SUFFIX CHART. PART DIMENSIONS PROVIDED IN THIS CHART ARE FOR REFERENCE ONLY.

2 SPECIFIED VENDOR: THOMSON INDUSTRIES, INC.
PORT WASHINGTON, NY
USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.





P/N SUFFIX CHART : 1

P/N SUFFIX	SHAFT Ø	VENDOR P/N	"T"	"OD"
-075	0.750	S- 750	0.125	1.254
-100	1.000	S-1000	0.187	1.567
-125	1.250	S-1250	0.375	2.004

VEN402-DDD

SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN402-DDD		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED					
	LINEAR +/-		N/A	TITLE SEAL, LINEAR BALL BEARING (THOMSON)		
	ANGLES +/-		N/A			
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	01 OCT 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	05 MAR 91
IBMCAD FILE LINSEAL.R3		INSIDE MAX	N/A	APPROVED	MEK	05 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN403-DDD
ASY571	1	MECHANICAL	MEK	05 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

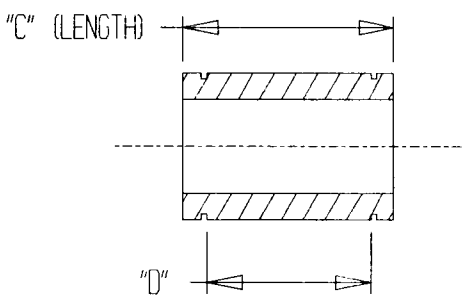
P/N SUFFIX CHART : [1]

P/N SUFFIX	SHAFT Ø	VENDOR P/N	"A"	"B"	"C"	"D"
-075	0.750	SUPER-12	0.7500	1.2500	1.625	1.160
-100	1.000	SUPER-16	1.0000	1.5625	2.250	1.750
-125	1.250	SUPER-20	1.2500	2.0000	2.625	1.875

NOTES:

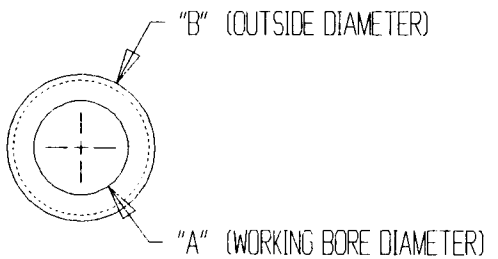
[1] VENDOR PART NUMBER AND RELEVANT REFERENCE DIMENSIONS ARE DETERMINED FROM P/N SUFFIX CHART.
PART DIMENSIONS PROVIDED IN THIS CHART ARE FOR REFERENCE ONLY.

2 SPECIFIED VENDOR: THOMSON INDUSTRIES, INC.
PORT WASHINGTON, NY
USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.

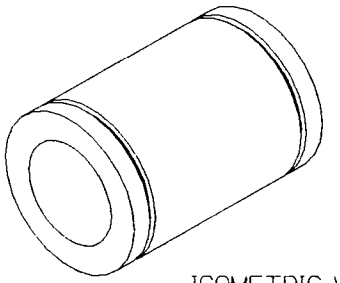


(DISTANCE BETWEEN RETAINING RINGS)

(1.00 DIA BEARING SHOWN)
SCALE: 1/2



(1.00 DIA BEARING SHOWN)
SCALE: 1/2

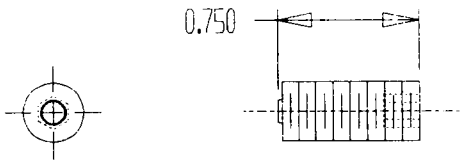


ISOMETRIC VIEW
"SCALE": 1/2
"-100 VERSION"

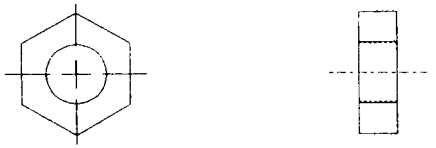
SCALE 1/2	DIMENSIONS IN INCHES		PART # VEN403-DDD		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE LINEAR BEARING, BALL SUPER BALL (SELF-ALIGNING)		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	18 OCT 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	05 MAR 91
IBMCAD FILE SUPERBRG2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	05 MAR 91

VEN403-DDD

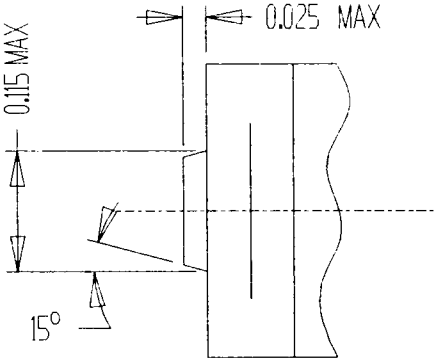
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN404
ASY571	2	MECHANICAL	MEK	06 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ADJUSTING SCREW
Ø0.312-18 UNC-2A
NOTE TIP DIMENSIONS AS SHOWN



LOCK NUT
Ø0.312-18 UNC-2B



TIP DETAIL
SCALE: 5:1
"FOR REFERENCE ONLY"

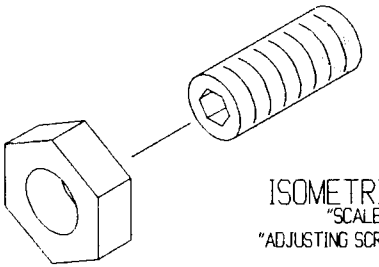
NOTES:

1 SPECIFIED VENDOR:
THOMSON INDUSTRIES, INC.
PORT WASHINGTON, NY

USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.

2 VENDOR P/N: BGS-4

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.



ISOMETRIC VIEW
"SCALE": 1:1
"ADJUSTING SCREW AND NUT"

SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN404		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED			TITLE ASSEMBLY, SCREW, ADJUSTING		
	LINEAR +/-		N/A			
	ANGLES +/-		N/A	DESIGNER	MEK	27 JUL 90
OTHER NOTES	RADII UNLESS NOTED		N/A	CHECKED	MEK	06 MAR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	APPROVED	MEK	06 MAR 91
IBMCAD FILE BGS-4 .R2		INSIDE MAX	N/A			

VEN404

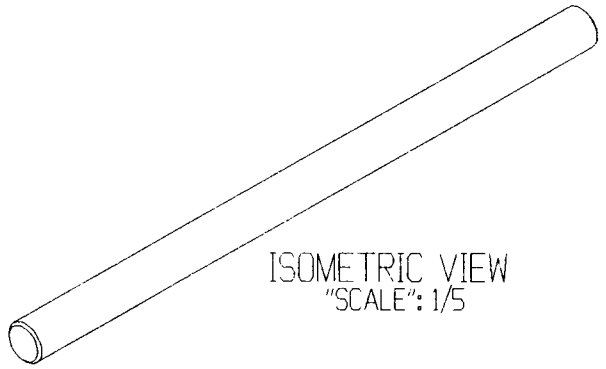
P/N SUFFIX CHART : [1]

NOMINAL SHAFT Ø	ACTUAL SHAFT Ø	P/N SUFFIX	"L"
0.750	0.7490/0.7485	-240	30.250
		-300	36.250
		-360	42.250
1.000	0.9990/0.9985	-240	32.000
		-300	38.000
		-360	44.000
		-420	50.000
1.250	1.2490/1.2485	-240	33.250
		-300	39.250
		-360	45.250
		-420	51.250

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY516-RRR	2	MECHANICAL	MEK	10 MAR 91			

P/N VEN406-XXX

"A" SIZE TEMPLATE 0 .25" REAL SIZE



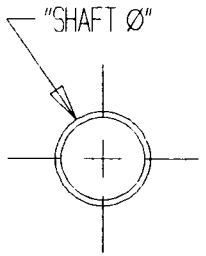
ISOMETRIC VIEW
"SCALE": 1/5

NOTES:

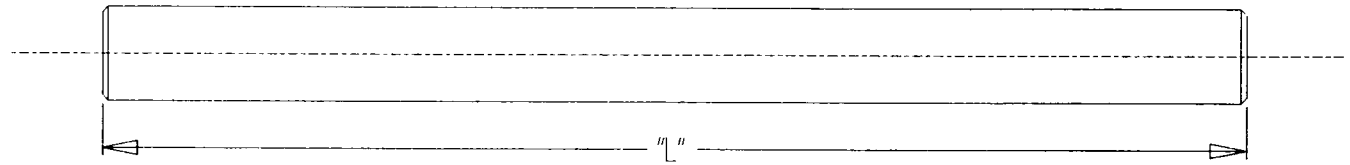
[1] RELEVANT REFERENCE DIMENSIONS ARE DETERMINED FROM P/N SUFFIX CHART. TO SELECT A SHAFT, BOTH DESIRED ROBOT TRAVEL (SHOWN IN P/N SUFFIX) AND A DESIRED SHAFT DIAMETER MUST BE KNOWN. SHAFT DIAMETER CAN BE DETERMINED FROM P/N SUFFIX OF XY SLIDER, P/N MEK021-DDD OR FROM ROBOT CONFIGURATION DATA.

2 SPECIFIED VENDOR: THOMSON INDUSTRIES, INC.
PORT WASHINGTON, NY
USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.

3 SHAFTING IS "SOLID STEEL 60 CASE SHAFT (Rockwell 60-65C)", TOLERANCE CLASS "S". NOMINAL SHAFT DIAMETER IS DETERMINED AS SPECIFIED IN NOTE 1. MATERIAL IS 1060 STEEL, CASE HARDENED TO Rc 60-65.



END VIEW
SCALE: 1/2
(1.00 SHAFT DIA. VERSION)



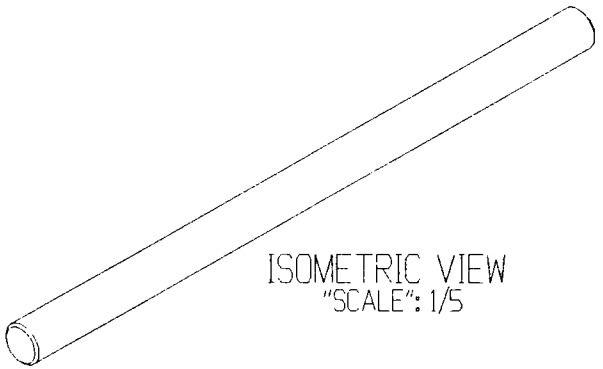
VEN406-XXX

SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN406-XXX		UT
MATERIAL SEE NOTE 3	TOLERANCES UNLESS NOTED		TITLE SHAFT, HORIZONTAL GUIDE (THOMSON)		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	10 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	10 MAR 91
IBMCAD FILE GSHAFT .R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	10 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN407-XXX
ASY516-RRR	1	MECHANICAL	MEK	11 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART : [1]

NOMINAL SHAFT ∅	ACTUAL SHAFT ∅	P/N SUFFIX	"L"
0.750	0.7490/0.7485	-240	32.750
		-300	39.750
		-360	45.750
1.000	0.9990/0.9985	-240	35.500
		-300	41.500
		-360	47.500
		-420	53.500
1.250	1.2490/1.2485	-240	36.750
		-300	42.750
		-360	48.750
		-420	54.750



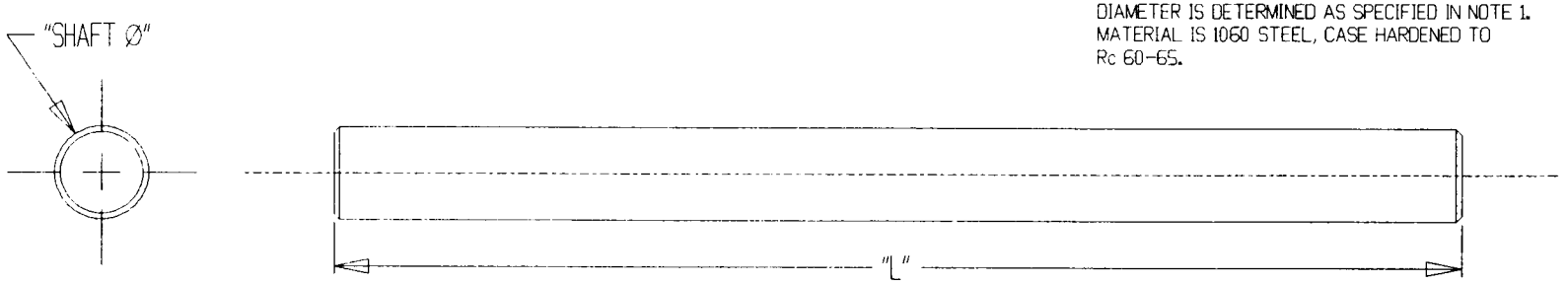
ISOMETRIC VIEW
"SCALE": 1/5

NOTES:

[1] RELEVANT REFERENCE DIMENSIONS ARE DETERMINED FROM P/N SUFFIX CHART. TO SELECT A SHAFT, BOTH DESIRED ROBOT TRAVEL (SHOWN IN P/N SUFFIX) AND A DESIRED SHAFT DIAMETER MUST BE KNOWN. SHAFT DIAMETER CAN BE DETERMINED FROM P/N SUFFIX OF XY SLIDER, P/N MEK021-DDD OR FROM ROBOT CONFIGURATION DATA.

2 SPECIFIED VENDOR: THOMSON INDUSTRIES, INC.
PORT WASHINGTON, NY
USE OF ANY OTHER VENDOR REQUIRES EXPLICIT ENGINEERING APPROVAL.

3 SHAFTING IS "SOLID STEEL 60 CASE SHAFT (Rockwell 60-65C)", TOLERANCE CLASS "S". NOMINAL SHAFT DIAMETER IS DETERMINED AS SPECIFIED IN NOTE 1. MATERIAL IS 1060 STEEL, CASE HARDENED TO Rc 60-65.



END VIEW
SCALE: 1/2
(1.00 SHAFT DIA. VERSION)

SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN407-XXX	UT
MATERIAL SEE NOTE 3	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE SHAFT, HORIZONTAL CONTROL (THOMSON)	
	ANGLES +/-		N/A		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK 11 MAR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK 11 MAR 91
IBMCAD FILE CSHAFT .R1		INSIDE MAX	N/A	APPROVED	MEK 11 MAR 91

VEN407-XXX

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN413
MEK063	1	MECHANICAL	MEK	04 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

MOTOR TECHNICAL SPECIFICATIONS

MECHANICAL		
MOTOR SIZE :	NEMA SIZE 23	
STEP ANGLE :	1.8	DEG (°)
STATIC TORQUE –		
* PARALLEL CONNECTED :	150	OZ*IN
* SERIES CONNECTED :	–	OZ*IN
ROTOR INERTIA :	0.109	LB*IN^2
MOTOR WEIGHT :	2.75	LB
MAX THRUST LOAD :	N/A	LB
MAX RADIAL LOAD :	N/A	LB
END PLAY (1 LB LOAD) :	N/A	IN
RADIAL PLAY (1.0 LB LOAD) :	N/A	IN

ELECTRICAL		
NUMBER OF LEADS:	6	
RATED VOLTAGE (PER PHASE):	3.4	VOLTS
RATED CURRENT (PER PHASE) :	2.9	AMPS
RESISTANCE (PER PHASE):	1.16	OHMS
INDUCTANCE (PER PHASE):	2.90	mH

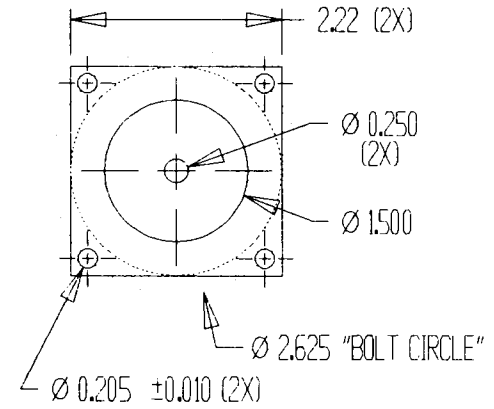
VENDOR DATA	
VENDOR NAME :	ANAHEIM AUTOMATION
VENDOR LOCATION :	ANAHEIM, CA
PART NUMBER :	23D306D

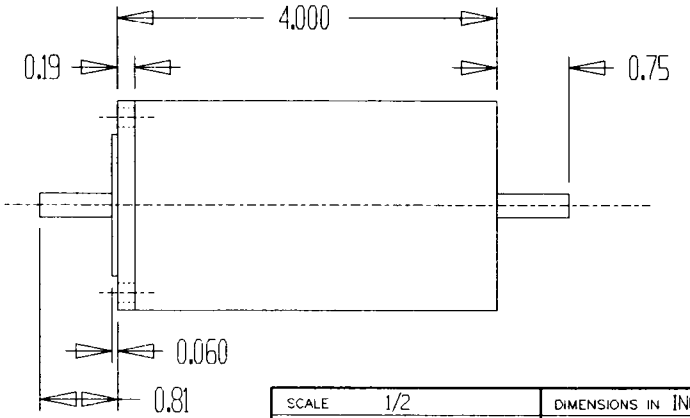
NOTES:

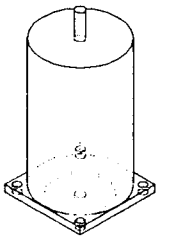
1 PART DIMENSIONS AND PERFORMANCE SPECIFICATIONS ARE PROVIDED "FOR REFERENCE ONLY". ADDITIONAL DATA SHOULD BE OBTAINED FROM VENDOR LITERATURE.

2 USE OF ANY OTHER MOTOR BRAND THAN THAT SPECIFIED REQUIRES ENGINEERING APPROVAL.

3 SUGGESTED DISTRIBUTOR:
MINARIK ELECTRIC
LOUISVILLE, KY







ISOMETRIC VIEW
"SCALE": 1/5
"SHAFT END DOWN" VIEW

SCALE 1/2	DIMENSIONS IN INCHES			PART # VEN413	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/–		N/A	TITLE MOTOR, STEPPER, SIZE 23, "THREE STACK", DOUBLE SHAFT	
	ANGLES +/–		N/A		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK 19 DEC 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK 04 MAR 91
IBMCAD FILE S23MTR3A.R3		INSIDE MAX	N/A	APPROVED	MEK 04 MAR 91

VEN413

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN414
MEK064	1	MECHANICAL	MEK	13 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

MOTOR TECHNICAL SPECIFICATIONS

MECHANICAL		
MOTOR SIZE :	NEMA SIZE 34	
STEP ANGLE :	1.8	DEG (°)
STATIC TORQUE -		
* PARALLEL CONNECTED :	150	OZ*IN
* SERIES CONNECTED :	N/A	OZ*IN
ROTOR INERTIA :	0.23	LB*IN^2
MOTOR WEIGHT :	3.25	LB
MAX THRUST LOAD :	-	LB
MAX RADIAL LOAD :	-	LB
END PLAY (1 LB LOAD) :	-	IN
RADIAL PLAY (0.5 LB LOAD) :	-	IN

ELECTRICAL		
NUMBER OF LEADS:	6	
RATED VOLTAGE (PER PHASE):	2.9	VOLTS
RATED CURRENT (PER PHASE) :	3.0	AMPS
RESISTANCE (PER PHASE):	0.95	OHMS
INDUCTANCE (PER PHASE):	3.8	mH

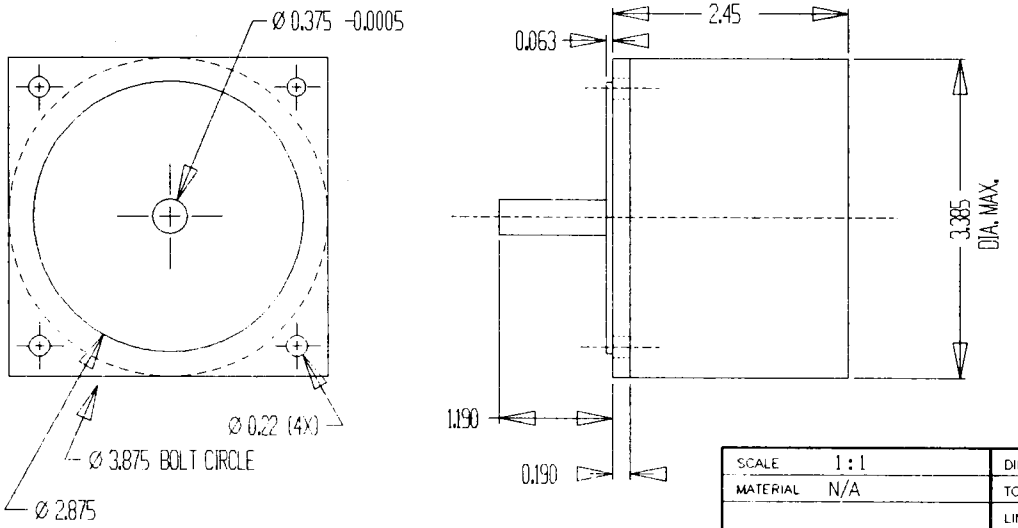
VENDOR DATA	
VENDOR NAME :	ANAHEIM AUTOMATION
VENDOR LOCATION :	ANAHEIM, CA
PART NUMBER :	34D106S

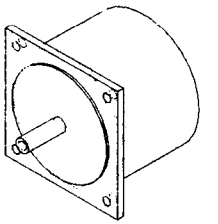
NOTES:

1 PART DIMENSIONS AND PERFORMANCE SPECIFICATIONS ARE PROVIDED "FOR REFERENCE ONLY". ADDITIONAL DATA SHOULD BE OBTAINED FROM VENDOR LITERATURE.

2 USE OF ANY OTHER MOTOR BRAND THAN THAT SPECIFIED REQUIRES ENGINEERING APPROVAL.

3 SUGGESTED DISTRIBUTOR:
MINARIK ELECTRIC
LOUISVILLE, KY





ISOMETRIC VIEW
"SCALE": 1/5
"SHAFT FRONT LEFT" VIEW

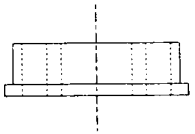
VEN414

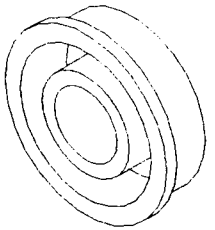
SCALE 1 : 1	DIMENSIONS IN INCHES		PART # VEN414		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE MOTOR, STEPPER,		
	ANGLES +/-	N/A	SIZE 34, "ONE STACK"		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	19 DEC 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	13 MAR 91
IBMCAD FILE S34MTR1.R3	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	13 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY591-ZZZ	2	MECHANICAL	MEK	18 MAR 91			
KIT611-RRR	8						
KIT621-RRR	2						

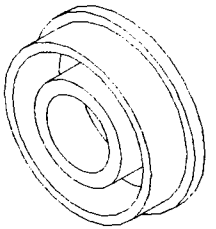
P/N VEN421

"A" SIZE TEMPLATE 0 .25" REAL SIZE





ISOMETRIC VIEW
"SCALE": 1:1
"FLANGE END VIEW"



ISOMETRIC VIEW
"SCALE": 1:1
"VIEW OPPOSITE TO FLANGE"

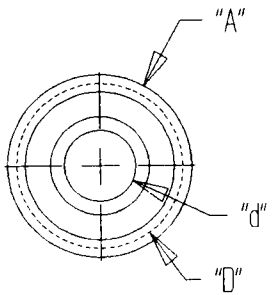
NOTES:

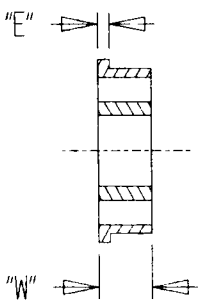
1 GENERIC PART NAME/REQUIREMENTS:
- BALL BEARING, RADIAL, FLANGED
- SEALED BOTH SIDES
- GREASE LUBE
- SINGLE ROW

2 RECOMMENDED VENDOR:
NATIONAL BEARING SERVICE
ST. PETERSBURG, FL

3 VENDOR P/N: FR6-2RS

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.





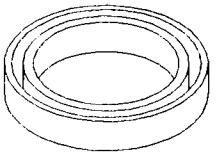
TECHNICAL DATA:

	ABEC CLASS :	1
"d"	BORE DIA. :	0.375
"D"	OUTER DIA. :	0.875
"A"	FLANGE DIA. :	0.969
"W"	WIDTH (TOTAL) :	0.281
"E"	WIDTH, FLANGE :	0.062

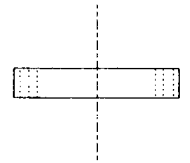
SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN422		UT
MATERIAL 52100 STEEL	TOLERANCES UNLESS NOTED		TITLE BEARING, BALL,		
	LINEAR +/-	N/A	RADIAL, 0.375 ID, FLANGED		
	ANGLES +/-	N/A	DESIGNER	MEK	31 JUL 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	18 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	18 MAR 91
IBMCAD FILE BBR0375.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

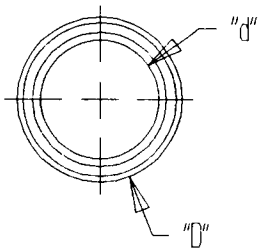
VEN421

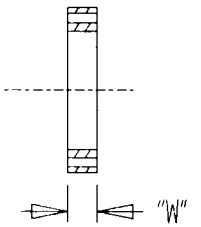
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN422
ASY551-ZZZ	2	MECHANICAL	MEK	11 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW
"SCALE": 1:1
HORIZONTAL ORIENTATION







NOTES:

1 GENERIC PART NAME/REQUIREMENTS:
- BALL BEARING, RADIAL
- SHIELDED BOTH SIDES
- GREASE LUBE
- SINGLE ROW

2 RECOMMENDED VENDOR:
NATIONAL BEARING SERVICE
ST. PETERSBURG, FL

3 VENDOR P/N: SR1028ZZ(A3)

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

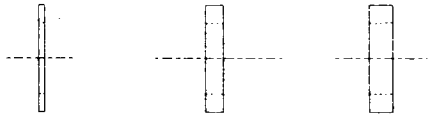
TECHNICAL DATA:

	ABEC CLASS :	1
"d"	BORE DIA. :	0.625
"D"	OUTER DIA. :	0.875
"W"	WIDTH (TOTAL) :	0.156

SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN422		UT
MATERIAL 52100 STEEL	TOLERANCES UNLESS NOTED					
	LINEAR +/-		N/A	TITLE BEARING, BALL,		
	ANGLES +/-		N/A	RADIAL, 0.625 ID, 0.875 OD		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	25 OCT 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	11 MAR 91
IBMCAD FILE BBRG625.R2		INSIDE MAX	N/A	APPROVED	MEK	11 MAR 91

VEN422

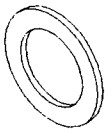
REL FOR ASM	QTY	REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN426-ttt
KIT611-RRR	AR	ASY511-RRR	8	MECHANICAL	MEK	18 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE
KIT621-RRR	AR	ASY581-RRR	2							
		ASY591-ZZZ	4							



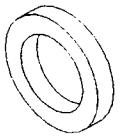
SIDE VIEW
SCALE: 1:1
-031 VERSION

SIDE VIEW
SCALE: 1:1
-093 VERSION

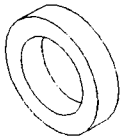
SIDE VIEW
SCALE: 1:1
-125 VERSION



ISOMETRIC VIEW
"SCALE": 1:1
-031 VERSION



ISOMETRIC VIEW
"SCALE": 1:1
-093 VERSION

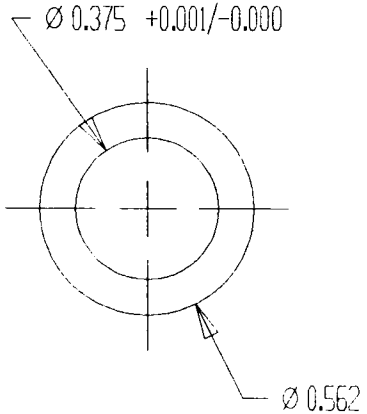


ISOMETRIC VIEW
"SCALE": 1:1
-125 VERSION

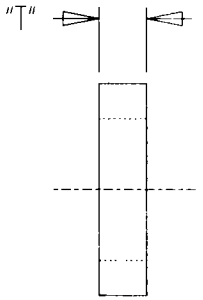
NOTES:

[1] SPACER THICKNESS IS DETERMINED BY THE P/N SUFFIX CHART.

2 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL



FRONT VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-125 VERSION SHOWN

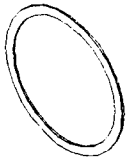
P/N SUFFIX CHART:

P/N SUFFIX	"T"
-031	0.031
-093	0.093
-125	0.125

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN426-ttt		UT
MATERIAL 1010 COLD ROLLED STEEL	TOLERANCES UNLESS NOTED		TITLE SPACER, INNER RACE, 0.375ID, 0.562 OD, 0.ttt THICK		
	LINEAR +/-	0.002			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	01 OCT 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	18 MAR 91
IBMCAD FILE SPACE375.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	18 MAR 91

VEN426-ttt

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN427-ttt
ASY551-ZZZ1	AR	MECHANICAL	MEK	11 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

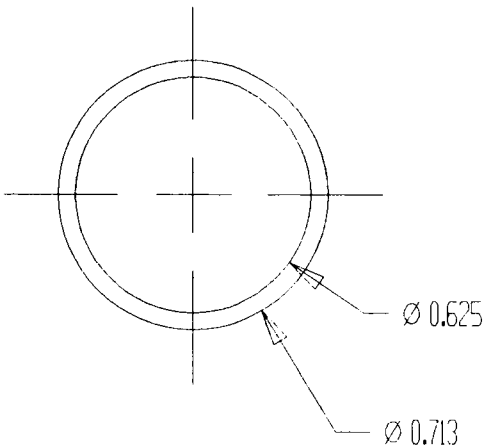


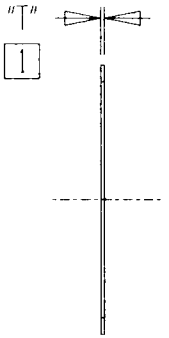
ISOMETRIC VIEW
"SCALE": 1:1
"T" = 0.010 SHOWN

NOTES:

[1] SHIM THICKNESS IS DETERMINED BY THE P/N SUFFIX CHART.

2 SUGGESTED VENDOR:
SUPERIOR WASHER AND GASKET CORP.
HAUPPAUGE, NY





P/N SUFFIX CHART:

P/N SUFFIX	"T"
-001	0.001
-002	0.002
-005	0.005
-008	0.008
-010	0.010
-015	0.015
-020	0.020
-025	0.025

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN427-ttt			UT
MATERIAL 303 STAINLESS STEEL	TOLERANCES UNLESS NOTED		TITLE SHIM, 0.625 ID, 0.713 OD, 0.ttt THICK			
	LINEAR +/-	0.001				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	27 JUL 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	11 MAR 91	
IBMCAD FILE SHIM625.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	11 MAR 91	

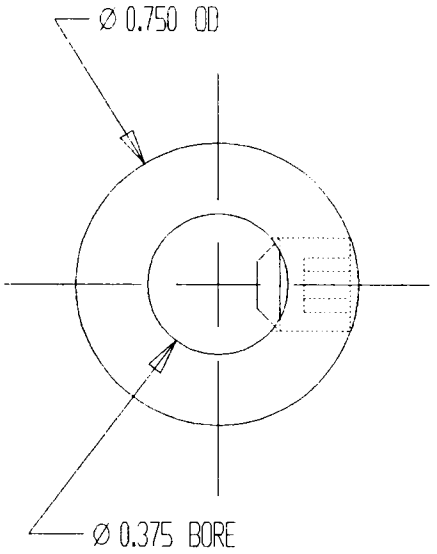
VEN427-ttt

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN428
KIT611	2	MECHANICAL	MEK	13 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

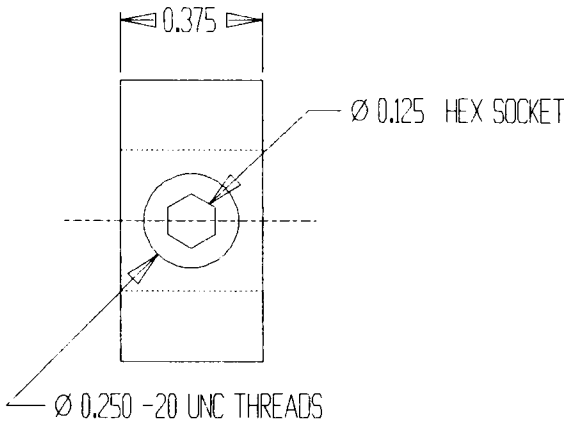
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

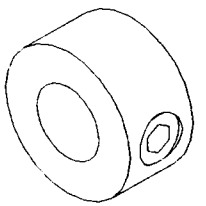
VENDOR P/N 6166K23



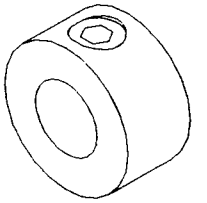
"FRONT" VIEW
"SCALE": 2:1



"SIDE" VIEW
"SCALE": 2:1



ISOMETRIC VIEW
"SCALE": 1:1
"SET SCREW ON SIDE"

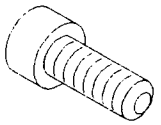


ISOMETRIC VIEW
"SCALE": 1:1
"SET SCREW ON TOP"

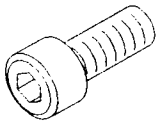
SCALE 2:1	DIMENSIONS IN INCHES			PART # VEN428			UT
MATERIAL SINTERED STEEL	TOLERANCES UNLESS NOTED						
	LINEAR +/-		N/A	TITLE COLLAR, SHAFT,			
	ANGLES +/-		N/A	0.375 BORE			
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	13 MAR 91	
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	13 MAR 91	
IBMCAD FILE SCOLLAR.R1		INSIDE MAX	N/A	APPROVED	MEK	13 MAR 91	

VEN428

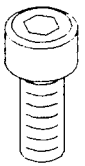
REF FOR ASM	QTY	REF FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN448-LLL
ASY561	4	ASY531	4	MECHANICAL	MEK	13 MAR 91				"A" SIZE TEMPLATE 0 25" REAL SIZE
KIT631	6	ASY532	4							
		ASY536	4							



ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
HORIZONTAL - THREAD END VIEW



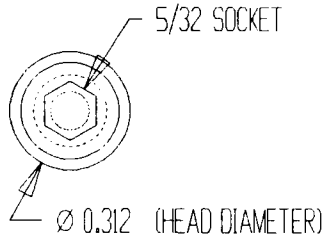
ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
HORIZONTAL ORIENTATION



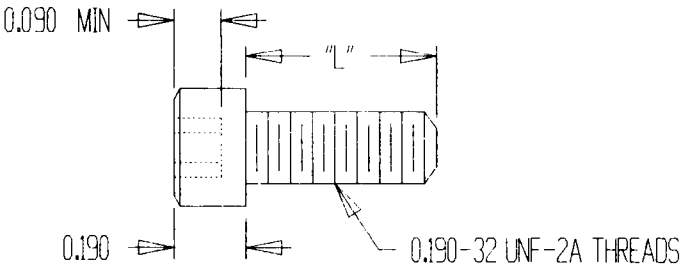
ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
VERTICAL ORIENTATION

NOTES:

1. SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.
2. SUGGESTED VENDOR:
   McMASTER-CARR SUPPLY COMPANY
   CHICAGO, IL



SOCKET END VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-050 (1/2 LONG) SHOWN

P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250

SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN448-LLL		UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		TITLE SCREW, SOCKET HEAD		
	LINEAR +/-	N/A	CAP, 0.190(#10)-32 UNF		
	ANGLES +/-	N/A	DESIGNER	MEK	29 SEP 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	13 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	13 MAR 91
IBMCAD FILE SHCS190.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

VEN448-LLL

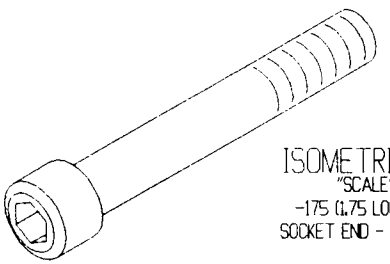
PEL FOR ASM	QTY
ASY561-ZZZ	2
ASY591-ZZZ	4

TECHNICAL APPROVALS		
MECHANICAL	MEK	13 MAR 91

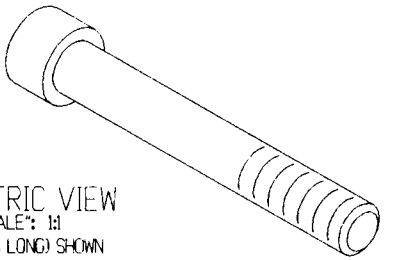
INIT	DATE	EC #

P/N VEN450-LLL

"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW
"SCALE": 1:1
-175 (1.75 LONG) SHOWN
SOCKET END - HORIZONTAL

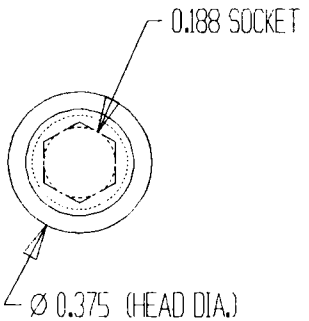


ISOMETRIC VIEW
"SCALE": 1:1
-175 (1.75 LONG) SHOWN
THREADED END - HORIZONTAL

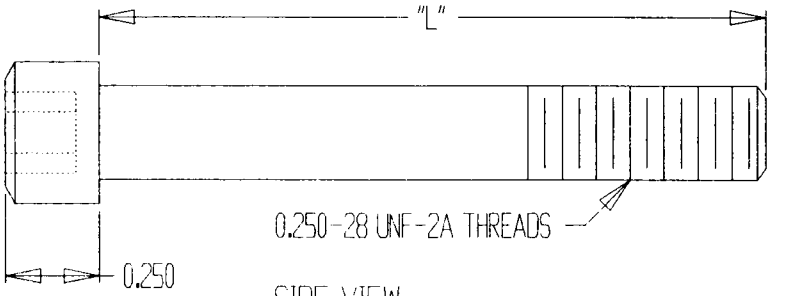
NOTES:

1. SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.

2. SUGGESTED VENDOR:
   McMASTER-CARR SUPPLY COMPANY
   CHICAGO, IL



SOCKET END VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-175 (1.75 LONG) SHOWN

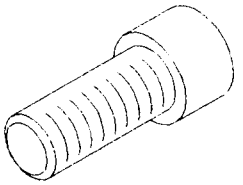
P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-050	0.500
-075	0.750
-100	1.000
-125	1.250
-150	1.500
-175	1.750

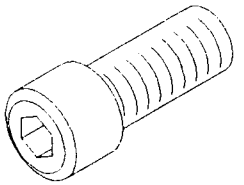
SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN450-LLL UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		
	LINEAR +/-	N/A	TITLE SCREW, SOCKET HEAD
	ANGLES +/-	N/A	CAP, 0.250-28 UNF
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 20 DEC 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 29 MAR 91
IBMCAD FILE SHCS250 .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK 29 MAR 91

VEN450-LLL

REL FOR ASM	QTY	REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN451-LLL
ASY516-RRR	8	ASY300-RRR	32	MECHANICAL	MEK	29 MAR 91				
ASY581-ZZZ	2	ASY506-RRR	3							"A" SIZE TEMPLATE 0 .25" REAL SIZE
		ASY511-RRR	8							



ISOMETRIC VIEW
"SCALE": 1:1
-075 (3/4 LONG) SHOWN
THREADED END - HORIZONTAL

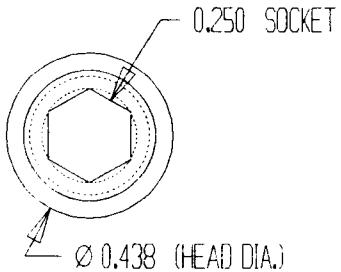


ISOMETRIC VIEW
"SCALE": 1:1
-075 (3/4 LONG) SHOWN
SOCKET END - HORIZONTAL

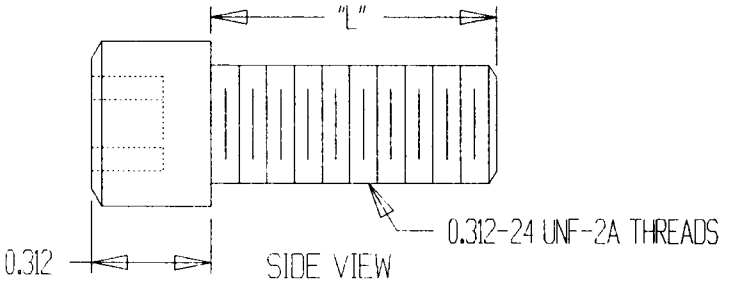
NOTES:

[1] SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.

2 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL



SOCKET END VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-075 (3/4 LONG) SHOWN

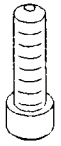
P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250

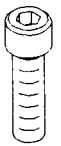
SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN451-LLL	UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		TITLE SCREW, SOCKET HEAD CAP, 0.312-24 UNF	
	LINEAR +/-	N/A		
	ANGLES +/-	N/A		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 16 OCT 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 29 MAR 91	
IBMCAD FILE SHCS312.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK 29 MAR 91	

VEN451-LLL

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN466-LLL
ASY540	4	MECHANICAL	MEK	29 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
VERTICAL ORIENTATION - UP

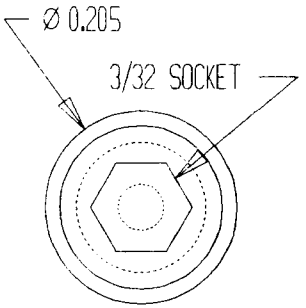


ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
VERTICAL ORIENTATION - DOWN

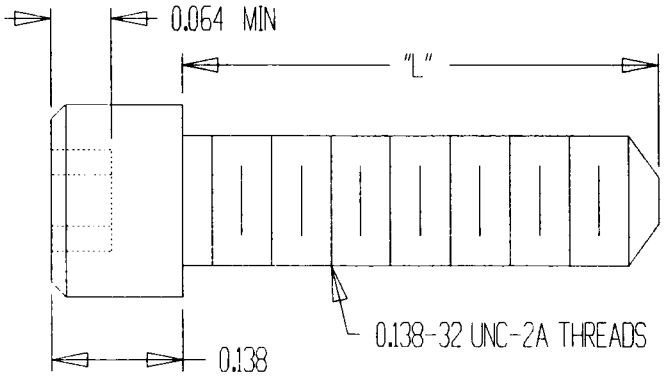
NOTES:

[1] SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.

2 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL



SOCKET END VIEW
SCALE: 5:1



SIDE VIEW
SCALE: 5:1
-050 (1/2 LONG) SHOWN

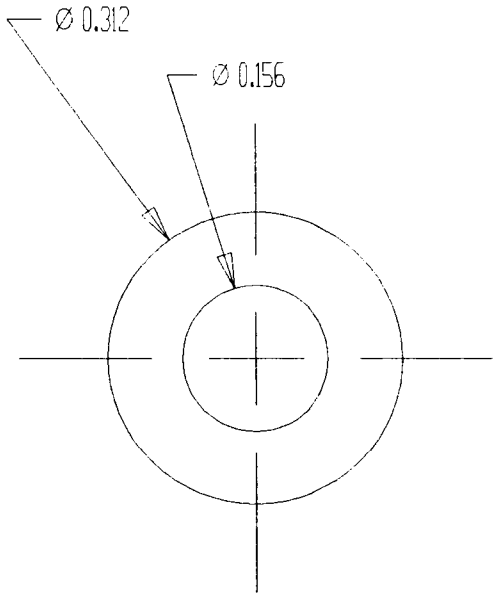
P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250

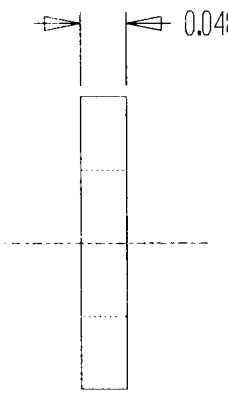
SCALE 5:1	DIMENSIONS IN INCHES		PART # VEN466-LLL	UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED			
	LINEAR +/-	N/A	TITLE SCREW, SOCKET HEAD	
	ANGLES +/-	N/A	CAP, 0.138(#6)-32 UNC	
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK	19 OCT 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK	29 MAR 91
IBMCAD FILE SHCS138C.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK	29 MAR 91

VEN466-LLL

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN482
ASY540	4	MECHANICAL	MEK	27 MAR 91				"A" SIZE TEMPLATE 0 25" REAL SIZE



"FRONT" VIEW
SCALE: 5:1

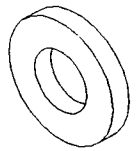


SIDE VIEW
SCALE: 5:1

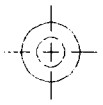
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

McMASTER P/N: 98019A114



ISOMETRIC VIEW
"SCALE": 2:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

VEN482

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN482			UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		TITLE WASHER, FLAT, FOR			
	LINEAR +/-	N/A	0.138(#6) NOMINAL DIAMETER			
	ANGLES +/-	N/A	DESIGNER	MEK	18 OCT 90	
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	27 MAR 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	27 MAR 91	
IBMCAD FILE WSHR138.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A				

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY531	4	MECHANICAL	MEK	27 MAR 91			
ASY532	4						
ASY536	4						

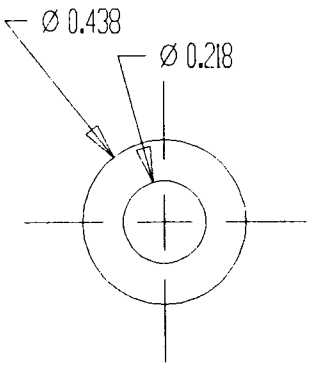
P/N VEN484

"A" SIZE TEMPLATE 0 — 25" REAL SIZE

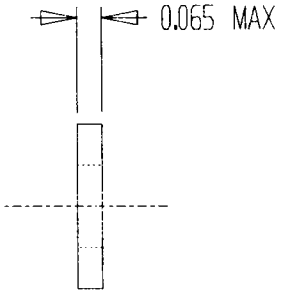
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

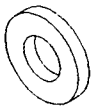
McMASTER P/N: 98019A130



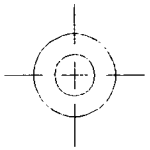
"FRONT" VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1

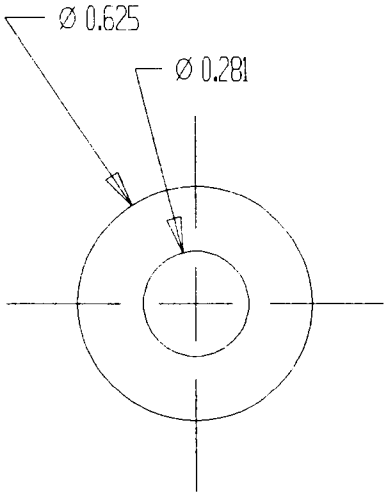


SIDE VIEW
SCALE: 1:1

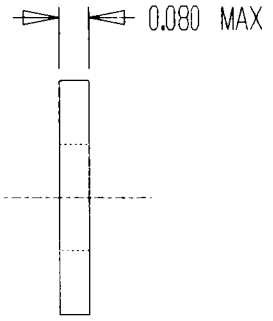
VEN484

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN484		UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE WASHER, FLAT, FOR		
	ANGLES +/-	N/A	0.190 NOMINAL DIAMETER		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	18 OCT 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	27 MAR 91
IBMCAD FILE WSHP190.R2	INSIDE MAX	N/A	APPROVED	MEK	27 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN486
ASYS01-ZZZ	4	MECHANICAL	MEK	27 MAR 91				
ASYS91-ZZZ	4							"A" SIZE TEMPLATE 0 .25" REAL SIZE



"FRONT" VIEW
SCALE: 2:1

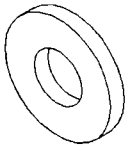


SIDE VIEW
SCALE: 2:1

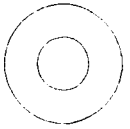
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

McMASTER P/N: 98019A155



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

VEN486

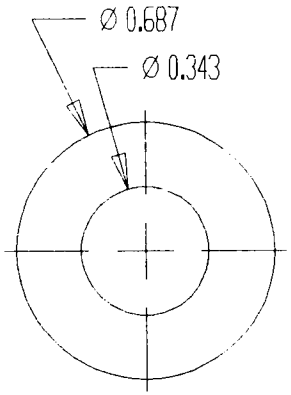
SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN486	UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED			
	LINEAR +/-	N/A	TITLE WASHER, FLAT, FOR	
	ANGLES +/-	N/A	0.250 NOMINAL DIAMETER	
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 18 OCT 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 27 MAR 91	
IGMCAD FILE WSHR250 .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK 27 MAR 91	

REL FOR ASM	QTY	REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN487
ASY581-ZZZ	2	ASY300-PRR	32	MECHANICAL	MEK	29 MAR 91				
		ASY506-PRR	3							"A" SIZE TEMPLATE 0 .25" REAL SIZE
		ASY511-RRR	8							

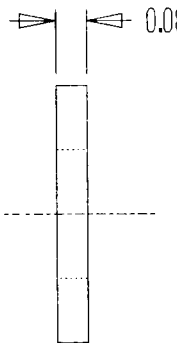
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

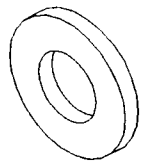
McMASTER P/N: 98019A185



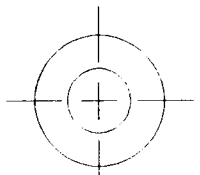
"FRONT" VIEW
SCALE: 2:1



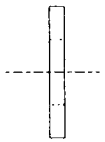
SIDE VIEW
SCALE: 2:1



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

VEN487

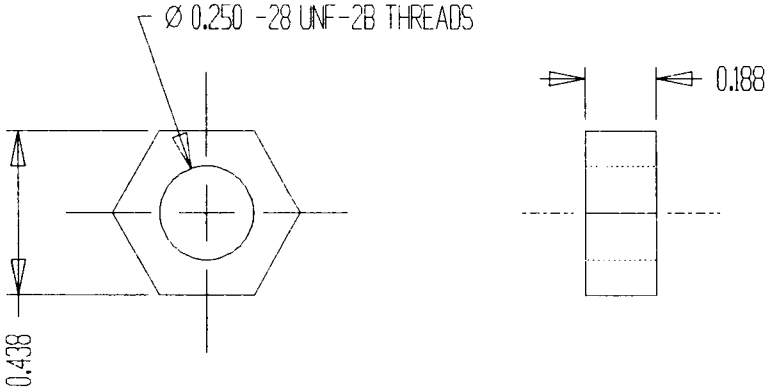
SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN487		UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		TITLE WASHER, FLAT, FOR		
	LINEAR +/-	N/A	0.312 NOMINAL DIAMETER		
	ANGLES +/-	N/A	DESIGNER	MEK	17 OCT 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	29 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	29 MAR 91
IBMCAD FILE WSHR312.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN490
ASY591-ZZZ	2	MECHANICAL	MEK	27 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

NOTES:

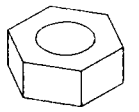
1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

McMASTER P/N: 90481A029

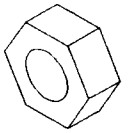


"FRONT" VIEW
SCALE: 2:1

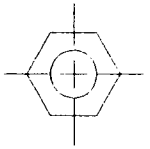
SIDE VIEW
SCALE: 2:1



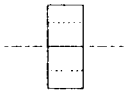
ISOMETRIC VIEW
"SCALE": 1:1
HORIZONTAL ORIENTATION



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

VEN490

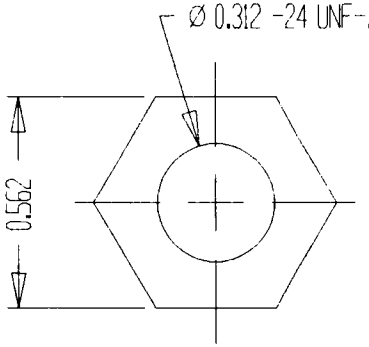
SCALE 2:1	DIMENSIONS IN INCHES			PART # VEN490		UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED					
	LINEAR +/-		N/A	TITLE NUT, HEXAGONAL,		
	ANGLES +/-		N/A	0.250-28 UNF		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	24 OCT 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	27 MAR 91
IBMCAD FILE HNUT250.R2		INSIDE MAX	N/A	APPROVED	MEK	27 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN491
ASY516-RRR	8	MECHANICAL	MEK	29 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

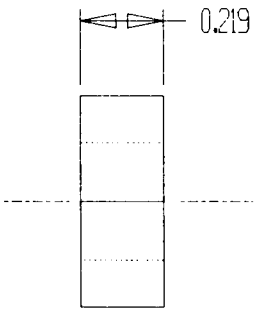
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

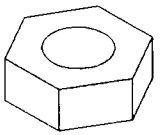
McMASTER P/N: 90481A030



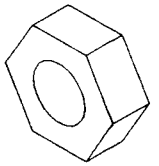
"FRONT" VIEW
SCALE: 2:1



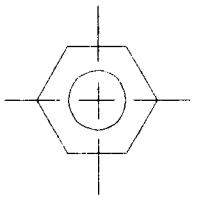
SIDE VIEW
SCALE: 2:1



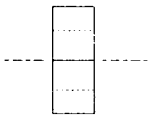
ISOMETRIC VIEW
"SCALE": 1:1
HORIZONTAL ORIENTATION



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN491		UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE NUT, HEXAGONAL, 0.312-24 UNF		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	24 OCT 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	29 MAR 91
IBMCAD FILE HNUT312.R2	INSIDE MAX	N/A	APPROVED	MEK	29 MAR 91

VEN491

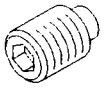
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN493-LLL
ASY551-ZZZ	2	MECHANICAL	MEK	07 MAR 91				
ASY561-ZZZ	2							"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250



ISOMETRIC VIEW
"SCALE": 1:1
"POINT END VIEW"
-037 (0.375 LONG) SHOWN



ISOMETRIC VIEW
"SCALE": 1:1
"SOCKET END VIEW"
-037 (0.375 LONG) SHOWN

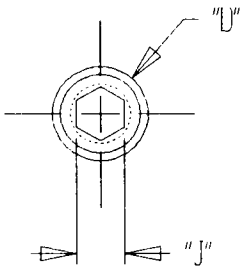
NOTES:

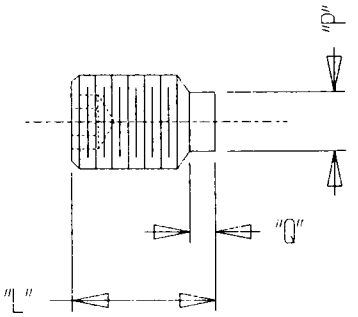
1 GENERIC PART NAME/REQUIREMENTS:
AMERICAN NATIONAL STANDARD
HEXAGON SOCKET SET SCREW
- HALF DOG POINT
- 0.250 (1/4) NOMINAL SIZE
- 0.250-28 UNF, 0.375 LONG

2 RECOMMENDED SUPPLIER:
KNOX BOLT AND SCREW INC.
KNOXVILLE, TN

3 SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.

4 TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.





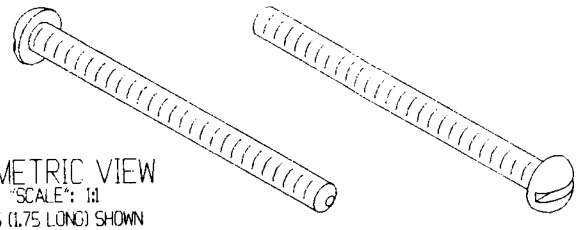
TECHNICAL DATA:

"D"	NOMINAL SIZE :	0.250
"J"	SOCKET SIZE:	0.125
"P"	POINT DIA. :	0.156
"Q"	POINT LENGTH:	0.067
	THREAD:	1/4 -28UNF
"L"	LENGTH :	SEE CHART

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN493-LLL			UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED		TITLE SET SCREW, HALF-DOG, 0.250 DIA., L.LL LONG			
	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	05 AUG 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	07 MAR 91	
IBMCAD FILE DOGPT .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	07 MAR 91	

VEN493-LLL

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN494-LLL
ASY551-ZZZ	2	MECHANICAL	MEK	13 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



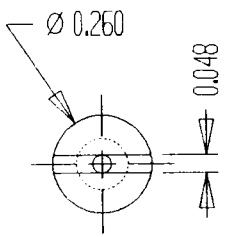
ISOMETRIC VIEW
"SCALE": 1:1
-175 (1.75 LONG) SHOWN
HORIZONTAL ORIENTATION -
THREAD END

ISOMETRIC VIEW
"SCALE": 1:1
-175 (1.75 LONG) SHOWN
HORIZONTAL ORIENTATION -
HEAD END

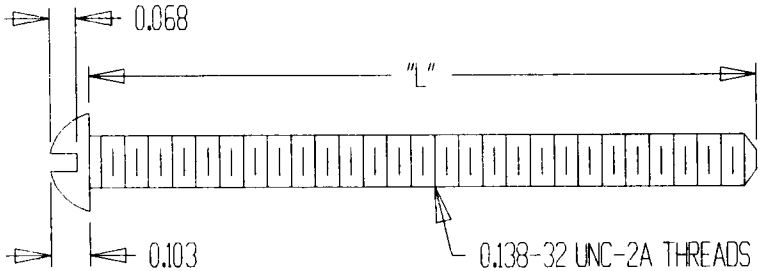
NOTES:

1. SCREW LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.

2. SUGGESTED VENDOR:
   McMASTER-CARR SUPPLY COMPANY
   CHICAGO, IL



HEAD END VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-175 (1.75 LONG) SHOWN

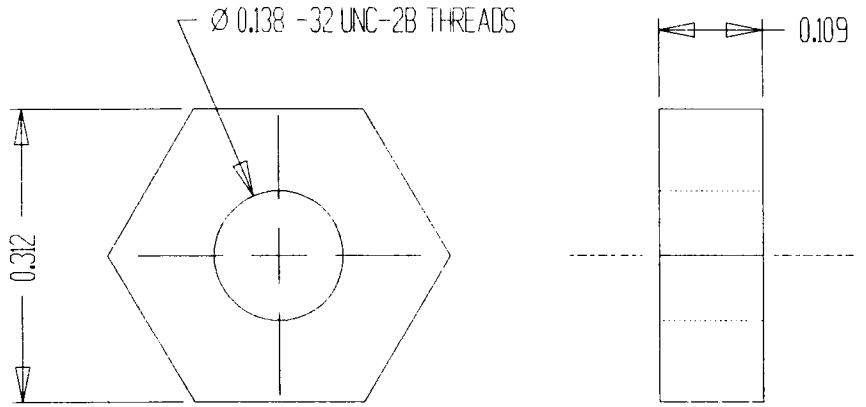
P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN494-LLL	UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED			
	LINEAR +/-	N/A	TITLE SCREW, ROUND HEAD	
	ANGLES +/-	N/A	0.138(#6)-32 UNC	
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK	22 OCT 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK	15 MAR 91
IBMCAD FILE SCRR138C.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK	15 MAR 91

VEN494-LLL

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN495
ASY551-ZZZ	2	MECHANICAL	MEK	15 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



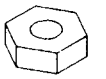
"FRONT" VIEW
SCALE: 5:1

SIDE VIEW
SCALE: 5:1

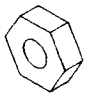
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

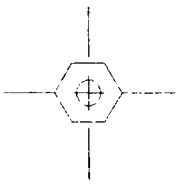
McMASTER P/N: 90480A007



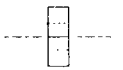
ISOMETRIC VIEW
"SCALE": 1:1
HORIZONTAL ORIENTATION



ISOMETRIC VIEW
"SCALE": 1:1
VERTICAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1

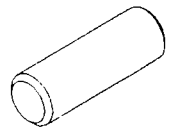


SIDE VIEW
SCALE: 1:1

VEN495

SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN495			UT
MATERIAL STEEL	TOLERANCES UNLESS NOTED					
	LINEAR +/-	N/A	TITLE NUT, HEZAGONAL,			
	ANGLES +/-	N/A	0.138(#6)-32 UNC			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	29 SEP 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	15 MAR 91	
IBMCAD FILE HNUT138C.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	15 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN496-LLL
ASY541-000	2	MECHANICAL	MEK	07 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



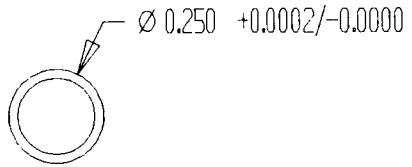
ISOMETRIC VIEW
"SCALE": 1:1
-075 (3/4 LONG) SHOWN
HORIZONTAL ORIENTATION



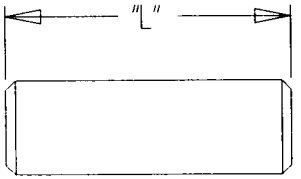
ISOMETRIC VIEW
"SCALE": 1:1
-075 (3/4 LONG) SHOWN
VERTICAL ORIENTATION

NOTES:

1. DOWEL LENGTH IS DETERMINED BY THE P/N SUFFIX CHART.
2. SUGGESTED VENDOR:
   McMASTER-CARR SUPPLY COMPANY
   CHICAGO, IL



END VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1
-075 (3/4 LONG) SHOWN

P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250

SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN496-LLL	UT
MATERIAL SOFT STEEL	TOLERANCES UNLESS NOTED			
	LINEAR +/-	N/A	TITLE DOWEL, 0.250 NOM. DIA.	
	ANGLES +/-	N/A		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK	16 OCT 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK	07 MAR 91
IBMCAD FILE DOWEL250.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK	07 MAR 91

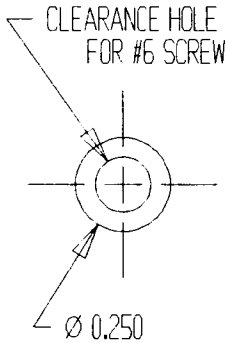
VEN496-LLL

PEL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN497
ASY591-ZZZ	1	MECHANICAL	MEK	10 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

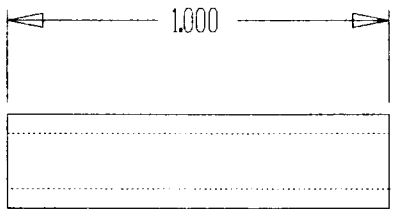
NOTES:

1 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

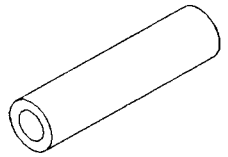
McMASTER P/N: 90309A133



"FRONT" VIEW
SCALE: 2:1



SIDE VIEW
SCALE: 2:1



ISOMETRIC VIEW
"SCALE": 1:1
HORIZONTAL ORIENTATION



"FRONT" VIEW
SCALE: 1:1



SIDE VIEW
SCALE: 1:1

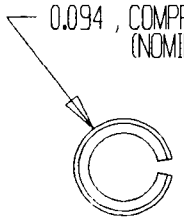
VEN497

SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN497	UT			
MATERIAL ALUMINUM	TOLERANCES UNLESS NOTED						
	LINEAR +/-	N/A	TITLE SPACER, UNTHREADED				
	ANGLES +/-	N/A	0.250 DIA., 1.00 LONG				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	22 OCT 90		
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	10 MAR 91		
IBMCAD FILE SPACER .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	10 MAR 91		

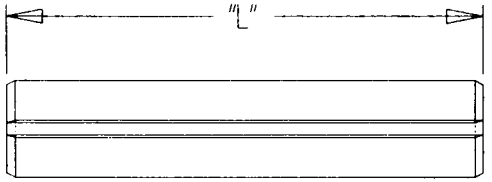
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN498-LLL
ASY538	1	MECHANICAL	MEK	25 MAR 91				
ASY551-ZZZ	1							"A" SIZE TEMPLATE 0 .25" REAL SIZE
KIT631	1							



ISOMETRIC VIEW
"SCALE": 1:1
-050 (1/2 LONG) SHOWN
HORIZONTAL ORIENTATION



END VIEW
SCALE: 5:1



SIDE VIEW
SCALE: 5:1
-050 (1/2 LONG) SHOWN

NOTES:

1 PIN LENGTH IS DETERMINED BY THE P/N SUFFIX, AS INDICATED BY THE P/N SUFFIX CHART.

2 SUGGESTED VENDOR:
McMASTER-CARR SUPPLY COMPANY
CHICAGO, IL

P/N: 92383A204

P/N SUFFIX CHART :

P/N SUFFIX	"L"
-025	0.250
-038	0.375
-050	0.500
-062	0.625
-075	0.750
-088	0.875
-100	1.000
-125	1.250



END VIEW
SCALE: 1:1

SIDE VIEW
SCALE: 1:1
-050 (1/2 LONG) SHOWN

VEN498-LLL

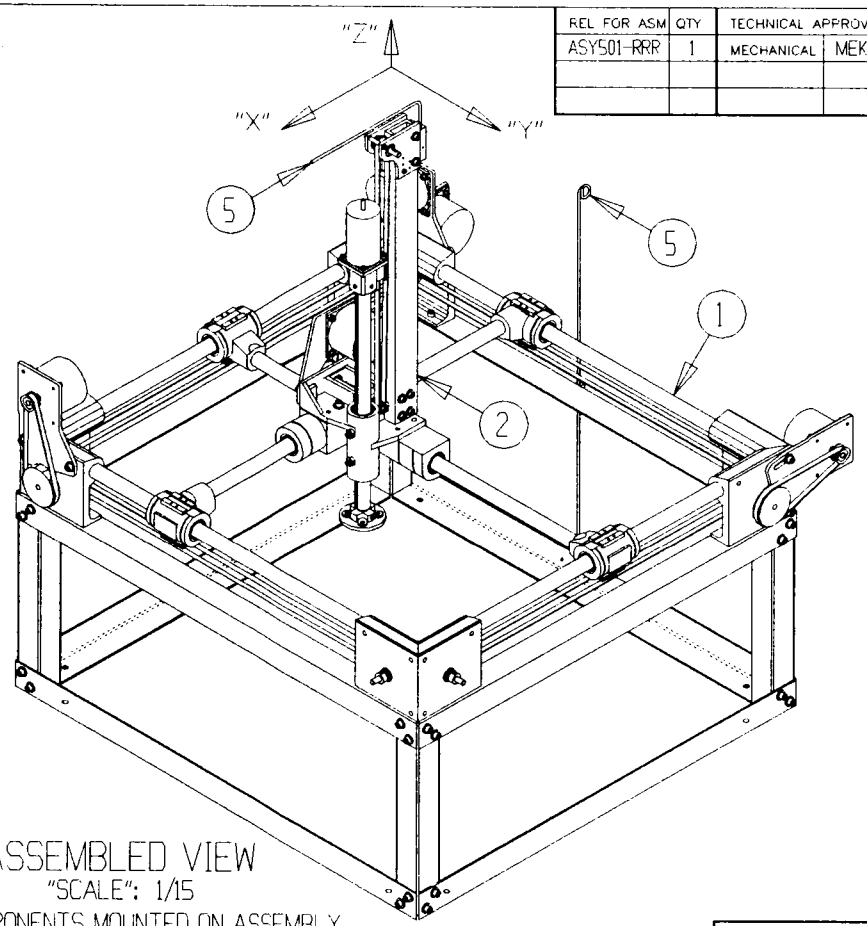
SCALE 2:1	DIMENSIONS IN INCHES		PART # VEN498-LLL			UT
MATERIAL STAINLESS STEEL	TOLERANCES UNLESS NOTED		TITLE PIN, ROLL, 3/32 IN. NOMINAL DIAMETER			
	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	17 OCT 90	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	25 MAR 91	
IBMCAD FILE RPIN094.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	25 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY501-RRR	1	MECHANICAL	MEK	19 APR 91			

P/N ASY506-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 2



ASSEMBLED VIEW
"SCALE": 1/15
ALL COMPONENTS MOUNTED ON ASSEMBLY
(SEE VIEW DETAILS FOR PART
ARRANGEMENTS AT ATTACHMENT LOCATIONS)

ASSEMBLY PARTS LIST

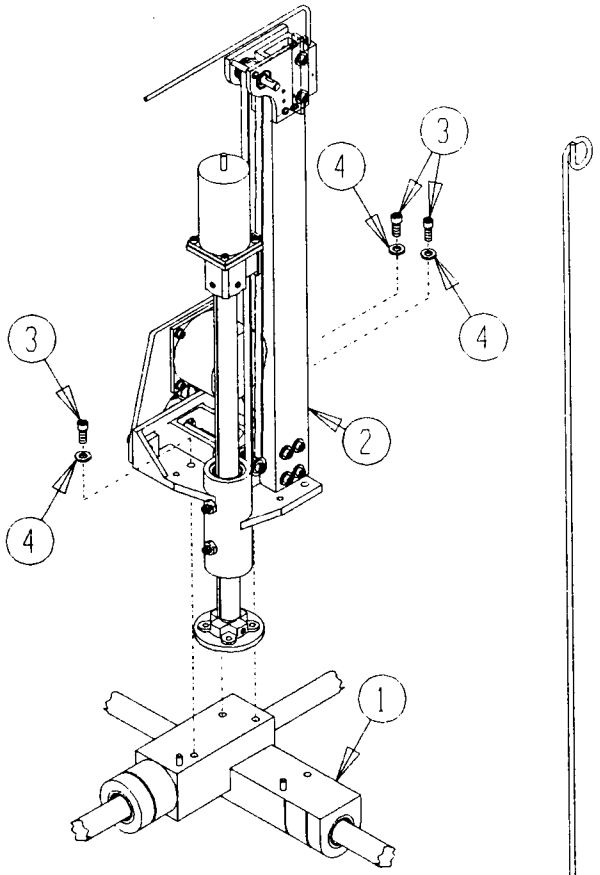
ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY511-RRR	ASSEMBLY, XY DRIVE
2	1	ASY581-ZZZ	ASSEMBLY, Z DRIVE
3	3	VEN451-075	SHCS, 0.312-24 UNF, 0.75 LONG
4	3	VEN487	WASHER, FLAT, 0.312 NOM DIA.
5	1	KIT631	KIT, WIRING MECHANICAL SUPPORT

SCALE 1/15	DIMENSIONS IN INCHES		PART # ASY511-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, ROBOT		
	LINEAR +/-	N/A	MECHANICAL		
	ANGLES +/-	N/A	DESIGNER	MEK	18 APR 91
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	19 APR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	19 APR 91
IBMCAD FILE RMECHAS1.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A			

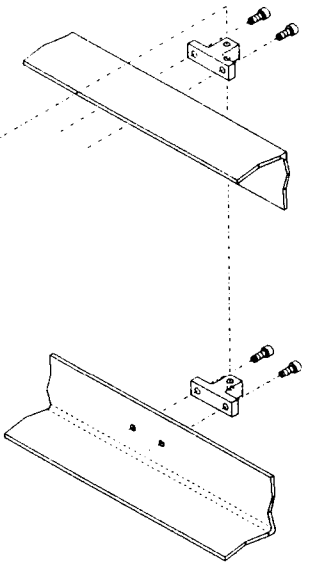
ASY506-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY506-RRR
ASY501-RRR	1	MECHANICAL	MEK	19 APR 91				
								"A" SIZE TEMPLATE 0 .25" REAL SIZE

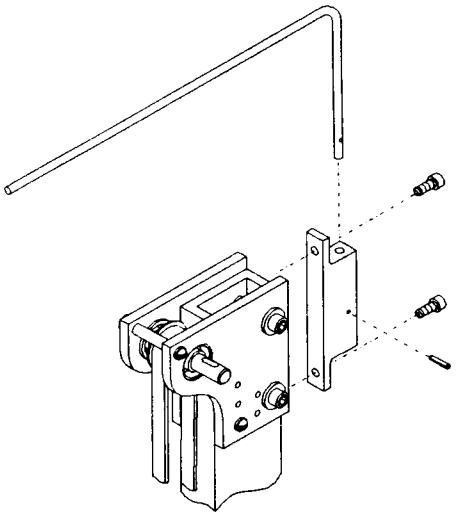
SHEET 2 OF 2



Z PLATFORM ATTACHMENT
"SCALE": 1/10
MOUNTING HARDWARE ARRANGEMENT SHOWN



FRAME WIRE SUPPORT
"SCALE": 1/10
FRAME ATTACHMENT SET INSTALLATION
(REFERENCE DETAIL OF KIT631, KIT, WIRING MECHANICAL SUPPORT)



MAST WIRE SUPPORT
"SCALE": 1/5
MAST ATTACHMENT SET INSTALLATION
(REFERENCE DETAIL OF KIT631, KIT, WIRING MECHANICAL SUPPORT)

SCALE 1/15	DIMENSIONS IN INCHES			PART # ASY506-RRR	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE ASSEMBLY, ROBOT	
	ANGLES +/-		N/A	MECHANICAL	
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER MEK	18 APR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED MEK	19 APR 91
IBMCAD FILE RMECHAS2.R1		INSIDE MAX	N/A	APPROVED MEK	19 APR 91

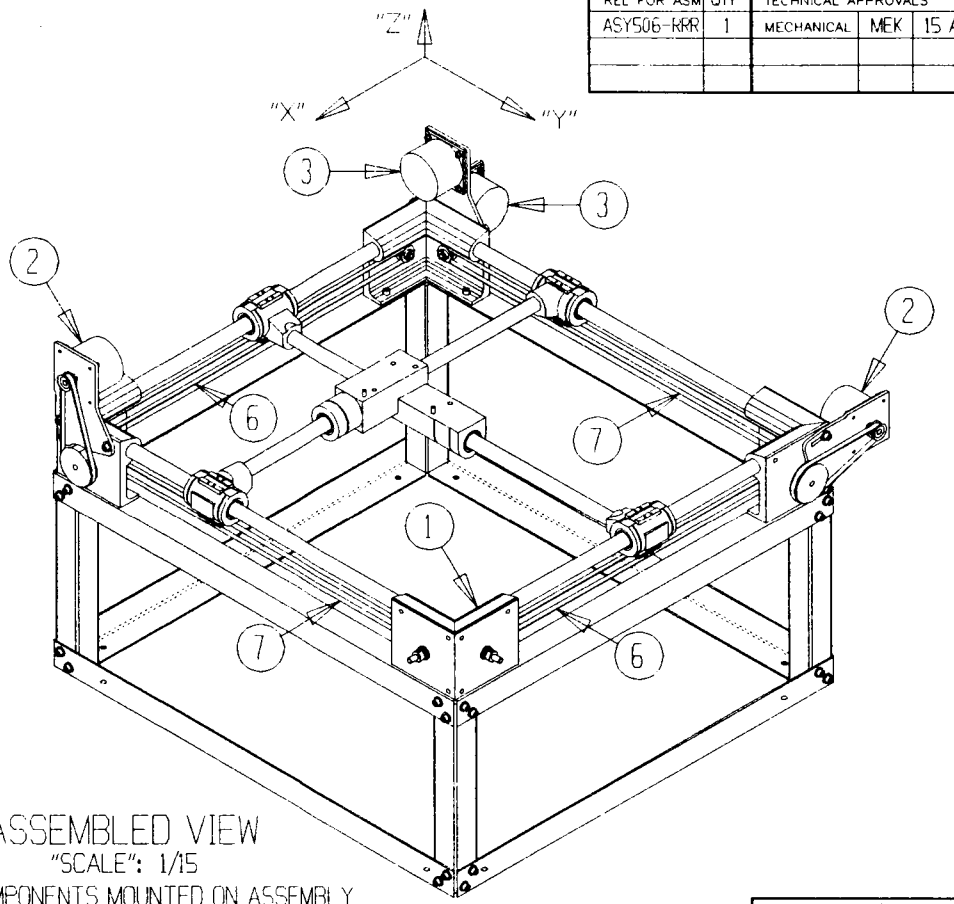
ASY506-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY506-RRR	1	MECHANICAL	MEK	15 APR 91			

P/N ASY511-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 3



ASSEMBLED VIEW
"SCALE": 1/15
DRIVE COMPONENTS MOUNTED ON ASSEMBLY
(SEE "COMPONENT LAYOUTS" FOR PART
ARRANGEMENTS AT CORNERS)

ASSEMBLY PARTS LIST

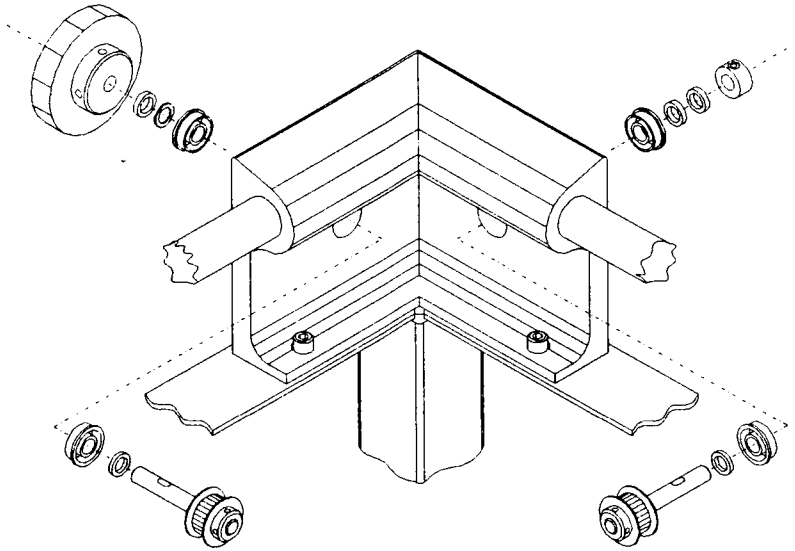
ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY516-RRR	ASSEMBLY, XY MOTION
2	2	ASY531	ASSEMBLY, XY MOTOR (LH)
3	2	ASY532	ASSEMBLY, XY MOTOR (RH)
4	1	KIT611-XXX	KIT, X REDUCTION DRIVE
5	1	KIT611-YYY	KIT, Y REDUCTION DRIVE
6	2	VEN843-XXX	BELT, TIMING, FOR X DRIVE
7	2	VEN843-YYY	BELT, TIMING, FOR Y DRIVE
8	4	ASY540	ASSEMBLY, BELT ATTACHMENT
9	8	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
10	8	VEN487	WASHER, FOR 0.312 SCREW

ASY511-RRR

SCALE 1/15	DIMENSIONS IN INCHES		PART # ASY511-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE ASSEMBLY, XY DRIVE		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	08 APR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	08 APR 91
IBMCAD FILE XYDRVAS1.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	15 APR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY511-RRR
		MECHANICAL						"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 2 OF 3



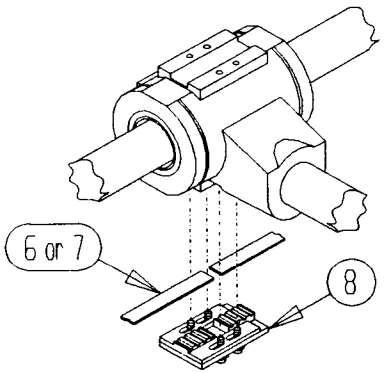
DRIVE SET ASSEMBLY LAYOUT
SHOWN ON THIS SIDE - FROM KIT611

IDLER SET ASSEMBLY LAYOUT
SHOWN ON THIS SIDE - FROM KIT611

DRIVE KIT ASSEMBLY DETAILS

"SCALE": 1/5

COMPLETE AS SPECIFIED ON ALL CORNER SUPPORTS



DRIVE BELT ATTACHMENT VIEW

"SCALE": 1/5

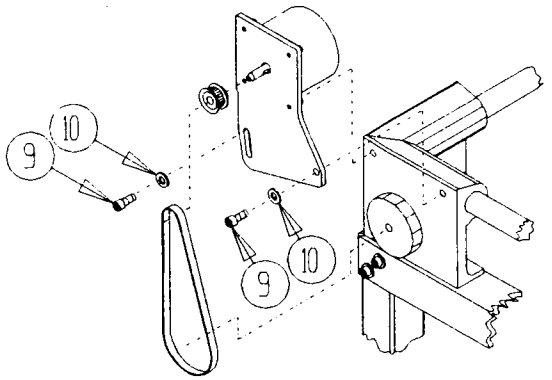
TO BE COMPLETED FOR EACH DRIVE BELT

SCALE 1/15	DIMENSIONS IN INCHES		PART # ASY511-RRR		UT
MATERIAL	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY DRIVE		
	LINEAR +/-				
	ANGLES +/-				
OTHER NOTES	RADII UNLESS NOTED		DESIGNER	MEK	08 APR 91
	EDGE/CORNER BREAKS OUTSIDE MAX		CHECKED	MEK	08 APR 91
IBMCAD FILE XYDRVAS2.R1	EDGE/CORNER BREAKS INSIDE MAX		APPROVED	MEK	15 APR 91

ASY511-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY511-RRR
		MECHANICAL						"A" SIZE TEMPLATE 0 .25" REAL SIZE

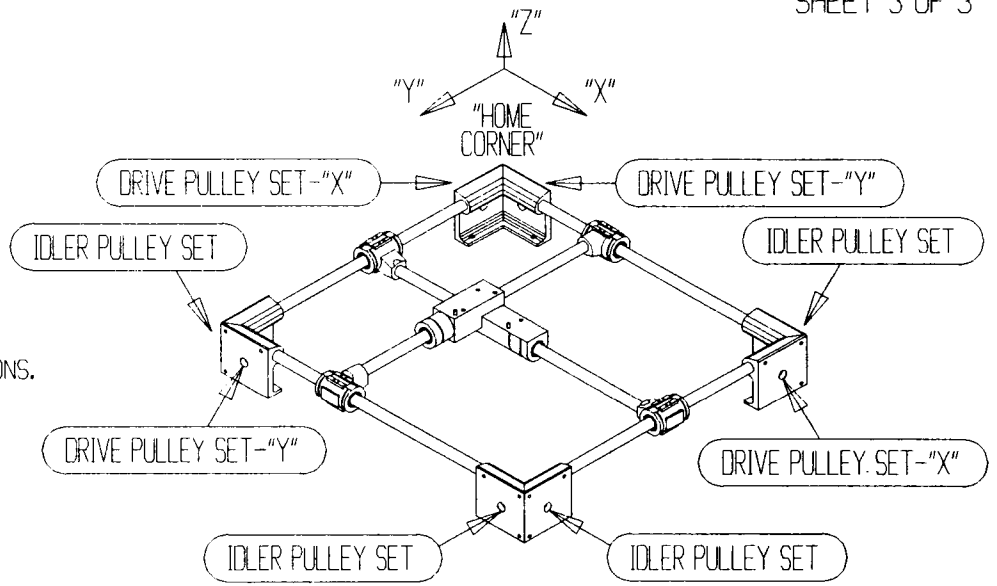
SHEET 3 OF 3



VERTICAL MOTOR MOUNT ASSEMBLY

"SCALE": 1/10

SEE ASSEMBLY ORIENTATION VIEWS FOR ASSEMBLY LOCATIONS.



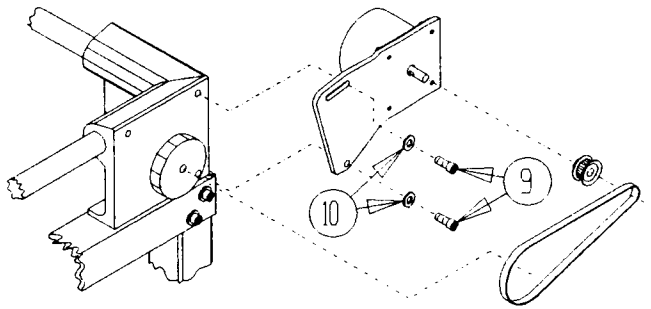
DRIVE SYSTEM LAYOUT

"SCALE": 1/10

KIT611 DRIVE AND IDLER SET ASSIGNMENTS

HORIZONTAL MOTOR MOUNTING REQUIRED WITH "X" DRIVE SETS

VERTICAL MOTOR MOUNTING REQUIRED WITH "Y" DRIVE SETS



HORIZONTAL MOTOR MOUNT ASSEMBLY

"SCALE": 1/10

SEE ASSEMBLY ORIENTATION VIEWS FOR ASSEMBLY LOCATIONS.

ASY511-RRR

SCALE 1/15	DIMENSIONS IN INCHES			PART # ASY511-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED			TITLE ASSEMBLY, XY DRIVE		
	LINEAR +/-					
	ANGLES +/-					
OTHER NOTES	RADII UNLESS NOTED			DESIGNER	MEK	08 APR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX		CHECKED	MEK	08 APR 91
IBMCAD FILE XYDRVAS3.R1		INSIDE MAX		APPROVED	MEK	15 APR 91

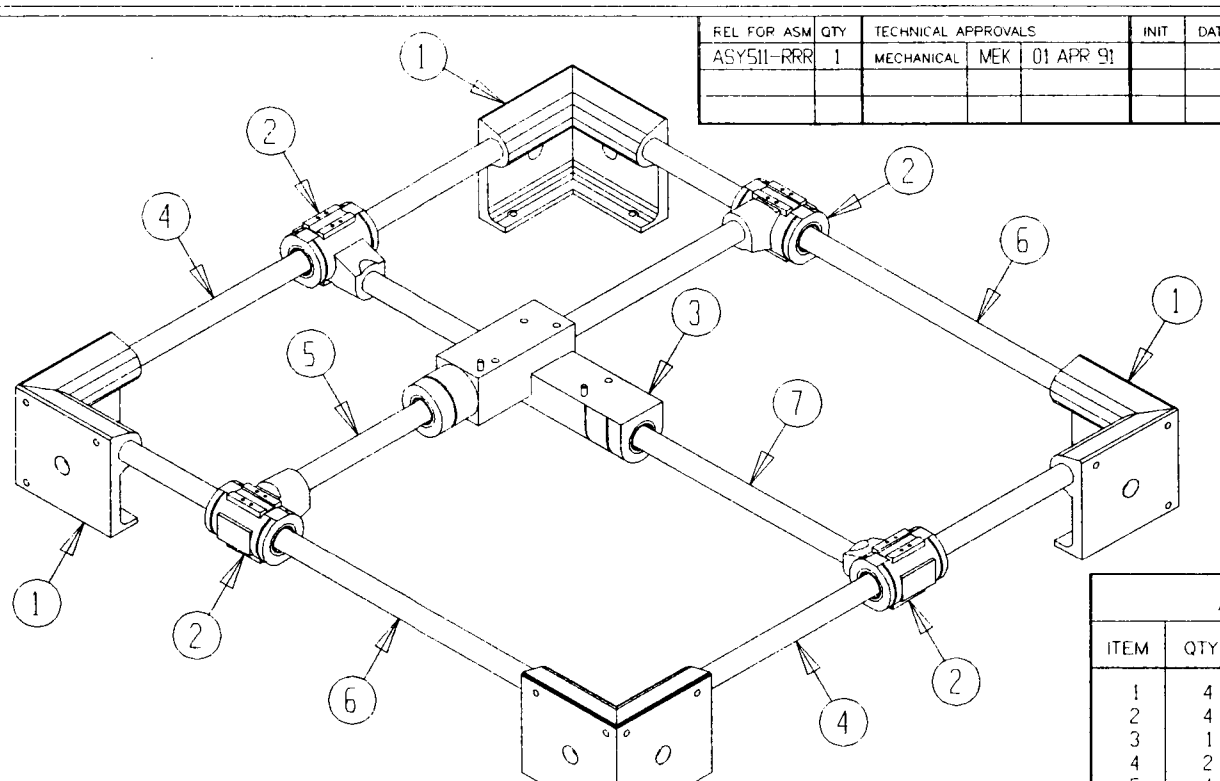
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY511-RRR	1	MECHANICAL	MEK	01 APR 91			

P/N ASY516-RRR

"A" SIZE TEMPLATE

0 .25" REAL SIZE

SHEET 1 OF 2



COMPONENT LAYOUT

"SCALE": 1/10

FRAME AND ATTACHMENT HARDWARE NOT SHOWN

(SEE SHEET 2 FOR MOUNTING AND FRAME ARRANGEMENT)

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	4	MEK001-DDD	SUPPORT, CORNER
2	4	ASY521-DDD	ASSEMBLY, XY SLIDER
3	1	ASY541-DDD	ASSEMBLY, CARTRIDGE, BEARING
4	2	VEN406-XXX	SHAFT, HORIZ. GUIDE, X AXIS
5	1	VEN407-XXX	SHAFT, HORIZ. CONTROL, X AXIS
6	2	VEN406-YYY	SHAFT, HORIZ. GUIDE, Y AXIS
7	1	VEN407-YYY	SHAFT, HORIZ. CONTROL, Y AXIS
8	1	ASY300-RRR	ASSEMBLY, FRAME
9	8	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
10	8	VEN491	NUT, HEXAGONAL, 0.312 UNF

SCALE 1/10	DIMENSIONS IN INCHES		PART # ASY516-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY MOTION		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	01 APR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	01 APR 91
IBMCAD FILE XYMOTASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	01 APR 91

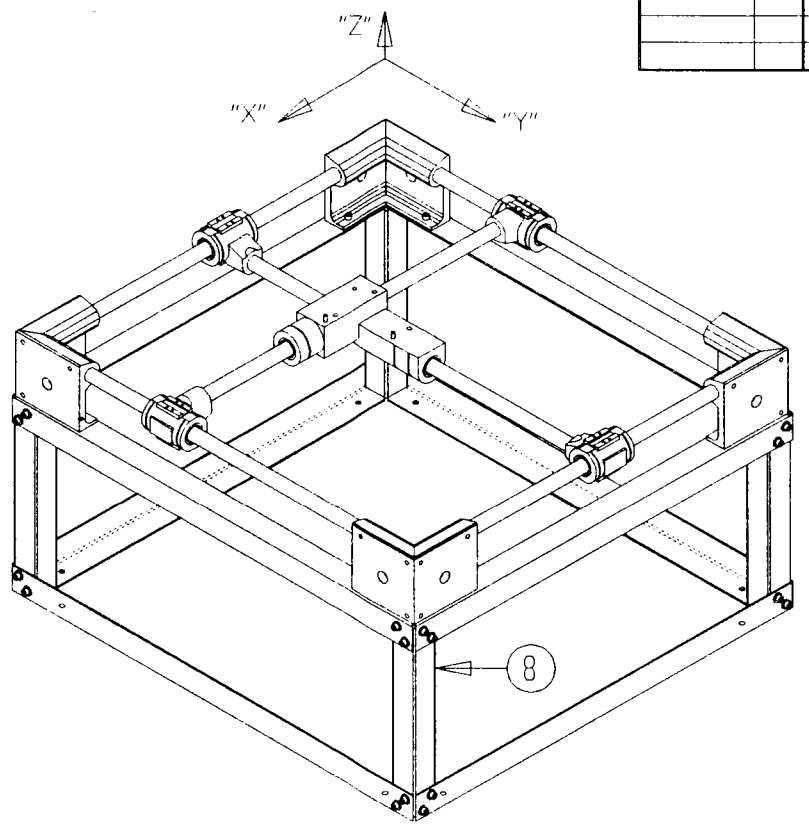
ASY516-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
		MECHANICAL					

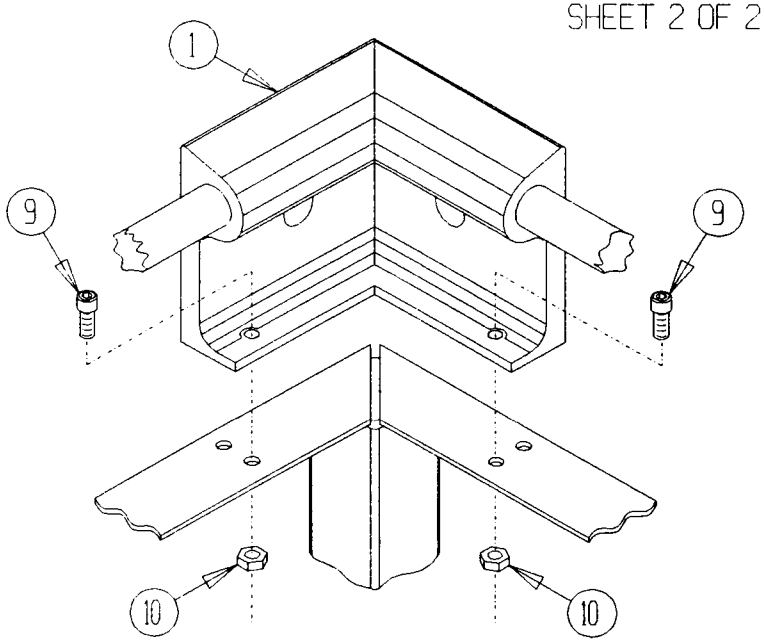
P/N ASY516-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 2 OF 2



ASSEMBLED VIEW
"SCALE": 1/15
COMPONENTS MOUNTED ON FRAME ASSEMBLY
(SEE "COMPONENT LAYOUT" FOR PART ARRANGEMENT ON FRAME)

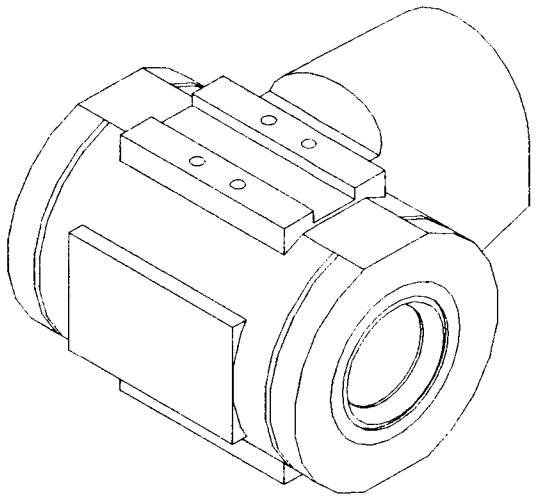


FASTENER DETAIL VIEW
"SCALE": 1/5
TO BE COMPLETED FOR EACH CORNER SUPPORT

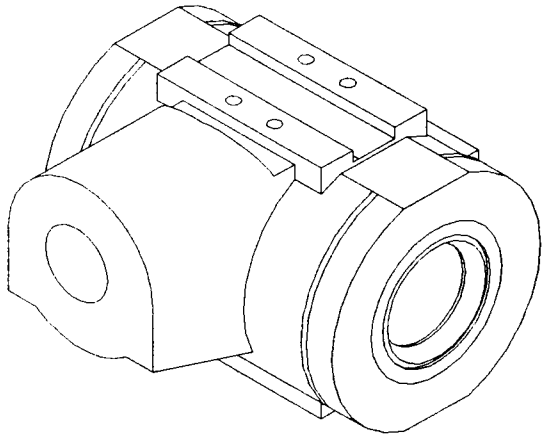
ASY516-RRR

SCALE 1/10	DIMENSIONS IN INCHES		PART # ASY516-RRR		UT
MATERIAL	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY MOTION		
	LINEAR +/-				
	ANGLES +/-				
OTHER NOTES	RADII UNLESS NOTED		DESIGNER	MEK	01 APR 91
	EDGE/ CORNER BREAKS OUTSIDE MAX		CHECKED	MEK	01 APR 91
IBMCAD FILE XYMOTASY.R1	EDGE/ CORNER BREAKS INSIDE MAX		APPROVED	MEK	01 APR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY521-DDD
ASY516-DDD	4	MECHANICAL	MEK	11 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASSEMBLED VIEW
"SCALE": 1/2
"REAR END VIEW - UPRIGHT ORIENTATION"



ASSEMBLED VIEW
"SCALE": 1/2
"FRONT END VIEW - UPRIGHT ORIENTATION"

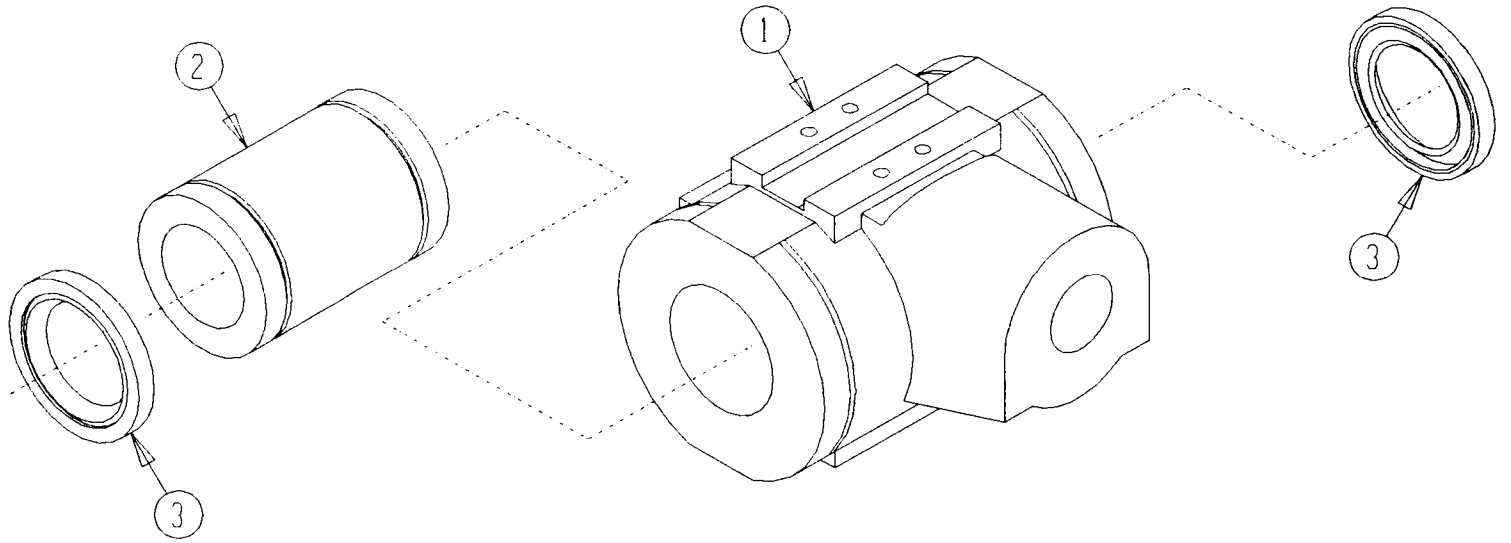
ASY521-DDD

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK021-DDD	HOUSING, SLIDER, XY
2	1	VEN401-DDD	BEARING, LINEAR BALL
3	2	VEN402-DDD	SEAL, LINEAR BALL BEARING

SCALE 1/2	DIMENSIONS IN INCHES			PART # ASY521-DDD	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED			TITLE ASSEMBLY, XY	
	LINEAR +/-		N/A	SLIDER	
	ANGLES +/-		N/A	DESIGNER MEK	29 SEP 90
OTHER NOTES	RADII UNLESS NOTED		N/A	CHECKED MEK	11 MAR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	APPROVED MEK	11 MAR 91
IBMCAD FILE SLIDEASY.R2		INSIDE MAX	N/A		

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY521-DDD
ASY516-DDD	4	MECHANICAL	MEK	11 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



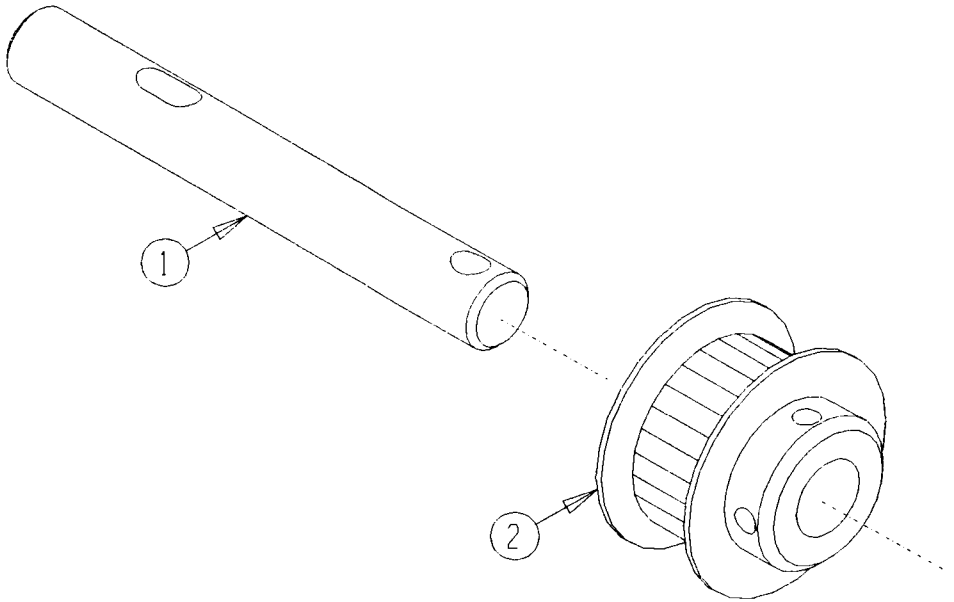
ASY521-DDD

ASSEMBLY PARTS LIST

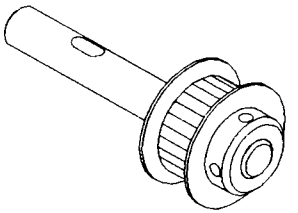
ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK021-DDD	HOUSING, SLIDER, XY
2	1	VEN401-DDD	BEARING, LINEAR BALL
3	2	VEN402-DDD	SEAL, LINEAR BALL BEARING

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY521-DDD		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY		
	LINEAR +/-	N/A	SLIDER		
	ANGLES +/-	N/A	DESIGNER	MEK	29 SEP 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	11 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	11 MAR 91
IBMCAD FILE SLIDEASY.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

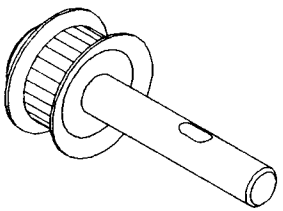
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY526
KIT611	4	MECHANICAL	MEK	06 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



EXPLODED VIEW
"SCALE": 1:1



ASSEMBLED VIEW
"SCALE": 1/2
"PULLEY END VIEW"



ASSEMBLED VIEW
"SCALE": 1/2
"SHAFT END VIEW"

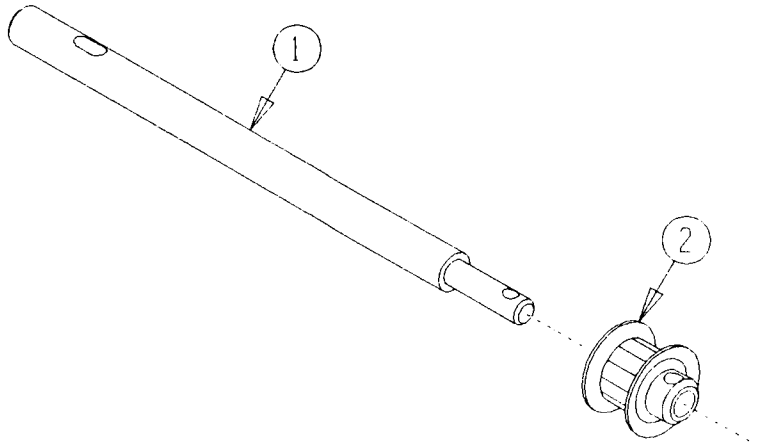
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK046	SHAFT, XY REDUCTION
2	1	VEN801	PULLEY, TIMING BELT, 0.955 PD

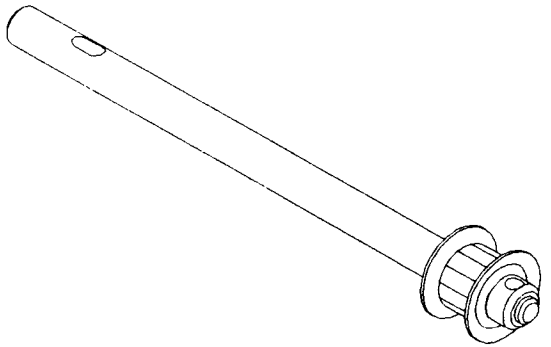
ASY526

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY526		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY REDUCTION SHAFT		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	06 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	06 MAR 91
IBMCAD FILE XSHAFASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	06 MAR 91

PEL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY527
KIT621	1	MECHANICAL	MEK	06 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



EXPLODED VIEW
"SCALE": 1/2



ASSEMBLED VIEW
"SCALE": 1/2

ASY527

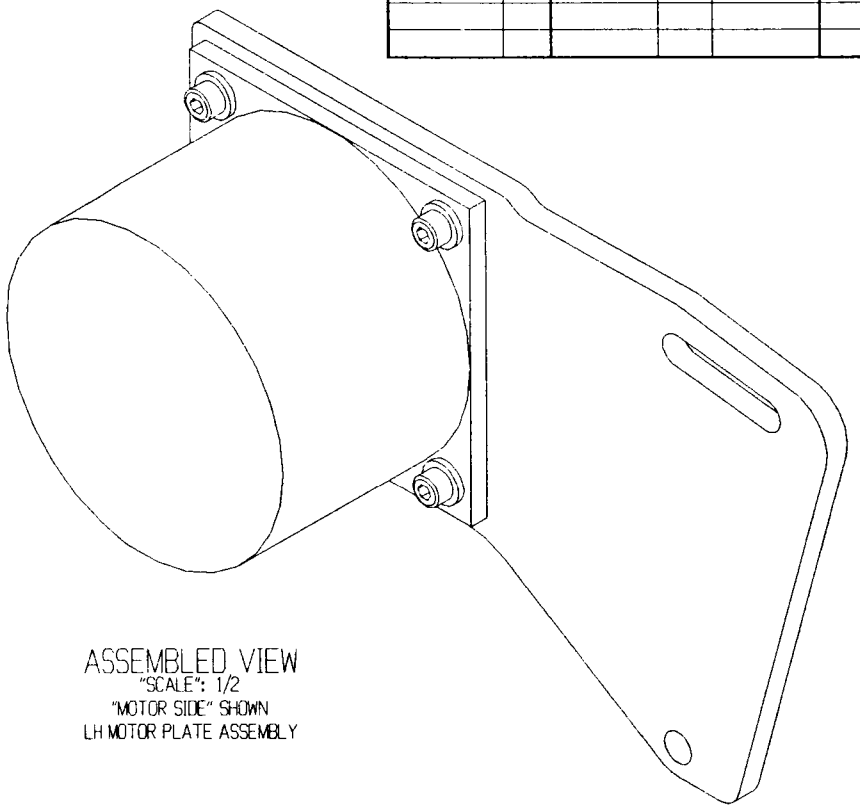
ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK047	SHAFT, Z REDUCTION
2	1	VEN836	PULLEY, TIMING BELT, 0.637 PD

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY527		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, Z REDUCTION SHAFT		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	06 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	06 MAR 91
IBMCAD FILE ZSHAFASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	06 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY516-RRR	2	MECHANICAL	MEK	13 MAR 91			

P/N ASY531

"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASSEMBLED VIEW
"SCALE": 1/2
"MOTOR SIDE" SHOWN
LH MOTOR PLATE ASSEMBLY

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK011	PLATE, MOTOR MOUNTING, LH
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

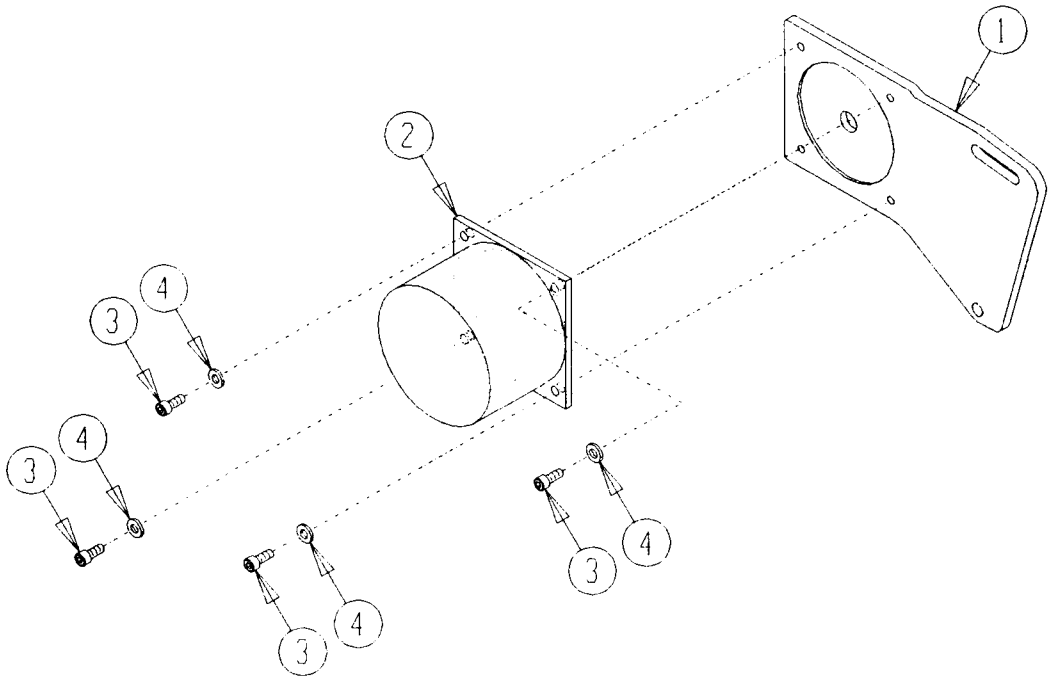
SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY531 UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		
	LINEAR +/-	N/A	TITLE ASSEMBLY, XY
	ANGLES +/-	N/A	MOTOR (LH)
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 08 NOV 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 13 MAR 91
IBMCAD FILE MTRLASY .R2	INSIDE MAX	N/A	APPROVED MEK 13 MAR 91

ASY531

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY516-RRR	2	MECHANICAL	MEK	13 MAR 91			

P/N ASY531

"A" SIZE TEMPLATE 0 .25" REAL SIZE



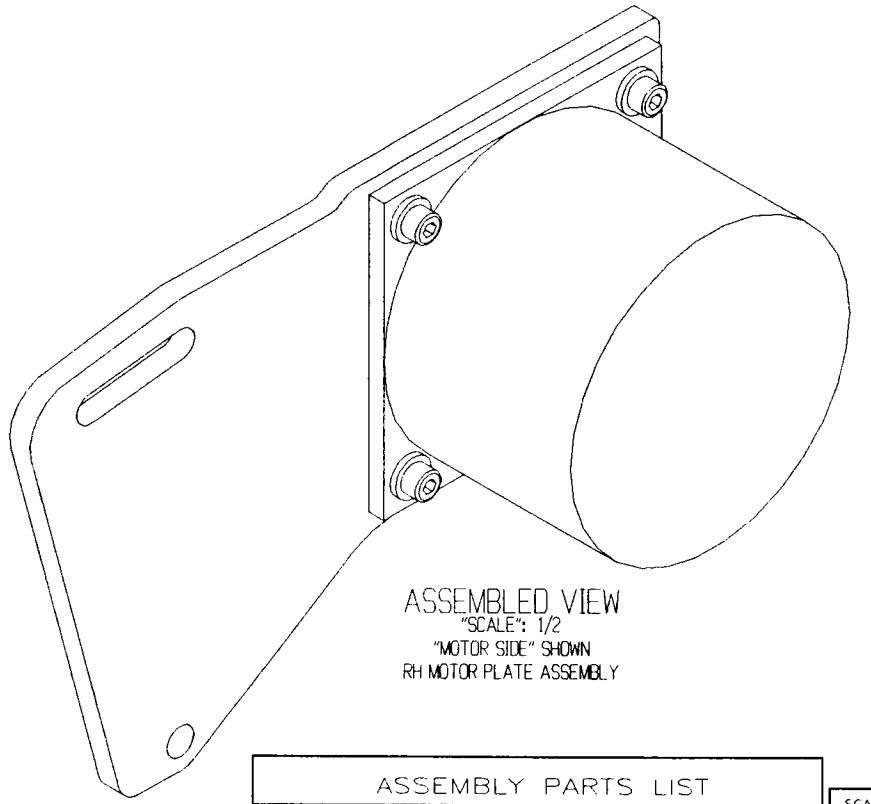
ASY531

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK011	PLATE, MOTOR MOUNTING, LH
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY531		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY		
	LINEAR +/-	N/A	MOTOR (LH)		
	ANGLES +/-	N/A	DESIGNER	MEK	01 OCT 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	13 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	13 MAR 91
IBMCAD FILE MTRLEXP .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY532
ASY516-RRR	2	MECHANICAL	MEK	13 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASSEMBLED VIEW
"SCALE": 1/2
"MOTOR SIDE" SHOWN
RH MOTOR PLATE ASSEMBLY

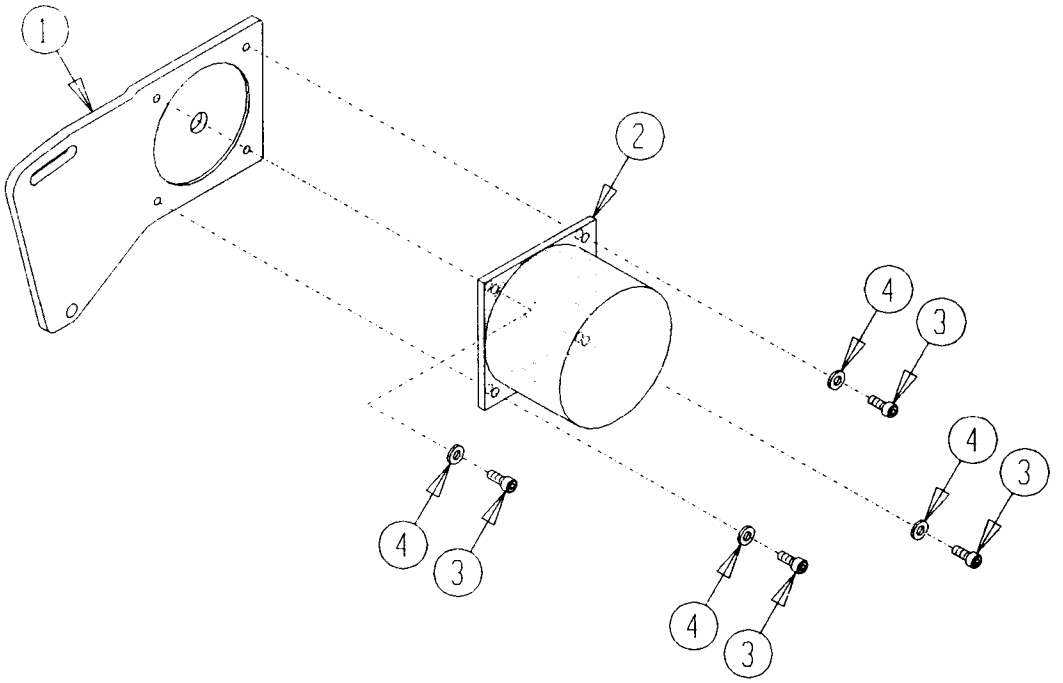
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK012	PLATE, MOTOR MOUNTING, RH
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

ASY532

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY532		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY MOTOR (RH)		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	09 NOV 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	13 MAR 91
IBMCAD FILE MTRRASY .R2	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	13 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY532
ASY516-RRR	2	MECHANICAL	MEK	13 MAR 91				
								"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASY532 ··

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK012	PLATE, MOTOR MOUNTING, RH
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY532		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, XY		
	LINEAR +/-	N/A	MOTOR (RH)		
	ANGLES +/-	N/A	DESIGNER	MEK	01 OCT 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	13 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	13 MAR 91
IBMCAD FILE MTRREXP .R2	EDGE/CORNER BREAKS INSIDE MAX	N/A			

REL FOR ASM	QTY
ASY581-ZZZ	1

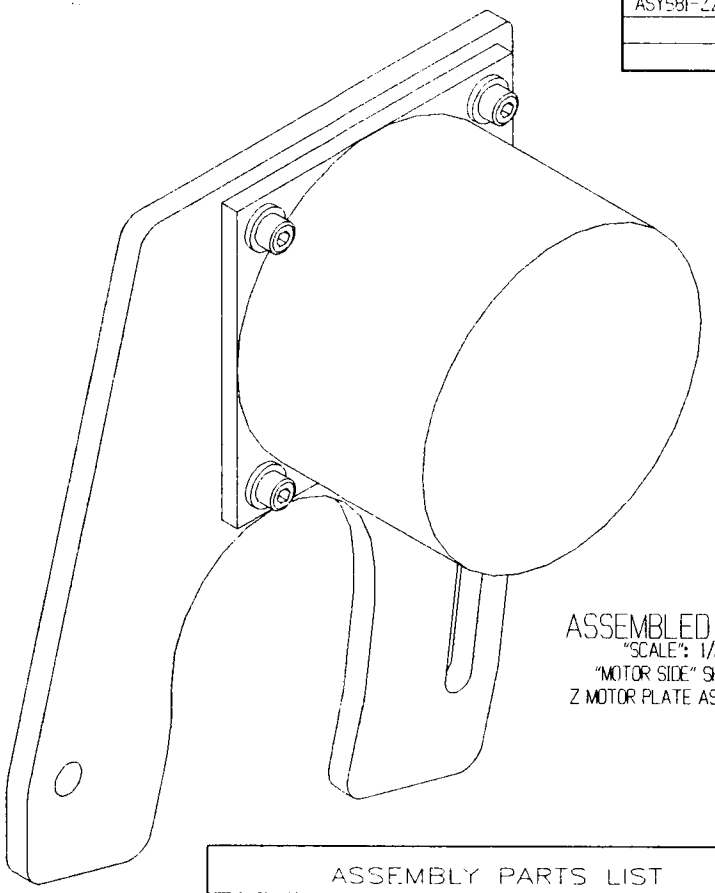
TECHNICAL APPROVALS		
MECHANICAL	MEK	13 MAR 91

INIT	DATE	EC #

P/N ASY536

"A" SIZE TEMPLATE

0 .25" REAL SIZE



ASSEMBLED VIEW
"SCALE": 1/2
"MOTOR SIDE" SHOWN
Z MOTOR PLATE ASSEMBLY

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK016	PLATE, MOTOR MOUNTING, Z
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

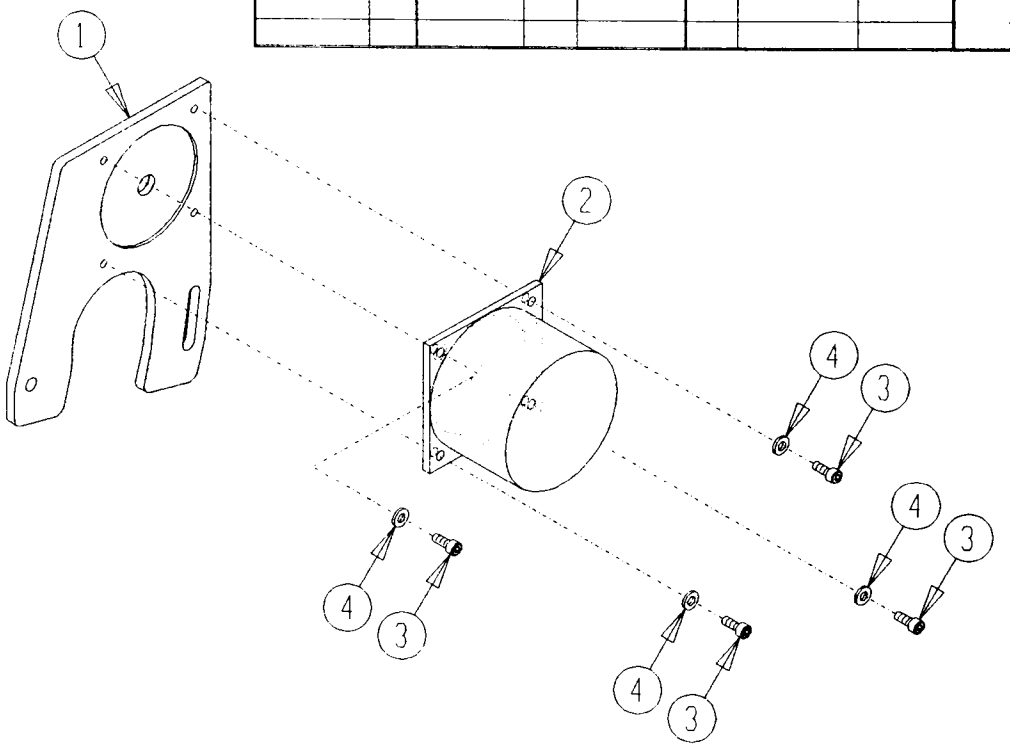
ASY536

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY536 UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		
	LINEAR +/-	N/A	TITLE ASSEMBLY, Z MOTOR
	ANGLES +/-	N/A	
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 09 NOV 90
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 13 MAR 91
IBMCAD FILE MTRZASY.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK 13 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY581-ZZZ	1	MECHANICAL	MEK	13 MAR 91			

P/N ASY536

"A" SIZE TEMPLATE 0 .25" REAL SIZE



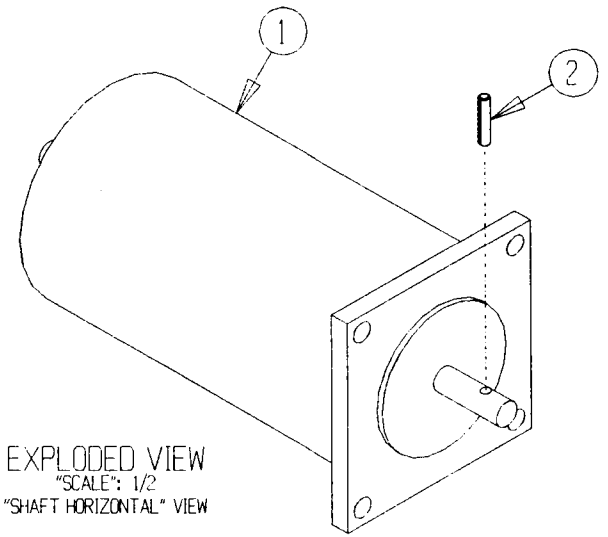
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK016	PLATE, MOTOR MOUNTING, Z
2	1	MEK064	MOTOR, STEP, TRANS, SIZE "1"
3	4	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
4	4	VEN484	WASHER, FOR 0.190(#10) SCREW

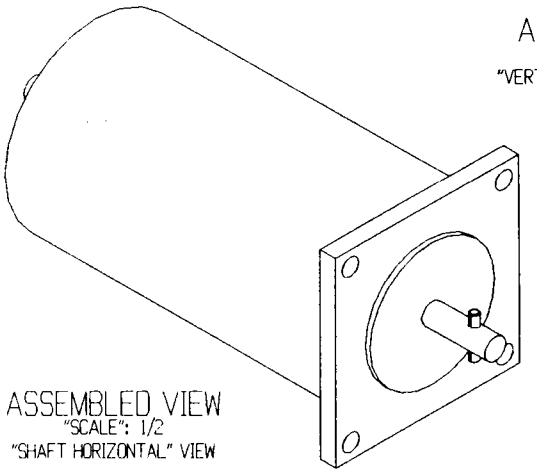
SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY536		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE ASSEMBLY, Z MOTOR		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	01 OCT 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	13 MAR 91
IBMCAD FILE MTRZEXP .R2	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	13 MAR 91

ASY536

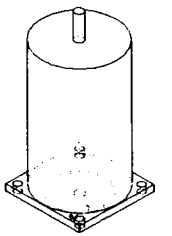
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY538
ASY561-ZZZ	1	MECHANICAL	MEK	04 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



EXPLODED VIEW
"SCALE": 1/2
"SHAFT HORIZONTAL" VIEW



ASSEMBLED VIEW
"SCALE": 1/2
"SHAFT HORIZONTAL" VIEW



ASSEMBLED VIEW
"SCALE": 1/5
"VERTICAL (IN USE) ORIENTATION"

ASY538

ASSEMBLY PARTS LIST			
ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK063	MOTOR, STEPPER, ROTATION SYS.
2	1	VEN498-050	PIN, ROLL, 3/32 DIA., 0.50 LONG

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY538		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, THETA MOTOR		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	04 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	04 MAR 91
IBMCAD FILE THMTRASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	04 MAR 91

REL FOR ASM	QTY
ASY511-RRR	4
ASY581-RRR	1

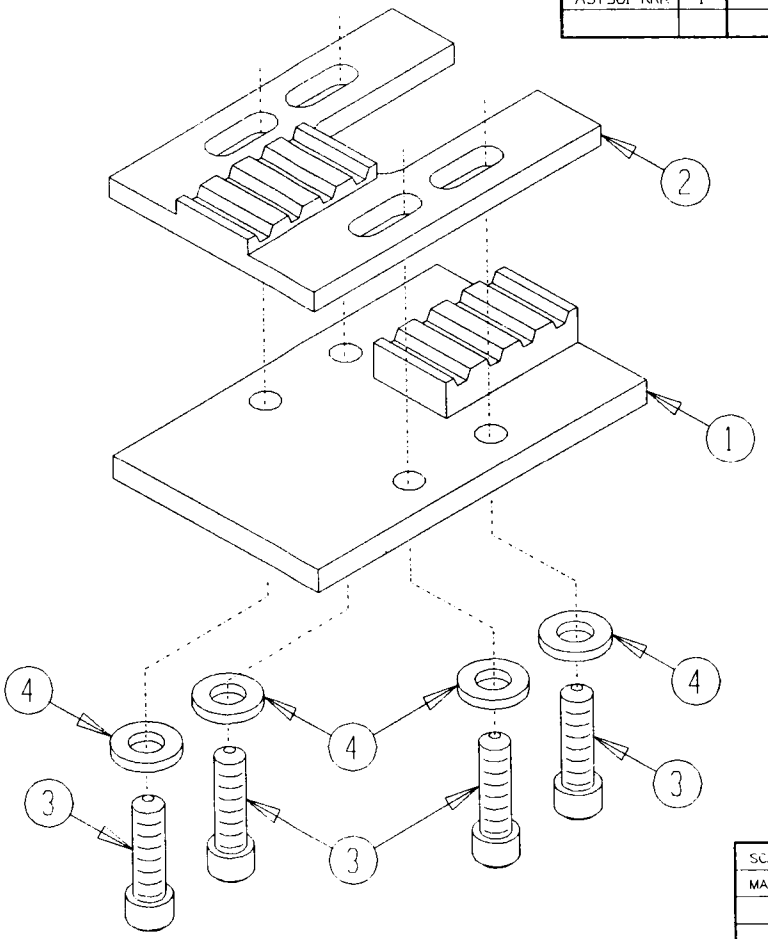
TECHNICAL APPROVALS		
MECHANICAL	MEK	15 APR 91

INIT	DATE	EC #

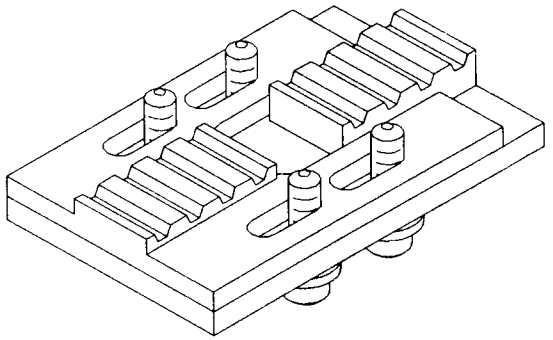
P/N ASY540

"A" SIZE TEMPLATE

0 .25" REAL SIZE



EXPLODED VIEW
"SCALE": 1:1



"ASSEMBLED" VIEW
"SCALE": 1:1

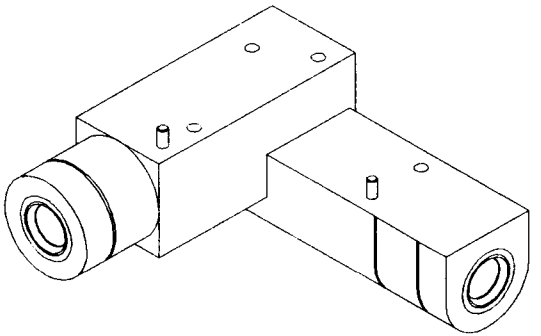
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK042	ATTACHMENT, BELT, FIXED
2	1	MEK043	ATTACHMENT, BELT, ADJUSTABLE
3	4	VEN466-050	SHCS, 0.138 (#6) UNC, 0.50 LONG
4	4	VEN482	WASHER, FLAT, 0.138(#6) NOM. DIA.

SCALE 1:1	DIMENSIONS IN INCHES		PART # ASY540 UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, BELT ATTACHMENT
	LINEAR +/-	N/A	
	ANGLES +/-	N/A	
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER MEK 20 JAN 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED MEK 25 JAN 91
IBMCAD FILE BLTCLASY.R3	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED MEK 15 APR 91

ASY540

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY541-DDD
ASY516-DDD	1	MECHANICAL	MEK	12 MAR 91				
								"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASY541-DDD

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK051-DDD	CARTRIDGE, BEARING, RIGHT ANG
2	4	VEN401-DDD	BEARING, LINEAR BALL
3	4	VEN402-DDD	SEAL, LINEAR BALL BEARING
4	2	VEN496-075	PIN, DOWEL, Ø0.250, 0.750 LNG

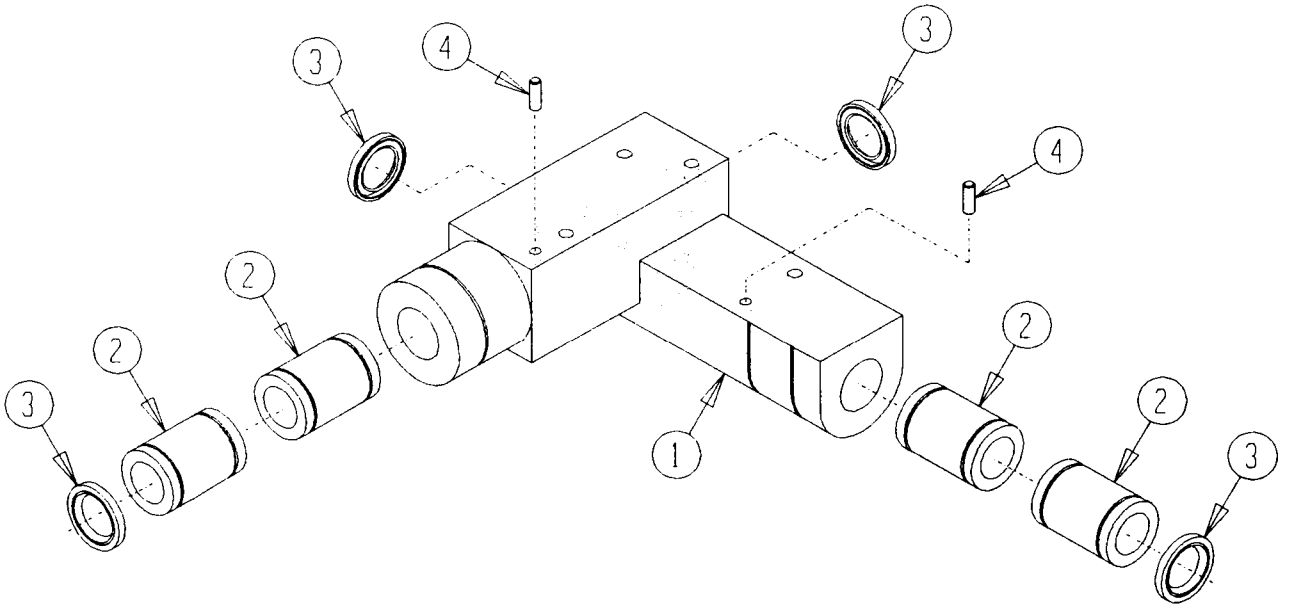
SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY541-DDD		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, CARTRIDGE, XY		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	09 NOV 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	12 MAR 91
IBMCAD FILE CARTASY .R2	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	12 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY516-DDD	1	MECHANICAL	MEK	12 MAR 91			

P/N ASY541-DDD

"A" SIZE TEMPLATE

0 .25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK051-DDD	CARTRIDGE, BEARING, RIGHT ANG
2	4	VEN401-DDD	BEARING, LINEAR BALL
3	4	VEN402-DDD	SEAL, LINEAR BALL BEARING
4	2	VEN496-075	PIN, DOWEL, Ø0.250, 0.750 LNG

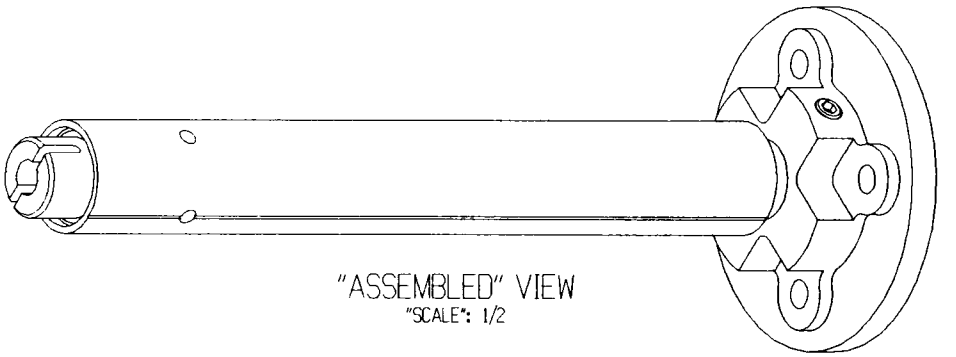
ASY541-DDD

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY541-DDD		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, CARTRIDGE, XY		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	07 AUG 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	12 MAR 91
IBMCAD FILE CARTEXP .R2	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	12 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY551-ZZZ
ASY561-ZZZ	1	MECHANICAL	MEK	12 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



INNER TUBE SUB-ASSEMBLY
"SCALE": 1/2
"USED IN COMPLETE ASSEMBLY SHOWN BELOW"



"ASSEMBLED" VIEW
"SCALE": 1/2

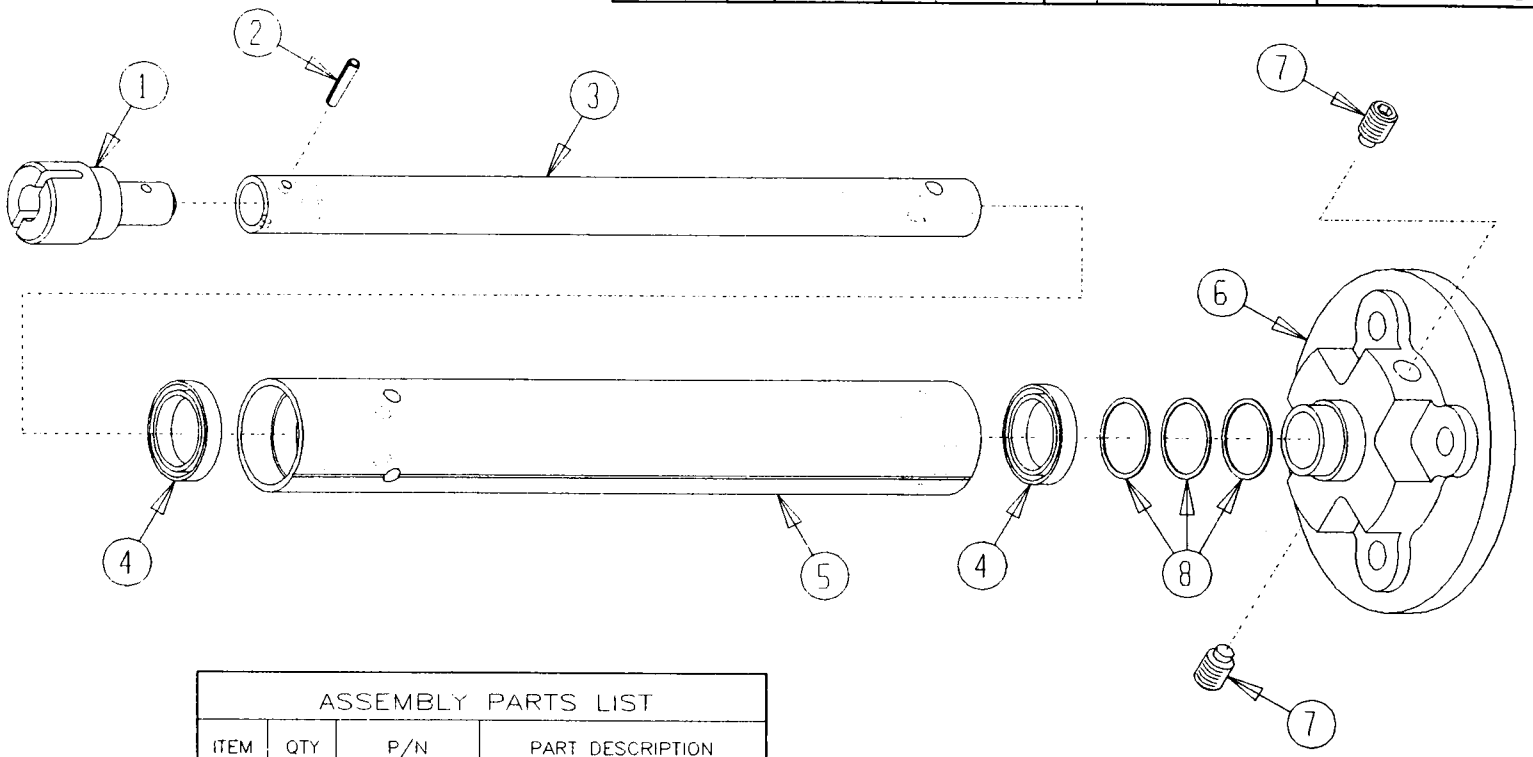
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK201	CONVERTER, MOTOR-TUBE
2	1	VEN498-050	PIN, ROLL, Ø 3/32, 0.500 LONG
3	1	MEK216-ZZZ	TUBE, TRANSMISSION
4	2	MEK422	BRG, BALL, RADIAL, Ø0.625/0.875
5	1	MEK211-ZZZ	TUBE, GUIDE, Z-AXIS
6	1	MEK231	MOUNT, END EFFECTOR
7	2	VEN493-037	SET SCREW, HALF-DOG, Ø0.250
8	AR	VEN427-ttt	SHIM, 0.625/0.713, 0.ttt THK.

ASY551-ZZZ

SCALE 1/2	DIMENSIONS IN INCHES			PART # ASY551-ZZZ		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED			TITLE ASSEMBLY, THETA MOTION		
	LINEAR +/-		N/A			
	ANGLES +/-		N/A			
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	20 JAN 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	12 MAR 91
IBMCAD FILE THETAASY.R3		INSIDE MAX	N/A	APPROVED	MEK	12 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY551-ZZZ
ASY561-ZZZ	1	MECHANICAL	MEK	12 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK201	CONVERTER, MOTOR-TUBE
2	1	VEN498-050	PIN, ROLL, Ø 3/32, 0.500 LONG
3	1	MEK216-ZZZ	TUBE, TRANSMISSION
4	2	MEK422	BRG, BALL, RADIAL, Ø0.625/0.875
5	1	MEK211-ZZZ	TUBE, GUIDE, Z-AXIS
6	1	MEK231	MOUNT, END EFFECTOR
7	2	VEN493-037	SET SCREW, HALF-DOG, Ø0.250
8	AR	VEN427-ttt	SHIM, 0.625/0.713, 0.ttt THK.

ASY551-ZZZ

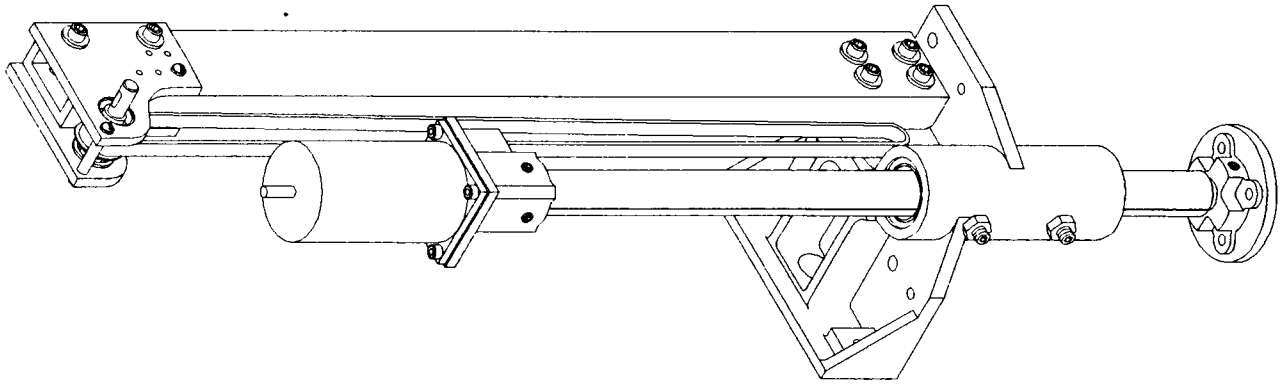
SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY551-ZZZ			UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, THETA MOTION			
	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	20 JAN 91	
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	12 MAR 91	
IBMCAD FILE THETAEXP.R3	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	12 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY581-ZZZ	1	MECHANICAL	MEK	04 MAR 91			

P/N ASY561-ZZZ

"A" SIZE TEMPLATE

0 25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY551-ZZZ	ASSEMBLY, THETA MOTION
2	1	ASY571	ASSEMBLY, Z PLATFORM
3	1	ASY591-ZZZ	ASSEMBLY, MAST
4	1	MEK081	MOTOR MOUNT, THETA
5	1	ASY538	ASSEMBLY, THETA MOTOR
6	2	VEN493-037	SET SCREW, HALF-DOG, Ø0.250
7	4	VEN450-175	SHCS, 0.250 UNF, 1.75 LONG
8	4	VEN486	WASHER, FOR Ø0.250 SCREW
9	4	MEK448-050	SHCS, 0.190(#10) UNF, 0.50 LONG

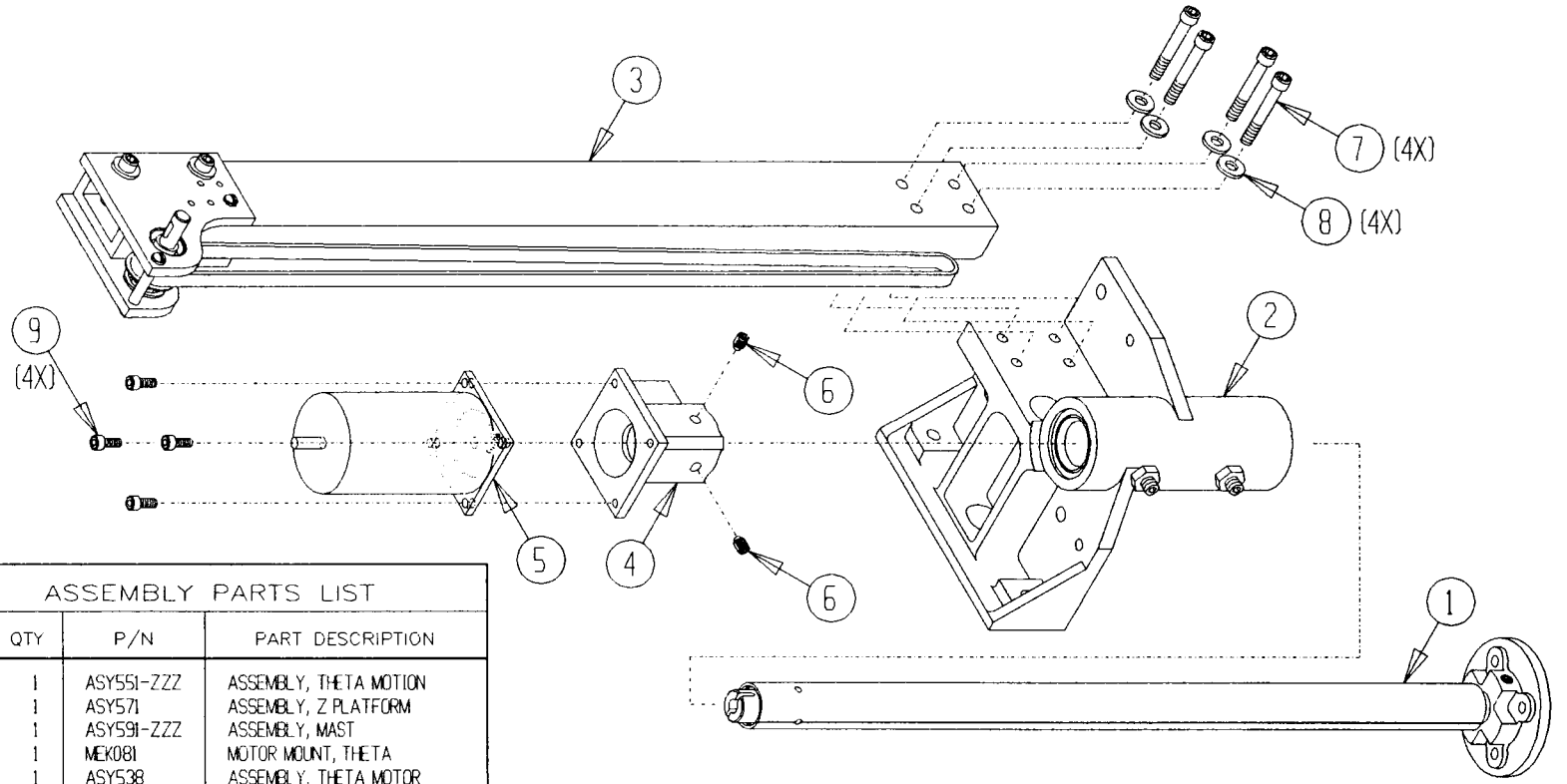
ASY561-ZZZ

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY561-ZZZ		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE ASSEMBLY, Z MOTION		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	04 MAR 91
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	04 MAR 91
IBMCAD FILE ZTHAASY .R2	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	04 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY581-ZZZ	1	MECHANICAL	MEK	06 MAR 91			

P/N ASY561-ZZZ

"A" SIZE TEMPLATE 0 — 25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY551-ZZZ	ASSEMBLY, THETA MOTION
2	1	ASY571	ASSEMBLY, Z PLATFORM
3	1	ASY591-ZZZ	ASSEMBLY, MAST
4	1	MEK081	MOTOR MOUNT, THETA
5	1	ASY538	ASSEMBLY, THETA MOTOR
6	2	VEN493-037	SET SCREW, HALF-DOG, Ø0.250
7	4	VEN450-175	SHCS, 0.250 UNF, 1.75 LONG
8	4	VEN486	WASHER, FOR Ø0.250 SCREW
9	4	MEK448-050	SHCS, 0.190(#10) UNF, 0.50 LONG

ASY561-ZZZ

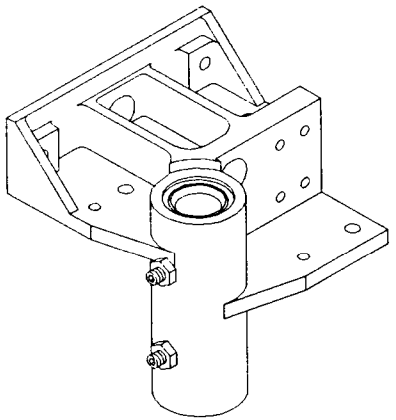
SCALE 1/5	DIMENSIONS IN INCHES			PART # ASY561-ZZZ	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE ASSEMBLY, Z MOTION	
	ANGLES +/-		N/A		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER MEK 06 MAR 91	
	EDGE/CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED MEK 06 MAR 91	
IBMCAD FILE ZTHAEXP .R2		INSIDE MAX	N/A	APPROVED MEK 06 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY561-ZZZ	1	MECHANICAL	MEK	07 MAR 91			

P/N ASY571

"A" SIZE TEMPLATE

0 .25" REAL SIZE



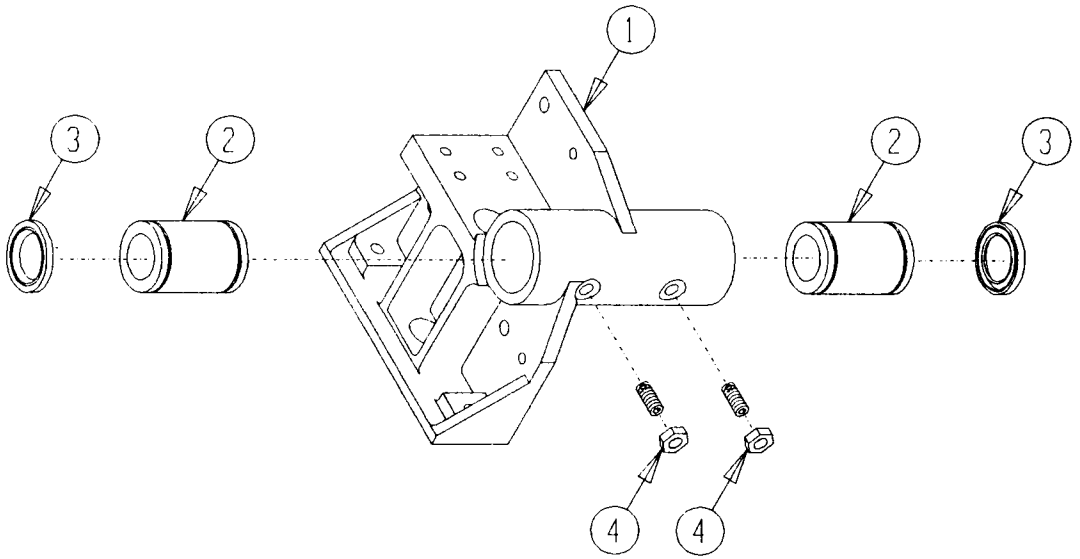
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK071	PLATFORM, Z-THETA
2	2	VEN403-100	BRG, LINEAR, "SUPER", 1.00 TUBE
3	2	VEN402-100	SEAL, LINEAR BRG, 1.00 TUBE DIA.
4	2	VEN404	ASSY, SCREW ADJUSTING

ASY571

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY571		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE ASSEMBLY, Z		
	ANGLES +/-	N/A	PLATFORM		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	07 JAN 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	07 MAR 91
IBMCAD FILE ZPLATASY.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	07 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY571
ASY561-ZZ2	1	MECHANICAL	MEK	07 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK071	PLATFORM, Z-THETA
2	2	VEN403-100	BRG, LINEAR, "SUPER", 1.00 TUBE
3	2	VEN402-100	SEAL, LINEAR BRG, 1.00 TUBE DIA.
4	2	VEN404	ASSY, SCREW ADJUSTING

ASY571

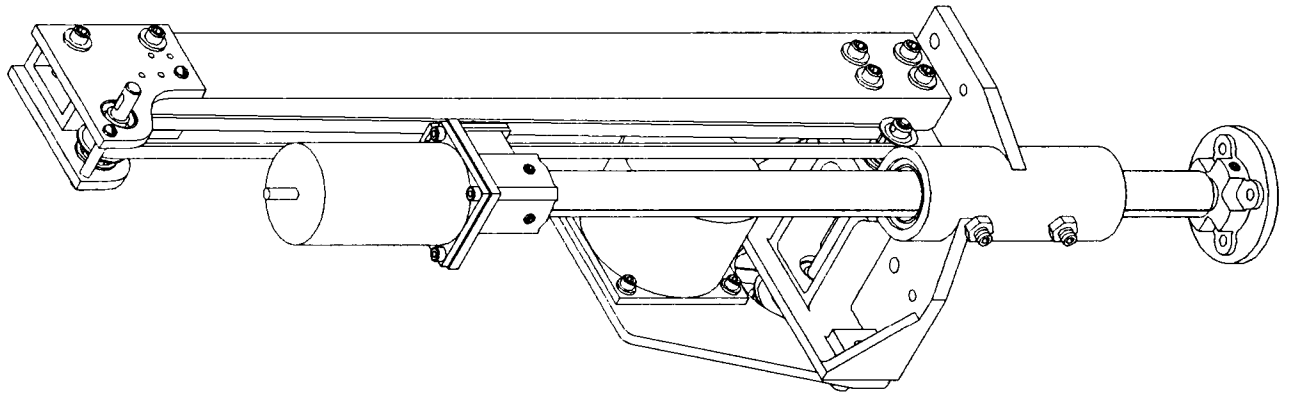
SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY571			UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, Z			
	LINEAR +/-	N/A	PLATFORM			
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	06 JAN 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	07 MAR 91	
IDEMCAD FILE ZPLATEXP.R2	INSIDE MAX	N/A	APPROVED	MEK	07 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY506-RRR	1	MECHANICAL	MEK	24 MAR 91			

P/N ASY581-RRR

"A" SIZE TEMPLATE

0 .25" REAL SIZE



ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY561-ZZZ	ASSEMBLY, Z MOTION
2	1	ASY536	ASSEMBLY, Z MOTOR
3	1	ASY540	ASSEMBLY, BELT ATTACHMENT
4	2	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
5	2	VEN487	WASHER, FOR Ø0.312 SCREW
6	1	KIT621	KIT, Z REDUCTION DRIVE

ASY581-RRR

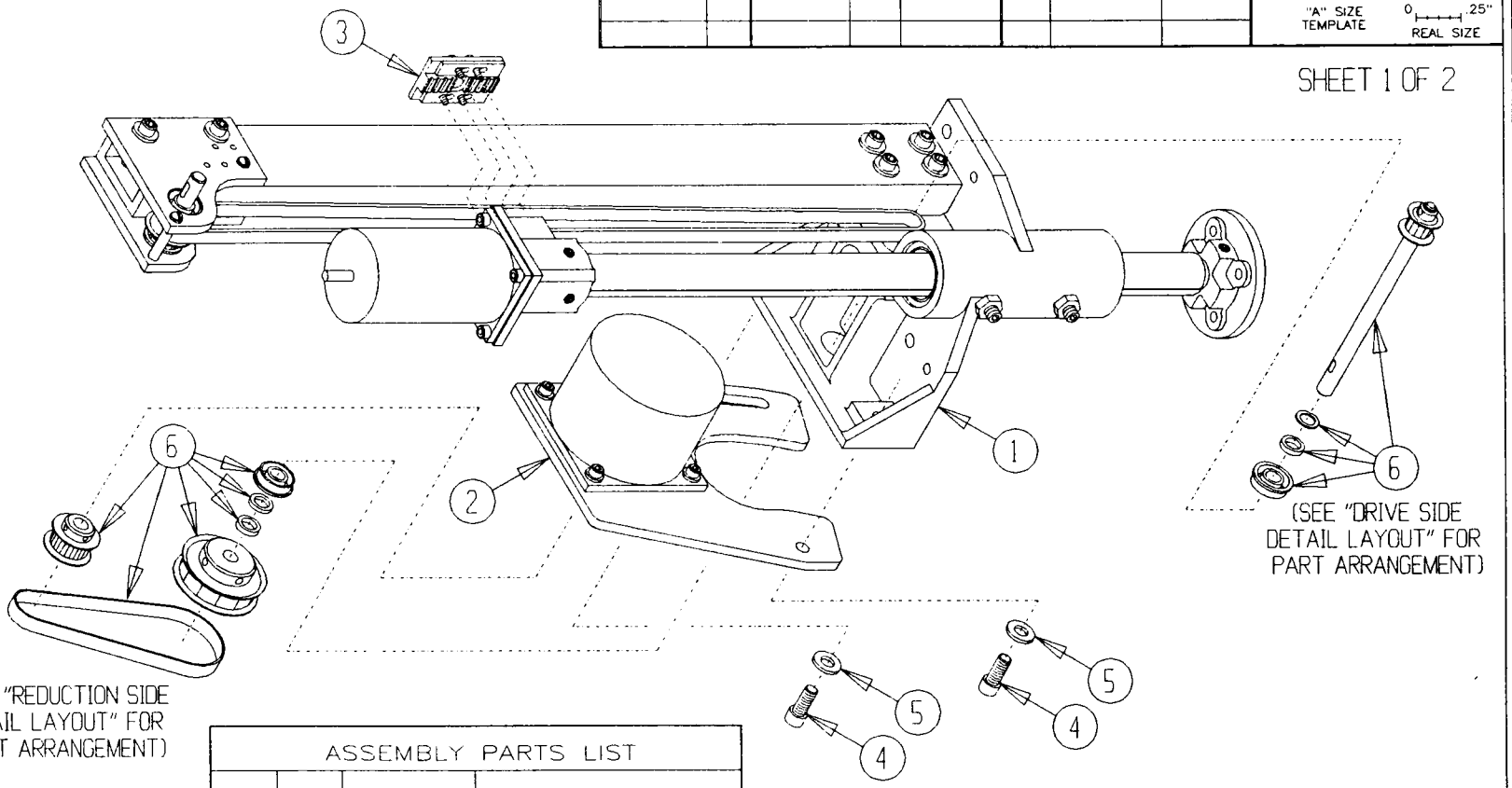
SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY581-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, Z-THETA DRIVE		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A	DESIGNER	MEK	24 MAR 91
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	24 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	24 MAR 91
IBMCAD FILE ZDRIVASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A			

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY506-RRR	1	MECHANICAL	MEK	24 MAR 91			

P/N ASY581-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 2



(SEE "REDUCTION SIDE DETAIL LAYOUT" FOR PART ARRANGEMENT)

(SEE "DRIVE SIDE DETAIL LAYOUT" FOR PART ARRANGEMENT)

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY561-ZZZ	ASSEMBLY, Z MOTION
2	1	ASY536	ASSEMBLY, Z MOTOR
3	1	ASY540	ASSEMBLY, BELT ATTACHMENT
4	2	VEN451-075	SHCS, 0.312 UNF, 0.75 LONG
5	2	VEN487	WASHER, FOR Ø0.312 SCREW
6	1	KIT621	KIT, Z REDUCTION DRIVE

ASY581-RRR

SCALE 1/5	DIMENSIONS IN INCHES		PART # ASY581-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, Z-THETA DRIVE		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	24 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	24 MAR 91
IBMCAD FILE ZDRIVEXP.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	24 MAR 91

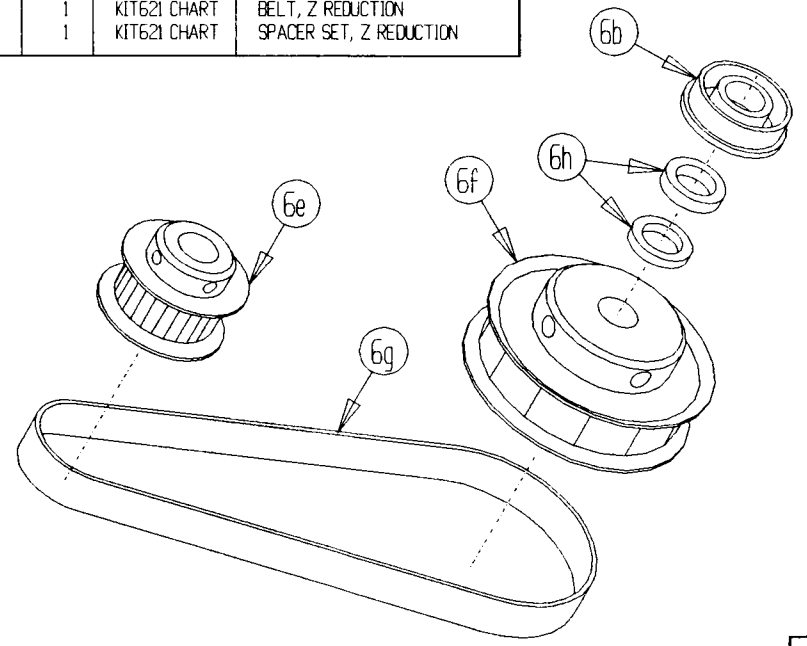
KIT 621 PARTS DETAIL			
ITEM	QTY	P/N	PART DESCRIPTION
6a	1	ASY527	ASSEMBLY, Z REDUCTION SHAFT
6b	2	VEN421	BEARING, BALL, 0.375 ID, FLANGE
6c	1	VEN426-031	SPACER, 0.375 BRG. ID, 0.031 THK
6d	1	VEN426-125	SPACER, 0.375 BRG. ID, 0.125 THK
6e	1	KIT621 CHART	PULLEY, MOTOR
6f	1	KIT621 CHART	PULLEY, Z REDUCTION
6g	1	KIT621 CHART	BELT, Z REDUCTION
6h	1	KIT621 CHART	SPACER SET, Z REDUCTION

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
		MECHANICAL					

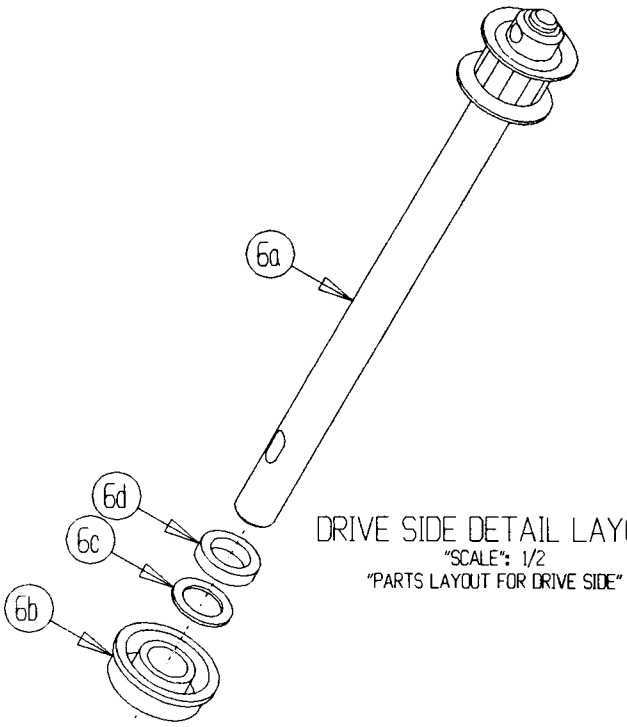
P/N ASY581-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 2 OF 2



REDUCTION SIDE DETAIL LAYOUT
"SCALE": 1/2
"PARTS LAYOUT FOR REDUCTION SIDE"



DRIVE SIDE DETAIL LAYOUT
"SCALE": 1/2
"PARTS LAYOUT FOR DRIVE SIDE"

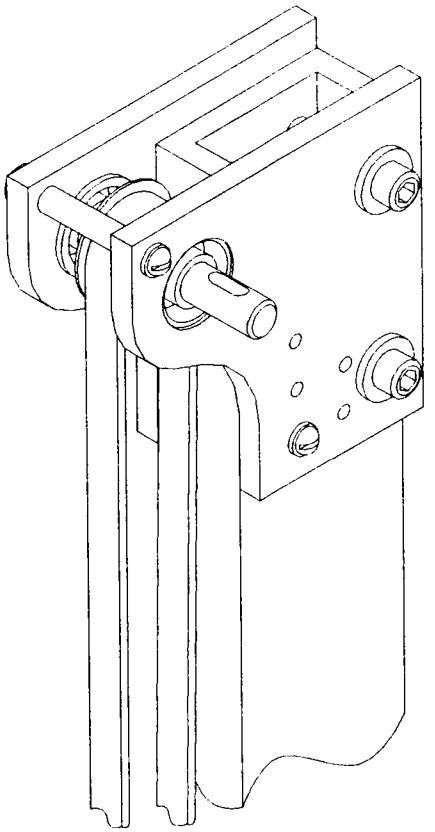
ASY581-RRR

SCALE 1/5	DIMENSIONS IN INCHES			PART # ASY581-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED			TITLE ASSEMBLY, Z-THETA DRIVE		
	LINEAR +/-		N/A			
	ANGLES +/-		N/A			
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	24 MAR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	24 MAR 91
IBMCAD FILE ZDRIVEXP.R1		INSIDE MAX	N/A	APPROVED	MEK	24 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY561-ZZZ	1	MECHANICAL	MEK	24 MAR 91			

P/N ASY591-ZZZ

"A" SIZE TEMPLATE 0 .25" REAL SIZE



"CLOSE-UP VIEW" OF ASSEMBLY
"SCALE": 1/2
"TOP PART OF MAST SHOWN"



"FULL VIEW" OF ASSEMBLY
"SCALE": 1/10
"FULL BELT AND MAST SHOWN"

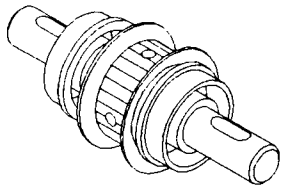
ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK093-ZZZ	MAST, Z-AXIS
2	2	MEK091	PLATE, MOUNTING, MAST
3	1	VEN832	PULLEY, T BLT, 0.955 PD, HBLESS
4	2	VEN421	BRG, BALL, RADIAL, Ø0.375/0.875
5	2	VEN426-031	SPACER, IR, 0.375 ID, 0.031 THK
6	2	VEN426-125	SPACER, IR, 0.375 ID, 0.125 THK
7	1	MEK048	SHAFT, Z MAST IDLER
8	2	VEN494-175	SCR, RND HD, Ø0.138 UNC, 1.75 LNG
9	2	VEN450-175	SHCS, 0.250-28 UNF, 1.75 LONG
10	2	VEN482	WASHER, FLAT, 0.138 NOM. DIA.
11	2	VEN495	NUT, HEXAGONAL, 0.138-32 UNC
12	4	VEN486	WASHER, FLAT, 0.250 NOM. DIA.
13	2	VEN490	NUT, HEXAGONAL, 0.250-28 UNF
14	1	VEN497	SPACER, UNTHDED, FOR #6, 1" LNG
15	1	VEN840	BELT, Z AXIS DRIVE

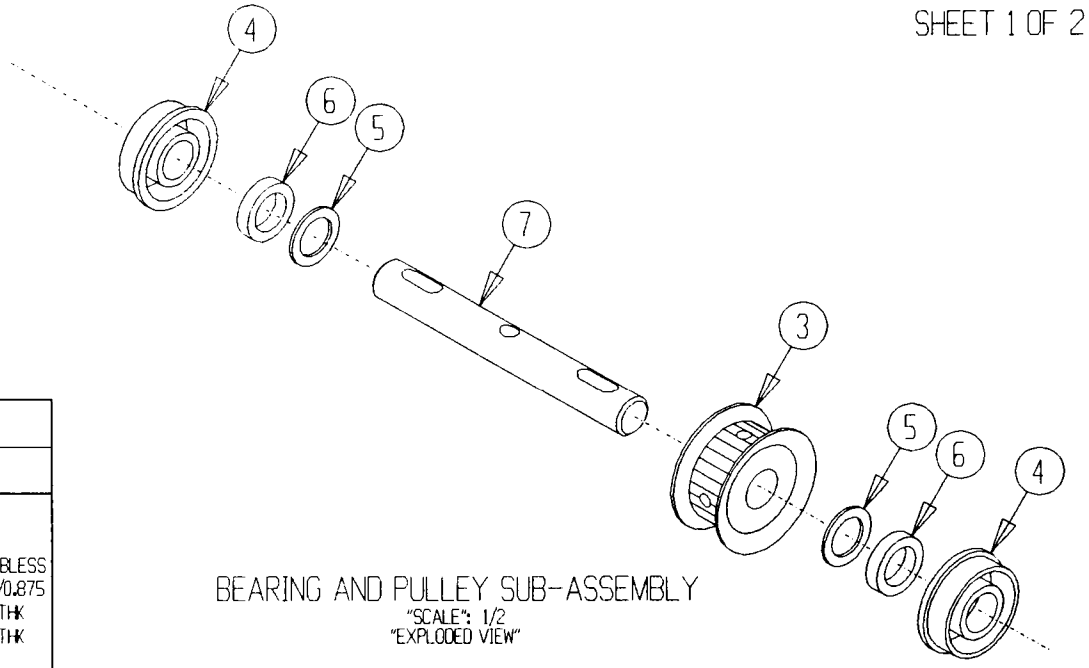
ASY591-ZZZ

SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY591-ZZZ			UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, Z MAST			
	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	14 JAN 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	24 MAR 91	
IBMCAD FILE ZMASTASY.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	24 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY591-ZZZ
ASY561-ZZZ	1	MECHANICAL	MEK	24 MAR 91				
								"A" SIZE TEMPLATE 0 .25" REAL SIZE



BEARING AND PULLEY SUB-ASSEMBLY
"SCALE": 1/2
"ASSEMBLED VIEW"



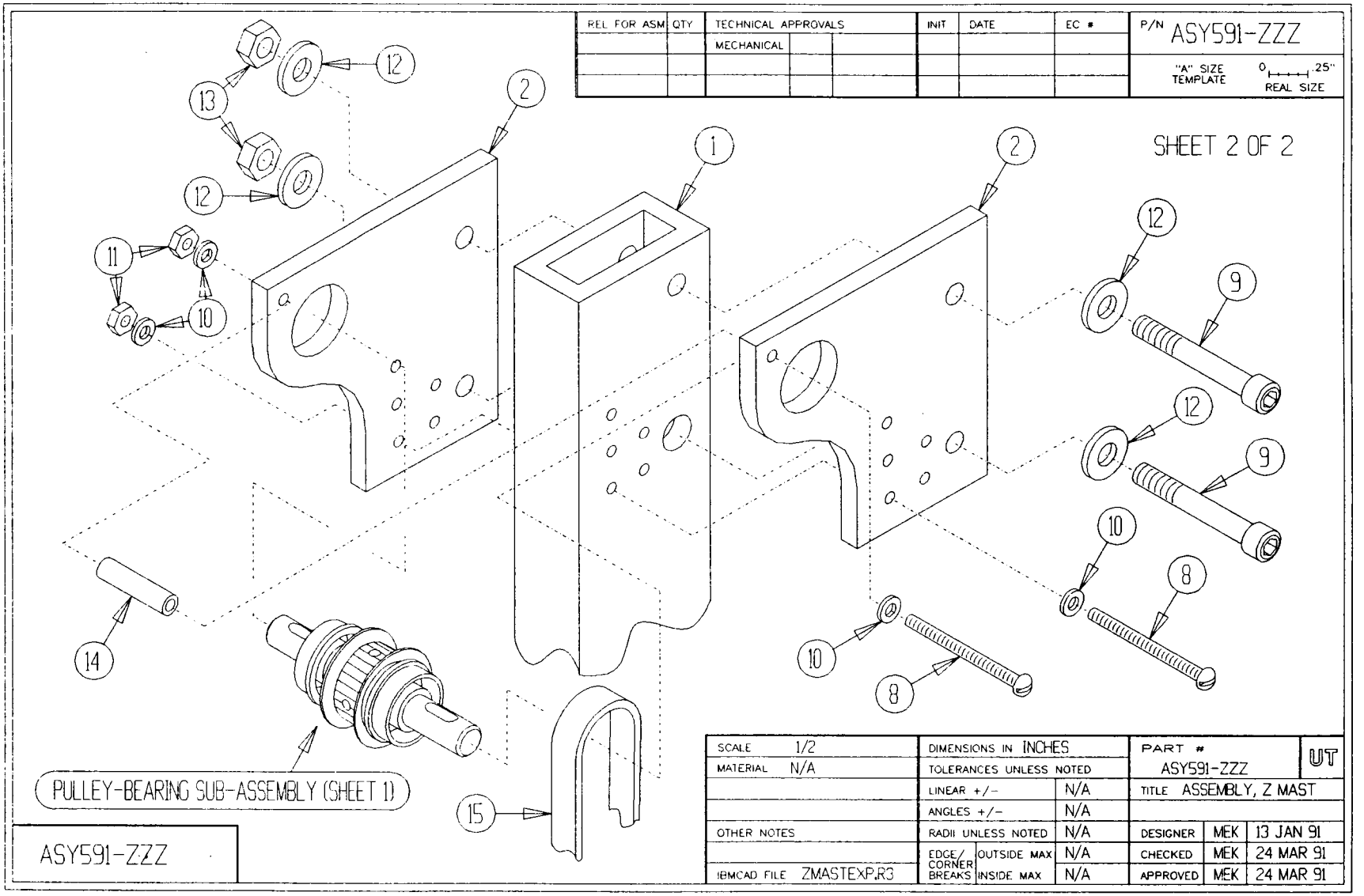
BEARING AND PULLEY SUB-ASSEMBLY
"SCALE": 1/2
"EXPLODED VIEW"

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK093-ZZZ	MAST, Z-AXIS
2	2	MEK091	PLATE, MOUNTING, MAST
3	1	VEN832	PULLEY, T BLT, 0.955 PD, HBLESS
4	2	VEN421	BRG, BALL, RADIAL, Ø0.375/0.875
5	2	VEN426-031	SPACER, IR, 0.375 ID, 0.031 THK
6	2	VEN426-125	SPACER, IR, 0.375 ID, 0.125 THK
7	1	MEK048	SHAFT, Z MAST IDLER
8	2	VEN494-175	SCR, RND HD, Ø0.138 UNC, 1.75 LNG
9	2	VEN450-175	SHCS, 0.250-28 UNF, 1.75 LONG
10	2	VEN482	WASHER, FLAT, 0.138 NOM. DIA.
11	2	VEN495	NUT, HEXAGONAL, 0.138-32 UNC
12	4	VEN486	WASHER, FLAT, 0.250 NOM. DIA.
13	2	VEN490	NUT, HEXAGONAL, 0.250-28 UNF
14	1	VEN497	SPACER, UNTHDED, FOR #6, 1" LNG
15	1	VEN840	BELT, Z AXIS DRIVE

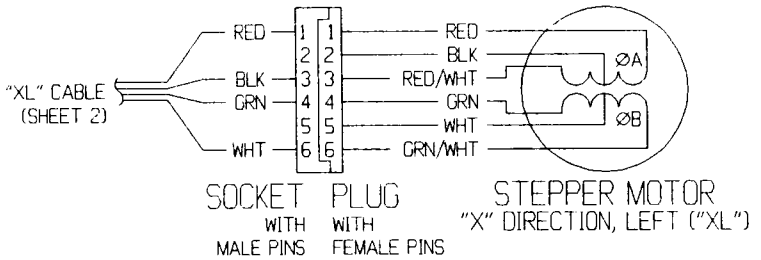
ASY591-ZZZ

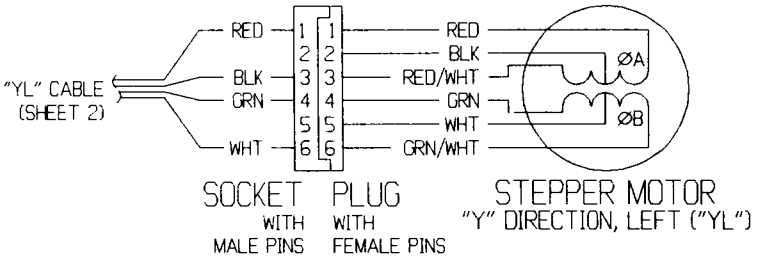
SCALE 1/2	DIMENSIONS IN INCHES		PART # ASY591-ZZZ		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE ASSEMBLY, Z MAST		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	13 JAN 91
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	24 MAR 91
IBMCAD FILE ZMASTEXP.R3	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	24 MAR 91

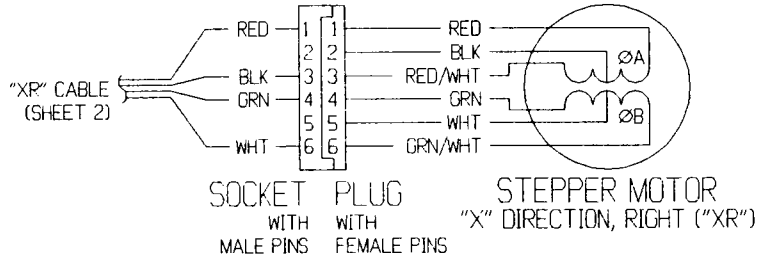

REL FOR ASM
QTY
TECHNICAL APPROVALS
MECHANICAL
INIT
DATE
EC #
P/N ASY591-ZZZ
"A" SIZE TEMPLATE
0 .25"
REAL SIZE
SHEET 2 OF 2
PULLEY-BEARING SUB-ASSEMBLY (SHEET 1)
ASY591-ZZZ
SCALE 1/2
MATERIAL N/A
OTHER NOTES
IBMCAD FILE ZMASTEXP.R3
DIMENSIONS IN INCHES
TOLERANCES UNLESS NOTED
LINEAR +/- N/A
ANGLES +/- N/A
RADII UNLESS NOTED N/A
EDGE/CORNER BREAKS OUTSIDE MAX N/A
INSIDE MAX N/A
PART # ASY591-ZZZ
UT
TITLE ASSEMBLY, Z MAST
DESIGNER MEK 13 JAN 91
CHECKED MEK 24 MAR 91
APPROVED MEK 24 MAR 91

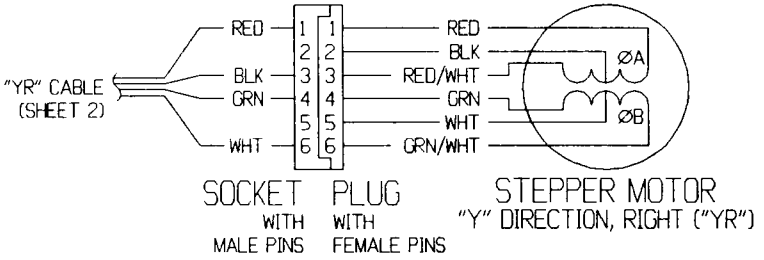
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY601
ASY501-RRR	1	MECHANICAL	MEK	16 APR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 3









ASSEMBLY PARTS LIST

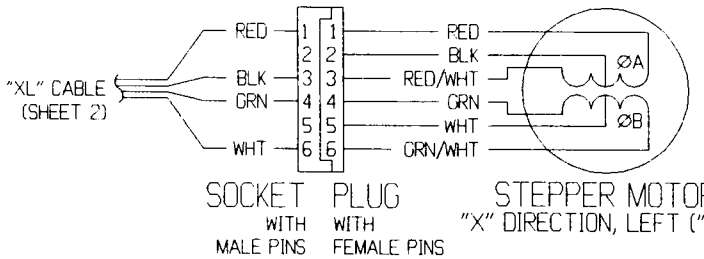
ITEM	QTY	P/N	PART DESCRIPTION
1	4	N/A	IMS463 STEPPER MOTOR DRIVER
2	6	N/A	MOLEX PLUG, 0.093" S, 6 CIRCUIT
3	6	N/A	MOLEX RCPTCLE, 0.093" S, 6 CIR
4	1	N/A	WIRE, 18AWG-4, 100 FT.
5	1	N/A	WIRE, 18AWG-2, 25 FT.
6	1	N/A	TERMINAL STRIP, 4 ACROSS

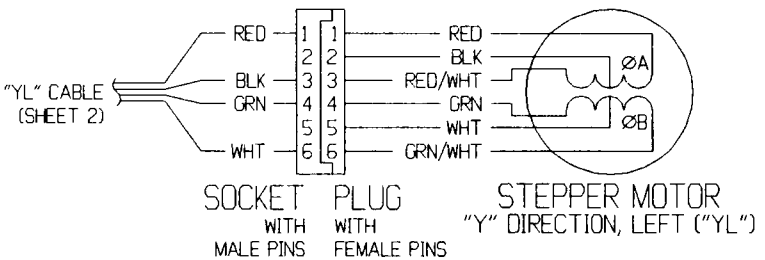
ASY601

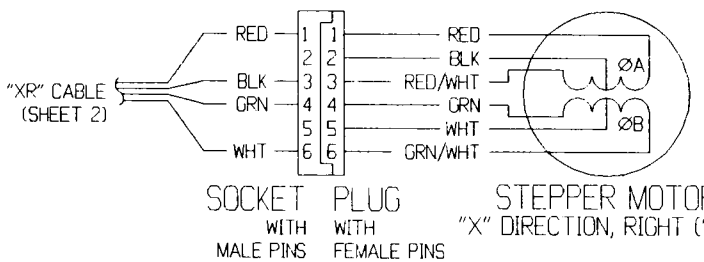
SCALE 1:1	DIMENSIONS IN INCHES			PART # ASY601	UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-		N/A	TITLE ASSEMBLY, ROBOT	
	ANGLES +/-		N/A	ELECTRICAL	
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK 15 APR 91
	EDGE/CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK 16 APR 91
IBMCAD FILE ELECTASY.R1		INSIDE MAX	N/A	APPROVED	MEK 16 APR 91

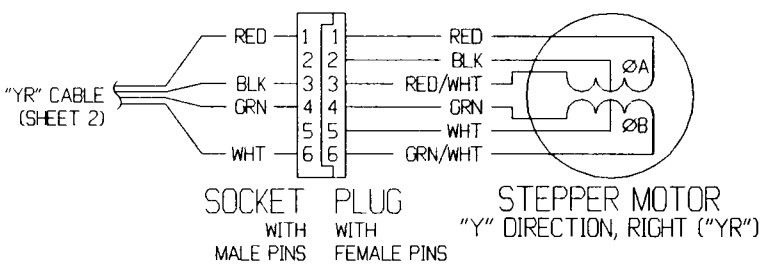
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N ASY601
ASY501-RRR	1	MECHANICAL	MEK	16 APR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 1 OF 3









ASSEMBLY PARTS LIST

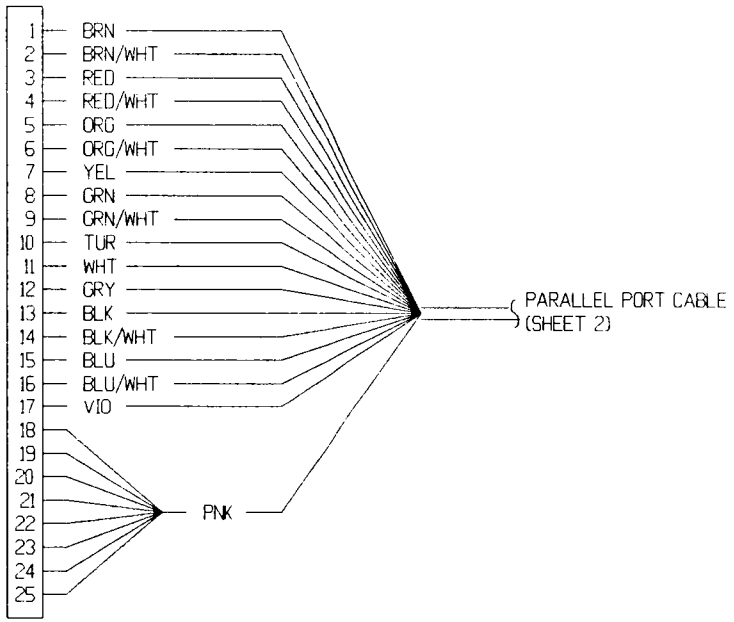
ITEM	QTY	P/N	PART DESCRIPTION
1	4	N/A	IMS463 STEPPER MOTOR DRIVER
2	6	N/A	MOLEX PLUG, 0.093" S, 6 CIRCUIT
3	6	N/A	MOLEX RCPTCLE, 0.093" S, 6 CIR
4	1	N/A	WIRE, 18AWG-4, 100 FT.
5	1	N/A	WIRE, 18AWG-2, 25 FT.
6	1	N/A	TERMINAL STRIP, 4 ACROSS

ASY601

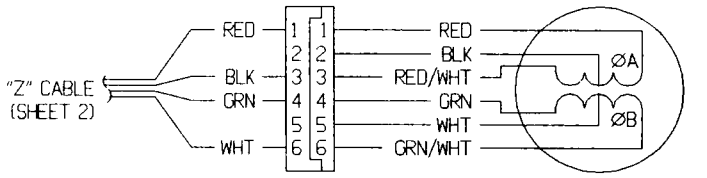
SCALE 1:1	DIMENSIONS IN INCHES		PART # ASY601		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE ASSEMBLY, ROBOT		
	LINEAR +/-	N/A	ELECTRICAL		
	ANGLES +/-	N/A	DESIGNER	MEK	15 APR 91
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	16 APR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	16 APR 91
IBMCAD FILE ELECTASY.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A			

REL FOR ASM	QTY	TECHNICAL APPROVALS		INIT	DATE	EC #	P/N ASY601
		MECHANICAL					"A" SIZE TEMPLATE 0 25" REAL SIZE
		ELECTRICAL					

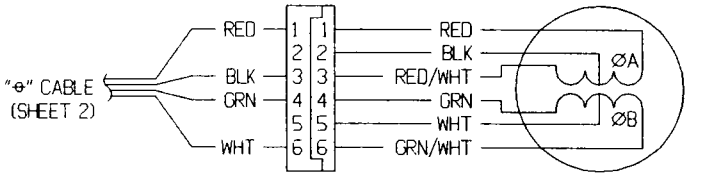
SHEET 3
OF 3



25 PIN CONNECTOR
PARALLEL PORT CABLE
MALE CONNECTOR
(ATTACH TO PC PORT)



SOCKET WITH MALE PINS
PLUG WITH FEMALE PINS
STEPPER MOTOR "Z" DIRECTION ("Z")



SOCKET WITH MALE PINS
PLUG WITH FEMALE PINS
STEPPER MOTOR "THETA" DIRECTION ("θ")

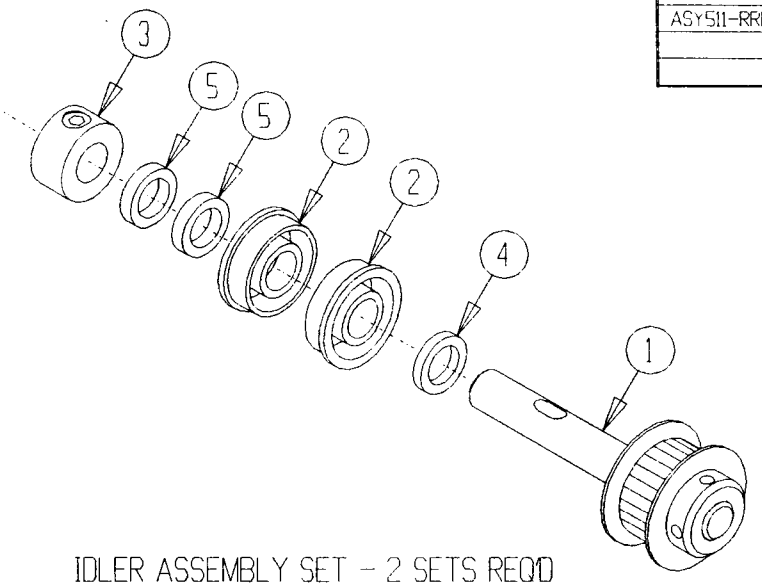
SCALE 1:1	DIMENSIONS IN INCHES	PART # ASY601	UT
MATERIAL	TOLERANCES UNLESS NOTED		
	LINEAR +/-	TITLE ASSEMBLY, ROBOT	
	ANGLES +/-	ELECTRICAL	
OTHER NOTES	RADII UNLESS NOTED	DESIGNER MEK 15 APR 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	CHECKED MEK 16 APR 91	
IBMCAD FILE ELECTASY.R1	INSIDE MAX	APPROVED MEK 16 APR 91	

ASY601

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY511-RRR	2	MECHANICAL	MEK	21 MAR 91			

P/N KIT611-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE



IDLER ASSEMBLY SET - 2 SETS REQ'D
"SCALE": 1/2
"IDLER PULLEY END VIEW"

NOTES:

1. PULLEY, TIMING BELT, AND SPACER PART NUMBERS DEPEND ON THE REQUIRED REDUCTION RATIO. PART REQUIREMENTS DEPEND ON THE P/N SUFFIX, AND ARE SPECIFIED IN THE SPECIFICATION CHARTS.

2. TOTAL SPACER THICKNESS LISTED FOR EACH RATIO OPTION MUST BE SUPPLIED. RECOMMENDED SPACER P/N SUFFIXES AND QUANTITY IS SPECIFIED IN CHART. P/N VEN426-ttt IS TO BE USED FOR ALL SPACERS.

REDUCTION BELT AND SPACER SPECIFICATION CHART : [1] [2]

X OR Y REDUCTION RATIO	P/N SUFFIX	REDUCTION BELT (ITEM 8: VEN841-LLL) -LLL	PITCH LENGTH	REQ'D SPACER THKNESS	RECOMMENDED SPACERS (ITEM 9: VEN426-ttt) -ttt	QTY	-ttt	QTY
1.000	-100	-081	16.20	0.312	-125	2	-031	2
1.500	-200	-091	18.20	0.219	-125	1	-094	1
2.000	-200	-088	17.60	0.219	-125	1	-094	1
3.000	-300	-095	19.00	0.125	-125	1	-	-

ASSEMBLY PARTS LIST

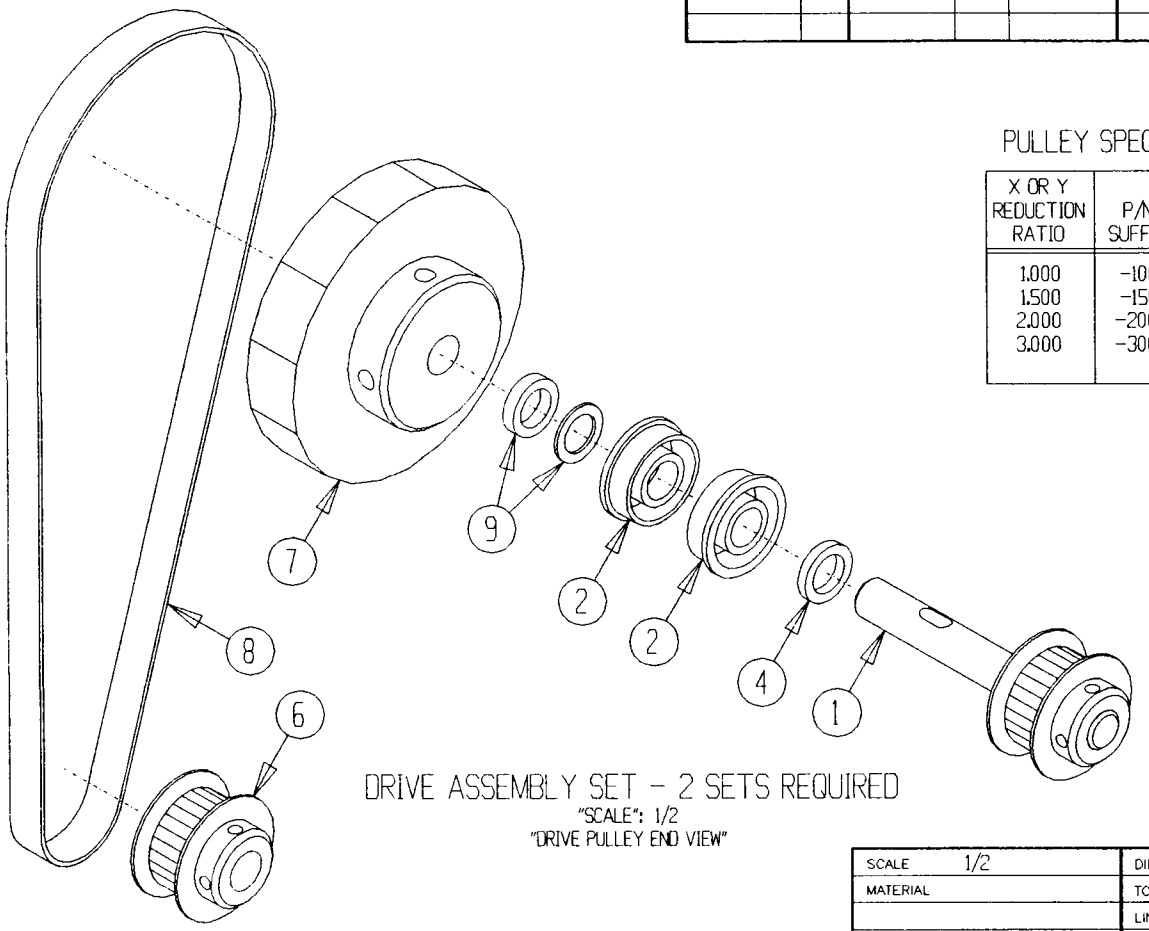
ITEM	QTY	P/N	PART DESCRIPTION
1	4	ASY526	ASSEMBLY, XY REDUCTION SHAFT
2	8	VEN421	BEARING, BALL, 0.375 ID, FLANGE
3	2	VEN428	COLLAR, SHAFT, 0.375 BORE
4	4	VEN426-094	SPACER, 0.375 BRG. ID, 0.094 THK
5	4	VEN426-125	SPACER, 0.375 BRG. ID, 0.125 THK
6	2	SPEC CHART	PULLEY, MOTOR
7	2	SPEC CHART	PULLEY, XY REDUCTION
8	2	SPEC CHART	BELT, XY REDUCTION
9	2	SPEC CHART	SPACER SET, XY REDUCTION

KIT611-RRR

SCALE 1/2	DIMENSIONS IN INCHES		PART # KIT611-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED		TITLE KIT, XY REDUCTION DRIVE		
	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	21 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	21 MAR 91
IBMCAD FILE KIT611 .R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	21 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N KIT611-RRR
		MECHANICAL						"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 2 OF 2



DRIVE ASSEMBLY SET - 2 SETS REQUIRED
"SCALE": 1/2
"DRIVE PULLEY END VIEW"

PULLEY SPECIFICATION CHART : [1]

X OR Y REDUCTION RATIO	P/N SUFFIX	MOTOR PULLEY (ITEM 6) P/N	MOTOR PULLEY (ITEM 6) PITCH DIA.	REDUCTION PULLEY (ITEM 7) P/N	REDUCTION PULLEY (ITEM 7) PITCH DIA.
1.000	-100	VEN801	0.955	VEN801	0.955
1.500	-150	VEN804	1.273	VEN811	1.910
2.000	-200	VEN801	0.955	VEN811	1.910
3.000	-300	VEN801	0.955	VEN826	2.865

SCALE 1/2	DIMENSIONS IN INCHES	PART # KIT611-RRR	UT
MATERIAL	TOLERANCES UNLESS NOTED		
	LINEAR +/-	TITLE KIT, XY REDUCTION DRIVE	
	ANGLES +/-		
OTHER NOTES	RADII UNLESS NOTED	DESIGNER MEK 21 MAR 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	CHECKED MEK 21 MAR 91	
IBMCAD FILE KIT611 .R1	EDGE/CORNER BREAKS INSIDE MAX	APPROVED MEK 21 MAR 91	

KIT611-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N KIT621-RRR
ASY581-RRR	1	MECHANICAL	MEK	24 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

PULLEY SPECIFICATION CHART : [1]

Z REDUCTION RATIO	P/N SUFFIX	MOTOR PULLEY (ITEM 5) P/N	MOTOR PULLEY (ITEM 5) PITCH DIA.	REDUCTION PULLEY (ITEM 6) P/N	REDUCTION PULLEY (ITEM 6) PITCH DIA.
1.000	-100	VEN801	0.955	VEN801	0.955
2.000	-200	VEN801	0.955	VEN811	1.910
2.500	-250	VEN803	1.146	VEN826	2.865
3.000	-300	VEN801	0.955	VEN826	2.865

NOTES:

[1] PULLEY, TIMING BELT, AND SPACER PART NUMBERS DEPEND ON THE REQUIRED REDUCTION RATIO. PART REQUIREMENTS DEPEND ON THE P/N SUFFIX, AND ARE SPECIFIED IN THE SPECIFICATION CHARTS.

[2] TOTAL SPACER THICKNESS LISTED FOR EACH RATIO OPTION MUST BE SUPPLIED. RECOMMENDED SPACER P/N SUFFIXES AND QUANTITY IS SPECIFIED IN CHART. P/N VEN426-ttt IS TO BE USED FOR ALL SPACERS.

KIT PARTS ARE SHOWN ON SHEET 2

REDUCTION BELT AND SPACER SPECIFICATION CHART : [1] [2]

Z REDUCTION RATIO	P/N SUFFIX	REDUCTION BELT (ITEM 7: VEN841-LLL) -LLL	REDUCTION BELT (ITEM 7: VEN841-LLL) PITCH LENGTH	REQ'D SPACER THKNESS	RECOMMENDED SPACERS (ITEM 8: VEN426-ttt) -ttt	QTY	-ttt	QTY
1.000	-100	-057	11.40	0.312	-125	2	-031	2
2.000	-200	-065	13.00	0.219	-125	1	-094	1
2.500	-250	-073	14.80	0.125	-125	1	-	-
3.000	-300	-073	14.80	0.125	-125	1	-	-

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	ASY527	ASSEMBLY, Z REDUCTION SHAFT
2	2	VEN421	BEARING, BALL, 0.375 ID, FLANGE
3	1	VEN426-031	SPACER, 0.375 BRG. ID, 0.031 THK
4	1	VEN426-125	SPACER, 0.375 BRG. ID, 0.125 THK
5	1	SPEC CHART	PULLEY, MOTOR
6	1	SPEC CHART	PULLEY, Z REDUCTION
7	1	SPEC CHART	BELT, Z REDUCTION
8	1	SPEC CHART	SPACER SET, Z REDUCTION

KIT621-RRR

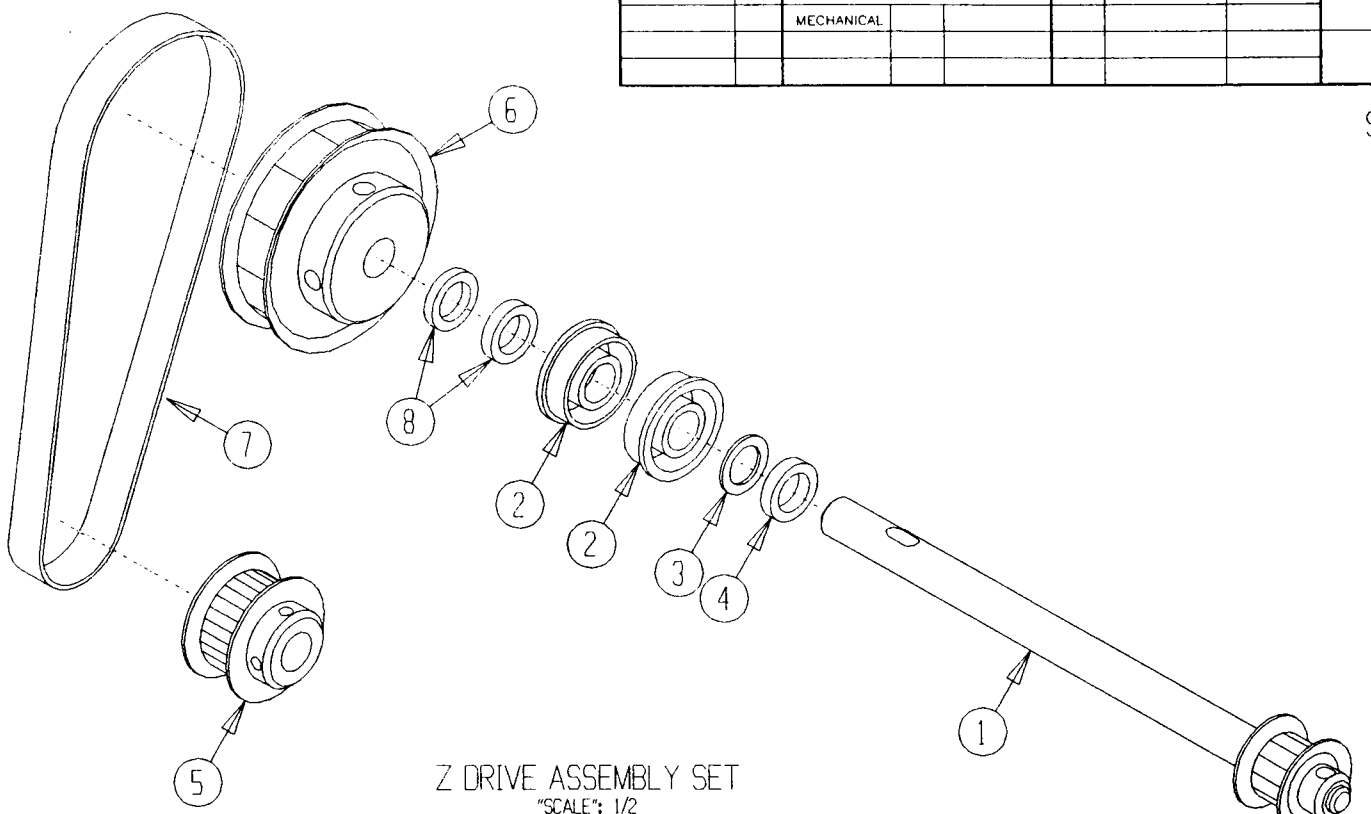
SCALE 1/2	DIMENSIONS IN INCHES		PART # KIT621-RRR		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE KIT, Z REDUCTION DRIVE		
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	24 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	24 MAR 91
IBMCAD FILE KIT621.DRI	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	24 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
		MECHANICAL					

P/N KIT621-RRR

"A" SIZE TEMPLATE 0 .25" REAL SIZE

SHEET 2 OF 2

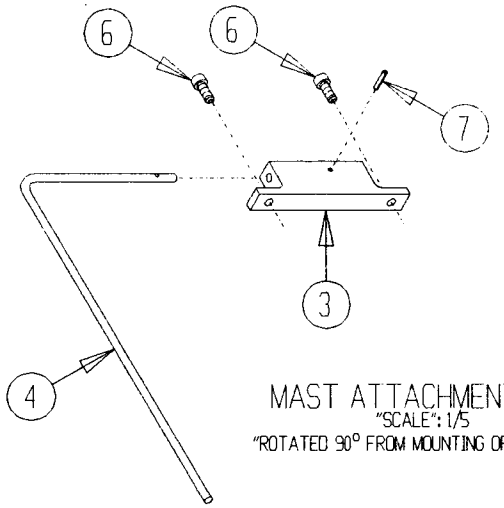


Z DRIVE ASSEMBLY SET
"SCALE": 1/2
"DRIVE PULLEY END VIEW"

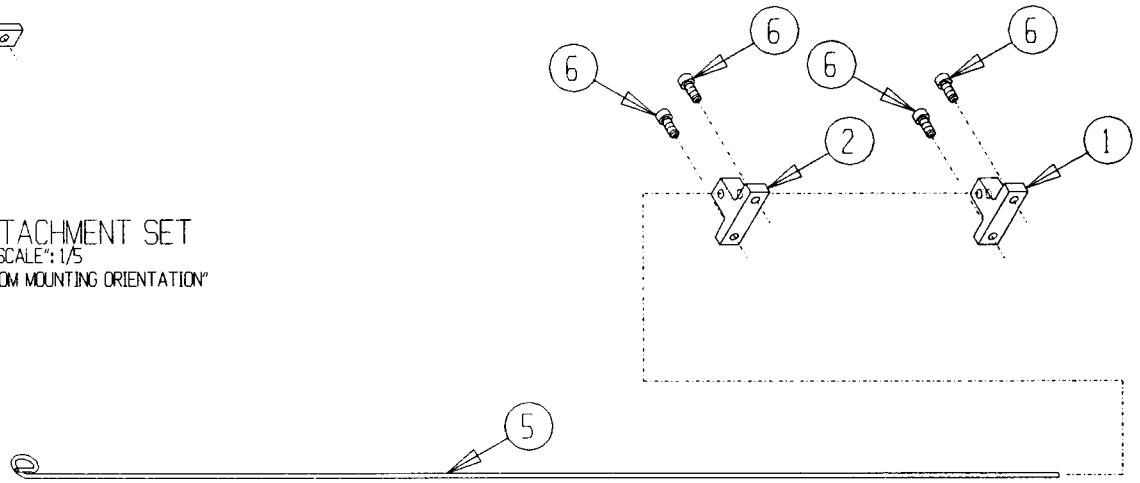
SCALE 1/2	DIMENSIONS IN INCHES		PART # KIT621-RRR		UT
MATERIAL	TOLERANCES UNLESS NOTED		TITLE KIT, Z REDUCTION DRIVE		
	LINEAR +/-				
	ANGLES +/-				
OTHER NOTES	RADII UNLESS NOTED		DESIGNER	MEK	24 MAR 91
	EDGE/ CORNER BREAKS OUTSIDE MAX		CHECKED	MEK	24 MAR 91
IBMCAD FILE KIT621 .R1	EDGE/ CORNER BREAKS INSIDE MAX		APPROVED	MEK	24 MAR 91

KIT621-RRR

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N KIT631
ASY506-RRR	1	MECHANICAL	MEK	30 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



MAST ATTACHMENT SET
"SCALE": 1/5
"ROTATED 90° FROM MOUNTING ORIENTATION"



FRAME ATTACHMENT SET
"SCALE": 1/5
ROTATED 90° FROM FRAME MOUNT ORIENTATION

ASSEMBLY PARTS LIST

ITEM	QTY	P/N	PART DESCRIPTION
1	1	MEK095	BRACKET, FRAME ROD, BASE
2	1	MEK096	BRACKET, FRAME ROD, INTERM.
3	1	MEK097	BRACKET, HANGER, Z MAST
4	1	MEK098	ROD, HANGER, Z MAST
5	1	MEK099	ROD, WIRE SUPPORT, FRAME MOUNT
6	6	VEN448-050	SHCS, 0.190 (#10) UNF, 0.50 LONG
7	1	VEN498-050	PIN, ROLL, 3/32 DIA, 0.50 LONG

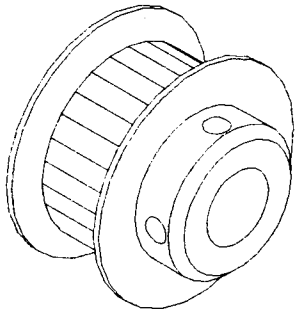
KIT631

SCALE 1/5	DIMENSIONS IN INCHES		PART # KIT631		UT
MATERIAL N/A	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE KIT, WIRING		
	ANGLES +/-	N/A	MECHANICAL SUPPORT		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	29 MAR 91
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	29 MAR 91
IBMCAD FILE KIT631 .R1	INSIDE MAX	N/A	APPROVED	MEK	30 MAR 91

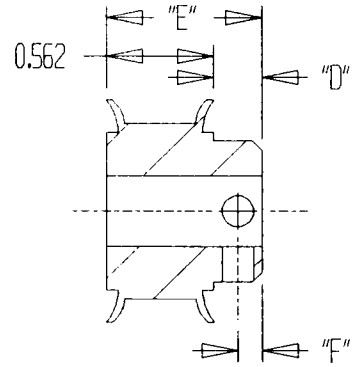
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
ASY527	1	MECHANICAL	MEK	06 MAR 91			
KIT611	AR						
KIT621	AR						

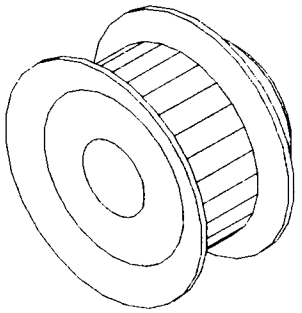
P/N VEN801

"A" SIZE TEMPLATE 0 .25" REAL SIZE

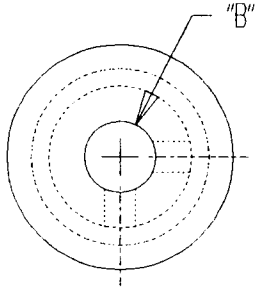


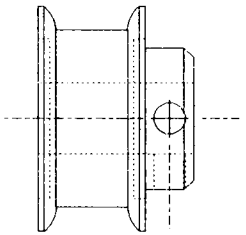
ISOMETRIC VIEW
"SCALE": 1:1
"HUB END VIEW"

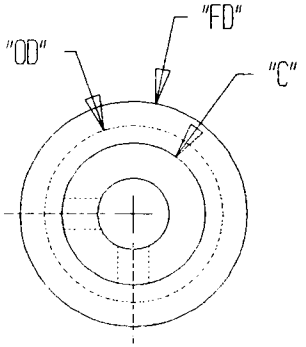




ISOMETRIC VIEW
"SCALE": 1:1
"GROOVE END VIEW"







NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

2 VENDOR P/N: 6A3-15DF3712

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

TECHNICAL DATA:

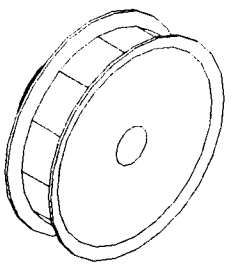
	# GROOVES :	15
"B"	BORE DIA. :	0.375
"PD"	PITCH DIA. :	0.955
"FD"	FLANGE DIA. :	1.187
"OD"	OUTER DIA. :	0.935
"C"	HUB DIA. :	0.750
"D"	HUB PROJ. :	0.250
"E"	LENGTH :	0.812
"F"	SCR OFFSET :	0.125
"S"	SET SCREW :	#8-32 (2X)

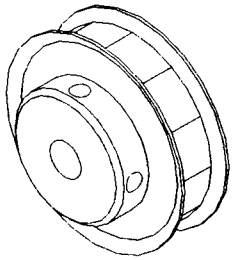
SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN801		UT
MATERIAL Aluminum	TOLERANCES UNLESS NOTED		TITLE PULLEY, TIMING BELT,		
	LINEAR +/-	N/A	0.955 PD, 0.375 BORE		
	ANGLES +/-	N/A	DESIGNER	MEK	30 NOV 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	06 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	06 MAR 91
IBMCAD FILE TBP095 .R3	EDGE/CORNER BREAKS INSIDE MAX	N/A			

VEN801

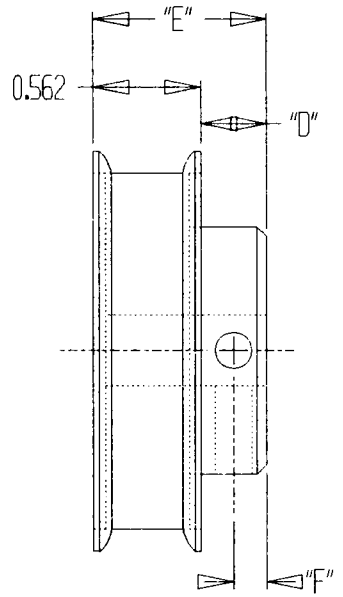
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN811
KIT611	AR	MECHANICAL	MEK	06 MAR 91				
KIT621	AR							"A" SIZE TEMPLATE 0 .25" REAL SIZE

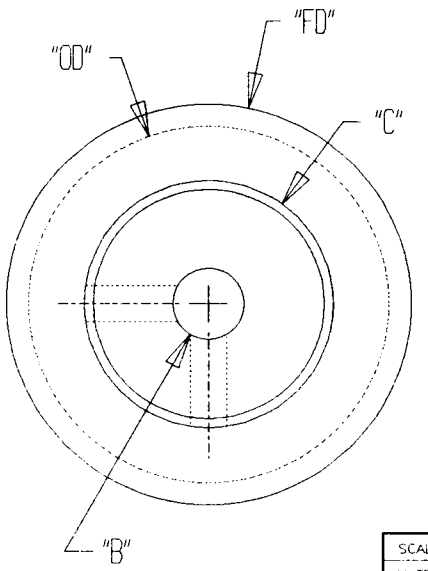
ISOMETRIC VIEW
"SCALE": 1/2
"GROOVE END VIEW"





ISOMETRIC VIEW
"SCALE": 1/2
"HUB END VIEW"





NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

2 VENDOR P/N: 6A3-30DF3712

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

TECHNICAL DATA:

	# GROOVES :	30
"B"	BORE DIA. :	0.375
"PD"	PITCH DIA. :	1.910
"FD"	FLANGE DIA. :	2.125
"OD"	OUTER DIA. :	1.890
"C"	HUB DIA. :	1.312
"D"	HUB PROJ. :	0.344
"E"	LENGTH :	0.906
"F"	SCR OFFSET :	0.172
"S"	SET SCREW :	#10-32 (2X)

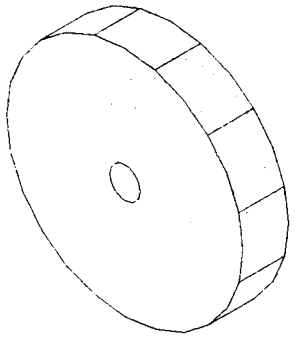
SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN811		UT
MATERIAL Aluminum	TOLERANCES UNLESS NOTED					
	LINEAR +/-		N/A	TITLE PULLEY, TIMING BELT,		
	ANGLES +/-		N/A	1.910 PD, 0.375 BORE		
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	14 DEC 90
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	06 MAR 91
IBMCAD FILE TBP191 .R3		INSIDE MAX	N/A	APPROVED	MEK	06 MAR 91

VEN811

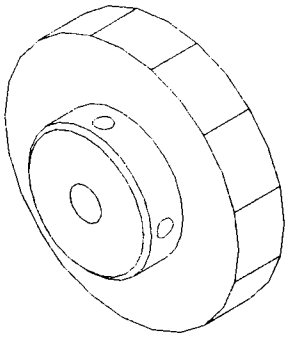
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #
KIT611	AR	MECHANICAL	MEK	16 MAR 91			
KIT621	AR						

P/N VEN826

"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW
"SCALE": 1/2
"BELT END VIEW"



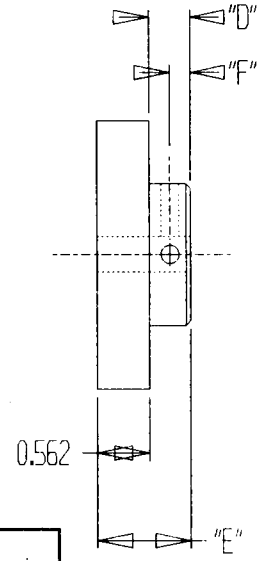
ISOMETRIC VIEW
"SCALE": 1/2
"HUB END VIEW"

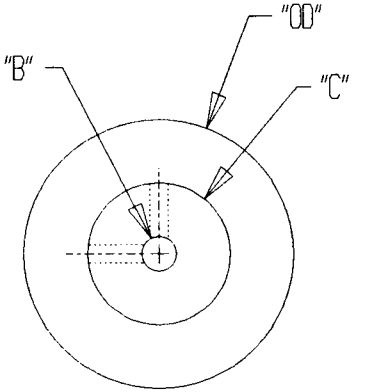
NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

2 VENDOR P/N: 6A3-45NF3712

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.





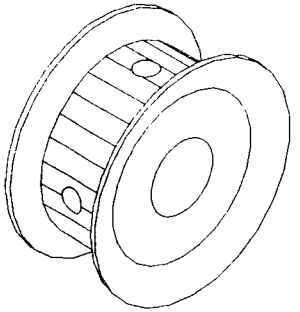
TECHNICAL DATA:

	# GROOVES :	45
"B"	BORE DIA. :	0.375
"PD"	PITCH DIA. :	2.865
"FD"	FLANGE DIA. :	–
"OD"	OUTER DIA. :	2.845
"C"	HUB DIA. :	1.500
"D"	HUB PROJ. :	0.438
"E"	LENGTH :	1.000
"F"	SCR OFFSET :	0.219
"S"	SET SCREW :	#10-32 (2X)

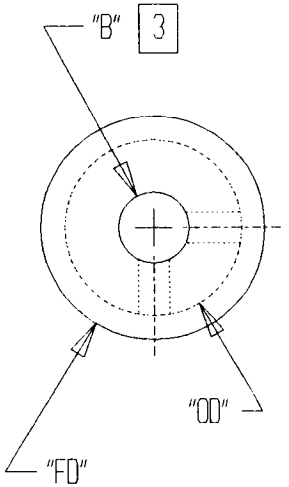
VEN826

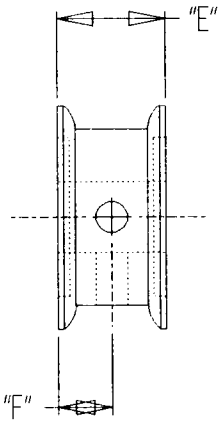
SCALE 1/2	DIMENSIONS IN INCHES		PART # VEN826		UT
MATERIAL Aluminum	TOLERANCES UNLESS NOTED				
	LINEAR +/-	N/A	TITLE PULLEY, TIMING BELT,		
	ANGLES +/-	N/A	2.865 PD, 0.375 BORE		
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	28 NOV 90
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	16 MAR 91
IBMCAD FILE TBP286 .R3	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	16 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN832
ASY591-ZZZ	1	MECHANICAL	MEK	16 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE



ISOMETRIC VIEW
"SCALE": 1:1
"VERTICAL ORIENTATION"





NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

2 VENDOR P/N: 6A3-15H3710

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

[3] NOTED VENDOR DIMENSION TO BE MODIFIED: BORE DIAMETER TO Ø 0.375 +0.001/−0.000.

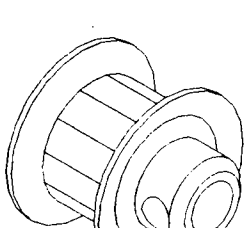
TECHNICAL DATA:

	# GROOVES :	15
"B"	BORE DIA. :	0.312 [3]
"PD"	PITCH DIA. :	0.955
"FD"	FLANGE DIA. :	1.187
"OD"	OUTER DIA. :	0.935
"C"	HUB DIA. :	---
"D"	HUB PROJ. :	---
"E"	LENGTH :	0.562
"F"	SCR OFFSET :	0.281
"S"	SET SCREW :	#8-32 (2X)

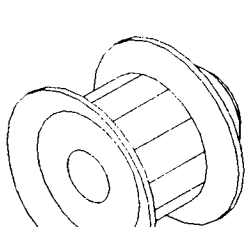
SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN832		UT
MATERIAL Aluminum	TOLERANCES UNLESS NOTED		TITLE PULLEY, TIMING BELT,		
	LINEAR +/−	N/A	0.955 PD, 0.375 BORE, HUBLESS		
	ANGLES +/−	N/A	DESIGNER	MEK	14 DEC 90
OTHER NOTES	RADII UNLESS NOTED	N/A	CHECKED	MEK	16 MAR 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	APPROVED	MEK	16 MAR 91
IBMCAD FILE TBP095H.R3	EDGE/CORNER BREAKS INSIDE MAX	N/A			

VEN832

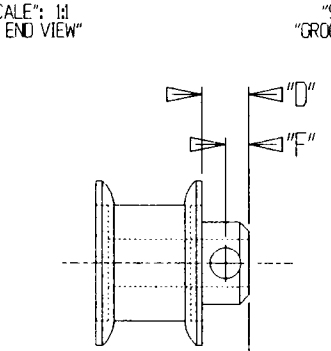
REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN836
ASY527	1	MECHANICAL	MEK	06 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

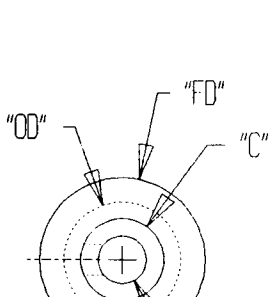


ISOMETRIC VIEW
"SCALE": 1:1
"HUB END VIEW"



ISOMETRIC VIEW
"SCALE": 1:1
"GROOVE END VIEW"





NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

2 VENDOR P/N: 6A3-10DF3708

TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

TECHNICAL DATA:

	# GROOVES :	10
"B"	BORE DIA. :	0.250
"PD"	PITCH DIA. :	0.637
"FD"	FLANGE DIA. :	0.875
"OD"	OUTER DIA. :	0.617
"C"	HUB DIA. :	0.438
"D"	HUB PROJ. :	0.250
"E"	LENGTH :	0.812
"F"	SCR OFFSET :	0.125
"S"	SET SCREW :	#8-32 (1X)

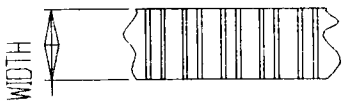
SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN836			UT
MATERIAL Aluminum	TOLERANCES UNLESS NOTED		TITLE PULLEY, TIMING BELT, 0.637 PD, 0.250 BORE			
	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	14 DEC 90	
	EDGE/ CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	06 MAR 91	
IBMCAD FILE TBP063S.R3	EDGE/ CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	06 MAR 91	

VEN836

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN840-ZZZ
ASY591-ZZZ	1	MECHANICAL	MEK	16 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART : [2]

P/N SUFFIX	NOMINAL "Z" TRAVEL	REQUIRED BELT LENGTH	NUMBER OF BELT TEETH	STOCK DRIVE PART NUMBER
-120	12.00	43.80	219	6R3-219037
-150	15.00	49.80	249	6R3-249037
-175	17.50	54.80	274	6R3-274037
-200	20.00	61.20	306	6R3-306037
-240	24.00	69.00	345	6R3-345037



VIEW A-A
SCALE: 1:1



ISOMETRIC VIEW
"SCALE": 1/10
-120 VERSION SHOWN

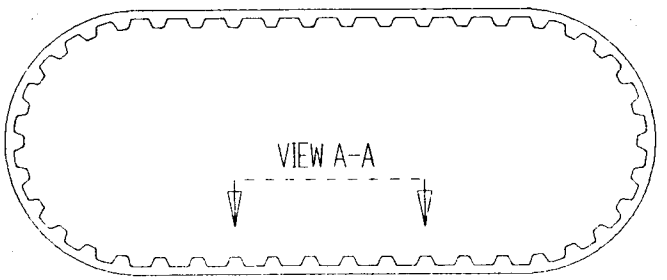
NOTES:

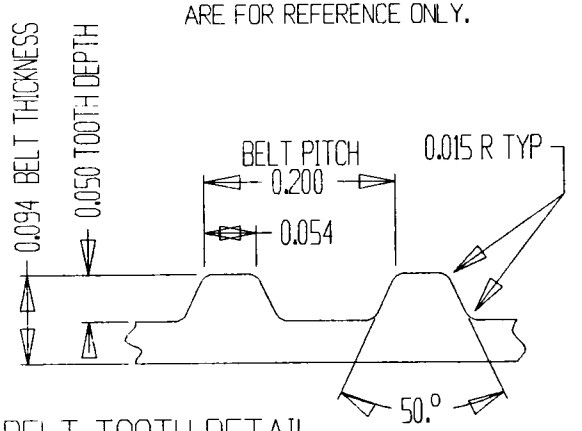
1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

[2] REQUIRED VENDOR P/N DEPENDS ON THE P/N SUFFIX, AS SHOWN IN THE P/N SUFFIX CHART.

3 TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

BELT LENGTH IS MEASURED "AROUND" AT BELT PITCH RADIUS





BELT TOOTH DETAIL
SCALE: 5:1

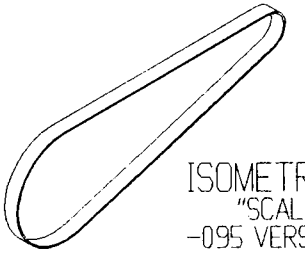
SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN840-ZZZ		UT
MATERIAL NEOPRENE, NYLON	TOLERANCES UNLESS NOTED		TITLE BELT, TIMING, Z DRIVE		
COVER, FIBER REINFORCED	LINEAR +/-	N/A			
	ANGLES +/-	N/A			
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	13 JAN 91
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	16 MAR 91
IBMCAD FILE ZDRVBLT.R2	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	16 MAR 91

VEN840-ZZZ

REL FOR ASM:	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN841-LLL
KIT611-RMR	2	MECHANICAL	MEK	21 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART : [2]

P/N SUFFIX	BELT PITCH LENGTH (in)	NUMBER OF BELT TEETH	STOCK DRIVE PART NUMBER
-081	16.20	81	6R3-081037
-088	17.60	88	6R3-088037
-091	18.20	91	6R3-091037
-095	19.00	95	6R3-095037



ISOMETRIC VIEW
"SCALE": 1/5
-095 VERSION SHOWN

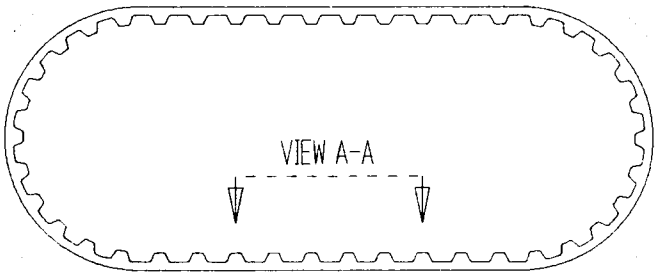
NOTES:

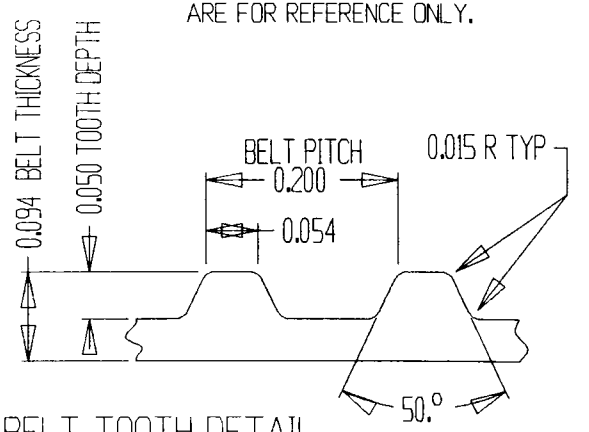
1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

[2] REQUIRED VENDOR P/N DEPENDS ON THE P/N SUFFIX, AS SHOWN IN THE P/N SUFFIX CHART.

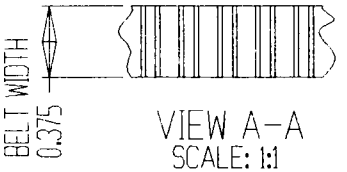
3 TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

BELT LENGTH IS MEASURED "AROUND" AT BELT PITCH RADIUS





BELT TOOTH DETAIL
SCALE: 5:1



VIEW A-A
SCALE: 1:1

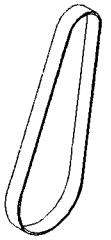
VEN841-LLL

SCALE 1:1	DIMENSIONS IN INCHES			PART # VEN841-LLL		UT
MATERIAL NEOPRENE, NYLON	TOLERANCES UNLESS NOTED					
COVER, FIBER REINFORCED	LINEAR +/-		N/A	TITLE BELT, TIMING, XY REDUCTION		
	ANGLES +/-		N/A			
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER	MEK	21 MAR 91
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED	MEK	21 MAR 91
IBMCAD FILE XYREDBLT.R1		INSIDE MAX	N/A	APPROVED	MEK	21 MAR 91

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN842-LLL
KIT621-RRR	1	MECHANICAL	MEK	21 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART : [2]

P/N SUFFIX	BELT PITCH LENGTH (in)	NUMBER OF BELT TEETH	STOCK DRIVE PART NUMBER
-057	11.40	57	6R3-057037
-065	13.00	65	6R3-065037
-073	14.80	73	6R3-073037



ISOMETRIC VIEW
"SCALE": 1/5
-065 VERSION SHOWN

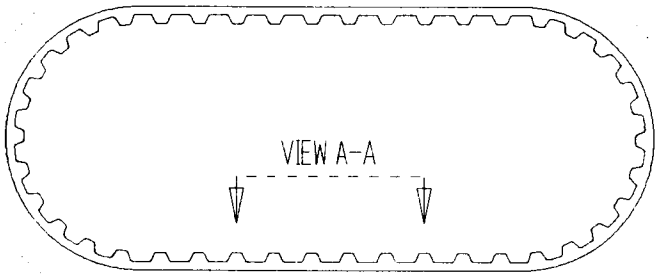
NOTES:

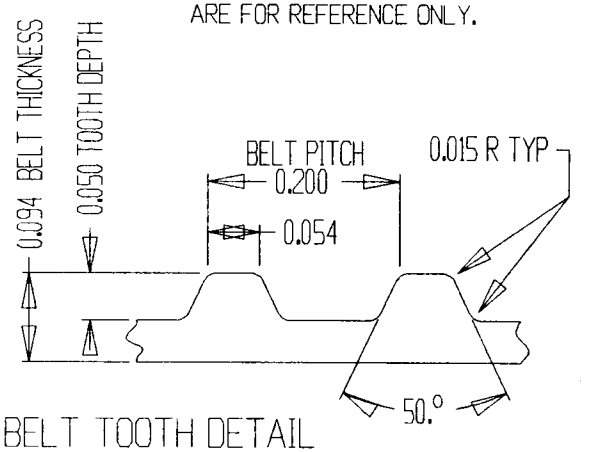
1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

[2] REQUIRED VENDOR P/N DEPENDS ON THE P/N SUFFIX, AS SHOWN IN THE P/N SUFFIX CHART.

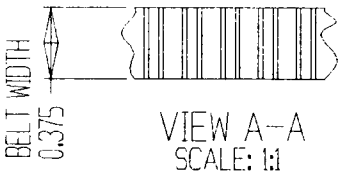
3 TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.

BELT LENGTH IS MEASURED "AROUND" AT BELT PITCH RADIUS





BELT TOOTH DETAIL
SCALE: 5:1



VIEW A-A
SCALE: 1:1

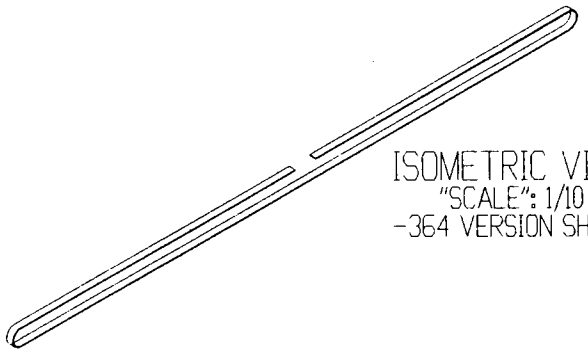
VEN842-LLL

SCALE 1 : 1	DIMENSIONS IN INCHES			PART # VEN842-LLL	UT
MATERIAL NEOPRENE, NYLON	TOLERANCES UNLESS NOTED				
COVER, FIBER REINFORCED	LINEAR +/-		N/A	TITLE BELT, TIMING, Z	
	ANGLES +/-		N/A	REDUCTION	
OTHER NOTES	RADII UNLESS NOTED		N/A	DESIGNER MEK 21 MAR 91	
	EDGE/ CORNER BREAKS	OUTSIDE MAX	N/A	CHECKED MEK 21 MAR 91	
IBMCAD FILE ZREDBLT.R1		INSIDE MAX	N/A	APPROVED MEK 21 MAR 91	

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N VEN843-LLL
ASY511-RRR	2	MECHANICAL	MEK	25 MAR 91				"A" SIZE TEMPLATE 0 .25" REAL SIZE

P/N SUFFIX CHART : [2]

P/N SUFFIX	BELT LENGTH (in)	NUMBER OF BELT TEETH
-347	69.40	347
-364	72.80	364
-377	75.40	377
-407	81.40	407
-424	84.80	424
-437	87.40	437
-467	93.40	467
-484	96.80	484
-497	99.40	497
-544	108.80	544
-557	111.40	557



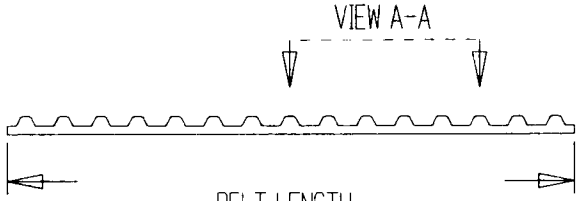
ISOMETRIC VIEW
"SCALE": 1/10
-364 VERSION SHOWN

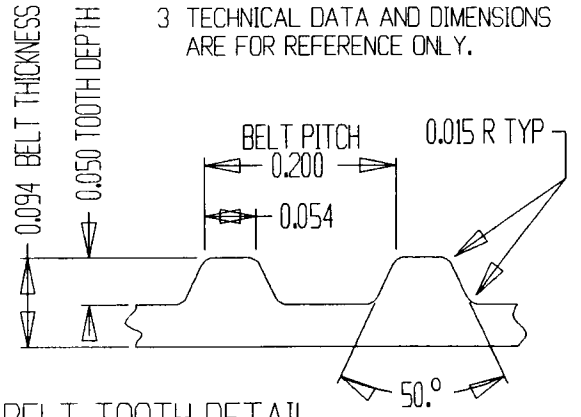
NOTES:

1 SPECIFIED VENDOR:
STOCK DRIVE PRODUCTS, INC.
NEW HYDE PARK, NY

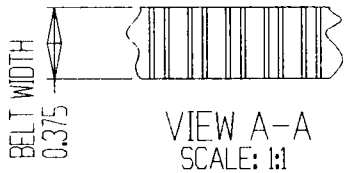
[2] REQUIRED BELT LENGTH DEPENDS ON THE P/N SUFFIX, AS SHOWN IN THE P/N SUFFIX CHART. CUT TO LENGTH STOCK DRIVE P/N 6R3-C037 BELT.

3 TECHNICAL DATA AND DIMENSIONS ARE FOR REFERENCE ONLY.





BELT TOOTH DETAIL
SCALE: 5:1



VIEW A-A
SCALE: 1:1

SCALE 1:1	DIMENSIONS IN INCHES		PART # VEN843-LLL			UT
MATERIAL NEOPRENE, NYLON	TOLERANCES UNLESS NOTED		TITLE BELT, TIMING, XY DRIVE			
COVER, FIBER REINFORCED	LINEAR +/-	N/A				
	ANGLES +/-	N/A				
OTHER NOTES	RADII UNLESS NOTED	N/A	DESIGNER	MEK	25 MAR 91	
	EDGE/CORNER BREAKS OUTSIDE MAX	N/A	CHECKED	MEK	25 MAR 91	
IBMCAD FILE XYDRVBLT.R1	EDGE/CORNER BREAKS INSIDE MAX	N/A	APPROVED	MEK	25 MAR 91	

VEN843-LLL

VITA

Michael Earl Kennedy was born April 3, 1963 in West Palm Beach, FL, and was raised in the nearby town of Jupiter. He attended The King's Academy, a private school in West Palm Beach, and graduated as valedictorian of his high school class in 1981.

Mr. Kennedy entered The University of Tennessee in September 1981 to pursue a B.S. degree in mechanical engineering. As a participant in the College of Engineering's Cooperative Engineering Program, he was employed as a co-op engineer with the IBM Corporation in Boca Raton, FL. During his senior year, Mr. Kennedy was elected president of his Tau Beta Pi collegiate chapter, was awarded a Chancellor's Citation for Extraordinary Academic Achievement, and was named as the Outstanding Engineering Senior. He was the Top Graduate for the College of Engineering when he was awarded the B.S. in Mechanical Engineering in June 1986.

After employment as a controls engineer with Pratt and Whitney (West Palm Beach, FL) for one year, Mr. Kennedy was awarded the IBM Graduate Fellowship and returned to The University of Tennessee to pursue the M.S. and Ph.D. degrees in mechanical engineering.

From his M.S. and Ph.D. efforts, Mr. Kennedy is the co-author of five technical papers pertaining to product development. He also is a co-author of one chapter, "Improving the

Product Development Process" in the recently published book, *Competing Globally Through Customer Value*. After a very short break, he will begin preparation of his doctoral dissertation.