5-1991

Fastener selection for assembly (FSFA): development of a coding system for selection of efficient fastening methods in automation

Khosrow Arabi-Esfahani

To the Graduate Council:

I am submitting herewith a thesis written by Khosrow Arabi-Esfahani entitled "Fastener selection for assembly (FSFA): development of a coding system for selection of efficient fastening methods in automation." I have examined the final electronic 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.

Stanley E. Becker, Major Professor

We have read this thesis and recommend its acceptance:

Wayne Claycombe, Clement Wilson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Khosrow Arabi-Esfahani entitled "Fastener Selection For Assembly (FSFA): Development of a Coding System for Selection of Efficient Fastening Methods in Automation." 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.

Stanley E. Becker

Stanley E. Becker, Major Professor

We have read this thesis
and recommend its acceptance:

Wayne Claycombe

Clement A. Wilson

Accepted for the Council:

C. W. Minkel

Associate Vice Chancellor
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

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

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Khosrow Arabi-Esfahani

Date April 26, 1991

FASTENER SELECTION FOR ASSEMBLY (FSFA): DEVELOPMENT OF A CODING SYSTEM FOR SELECTION OF EFFICIENT FASTENING METHODS IN AUTOMATION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Khosrow Arabi-Esfahani

May 1991

I dedicate this thesis to:

My Father, Parviz, my Mother, Manijeh,
and my Sister, Neda Arabi-Esfahani.

تقدیم به بابا، مامان، ندا عزیز

ACKNOWLEDGMENTS

The completion of this thesis was achieved with support and help of many individuals who offered their time and attention sincerely. Throughout the years, from the elementary school until now, my teachers, piece by piece, gave me the education and the training that I have gained. Now, I find it appropriate to extend my deep gratitude and appreciation to all of them.

I am particularly grateful to my kind advisor Dr. Stanley E. Becker for his continuous support and encouragement. I wish to express my sincere appreciation to my other committee members Dr. Wilson and Dr. Claycombe for their valuable comments and academic instruction. I would like to thank the Interlibrary loan staff for their assistance, Ms. Ann Lacava and Mr. Mobasheran for their comments on editing, and other faculty members of the Mechanical Engineering department for their guidance. My appreciation is expressed to my coach Mr. James Rice for his valuable training of Taekwando which enhanced and improved my academic performance as well.

I wish to express my appreciation to my family for their continuous support and encouragement throughout the years. Special thanks to my Mother for her hospitality during the past four months that I was busy preparing this document. I sincerely thank all of my friends and relatives who always wished me luck and success. Deep gratitude extended to my late grandfather, Papajoun, whose memories and advices are valuable to me.

ABSTRACT

Engineers have long sought a well defined method for selecting suitable parts or fasteners for automation. To facilitate the selecting process, hundreds of mechanical fasteners and various joining methods were investigated. The role of designing parts for automation was further defined and the importance of part geometry and symmetry was realized. Part classification eases orienting and feeding sequence. Assigning codes to parts or processes improves the task of identifying products and computerizing the manufacturing system. Design For Assembly minimizes the number of parts or fasteners in a product and facilitates feeding, orienting, and alignment of elements or subassemblies. Investigating major issues and problems in automation provides insight to advantages and disadvantages of automating a production. Fastener Selection For Assembly (FSFA) provides insight into valuable information on the selection process for an efficient assembly operation. FSFA identifies, groups, and assigns an alpha- numeric code to a fastener or fastening operation while suggesting solutions and alternatives for a better joining method. The code can also be used in flexible assembly systems for controlling the type and configuration of tooling for various fasteners. It was determined that, the important criteria for choosing the right fastener is based on feeding and orienting techniques, part symmetry, stability and locking action, material selection, hole or work preparation, tooling and assembly equipment, quickness of operation, and part accessibility.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

FSFA	Fastener Selection For Assembly
DFA	Design For Assembly
FAS	Flexible Assembly System
FMS	Flexible Manufacturing System
CAE	Computer Aided Engineering
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
GT	Group Technology
L/D	Length over Diameter ratio
MTM	Method Time Measurement
DFX	Design For X
PDM	Product Design Merit
DFS	Design For Simplicity
NC	Numerical Control
AFC	Automated Fastening Cell
AFM	Automatic Fastening Machine
NC	American National Coarse thread
UNC	Unified Coarse thread
UNF	Unified Fine thread
LH	Left Hand thread
OPCF	One Piece Complete Fastener
OPIF	One Piece Incomplete Fastener
OPSF	One Piece Simultaneous Fastener
TPCF	Two Piece Complete Fastener

CHAPTER 1

INTRODUCTION

Fastener Selection For Assembly (FSFA) is a critical issue when designing products for automation. The purpose of this research is to identify and group major problems related to automatic fastening operation. Certain rules for the selection process of mechanical fasteners and other components of a product are established. Design For Assembly (DFA) fundamentals is used as a guide for establishing the major principles of assembly and fastening operation.

1.1 Background and major issues

"Since fasteners sometimes constitute less than three percent of total production costs, they are often given low priority by design engineers" [1]. In a mass production system, selecting a suitable joining method is extremely important Since it results in reduction of production cost and saving in time by elimination of excessive movements. A manual fastening method is commonly selected by the designers who are not willing to adopt DFA and follow its concepts. The availability of fasteners is being taken for granted to the point that the designers are concentrating on part analysis rather than fastener design. Smoothness and ease of assembly is destroyed because many of the selected joining methods are not suitable for automated assembly. Many of these methods are not even a good choice for manual assembly. A worker can compensate for a poor design of a part or fastener by performing rigorous and difficult fastening operations.

Incorporating manual assembly into automation is what makes the manufacturers less concerned about the efficiency of the type of fastener used in the system. Designers mostly concentrate on how the product must function and do not realize how the product effects the assembly or fastening operation. "Concentration on a single project can lead to "tunnel vision" where the design team can no longer see certain problem because they are close to the work" [3].

Thousands of fasteners are available in the market and designers have to carefully search for one for their products. The biggest constraint in any fastening operation is the poor design or unsuitable selection of the fastener for that particular stage of production. New trends in industry are forcing the designers to reconsider fastener selection from its assemblability point of view. Feasibility of automation relates to the assembly process for a product. It is estimated that:"....increase of 100% to 200% in assembly productivity are readily attainable through proper consideration of assembly at the design stage" [2].

In addition to fasteners, equipment and type of tooling must be carefully selected for automation. The fast pace of the assembly line introduces a new problem which is supply of parts and more frequent maintenance of industrial equipment. Fasteners in automated cells have to be reliable and free of defects. The time spent on fastening usually varies according to the type of the fastener and tooling used. Due to rapid technological improvements on tools and materials used for fasteners, it is difficult to estimate and compare assembly operations precisely. For example, an advanced power tool might be able to drive and fasten a bolt into the drilled hole quicker than a pneumatic riveter. This is in contrast to our previous knowledge about rivets as quick fasteners. To deal with this sort of problems, the author assumes that the tools that are used in an assembly line are readily available on market, and are neither customized nor high tech equipment.

Fastener selection for assembly is part of a big picture that must be kept in mind when dealing with Flexible Assembly Systems (FAS). Quality, design flexibility, feeding machines, material handling equipment, and inspection devices are some of the elements which are affected by the improper selection of fastening sequence on an assembly line.

Improvements in manufacturing methods enables engineers to design and manufacture products which have fewer number of parts and in some cases the whole product or subassembly can be built as one piece. The new molding processes and improved plastic materials bring flexibility in design and eliminate non-essential assembly steps. Many products are not designed to optimize automated assembly therefore companies may spend unnecessary capital investment to automate their production lines where it is not needed.

The best method to improve assembly is to eliminate it all together. Reducing the number of parts influences the cost of the whole system. For many small parts or fasteners, a feeding and orienting device is needed. Elimination of a 2 - cents fastener can save thousands of dollars worth of machinery. FSFA provides insight into valuable information on the selection process for an economic operation.

Industrial automation has stimulated the existence of a variety of fasteners in the market. Fastener size and material varies according to type of the product. They can be either a set screw for a wrist watch or one of the bolts used in holding joints in a railroad bridge. Fasteners became more common after world war II. Many western countries including the United States contributed to the development and improvements in fasteners design and production. It is estimated that there are more than two million kinds of fasteners on the market.

The type of application or the environment that the fastener must operate in is an important factor during the initial selecting process. A bolt used in a dynamic mechanism, as inside an internal combustion engine, must be selected more carefully than a screw for a computer panel assembly. Environmental temperature, mechanical vibration, type of loading (static or dynamic), quality of the fastener, and method of assembly are some of the many points that must be considered when choosing a fastener for a joint.

Threaded fasteners face competition from new joining methods such as adhesives. Adhesives replace many conventional fastening operations such as threading, knurling, and press fitting. Even though adhesives facilitate assembly and save time and money, much new industrial equipment relies on threaded or mechanical fasteners during product development.

A perfect fastener for assembly must feature easy feeding and orienting characteristic, simple tooling, minimum fastening movement, and quick installation. Assembly parts must also feature easy alignment, easy work access, and simple geometry.

1.2 Method of attack

Assembly operation consists of feeding and orienting parts, preparing work material for installation, and fastening. To properly feed and orient parts, a well defined strategy and governing rules are suggested in Chapter 2. Efforts have been taken to identify and reorganize the existing pieces of informations in order to make them compatible with the newly developed system of FSFA. Applying DFA principles is essential to minimize problems related to automated assembly. Chapter 3 analyses major issues of DFA and investigates important research conducted in this area.

Industrial automation and problems related to fastening are analyzed in Chapter 4. The need for automation is studied and issues related to automating a system are investigated. Machines and equipment used for assembly and fastening operation are also mentioned. In Chapter 5, six major groups of fasteners such as screws, inserts, snap ins, rivets, bolts and nuts, and washers are carefully evaluated in details. Each group represents unique problems related to automatic fastening.

Finally in chapter 6, the governing rules for FSFA are shaped. The 21 major categories for selecting an efficient method of fastening is identified and an alpha - numeric code for a particular fastener or joining method is established. The role and the importance of the coding system is also summarized as the conclusion of this report.

CHAPTER 2

PART CLASSIFICATION AND CODING SYSTEM

Identification systems are used to improve productivity by speeding the flow of material throughout the plant with less labor dependence. Various coding systems exist which provide information about the part and its nature. The code is basically used in areas of manufacturing, assembly or fastening, packaging, material handling, and shipping. Automatic identification helps the manufacturer to achieve greater productivity by receiving feedback from their dynamic environment on the assembly line.

Implementation of flexible manufacturing systems (FMS) requires broad and precise knowledge of the system, individual equipment, and the components of the final product. Flexibility is the key function of a fully automated system. Hard automation, in contrast has no flexibility in its capability to produce a variety of parts and products. A flexible system can manufacture or assemble different types of products and is able to adopt to any changes as the result of variations in parts and products. The need to categorize parts and products arises when dealing with FMS. To group and identify any component, detailed knowledge of its geometric configuration, parts feeding equipment, and assembly method is required. To achieve this goal, a well organized plan and set of instruction for identifying the part must be developed.

Computer Aided Engineering (CAE) provides a mathematical method to analyses parts and products in a system. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) implement, organize, and control the production system.

Using Group Technology (GT), manufacturing parts which must undergo similar machining operations like drilling, turning, grinding, can be processed all in one cell. Assembly operations can also benefit from the same concept by grouping parts with similar geometric shapes and similar functions prior to assembly. Feeding machine later transfer these parts to the assembly line.

2.1 Boothroyd's coding system

Few coding systems have been developed to facilitate feeding and orienting of small parts for automated assembly. The most famous and useful system is developed by G. Boothroyd at the University of Massachusetts, Amherst [4]. The technique emphasizes the effects of product design on assembly operation. Cost reduction, part minimization, and time saving are defined as what makes the assembly more efficient. The most important aspect of the coding system is the analysis of part symmetry. Two kinds of symmetry for a part are defined, alpha symmetry and beta symmetry. "If a part has 180 degrees rotational symmetry about at least one of its transverse axes, then it does not require orientation end-to-end and is alpha symmetric" [4]. For beta symmetry: "If a part does not require orientation about its principle axis, then it has beta symmetry" [4]. Assuming that the part is a cylindrical rod, the principle axis is passing through the length of the cylinder and the two transverse axes are perpendicular to it (Figure 2.1).

Usually parts are classified according to their geometric shapes and configuration in three major groups as: Parts with rotational, triangular or square prismatic, and rectangular cross section. In addition to these groups, there are parts which are difficult to feed or orient such as springs, clips, wires, and etc. To determine the geometry of a part, the term envelope is defined as "The smallest cylinder, regular prism or rectangular prism that can completely enclose the part" (Figure 2.2) [4]. Basically two major steps must be taken in order to group any part. First assigning a code number to the part based on its geometric shape and its external or internal features such as grooves, steps, chamfers or tapers (Figure 2.3) and second, finding a suitable feeder which can best orient and feed the part on the assembly line .

During this process, difficulties associated with feeding and orienting steps is also defined. The coding system designed by Boothroyd uses digits to assign a code to a part (Figure 2.4). First digit determines geometrical characteristics of the envelope enclosing the part. Second and third digits provide more information about the part's external or internal features.

Finally a three digit code number is assigned to the part. One of the major draw backs of this method is its limited range of only ten possible values for each digit. To overcome this problem, an alphabetic coding method is suggested. In this system, numbers are replaced by letters. The following example can explain the difference of the two systems. Using Boothroyd's

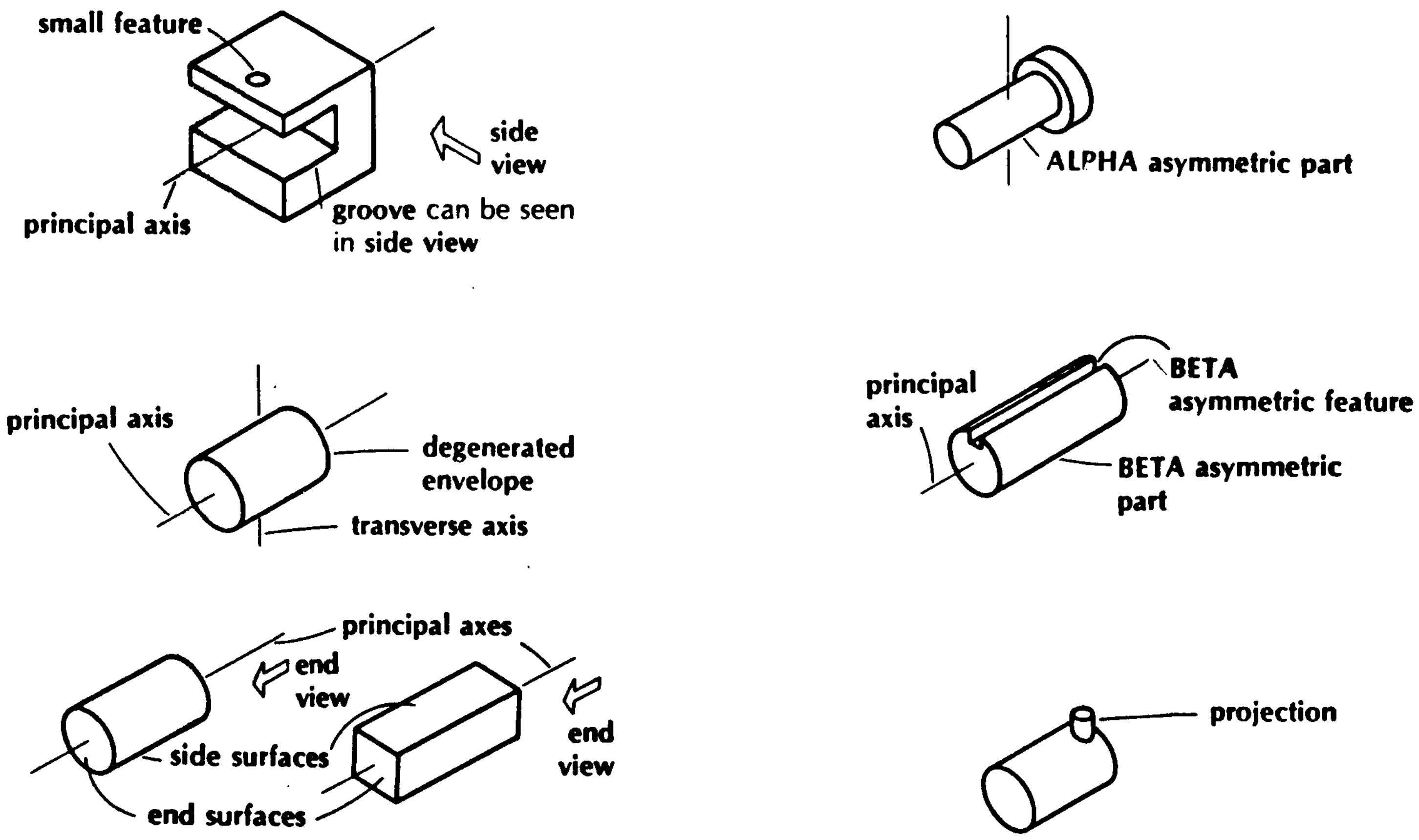
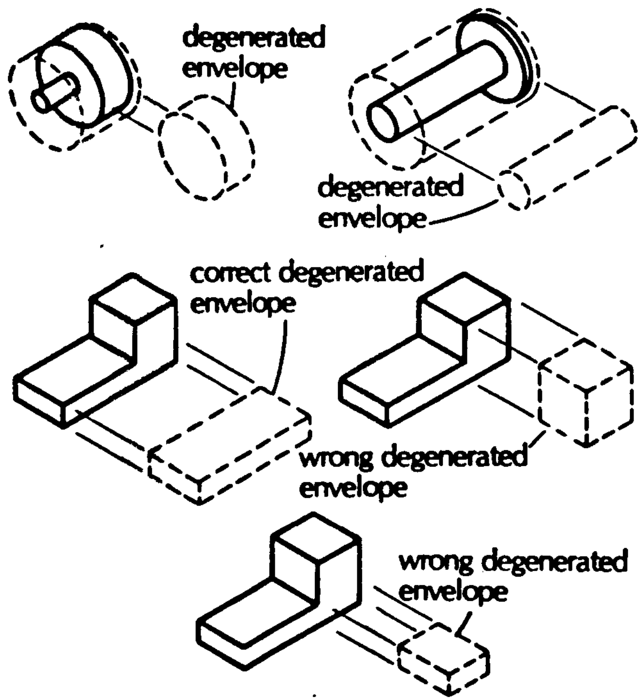


Figure 2.1. Part geometry and symmetric features.

Source: Boothroyd, G., "Handbook of feeding and orienting techniques," University of Massachusetts, Amherst.



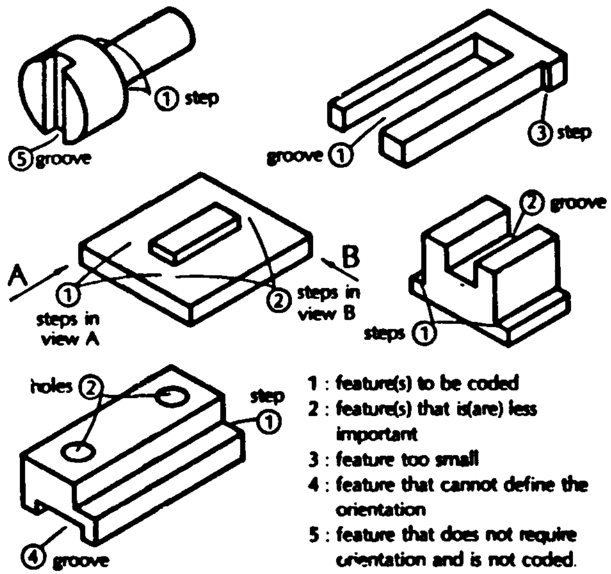


Figure 2.2. Degenerated envelope for various parts.

Figure 2.3. Relative importance of features.

Source: Boothroyd, G., "Handbook of feeding and orienting techniques"

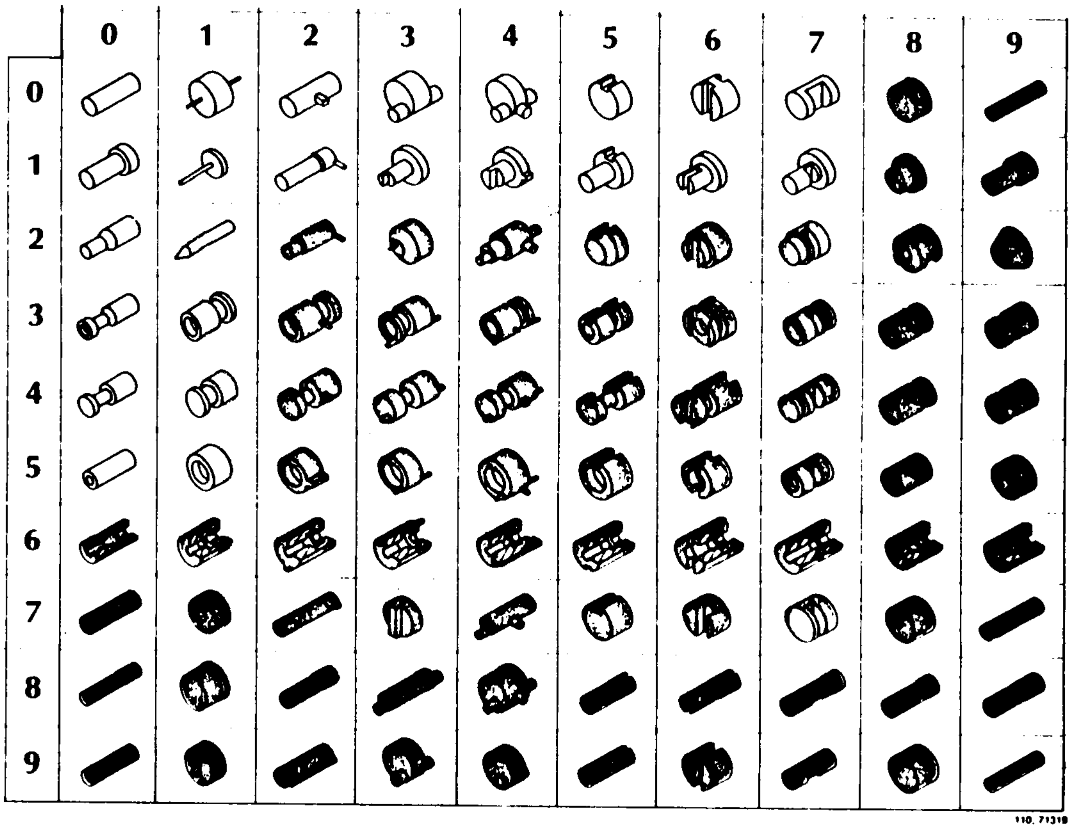


Figure 2.4. Coding system for rotational parts.

Source: Boothroyd, G., "Handbook of feeding and orienting techniques."

chart, a code number of 111 is assigned to a short cylinder which is not alpha symmetric and must be fed side by side. The revised method uses almost the same criteria to code the part, except from its use of alphabets. A short cylinder which is not alpha symmetric and has its center of mass below the supporting surface, and must be fed side by side, is coded AAA. Obviously, letters have the broader range of 26 possibilities as compared to numbers which is only ten.

The limitations imposed by the use of numbers in Boothroyd's chart, raises the question whether the tables were either stretched or were cut deliberately in order to fit his system. Letters allow the chart to expand from a 9x9 to a 26x26 matrix of data.

Mechanical fasteners can also be grouped and coded similarly. The code for each fastener provides different types of information needed for different purposes. The coding system developed is a hierarchical code structure (Figure 2.5). "In a hierarchical code, each position relates to the preceding position. thus if the first digit or letter defines a main shape, such as rotational, the second will define a feature related to a rotational part,..." [5].

2.2 Fastener symmetry

Difficult-to-orient parts are sometimes very small or have low (L/D) ratio. L is the length and D is the diameter of the generated envelope (Figure 2.2). Parts with internal asymmetry and an undesirable center of gravity location are more difficult to feed or orient. For an asymmetric part, making the

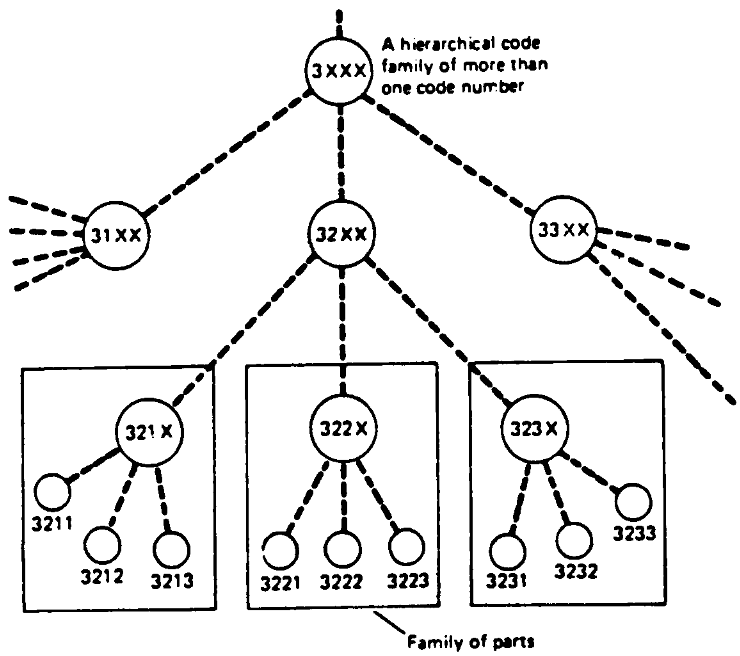


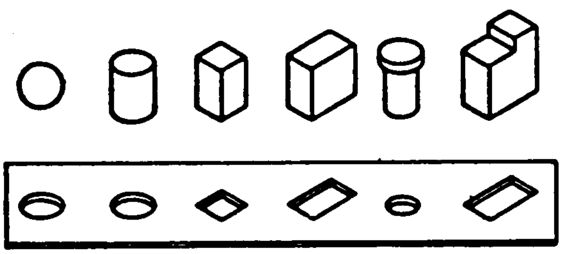
Figure 2.5. The structure of classification and coding system based on a Hierarchical principles.

Source: Teicholz, E., "CIM handbook," 1987.

external feature more distinctive, facilitates orienting. In other words, if part is not symmetric, it is then preferable to handle parts with external asymmetry instead of internal projections.

Fastener symmetry effects its feeding, orienting, insertion, and the fastening operation. By combining the concept of part symmetry and head configuration, the effects of head symmetry on an assembly line can be studied. For instance, the type of head, whether it requires internally or externally driven tooling, can effect the time spent to firmly grip the fastener and proceed with the fastening operation. The majority of fasteners have a cylindrical, square or hexagonal head cross section. Symmetry of each fastener is therefore affected by its geometry. A square head has 90 degrees beta symmetry and a hex or socket head has 60 degrees beta symmetry. A 60 degrees beta symmetry part must be rotated 60 degrees in order to resume its previous orientation, therefore the tooling must turn at least 60 degrees before it can engage the head. Hex head engages faster than a phillips head or a square head configuration. For the next category of parts with 90 degrees beta symmetry, a similar definition can be established, while remembering that the part must be rotated 90 degrees to resume the same orientation (Figure 2.6).

As was mentioned, assembly time is effected by head symmetry. One of the methods for determining assembly times in industry is the Method Time Measurement (MTM) (Figure 2.7). "In the MTM system, the maximum possible orientation is employed which is one half the beta rotational



α	0	180	180	180	360	360
β	0	0	90	180	0	360

Figure 2.6. Alpha and beta rotation symmetry of various parts.

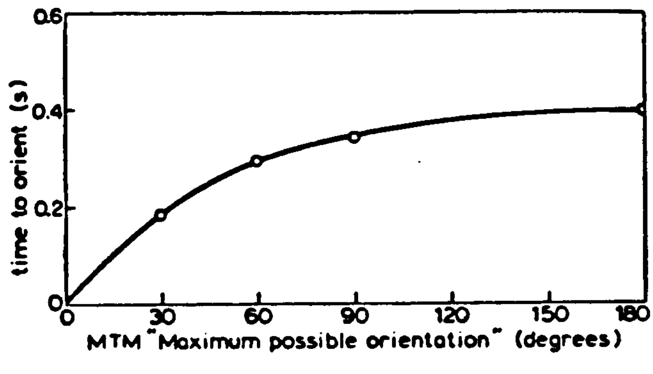


Figure 2.7. The relation between MTM performation and the maximum possible orientation.

Source: Yousofian, Z., "Effects of part symmetry on manual assembly times," Journal of manufacturing systems.

symmetry of a part" [6]. Using this method and some experimental data, the graph of MTM vs. one half beta symmetry angle can be obtained.

"On the average, the parts in each category takes approximately 330 mili seconds longer to orient than the part in the preceding category" [6]. If the tooling must be threaded into the fastener like thread inserts, a cylindrical cross section head can be assumed for the fastener. With a cylindrical head, the fastener can be considered to be fully symmetric. For instance a bolt with square head or a screw with phillips recess has 90 degrees head - beta symmetry. As mentioned before, most fasteners have 360 alpha symmetry, meaning that they must be rotated 360 degrees about an axis perpendicular to their rotational or insertion axis in order to resume their orientation.

Therefore, it is important to be able to distinguish between fastener symmetry and the head symmetry. Fastener symmetry effects feeding, alignment, and installation, while head symmetry relates to pick up and tool engagement prior to fastening.

CHAPTER 3

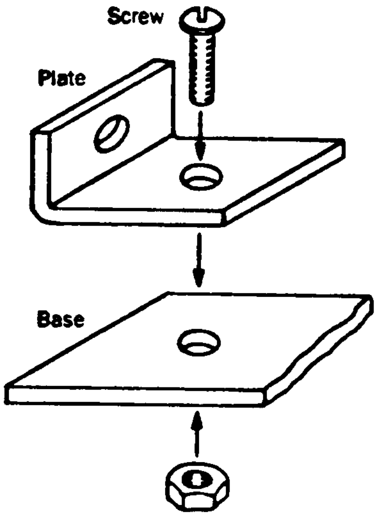
DESIGN FOR ASSEMBLY

Henry Ford designed the first assembly line around the turn of century. His goal was to mass produce cars so that the prices could be lowered. To accomplish this , he invented the assembly line by bringing the parts to the worker. Ford engineers had to be concerned about their design for assembly in order to facilitate a smooth flow of material. This was the start of a new era in the industrial world and was commonly refered to as the Design For Assembly. In recent years manufacturers are implementing the idea more carefully as they design new products.

3.1 Why DFA?

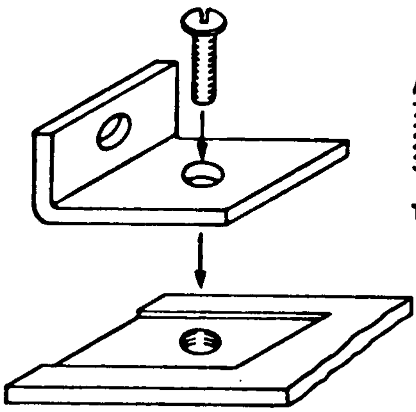
Often a perfect design is not suitable for assembly, because the problems of joining the manufactured parts is not looked into carefully. DFA minimizes the number of parts and improves the assemblability of other essential elements. "Improved reliability and serviceability results when there are fewer parts in a design that can fail or be assembled incorrectly" [7].

One of the first major steps which can be taken to minimize assembly time and improve the design simplicity, is to simplify positioning and fastening operation. (Figure 3.1) clearly illustrates the advantages of applying Design For Simplicity (DFS) by elimination of a nut in other side of work station and maintaining a more stable fixture to position the two parts precisely.



Assembly step	Penalty points
1. Position base	0
2. Move plate downward	0
and maintain position until screw is inserted	40
3. Move nut upward	30
and maintain position until screw is inserted	40
4. Move screw downward	0
and turn into nut	30
Total	140

Design 1



Assembly step	Penalty points
1. Position base	0
2. Move plate downward	0
3. Move screw downward	0
and turn into base	30
Total	30

Design 2

Figure 3.1. Design For Simplicity (DFS). Design 2 eliminates fixturing and reduces the penalty points.

Source: Watson, G., "Mechanical Equipment Design For Simplicity," AT&T technical journal, 1990.

Designers can be overloaded by various inputs as they try to establish the DFA principles. They can no longer keep the whole picture of the problem in mind while paying attention to the individual components. By introducing more terms and definitions to the manufacturing , the problems are multiplied. Improvement leads to complexity and need for simplification. Breaking down the problem into smaller and more organized pieces is one way of achieving simplicity. One of those small pieces, which has great importance, is selecting a suitable fastener. Preliminary design should consider both requirement of the assembly system and ability of combining parts with each other.

DFA can save money and time since making changes on the drawing board is less expensive than modifying parts or assemblies after they are manufactured. For example, if a poor design for assembly or fastening operation requires side way insertion in addition to vertically downward or upward motion, the assembly machines or robots to perform the movements are expensive. Eliminating unnecessary parts and fasteners and adding of "snap together" components will ease and speed up the assembly operation (Figure 3.2).

Multiple changeovers for gripper, fixture, tooling, and fastening is a burden to the assembly line and makes the operation inefficient. When the volume of production is in the scale of thousands or millions, small changes on production might lead to millions of dollars in saving and assembly efficiency.

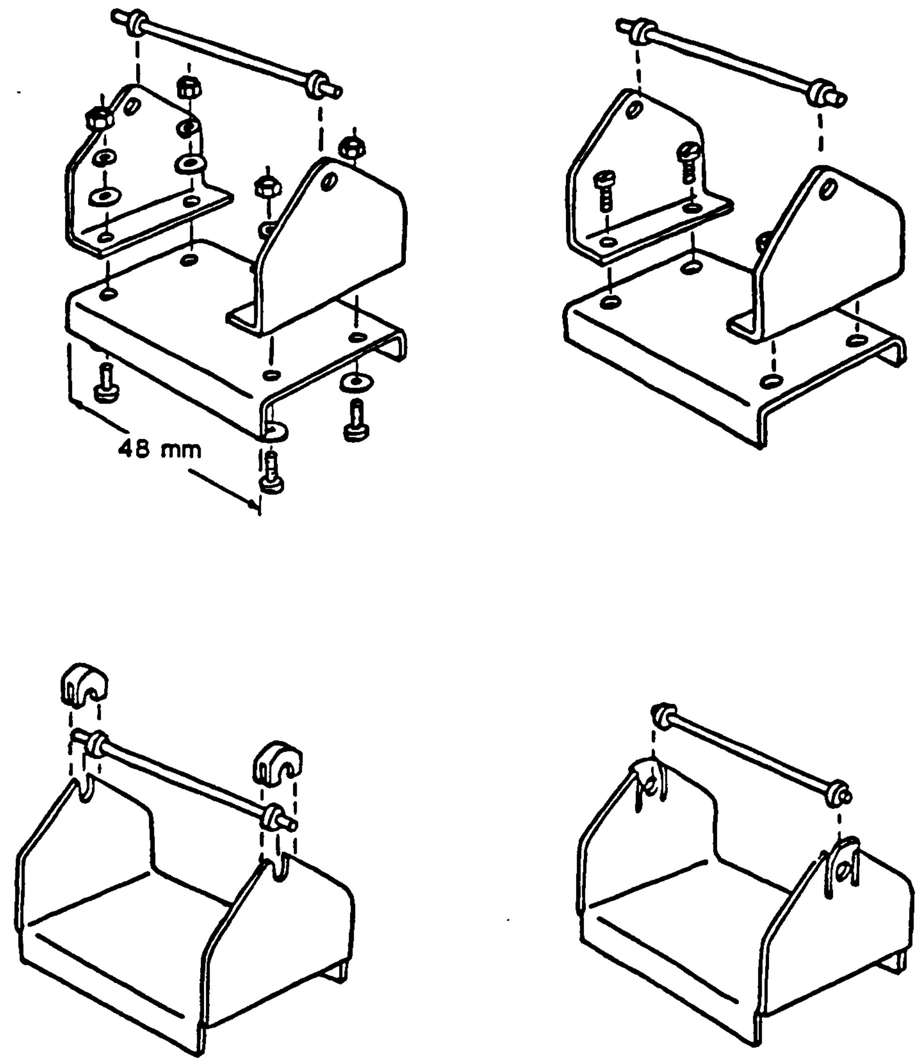


Figure 3.2. Sequence of improvements in DFA. Reduction and elimination of fasteners and parts.

Source: Boothroyd, G., "Product design. Key to a successful robotic assembly," Assembly Engineering, 1986.

The range of products for DFA should be limited to electro - mechanical equipment and must exclude heavy machinery and industrial equipment. Besides, since parts are fed to the system automatically, their size is limited to the capacity of feeders, which can not handle big parts. Usually, orientation of products prior to assembly is a costly and time consuming operation and should be minimized or avoided.

DFA can be a rigorous task for engineers who are not willing to take chances in changing a working design. They do not believe that a part designed for automation or robotic assembly functions the same way as a part which is perfectly engineered but ignores assemblability. "A philosophy of design for robotic assembly will result in improved value, reduced cost, and better design regardless of the final assembly method" [8]. Today's designers are challenged by different elements in the manufacturing environment and are competing with each other more seriously than before. Their role in technology is more crucial than ever before. Even though computers are aiding them in their design and decision making, the variables of the problems to be solved have increased exponentially. "Design of assemblies and the process that assembles them presents a chicken and egg problem" [9]. Boothroyd uses this example to further describe the relation between design and assembly. "The production process cannot be well defined until the assembly is designed, but the assembly cannot be well designed until the process is defined" [9].

3.2 DFA requirements

The most important component of a product is the base component. Careful design of the base component facilitates feeding, insertion, fastening, and most important handling (Figure 3.3) when using a well designed base, parts are inserted in the base component and transfered to the next work station. It is recommended to design parts which minimize the positioning and alignment problems. Notches, punched holes, chamfers, and clips align and position the mating parts before the fastening operation starts (Figure 3.4).

When selecting a suitable head configuration for a fastener, avoid round heads or heads which do not have a steep angle. Avoid over stocking of parts in vibratory feeders. If fastener is not fully symmetric (it has grooves or pin hole which must be oriented precisely), asymmetry of part should be evaluated and used for orienting purposes. If the feature which has caused the asymmetry is not large enough or prominent enough to effect and enhance orientation, addition of asymmetric grooves will improve the handling and eliminates orienting problems (Figure 3.5).

Some important issues related to DFA are listed as [10]:

-Design for minimum number of parts

-Develop a modular design. Assign common functional requirements to standard modules

-Do not fight gravity

-Reduce processing surface

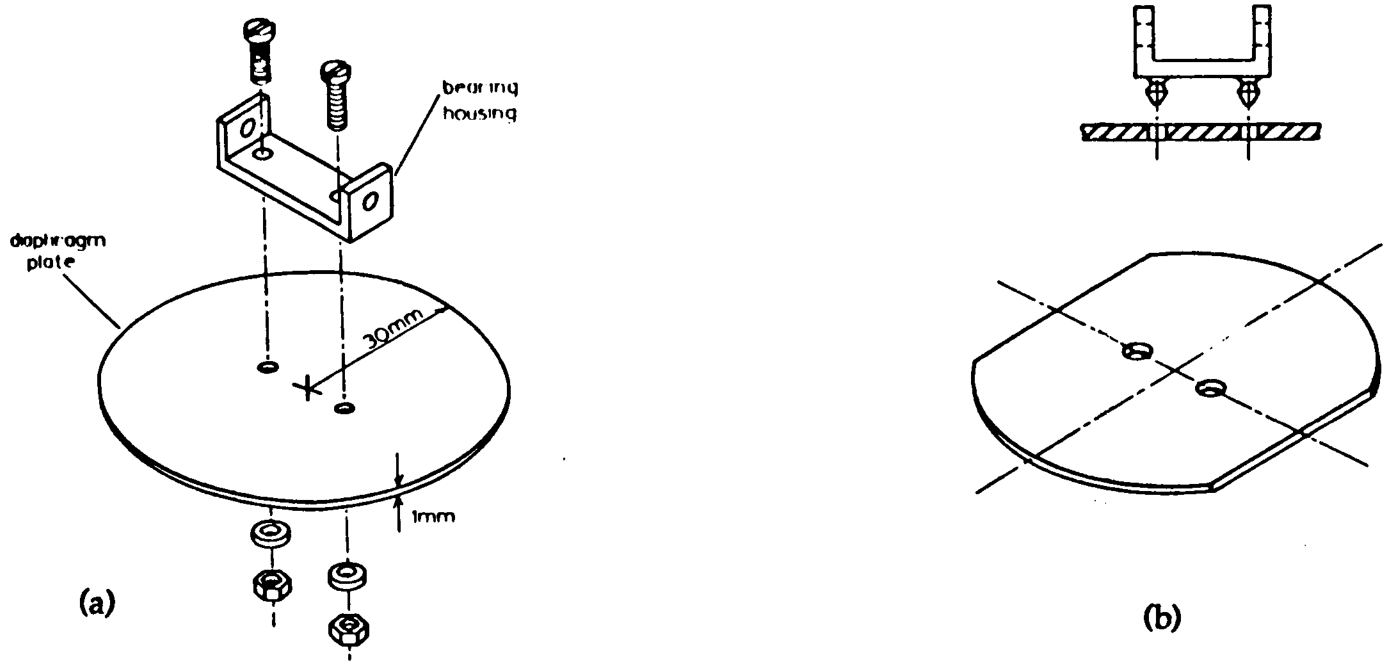


Figure 3.3. Design For Assembly. a) The initial design configuration b) Improved design. Fastener eliminated, plate redesign for easy alignment.

Source: Boothroyd, G., "Automated Assembly," Marcel Dekker, 1982.

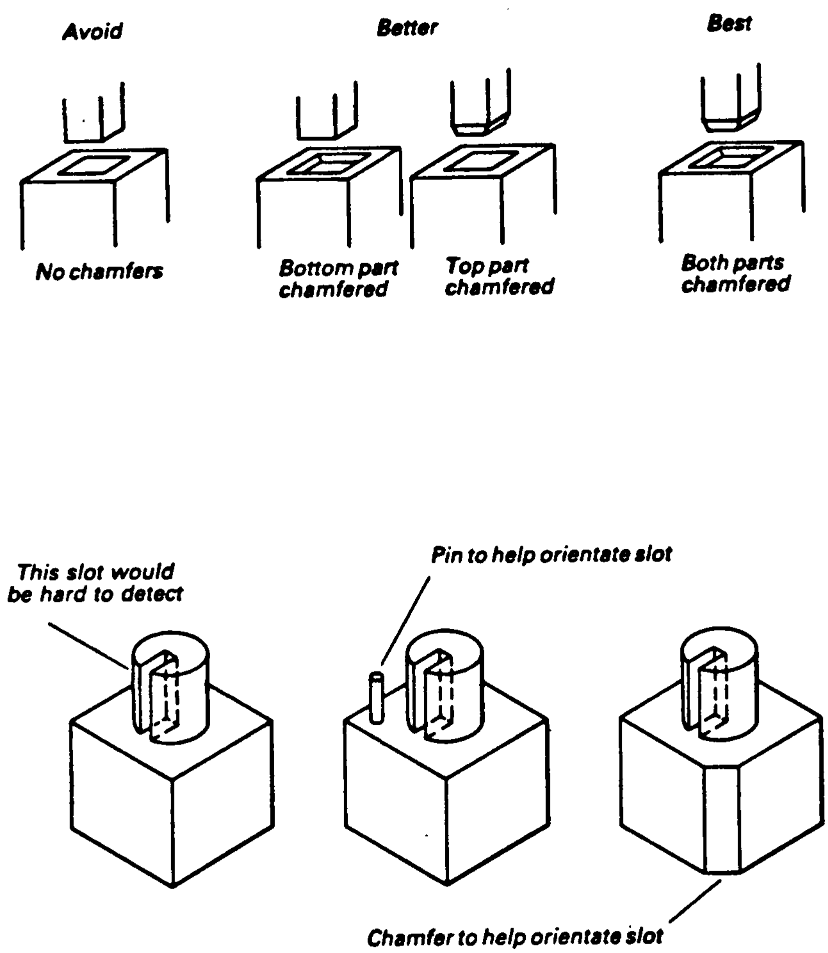
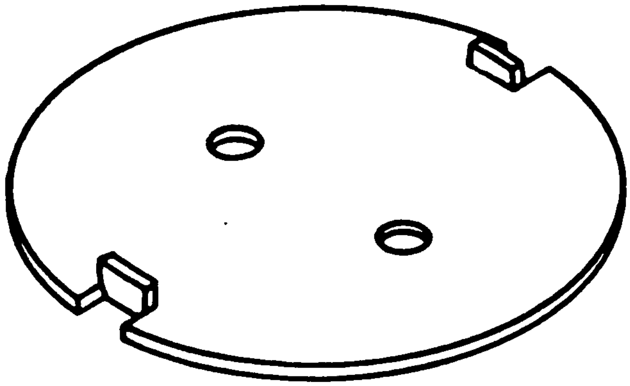


Figure 3.4. Chamfers and non-functional external features to help feeding and orienting.

Source: Rathmill, K., "Robotic assembly," 1985.



Use of tabs to define orientation.

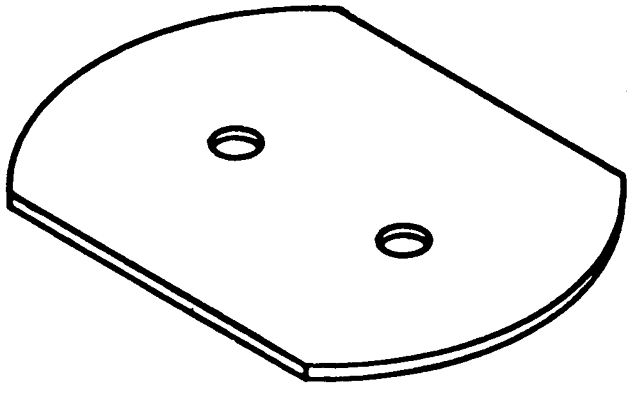


Figure 3.5. Redesign of plate for easier alignment.

Source: Boothroyd, G., "Product design for assembly," 1987.

-Assemble in the open. Provide easy access and clear view

-Eliminate fasteners where possible

-Design for part identity

In a robotic work cell, feeders and robots are located close to each other for easy reach of the robot. The tooling attached to the end effector performs the fastening operation after the part is grasped and positioned over the work. To further improve the feeding sequence, fasteners should be fed directly to Automatic Fastening Machines (AFM). Using this method, the number of movements required to transfer a part to the work is minimized. If various types of fasteners are used in one work station, then a computerized FMS consisting of robots and feeding machines can perform the assembly operation more efficiently. It is important to minimize parts variation in a particular product in order to distribute the work load equally in the work cells and prevent bottleneck effects in a system.

3.3 Existing DFA methods

DFA and Design For Manufacturing (DFM) have been defined and are well known to manufactures and designers. Design for X (DFX) is a new concept which is developed by researchers at the AT&T corporation [11]. "X stands for manufacturability, installability, reliability, safety, serviceability and other down stream considerations beyond performance and functionality" [11]. A well planned selection process for a suitable fastener for automatic assembly follows the same path and obeys the same rules as established for DFX.

Product Design Merits (PDM) [12] is a menu driven PC program which measures assemblability of a product design. PDM assumes three fundamental functions in assembly of mechanical products as: feeding , inserting, and fastening of parts. The best insertion parameter is vertically down and the worse is vertically up. Other parameters lie between these two limits. The remaining parameters are arranged according to the angle of insertion or rotation. Feeding and fastening parameters are arranged similar to insertion parameters. "Numerical scales ranging from 100 to zero are assigned to the feeding and fastening assembly function coordinates just as was done for the insertion parameter coordination" [12]. PDM lists common fastening methods under fastening parameters and tabulates conventional feeding machines as its feeding parameters.

DFA, PDM and other assembly analysis tool kits like Xerox corporation DFA guide, do not emphasize detailed analysis needed to select the right fastener for the job. The FSFA has the solution to many unanswered questions regarding feasibility in fastening operation. Fasteners characteristics are easily identified by FSFA.

Hewlette - Packard's design for assembly strategy analyzes assemblability, assembly time, number of parts, and number of difficult to automate assemblies [13]. "The analysis method consists of defining motions and operations necessary to assemble each part, then assigning penalty points for anything other than a simple downward motion" [13]. Some of the guidelines stressed by the engineers in Hewlette - Packards Corporation are listed as:

-Develop a modular subassembly design...
-Use the largest component as an assembly base...
-Minimize assembly levels.
-Design for one dimensional assembly(build from bottom up)
-Provide self locking features....
-Avoid designs calling for two-handed assembly.
-Choose efficient joining methods....
-Taper all parts to be inserted and chamfer the holes....
-Facilitate parts handling....
-Eliminate wiring hareness wherever possible.
-Avoid electrical and mechanical adjustments.
-Minimize the number of parts....

Boothroyd summarizes his conclusion and comments about improvement to make the design simpler for robotic assembly as [14]:

- Most existing products are not suitable for robotic assembly....
- ... Changing the design may in some cases provide such considerable simplification that automation is no longer necessary.
- ... Each part represents an assembly operation....
- If possible, the design should be such that all parts can be inserted in one direction....
- ... Changing tools add to assembly cycle time and assembly costs.
- All insertion locations must be easily accessible....
- As much as possible parts should be self locating and not require holding in position while another assembly operation is being carried out....
- Robot should perform all assembly operations easily without parts joining and without involving excessive force during assembly.
- ...The biggest problem in using robots for assembly is the product design itself and not the design of the assembly system.

CHAPTER 4

AUTOMATION

Due to increase in labor cost and mass production, the need to automate assembly operations becomes more evident. "Automation is defined as any means of helping workers perform their tasks more efficiently" [15].

4.1 Automation or not

Manufacturers have different prospectives about automation and replacing human workers by a robot. Economic aspects of this replacement must be studied carefully prior to purchase of new machines. The volume of production has to be taken into account. The effects of new systems on the layout of the plant and the environment can not be ignored. Training workers and the machine operators must be completed before production starts. "One essential element of the technology selection and development process is to evaluate, the ability of a selected technology to accomplish its intended purpose" [3]. The decision of automating the production of any product should consider the market demand. "Significant fluctuations in demand, such as may occur with sports equipment, must be accommodate by stockpiling. The cost of stockpiling may rule out automatic assembly for some products" [2].

Some times the company management will not consider automation because no systems have been installed in their industry with their exact product. The company management believes that they already have an automated factory. Management will not automate because they made an attempt once in the distant past and it was a failure. Management is reluctant to change the existing operation because it is tried and proven. Management does not understand automation. People are not aware of what is being accomplished by automation and the company is not willing to accept the risk of implementing new automated systems [16].

Automation can make the work area a safe or a hazardous place. It can also help to solve the inventory problems or make them more complicated. Initial investment in automation can be profitable in the long run or lead to bankruptcy. In other words automation either works or does not.

Automobiles, electronic equipment, and thousands of other products can be automatically produced. These products have parts or subassemblies which can be handled and assembled mechanically by either robots or fixed automation. A suitable product for assembly should be fed fast, oriented easily, and assembled flawlessly by the help of available equipment or machines. Some electronic products usually have inefficient assembly characteristics. Wiring of electronic elements is not a friendly operation for automation.

Assembly technology is divided into two categories: 1) system issues 2) component issues [17].

System issues consist of :

-Product design for assembly

-Analytical tools and simulation to analyze part mating or assembly
-Part feeding either by fixed feeder or robot to feed unoriented parts.
-Inspection systems
-Software and hardware control system .
-Teaching methods for robot to perform specific operation.
Component issues:
-Design issues for robots such as kinematic, dynamic,
-Parts feeder and inspection devices.
-Tools and grippers
-Sensing systems
-Adaptive devices to handle both common and complex assembly tasks.

Application and product specification must be considered simultaneously in automation. "Product specification is essentially a manufacturing control document and normally identifies the specific material finish and method of manufacturing" [18]. In order to incorporate fasteners as an essential element in assembly, design specification is also required. "Design specification normally outlines the condition for use of the fastener" [18]. CAD and CAM systems are essential elements for product specification, while FSFA deals with design and fastener specification.

4.2 Automation and machines

Fastening can be accomplished by manual, fixed automation, robotic assembly, and a combination of all (Figure 4.1). Customized machinery is used in automated cells to meet the production requirements. Tool and

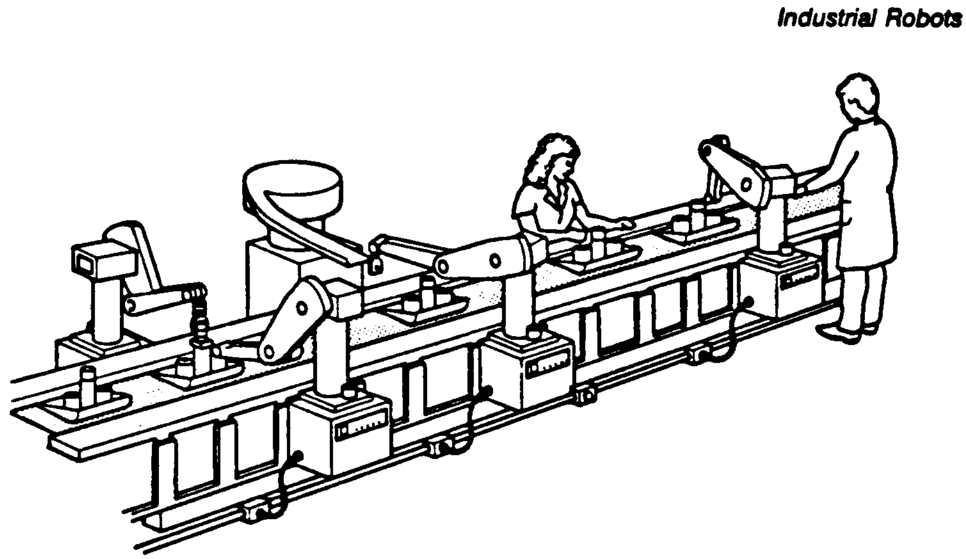


Figure 4.1. Possible arrangement for an adoptable programming assembly system using robots.

Source: Groover, M., "CAD/CAM," 1984.

feeder selection, fixture design, and the arrangement of the work station are the final steps which must be taken into consideration for design of an Automated Fastening Cell (AFC).

Some flexibility in operation of the industrial machines can greatly improve the production rate and enhance the simplicity of the assembly line. In small batch production (Figure 4.2), machines must be frequently set up and adjusted for products, but in large batches or mass production, hard automation with large set up time can be justified. "Mass production is characterized by large numbers of components of the same configuration for which the demand is relatively constant and predictable" [15].

Programmable automation is used for machines which can be programmed to perform different operations. Numerical Control machining equipment (NC) are widely used in factories. The program is electronically fed to the machine to perform a certain task. Changeover is quickly achieved by the use of NC machines.

Transfer machines are also used in assembly lines. Components are transfered from the preceding stages by this equipment. Assembly machines are classified according to their arrangement on the assembly line. "In line" machines are positioned in a straight line and "Rotary" machine are in a circle (Figure 4.3). Rotary transfer machines are limited in the number of operations they can perform in contrast to in-line machines which are not restricted to the size or the number of stages involved for assembly of a product.

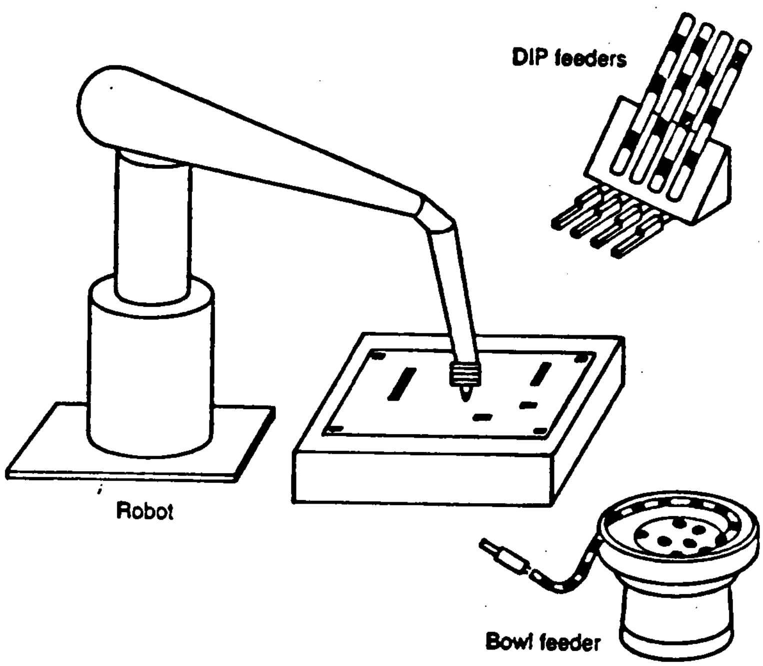


Figure 4.2. A typical robot cell with feeders.

Source: Rajan, A., "Assigning component to robotic work cell for electronic assembly," AT&T technical journal, 1989.

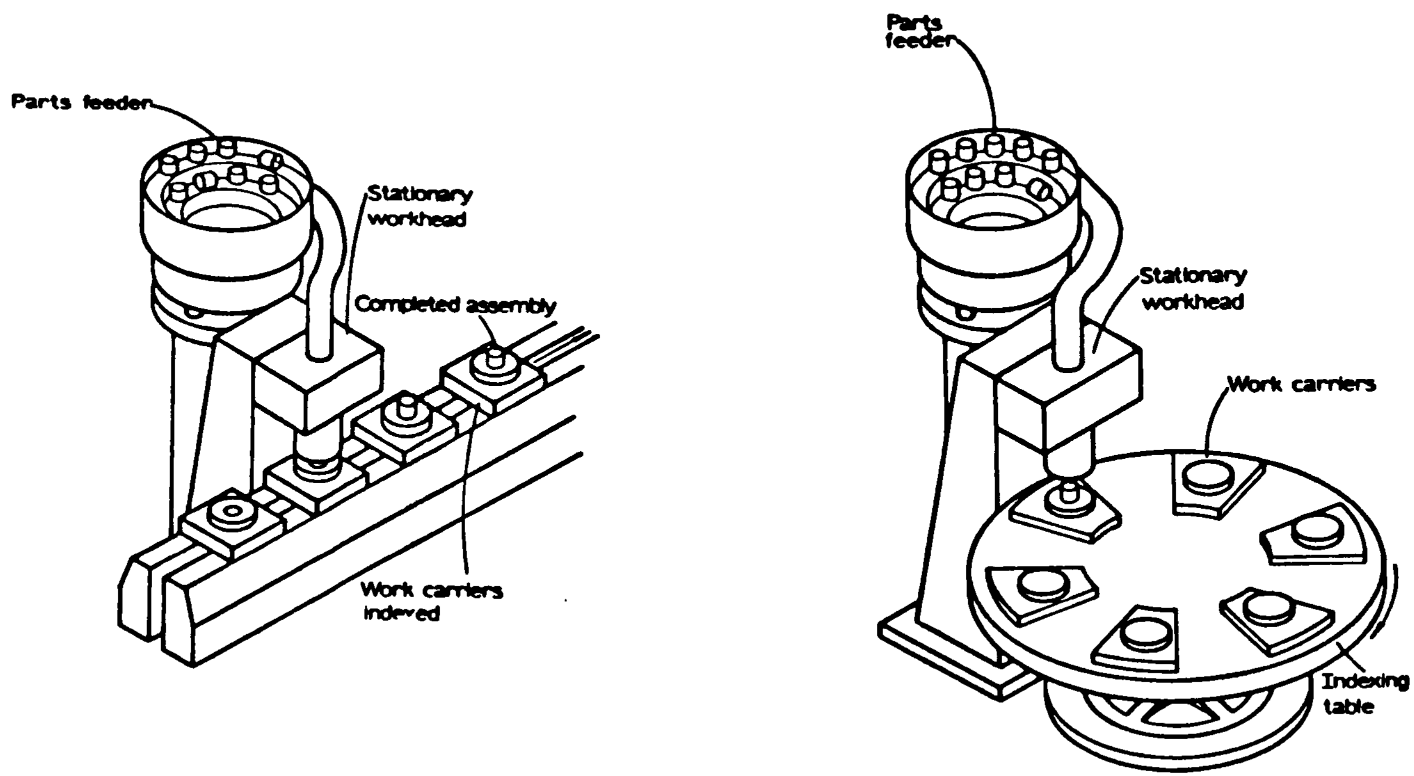


Figure 4.3. In line and Rotary indexing machine.

Source: Boothroyd, G., "Automated Assembly," Marcel Dekker, 1982.

Robots are preferred for automatic installation of fasteners, since they are easily programmed or adjusted to meet the demands of the production line. They are also able to precisely locate and align parts before installation. The operating speed and the level of intelligence of a robot is a determining factor when incorporating it into the assembly line. "A typical time for a robot to acquire one part and place it in an assembly, providing that there are no grasping or insertion difficulties, is 3 seconds " [14]. Gripper exchange can take twice as much time. Friction and strength of parts should be evaluated when using a gripper to pick up and handle fasteners. Excess or lack of adequate force causes deformation or slippage, respectively.

Three basic types of robot assembly systems are: single station, one arm system, single station two arm systems and multistation systems [14]. Common robot configurations are: polar coordinate, cylindrical, jointed arm, and cartesian coordinate (Figure 4.4).

AFM are the solution to increased productivity and systems efficiency. Two step fastening is not a suitable application for AFM. In many cases two independent robots are placed opposite to each other in the work station in order to simulate an assembly method which requires the use of both hands. Usually, design and utilization of this kind of automatic cell is costly and time consuming.

Automated assembly influences the design of special fasteners which are rather different from fasteners used for manual assembly. The biggest challenge is to design fasteners which are easily adapted to the newly

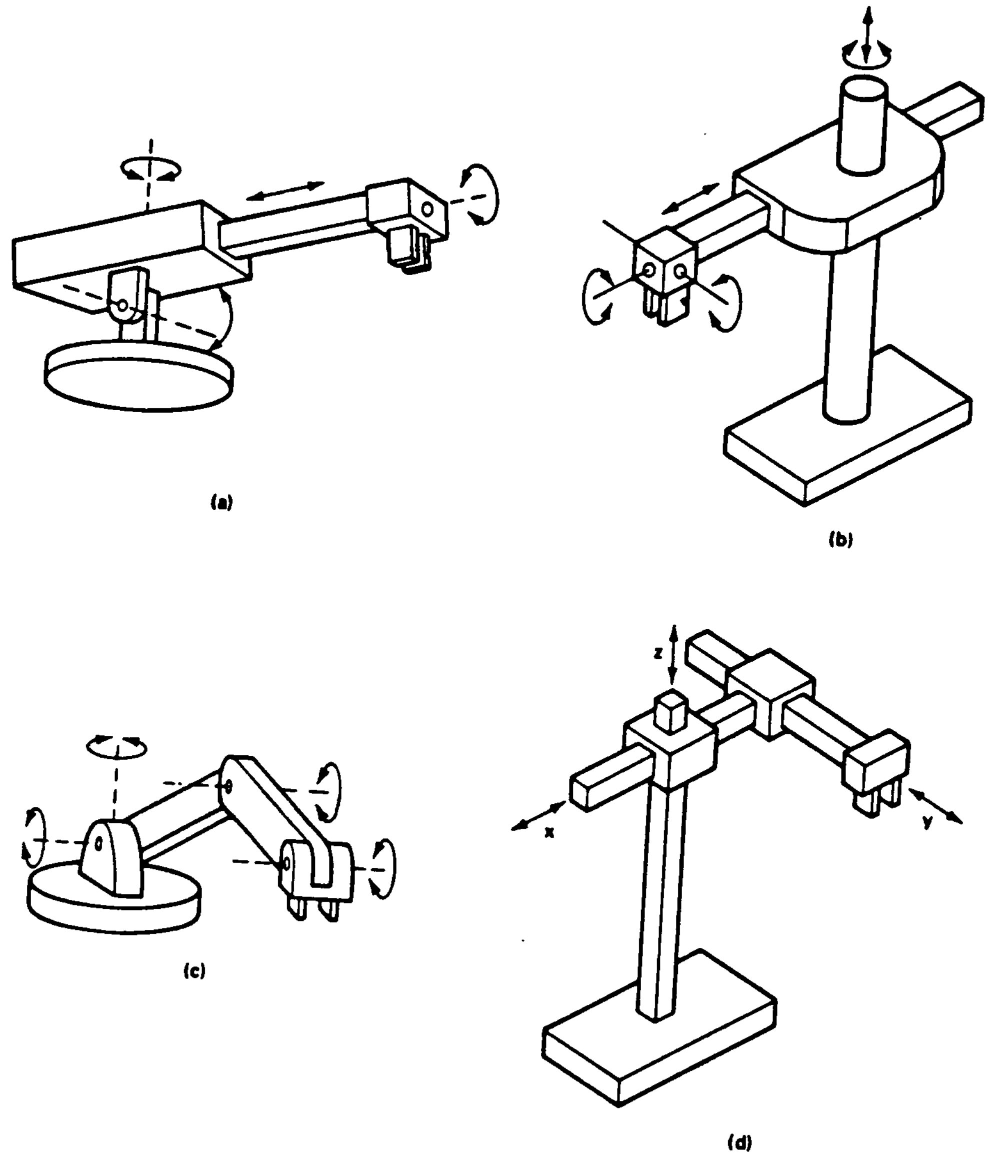


Figure 4.4. Robot configurations; a) Polar. b) cylindrical.
c) Jointed arm. d) Cartesian coordinates.

Source: Groover, M., "CAD/CAM," 1984.

automated systems where human interaction or assistance is minimum. Currently the number of fasteners which can demonstrate ability to adapt to an automated cell is very low. Fortunately many fasteners found on the market can be used by AFM after a few modifications on the machines.

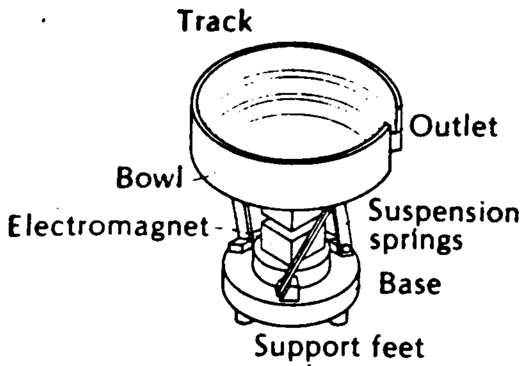
AFM should feature a tension control system in order to avoid exerting extra clamping force. Material type, sealant, type of thread or fit, and lubricants effect the input torque. As the variation in type and method of assembly increases, the installation of a central computer control system becomes inevitable. An experienced worker, when performing manual assembly, detects any error and adjusts the input elements to the system. Applied torque is the primary measure of tension for tightening joints according to the design specification. AFMs are powerful and fast operating equipment. When selecting fasteners for automated assembly, the designer must consider the strength and ability of the parts involved in the hostile environment of automation.

A flexible part feeder may use optical sensors to accurately determine the position of the part and its orientation. In this system, vibratory feeders feed the part regardless of its orientation, optical sensors detect its location, and a robot grips them based on the information it receives from the sensors. To simplify and eliminate complicated equipment, use of magazines or bands to feed components is suggested.

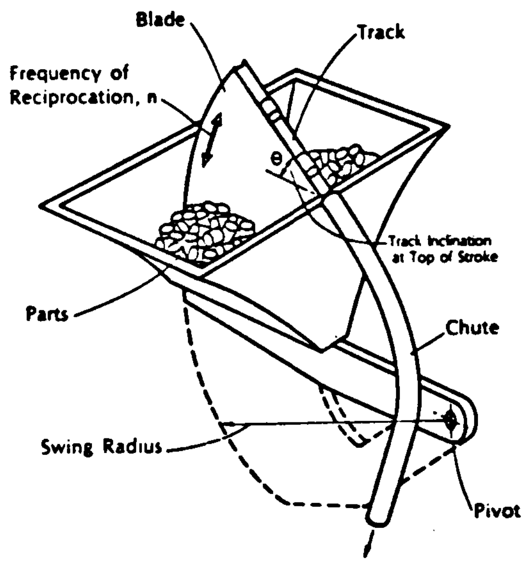
Vibratory bowl feeders are commonly used to feed the parts to the assembly line (Figure 4.5-a). Obviously these feeders are limited to the size of the part that they can handle. This is probably the reason for assigning a code to only small parts. Vibratory feeders use orienting devices to orient small parts as they pass through the spiral channel on the interior wall of the feeder. Figures for various orienting devices are included in Appendix B.

The inclination of the wall is carefully selected for each family of parts based on their size, shape, resting aspect, friction coefficient, and conveying velocity. Parts which pass all the orienting devices reach the outlet. The part's velocity and direction of motion changes as it travels on the track. "It is possible for a part to hop forward, land, slide forward relative to the track and then slide backward in the period of one vibration" [19]. The probabilities of the natural resting aspects of parts varies based on their material, size, and geometric configuration. Before arranging orienting devices in a vibratory bowl feeder, statistics obtained from tests to find resting aspects of part, must be studied and used as the basic rule to choose and arrange a suitable orienting device. Boothroyd has performed statistical analysis based on distribution of natural resting aspects of parts for automated assembly. He has designed vibratory feeders, hopper feeder, and orienting devices according to these data.

Hopper feeders are also used to feed small parts to the assembly line (Figure 4.5-b) . When selecting a non vibratory bowl feeder, the size, weight, and friction coefficient of the fastener must be evaluated . Most non-vibratory



(a)



(b)

Figure 4.5. Industrial feeders. a) Vibratory bowl feeder. b) Hopper feeder.

Source: Boothroyd, G., "Handbook of feeding and orienting techniques."

bowl feeders have reciprocating blades or a centerboard hopper. A complete listing of hopper feeders is included in Appendix B.

Simplicity in tool selection for assembly is an important factor. Obviously not every tool can be used for any kind of fastener. Hand tool and power tools exist in variety of shapes and prices. Choosing fasteners from similar groups which can share a common type of tooling can make the assembly more efficient. Most power tools trace their origins back to hand tools. Power requirement, speed, and accuracy lead to production of power tool. These tools have linkages and arms which are driven or activated by an external power source such as air pressure or electricity.

4.3 Quality automation

Quality control can ensure the flow of quality fasteners and products in the assembly line. Data can be gathered either automatically or manually for analyzing the quality of parts and productivity of the system. Computers linked to data gathering systems can provide a real time analysis and update of information. Visual inspection and other measurement techniques can detect any problem before and after the fastening operation. Having a reliable quality control at the beginning of the cycle of production, where in this case is the cold or hot forming stage of the fastener, can greatly improve the efficiency of later operations. Fastener failure can cause property damage or bodily injuries. Safety precaution is an important issue when choosing a joining method. Fastener loosening is the most common type of joint failure.

Today's industrial machines have some sort of memory to insure the quality of products. If a defective part is spotted during its passage through a work station, no more work is done on it until it is rejected from the assembly line. Machine memory is particularly important during the fastening operation. If the fastener breaks or destroys the work, it must be detected and remembered by the inspection devices or computers. The probability of having defective fasteners is increasing by the introduction of low quality import fasteners in the United States market

CHAPTER 5

FASTENERS

Currently there are more than 2 million different types of fasteners on the market. These fasteners are usually differentiated and distinguished based on their size, material, application, and method of assembly. The number of fasteners which can be used for automation is much lower. In fact many major groups of fasteners are designed only for manual assembly, like panel fasteners or latches. In order to investigate major issues in automatic fastening, six different families of fastener were studied. Each group represents a unique issue related to automation. Whenever possible, examples and figures are included to further describe the characteristics of a particular joining method. The six groups are: Screws, Inserts, Snap ins, Rivets, Nuts and Bolts, and Washers.

5.1 Screws

Screws are among the most basic form of fasteners. They feature a simple design and installation method. Even though the installation sequence is simple, its cost can be six to ten times the cost of the screw itself [8]. Since nuts are not usually used in conjunction with screws for assembly, access to the work can be achieved from one side. Screws are not usually used in moving machine parts. Their application are limited to mostly static products or for parts which are not subject to dynamic loading.

Tapping , self drilling , and set screws are commonly used in industries Tapping screws are either threadcutting or threadforming. Threadcutting screws are more suitable for hard or brittle material but if they are not aligned perfectly it may result in damage or chipping in the work. If frequent disassembly is required, screws and especially thread cutting screws are not recommended. Each time the screw is threaded into the part, chips are formed and threads are cut. Obviously, using the same threaded hole is not considered to be a safe practice. Thread forming screws are prefered to thread cutters since they provide more mechanical advantage and are less troublesome for frequent disassembly.

Thread forming screws have more surface contact of closer fit with the hole, and are locked in place without the need of incorporating a locking mechanism. Thread cutting screws produces chips which can be a problem if used in blind holes. A thru hole is recommended for chips to be removed. Fastening must be done from the top so the excessive material is removed with the help of gravity. Also, a hole which is longer than the length of the screw provides storage space for chips.

Thread forming screws are usually used for sheet metals of soft plastics which can flex easily. But thread rolling screws are used in harder plastics. Self tapping screws are grouped and identified by the type of thread and its cutting edges (Figure 5.1).

Self drilling or broaching fasteners increase manufacturing options and improve the assembly methods by eliminating the need to drill and prepare

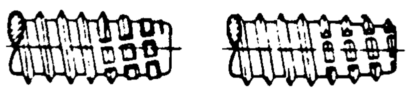
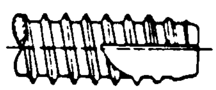
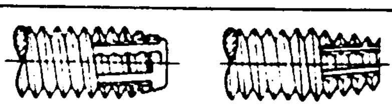
Pictorial Representation	ANSI/ASME Designation
	AB
	B
	BP
	BF
	BT
 *Not Recommended For New Designs*	C
	D
	F
	G
	T
	U

Figure 5.1. Self tapping screws.

Source: Industrial Fasteners Institute, " Fastener Standards."

the hole. Self broaching fasteners are suitable for plastics or soft material as they are installed easily and make a strong bond.

Screws are symmetric fasteners and available in a variety of head types or sizes. Industrial tools are usually bulky, heavy, and need a large operating space. These tools are fast, powerful, and the majority of them do not have sensors to detect any problem while threading, screwing, or pressing. Therefore, selecting a suitable head type for automated assembly is as critical as selecting the right fastener. Automatic tooling for a hex head is similar to conventional hand tools or wrenches. Use of a hex head is advantageous to a phillips type screw head since the cam out effect, which is the deformation of the drive recess, is eliminated. Head screws with flat vertical side facilitate vacuum pick up, and prevent over lapping of fasteners in feeding and orienting stages (Figure 5.2).

The phillips head is preferable to the grooved head as the tool can be engaged with the head of the fastener easier (90 degrees beta symmetry is prefered to 180 beta symmetry) and can remain engaged more securely. If the holes are closely positioned together, hex head fastener might cause problem due to lack of space for industrial tools to perform the fastening operation. Fasteners with internal driven heads like socket or phillips head require less work space.

Set screws are used for positioning of moving parts on their bases. Set screws are inserted to a predetermined number of threads. Counting the

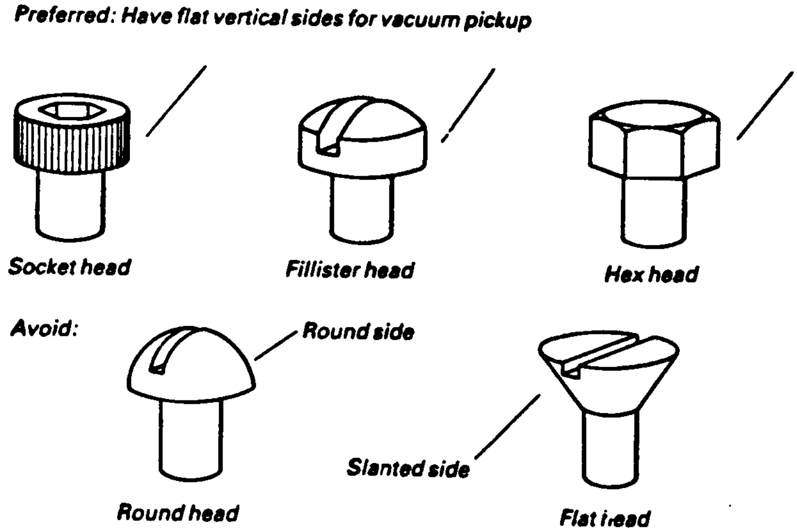


Figure 5.2. Suitable and unsuitable screw heads for assembly.

Source: Rathmill, K., "Robotic Assembly," 1985.

number of turns of tooling might not be an accurate measure of insertion depth, since tooling may make a few turns before engaging the head.

On some electrical appliances, screws are inserted to full depth then back out a few turns for wiring purposes. Some means of determining the depth of insertion must exist in order to avoid any damage to the material as the result of excessive torque.

Screws with high L/D ratio are easier to orient. Screw feeding systems either hold the screw by the threads or by the head. Head configurations that facilitate vacuum pick up of better tool engagement are prefered for automatic assembly.

To further understand the mechanics of screws it is necessary to define screw threads and some important related issues. "A screw thread is a ridge of uniform section in the form of a helix on the external or internal surface of a cylinder" [21]. The screw threads on bolts, screws and studs are considered as external while nuts inserts and tapped hole feature internal threads (Figure 5.3).

Different identification systems for threaded fasteners have been defined. The three most commonly used systems are: Unified coarse Threaded (UNC), American National Coarse Thread (NC). Unified Fine Thread (UNF) and Left Hand Thread (LH).

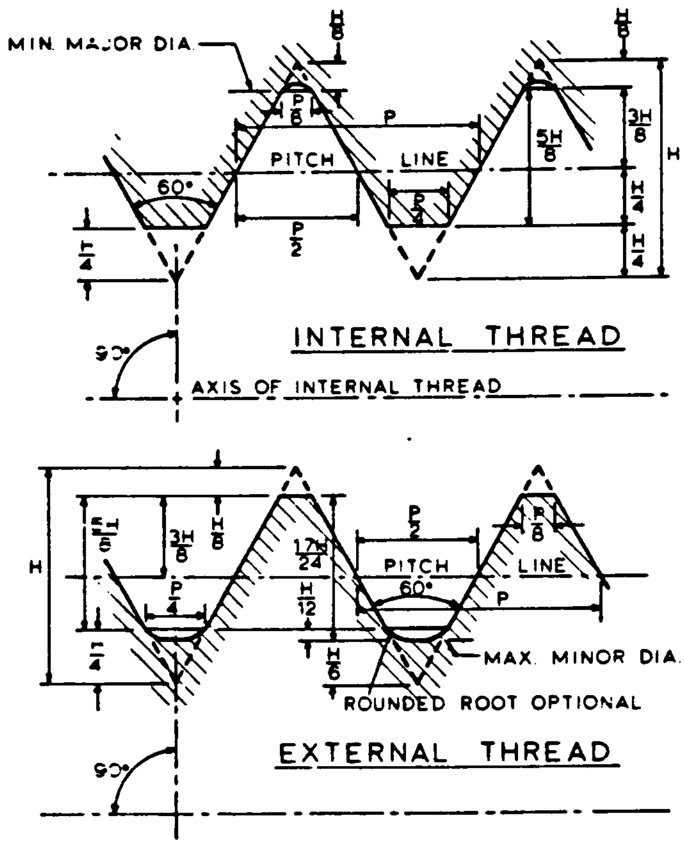


Figure 5.3. Internal - External thread cross section.

Source: Parmley, R., "Standard handbook of fastening and joining," 1989.

Screw threads with flat or rounded roots mate easier than screws with sharp threads. The clearance between the mating threads is normally lower in sharp roots. Fine threads have better accuracy, provide more torsional strength in the joint and are tightened with a greater degree of certainty against loosening. Generally, assembly of coarse thread screws is quicker and has more advantages over finer threads as they are used in a mass production environment.

Three classes of fit are defined for external and internal threads as (1A,2A,3A) and (1B,2B,3B) respectively. "Fit is a measure of looseness or tightness between mating threads. Classes of fit are specific combination of tolerances and allowances as applied to external and internal threads" [21]. 1A and 1B have loosest fit while 3A and 3B are tightest. The degree of looseness of fit does not effect the quality of assembly, but effects amount of time spent to align and fasten a screw thread. Loosely toleranced classes like 1A or 1B are recommended to be used for automated assembly. Tensile strength experiments conducted at the University of Massachusetts confirmed that: " Class 1 and 3 fit were equally good and there was no reason to make fasteners with tolerance closer than those of class 1" [21].

Fasteners which have a built in locking mechanism are prefered since they are fastened and locked in place quicker. The majority of locking mechanisms used for screw threads add to the thickness and size of the part. Bolts with built in plastic pellets or coated with locking liquids, have less clearance with other parts. Class 3A threads are not suitable if the screwthread should feature a locking mechanism or a layer of corrosion protective material.

Often the fast pace of the fastening operation in an assembly line causes parts overheating. Obviously having more clearance between parts is desirable while operating in hot environments. For fasteners used in high temperature service, above 300 degrees F , it is desirable to provide a positive allowance between the mating threads and allow for lubrication and expansion. There is an equal trade off between choosing a closely fitted fastener and a fastener with more clearance. The fastening operation is more difficult and challenging for fine screw threads. On the other hand, a locking mechanism can be ignored if finer threads are used. Therefore, it is the designers choice to select a fastener which suit his needs best and also eases the assembly operation.

Usually assembly lines are hostile environments. Parts going through the line must be able to resist damage or deformation before they are assembled completely. Being able to sustain damage and continue to be a quality part is an important factor which must be studied in details. A screw thread can be damaged as it travels inside a bowl feeder or during fastening by power tools. Threads with more clearance can receive more punishment and still be a quality part than other parts with less clearance.

5.2 Inserts

Inserts are defined as: "...a special type of fasteners that acts as a tapped hole in both open and blind applications. It provides a strong, wear resistant anchor for standard screws in weak materials..." [20]. Increasing the ratio between drive torque and strip failure torque, improves the design and the reliability of joint in the plastics. Inserts are frequently used in plastic parts as they provide a strong base for fastening operation at later stages. Plastics are made of different material and compositions. Therefore, not all of them are suitable for use as a base for threaded fasteners. Plastics should resist the effects of creep and cracking in addition to corrosion and high temperature exposure. Fastening can be accomplished from one side of the work but obviously the joining of material is not complete until a bolt or a machine screw is used to join the second part. The internal thread of metal inserts has a longer lifetime when compared to threads formed at the wall of a drilled hole in plastics. Insert installation is a delicate task, so their use in plastics is usually limited to parts which are disassembled more frequently and require stronger joints.

Inserts are One Piece Incomplete Fasteners (OPIF) meaning that the joining operation can not be completed at one stage. Captive or machine screws are usually needed to fasten parts with inserts embodied in them. A complete listing of technical names assigned to a fastener is included in the section 5.5.

Power tools used for insert installation can be easily adjusted for different type of applications. The tools are air or electrically driven. Inserts are replacing nuts and bolts in many automated assembly operations. Fastening by means of nuts and bolts on average takes three times longer to assemble.

Key Insert are installed in two sequences of first, threading of the tool into the insert and then, tapping the keys into the hole by a hammer. If the orientation of the key is not important then the fastener is symmetric, other-wise it is 90 or 180 degrees symmetry. most parts with grooves or projections on their surface are difficult to feed and orient. The threads on the outer surface complicate feeding and fastening operations and prevent a smooth flow of parts through the system. Tool engagement is time consuming and requires a special fixture to hold the fastener in place.

The time spent for threading of the tool into the insert, plus threading of insert into the work is not a desirable element in automation. Inserting the key further complicates the type and method of tooling. Tools must be programmed to follow the assembly sequence precisely and be able to adjust to the variation of movements involved in assembly. Insertion and fastening can be done in one work station which is an advantage on the assembly line. If possible, the number of threads should be minimized in order to speed up the fastening .

Cast inserts are installed easily. Due to the paste like nature of the material, cast inserts must be positioned into the work vertically from above. Tooling is simple and needs no special movement. Since the work material is in the form of liquid or paste, special equipment and a separate work station is needed to bring it to a non - solid form either by the use of heat or other methods. Even though assembly is not completed in one work station, the absence of a drilled hole is the advantage for this type of fastening. Positioning of the insert in the die is a slow process and not suitable for a fast pace assembly line. The most common type of cast inserts are diamond knurled inserts which resist turning or pulling out. The external surface of a cast insert should be formed to prevent rotation or pulling out of the insert. Knurls, grooves, and recesses provide the locking action after the material is solidified around the insert.

To prevent the flow of material into the tapped hole, the two ends of the insert must project beyond the surface. The projection shoulder causes a clamping force to be transmit to the insert's ends. Prevention of flow of material into the tapped hole and positioning of the insert correctly into the die are two most important steps for assembly. Therefore, precision tooling must be used in order to hold the insert in a correct location. Concrete inserts, even though not used for automation, are in the same family as the cast insert. They are installed before the work material sets. They are usually zinc alloy for rust protection. Almost all of the above inserts are symmetric.

Floating Inserts can fit the group for adjustable fasteners which are some times used for quick set up of machines or are applied in curved surfaces. Later stages of assembly can benefit from the use of floating inserts by solving some alignment problems. Alignment of parts or fasteners for insertion is an important problem which must be dealt with carefully. Use of a floating insert in one work station can improve the quality of fastening in another. It is the designer's responsibility to evaluate the feasibility of incorporating special fasteners which can improve the quality of the product and save time and money.

Coil Thread Inserts pose great difficulty for feeding and orienting. The coil is usually an 18-8 stainless steel with locks incorporated as one or more coils with hexagon cross section. Spring and coils are known to be "very difficult to feed parts" as they are tangled together easily. If a coil insert is used in soft material, threads on the walls of the drilled hole are not formed until the screw is driven into the insert and presses the coils outward against hole. Coil inserts are rotational symmetric parts and in most cases are alpha symmetric as well. The simple design and light weight of these fastener are their major advantages.

Ultrasonic inserts are installed by use of localized heat that melts away the plastic and places the insert into the material which is usually plastic or hardened rubber. Soft plastics are relatively more difficult application for ultrasonic weld. The melting of plastic eliminates the need for close tolerance or keyway insertion. Electronic industries use ultrasonic inserts in great numbers. Similar to cast inserts, after the fastener is positioned in place the success of fastening operation is completely dependent on the the time it takes for the material to solidify.

The knurled surface of the insert provides the locking action in the joint. Fastening is a clean operation since there is no chipping. Even though the fastener does not under go a permanent deformation, it can not be reused as it destroys the work material. Like other family members of inserts, fastening and insertion are an integral part of each other and are both accomplished in the same work station. Polypropylene, polyethelyne, polyester, olefins, nylon, some vinyls, and thermoplastic polyurethans are suitable material for ultrasonic processes. In addition to ultrasonic insert installation, induction and conduction methods of heating is used to melt the area around the insert.

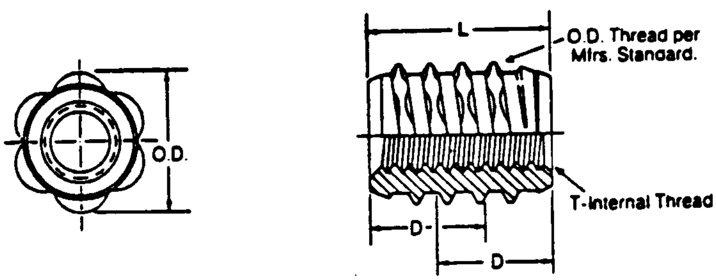
Self Drilling Inserts eliminate the tapping, cleaning, and gaging operations. The insert as screwed into the hole, cuts its own thread and locks itself in place. To simplify orienting of the part in a bowl feeder, a flat surface must be molded around the open end of the insert. The insert will rest on the flat surface as it emerges from the bowl feeder. This is an example of adding asymmetry external projection in order to facilitate handling and orienting. The external wave form threads are for easy assembly of the inserts. The fastener rolls its way into the drilled hole and leaves no chipped material. Wave shaped thread reduces the pressure of insertion and provides a strong grip which stands high pullout forces. It is fast and a good choice for assembly. Self drilling inserts which are alpha symetric require little orientation. Installation is done by a special power tool which threads the insert into the material. For manual fastening, a hand tool is screwed into the insert and the assembly is attached to a drill chuck.

Coarse screw threads are usually used for this kind of insert. The advantage of coarse threads to fine screw threads is their quickness, strength, and ability to form thread in brittle material where chipping is a problem for fine screw threads. Elimination of hole preparation is the biggest advantage of self drilling inserts. External threads can cause feeding problems which are common to all threaded fasteners. These inserts are fastened and locked in place by the help of waved form threads. Fasteners with self locking features make the assembly more efficient. If keys, like in key insert, are used to lock the fastener in place, one undesirable additional step, which is inserting of the keys, is added to the operation.

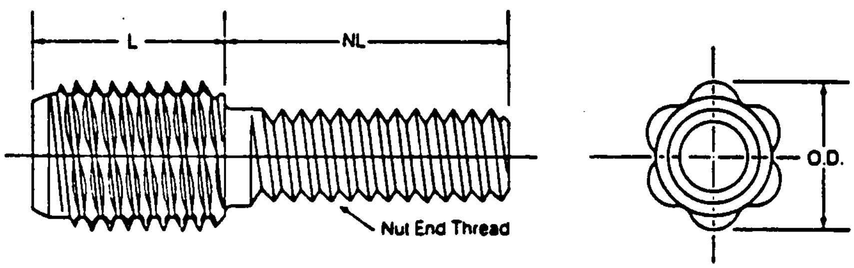
Press-in inserts are one of the largest families of inserts. They are fastened by pressing into the material. Press ins are not suitable for use in hard metals. The material is usually deformed due to the insertion force. Press ins feature locking action in different ways. The most common has a knurled surface which is in contact with material that it has deformed. Various types of knurled surfaces are available where each is suitable for a different material. Tooling for the press-in is simple since it is a simple press-in operation. No threading or hole preparation is required. The knurled surface provides the locking action. The fastener is also a rotational symmetric part. Therefore no special orientation is needed before fastening. Sometimes, press-ins are alpha symmetric parts too, which means they can be fed from either end. The knurled surface causes problems for feeding and orienting of the fastener and prevents a smooth flow of parts through the feeding machines. The fastening operation is considered to be a press fit and the fastener retains its geometry after the installation. Most press-ins are used for low strength applications. The hole diameter is slightly larger that the insert's outer diameter. Sheet edge inserts are installed from side to side. They are basically used for materials ranging from wood to soft metals.

Rivet inserts share the same characteristics as rivets. The installation tool pulls the threaded portion of the insert toward the blind side of the work and forms a bulge in the unthreaded section of the fastener. The insert provides a reliable threaded hole for a bolt or a machine screw. The formation of the bulge also provides a firm locking action. The tool must be threaded into the fastener prior to assembly and be unscrewed after the riveting is completed. Therefore three separate movements are required by the tooling for installation. Obviously this is a time consuming operation and not a suitable method for assembly automation. Their applications are automotive and appliances.

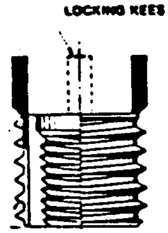
Stud inserts are installed similar to other family members of inserts. Self drilling, cast, press in, keyed, and threaded studs are widely used. Studs are mostly used in pressure vessels, valves, flanges, and high temperature applications. Studs can cause feeding and handling problem if they have unequal thread size and length at either end. Most studs are not a alpha symmetric. Unequal length threaded studs are more difficult part to orient. Feeding or orienting the studs is a more challenging task than for other fasteners. Finding the correct end of stud is more difficult than orienting head screws. The variation in the type of screw thread at either end (fine and coarse) and the knowledge of the location of center of gravity can improve feeding and orienting techniques. Inserts : (Figures 5.4-5.7)



(a)



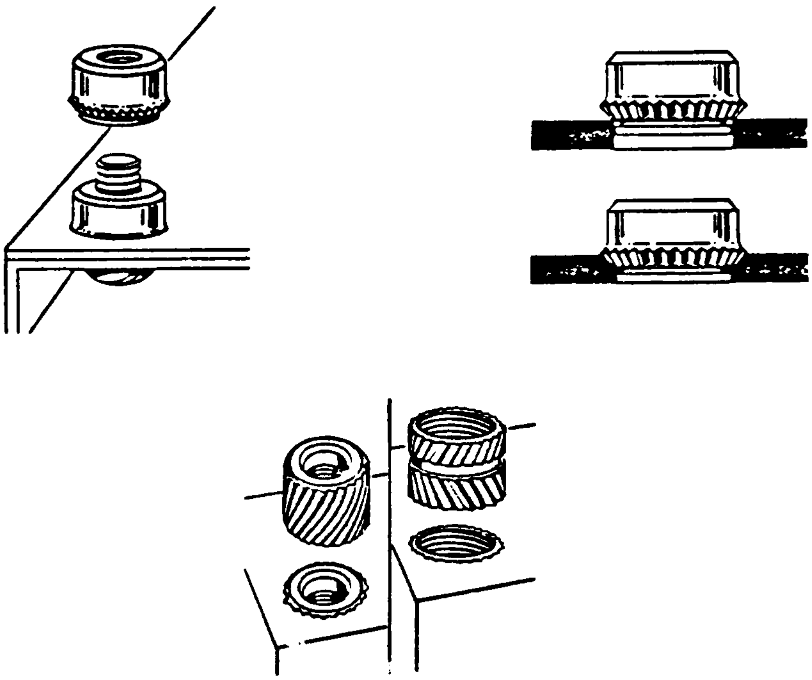
(b)



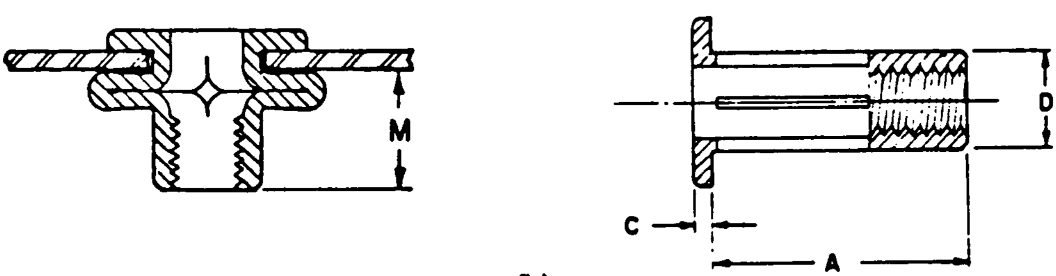
(c)

Figure 5.4. Threaded inserts. a) Self threading insert. b) Self threading Stud - Insert. c) Key insert.

Sources: a) Camloc fastener, Catalog, 1990.
b) Camloc fastener, Catalog, 1990.
c) Tridair inserts, Catalog, 1990.



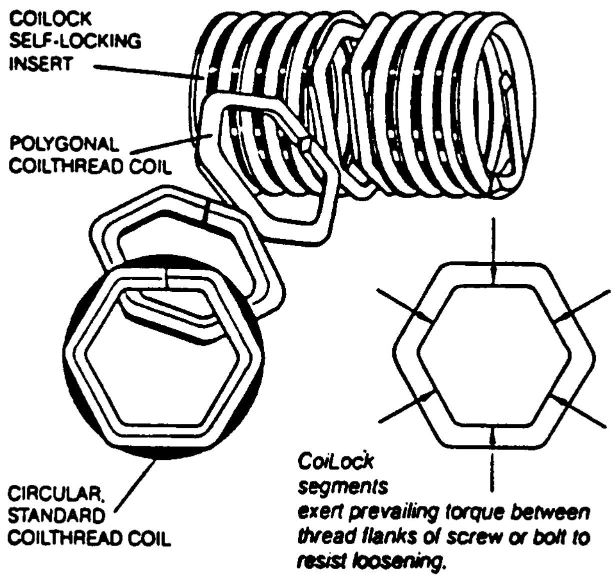
(a)



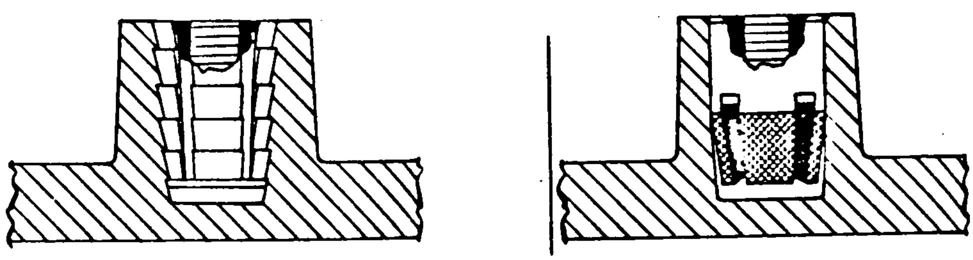
(b)

Figure 5.5. Press and rivet inserts. a) Press in insert. b) Rivet insert.

Sources: a) Southco fastener, Catalog, 1989.
b) BF Goodrich, Catalog, 1986.



(a)



(b)

Figure 5.6. Inserts for plastics. a) Coil insert. b) Ultrasonic insert.

Sources: a) Camloc fastener, Catalog, 1990.
b) Edwards, c. "Seven mechanical fasteners speed assembly of thermoplastics," Material Engineering, 1974.

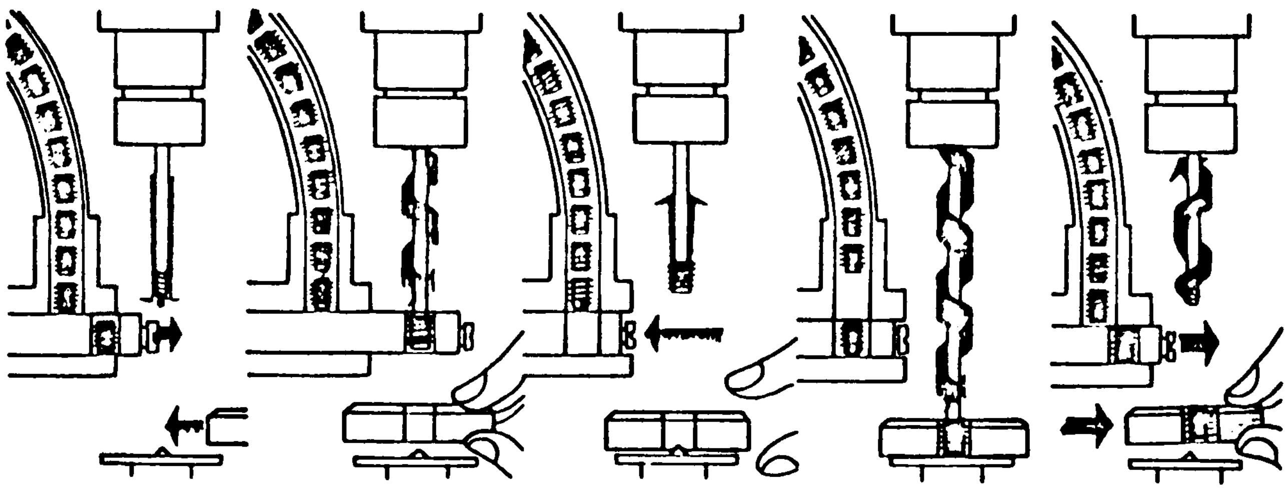


Figure 5.7. Feeding and installation of self tapping inserts.

Source: Dunton, R., "Threaded inserts," Assembly Engineering, 1980.

5.3 Snap ins

Snap ins serve different purposes from covering holes to cosmetics, spacers and fasteners. Some of the more popular snaps like accordion, single loop, and Christmas tree have rotational symmetry about their principle axes and feature a simple construction with easy installation. They can also hold two or more thicknesses and are fast and efficient. Snap ins are vibration proof, since there is no energy stored in the fastener during the installation sequence. The fastener is no longer under stress or load as is fully inserted and deformed members are back to their original position. Common Snap ins are either cantilever or hollow cylinder (Figure 5.8). Cantilevers are used in different ways and orientations and it is a simple design to manufacture.

Snap ins absorb vibration, seal the joint, and provide locking action without addition of washers. Snaps are different from rivets since they can be removed, reused, and do not undergo permanent deformation. When designing snap-fit fasteners of plastics, snap-in and snap out force must be calculated precisely based on information on joint friction, plasticity of material and its yield point. Plastic fastener can be molded into any shape. Since different types of plastics with different mechanical and material characteristics exist, designers must ensure a reliable joint by carefully selecting the plastic material. Plastic fasteners are limited to use in so called non-hostile environments. New designs and materials must be selected where combustible substances, extreme heat, or acidic chemicals are present.

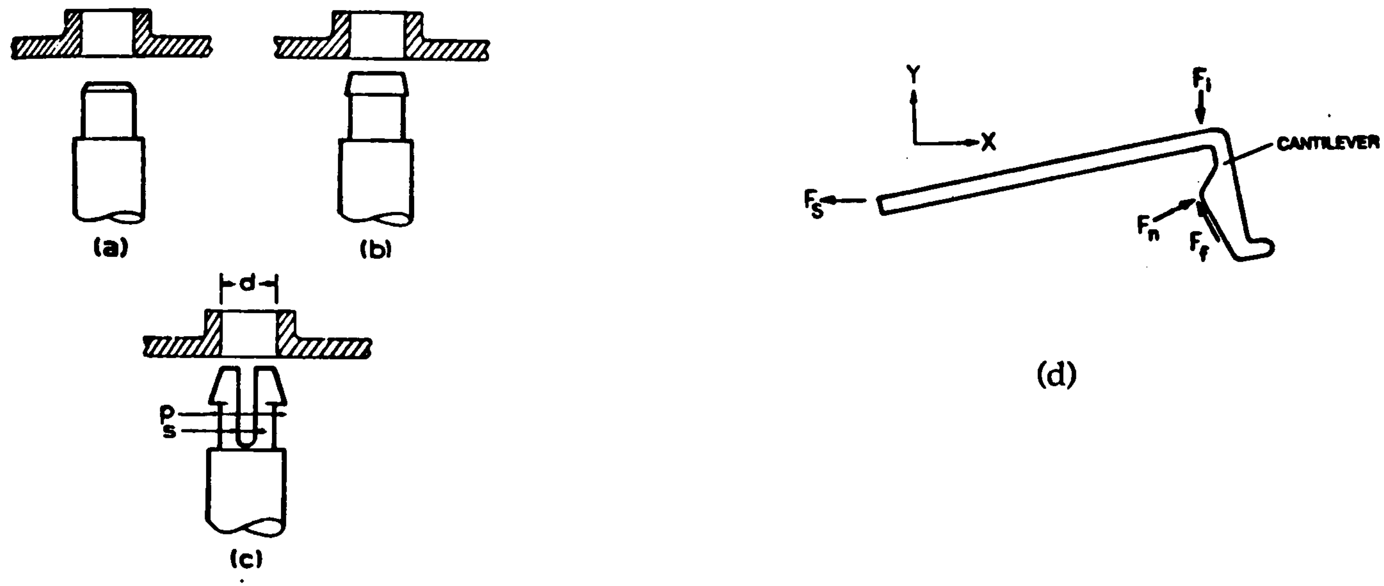


Figure 5.8. Comparison of : a) Press fit. b) Hollow cylinder snap. c) Dual cantilever snap . d) Forces acting on a cantilever.

Source: Chow, W., "Snap fit design," Mechanical Engineering, 1977.

If frequent disassembly is needed or the joint is subjected to dynamic loading, snap fits do not provide a reliable method of joining. A snap fit is not a function of time, in contrast to a press fit which can loose its grip over a long period of time. In a press fit, the pull out force is a function of friction coefficient of the material and the press in force of the installation. Interference fit, push or snap in is not a suitable method where column or tensile strength is required.

Fastening of retaining rings is similar to snaps but they are extremely difficult parts to feed, orient, and fasten automatically (Figure A.7). Manual assembly is recommended for this group of fasteners. They are mostly used to retain or lock different machine components such as the parts which are under dynamic loading, like rotating shafts.

Plastics are commonly used in electrical - mechanical products. Electrical conductivity is an important issue when selecting material for electronic products. Plastics offer flexibility in design related to electrical equipments. When selecting plastics for structural use, care must be taken as the mechanical and structural properties of plastics are affected by being exposed to some chemical products or being in contact with hot parts or environment. This selection process is more critical than selecting fasteners for joining of metals.

Plastics are easily formed and shaped as hinges, latches or holes in the part. Therefore, the fastener is embodied as an integral element in the part. Unfortunately, not every assembly operation is suitable for joining plastics.

Metallic mechanical fasteners are used mostly when the parts are subject to dynamic and heavy loading and are frequently disassembled. The majority of fasteners used for plastics can also be incorporated with soft or thin metal sheets. Plastics are increasingly used by engineers when choosing a corrosion resistive, light, cheap, and static dissipating material. When incorporating fasteners as an integral part of components, cost of joining is greatly reduced. "In many applications using plastics, the final product cost depends predominantly on the method of assembly" [22].

Molded one piece plastic fasteners make the assembly more efficient by reducing the number of parts in a product. Therefore fewer feeding machines are needed to supply the assembly line. Plastic snap - ins with a low flextural modulus permit closer tolerance and better fit as they compress, stretch or bend during fastening.

Power screwdrivers are commonly used to install fasteners in plastics. The Capital investment for these tools is not as important as the overall cost of fastening operation. In a mass production system a proper tooling can save money by eliminating undesirable setups and adjustments. Fortunately most plastic parts are one piece molded which require little or no machining. Several major companies use this method of production as a way to eliminate difficult machining operations. Some of the common snap ins are shown in next page (Figure 5.9).

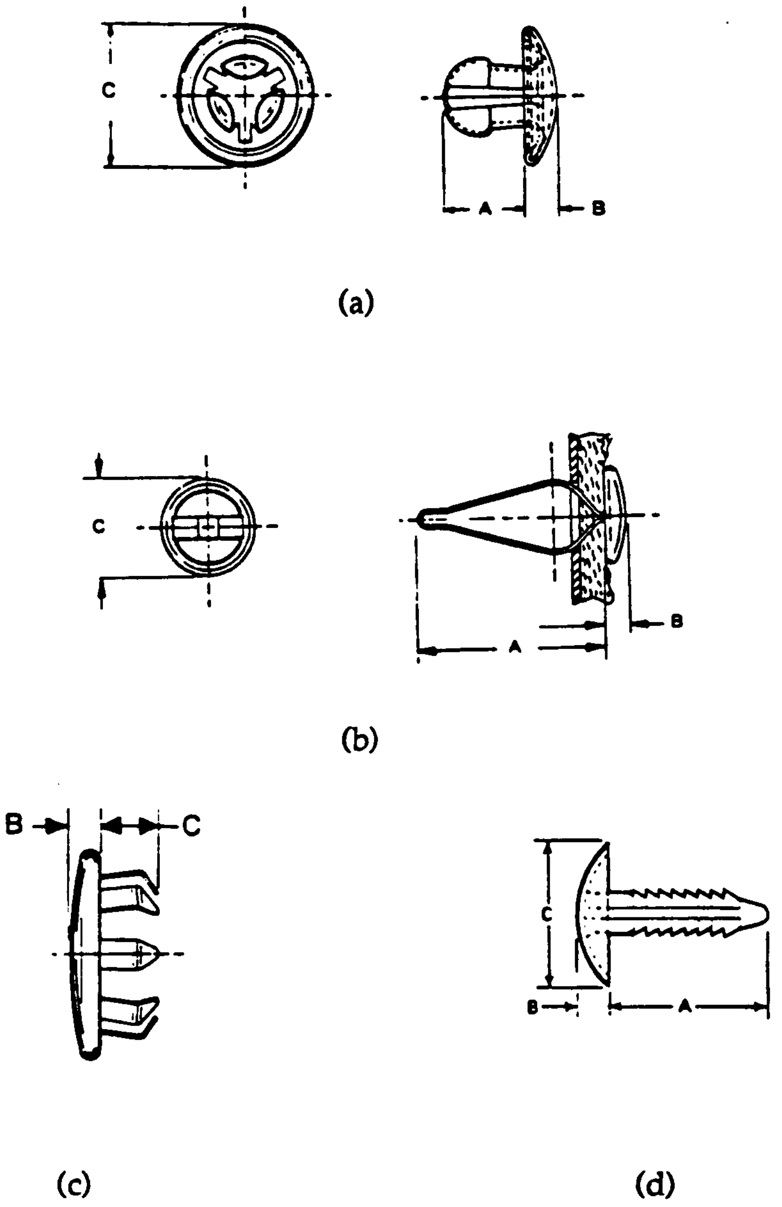


Figure 5.9. Snap ins. a) Capped snap. b) Capped single loop. c) Plug button d) Push panel snap.

Source: TRW fastener, Catalog, 1990.

5.4 Rivets

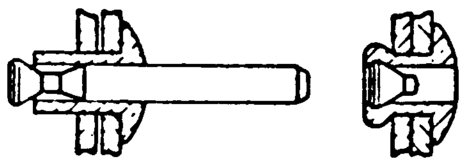
The fast pace of assembly lines demand quick fastening machines. Riveting is a fast operation where up to 1 rivet per second can be installed. Rivets are tamper proof and self locking. Rivets require no hole preparation, but the majority of them do require a drilled hole. Rivets can not be disassembled and reused. They should be replaced by a new one if removed.

Rivets under go permanent deformation. Some rivets deform the material too. If unable to control the expansion, riveting can cause deformation in composite material where extreme force is applied to the surface of the drilled hole. When rivets are used in brittle material, washers must be added to prevent breaking or cracking of material due to the force exerted on the joint and the fastener. Good control over the expansion of blind fasteners in a drilled hole makes them a good candidate for use in composite material where chipping and cracking is an important issue. The accuracy of hole preparation is essential when dealing with threaded fasteners, while holes used for rivets or other blind fasteners need not be as accurate. The amount of expansion of the rivet shank can be changed or controlled for a closer fit.

Riveters are simple tools which operate on a hydraulic or electric power source. Assembly consists of two steps. First the insertion, then pulling of pin(if a pin is used) and last, breaking of the pin if it is self plugging. Broken pins of rivets can cause jamming problems in feeding and assembly machines and must be dealt with carefully when the riveting is completed.

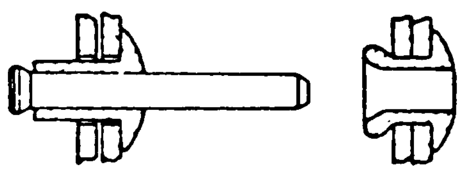
Rivets are rotational symmetric parts and require no orientation about the principle axes. Even though rivets have two parts(pin and sleeve), they are considered as one piece fastener which requires no other part to complete the joining. Insertion of the fastener into the hole is without resistance. Unlike some inserts, feeding of the fastener to the tool head is not difficult. Magazines or bands are often used for this purpose.

Generally four families of rivets are available according to their installation method: 1) In this group the sleeve is deformed by the pulling force of the pin (Figure 5.10-a). Later the pin is broken off. In most cases a third of the pin remains inside the sleeve forming a self-plugging blind rivet. 2) In the other group, the pin is pulled through the shank The deformation caused by pulling the pin makes a tulip head at one end and expands the shank throughout the hole (Figure 5.10-b). The pin is later discarded. During this operation the shank remains hollow and is mostly used for high tension applications rather than shear force. 3) The third group has characteristics similar to self plugging rivets but different in the role of the pin in the fastener. The pin is driven into the sleeve and causes the deformation. The pin does not break nor is it removed by the tooling. It provides a strong joint, too (Figure 5.10-c). 4) Compression rivet has no pin for assembly and is a one piece fastener (Figure 5.11). The deformation at the other end is caused by a die or by the pushing force of the tool into the material. The need for a die at the other side of the work makes the fastener an unsuitable choice for automation



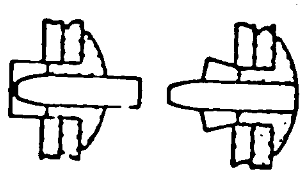
self plugging rivet

(a)



Pull through rivet

(b)



Drive pin rivet

(c)

Figure 5.10. Common blind rivets. a) Self plugging. b) Pull through. c) Pin drive

Source: "Assembly Engineering," July, 1990.

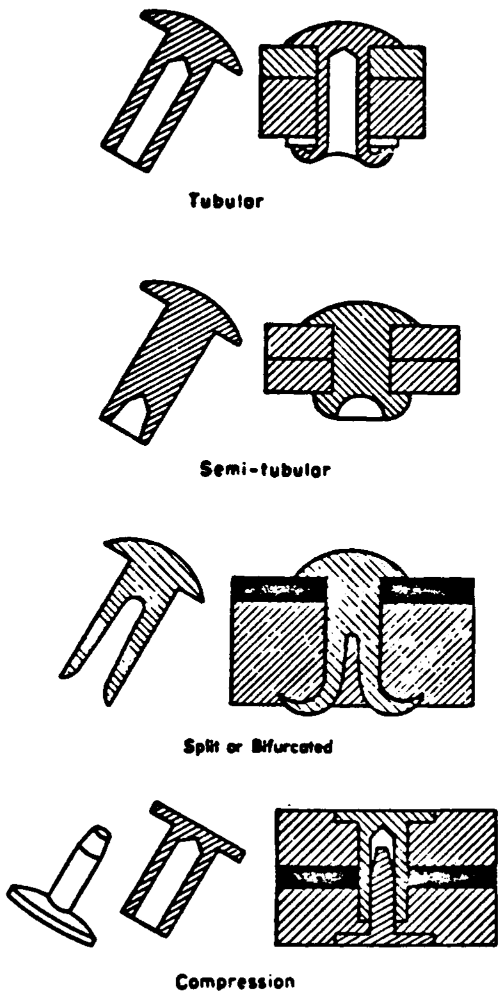


Figure 5.11. Compression or piercing rivets.

Source: Laughner, V., "Handbook of fastening and joining of metal parts," 1956.

Riveting can be divided into three major categories. For self plugging and expansion rivets: 1) Downward motion needed for inserting the rivet into the hole. 2) Pulling the pin upward. 3) discarding the pin. For compression or drive pin rivet there is no pulling upward; only a simple press fastens the parts. It is concluded that simplicity of installation sequence varies from one rivet to another.

Huckbolts can be grouped under rivets family as they form a permanent joint (Figure A.6). Some Huckbolts do require access from both sides of the work while others are considered blind fasteners. Since these fasteners are used in heavy machinery, they are not given priority while studying fasteners for assembly.

5.5 Bolts and Nuts

"A bolt is defined as an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut" [23]. Bolts and screws are commonly used to fasten two or more parts together. Bolts are readily available on the market. The necessary tools are known to everybody with basic mechanical knowledge. They have been the basic and common form of fastening for many years and will continue to dominate the fastening operation in the future. Nuts and bolts are symmetric fasteners and do not require special hole preparation.

Headed threaded fasteners like bolts and screws are suitable when the joint is under tension, while fasteners without a head exert compressive force. The clamping force applied to a bolt causes elongation in the fastener and compression in the joint. As the result of this phenomena, mating threads provide the locking force in the joint. This is commonly refered to as "preloading". The stress caused by preloading must be greater that the one exerted to the joint during operation of the product. Threaded fasteners fail due to shear and torsion stress, tension force, bending moment, and thread stripping.

Fastening machines must have special devices to accurately sense the loads on the fastener and the joint. The applied torque or strain should not exceed the elastic limits of the material. Torque control equipment measures the rate of tightening and applied force. As the rate of applied torque over the insertion speed changes, that indicates that the fastener is passing its elastic limit. From that point it is the operator's choice to continue the torque input in order to get a preload torque to further stretch the fastener.

The number of fasteners used in a joint effects the torque requirement, therefore it is the designers option to choose between shorter assembly time by having fewer fasteners, or exerting less torque by having more fasteners per joint. Safety and design quality must be considered too.

The number of threads on a bolt determines the rate of fastening. Also bolts must be relatively more flexible than the joint. This means that L/D ratio must be selected according to the required stiffness.

Part mating is an important process in fastening. Round holes with chamfered corners are frequently used to facilitate part mating. If chamfered holes are used, it is better to use a flush head or countersunk head screw or bolt. Fasteners with a chamfered tip are also recommended for easier alignment and insertion.

Locking devices effect the efficiency of the fastening operation. Therefore selecting an efficient locking system is an essential element in assembly. Various locking devices have been developed for threaded fasteners. Nylon pellets which are permanently embeded into the body of a fastener, toothed washer, chemical locking, and springs are some of the most common.

Self locking bolts eliminate the need for the addition of an external locking mechanism or lock washer, consequently saving time and reducing cost. Chemicals are also used to lock threaded fasteners. When incorporating chemical thread locking action in a fastener, the designer must be careful that the torsional strength of the material is higher than the strength of the thread locking chemicals. Effects of temperature and the type of application must also be considered when applying chemicals for locking purposes.

Free spinning and prevailing torque are commonly used to lock the fastener. Free spinning locking includes toothed washers. Prevailing torque locking action is achieved by either deformed threads or nylon pellets embeded in the fastener. The torque setting in the free spinning locking method should not exceed breakloose torque which flattens the toothed washer. One advantage of this system is the relatively low torque needed to secure the joint. In contrast to freespinning, the prevailing torque method requires more torque to drive the deformed threads or plastic pellets into the prepared hole.

Specially designed locking screw threads are a very efficient locking system. Female threads have a 30 degrees wedge ramp cut at their root. Under tightening torque, thread contact force is applied at 60 degrees instead of 30 degrees as in other conventional threads. The increase in angle of contact force provides more locking friction between threads (Figure 5.12).

Bolts are inserted from one side and are mated by a nut from the other side. This is obviously not a suitable application for automation. The joining operation needs tooling at both sides of the work piece (two hand fastening). The fastener is inserted or is an extension of a part to be fastened. The best fastener is the one that does not need to be held in place during assembly.

If a fastener is able to complete the joining operation in a single step, then it is a "One Piece Complete Fastener (OPCF) like rivets. If a fastener is one of the fasteners in the joint but is installed separately to the work, then it is a "One Piece Incomplete Fastener (OPIF) like inserts. If the fastener is one of the fasteners involved in the joining operation and must be mated with the other fastener simultaneously to complete the fastening , then it is a

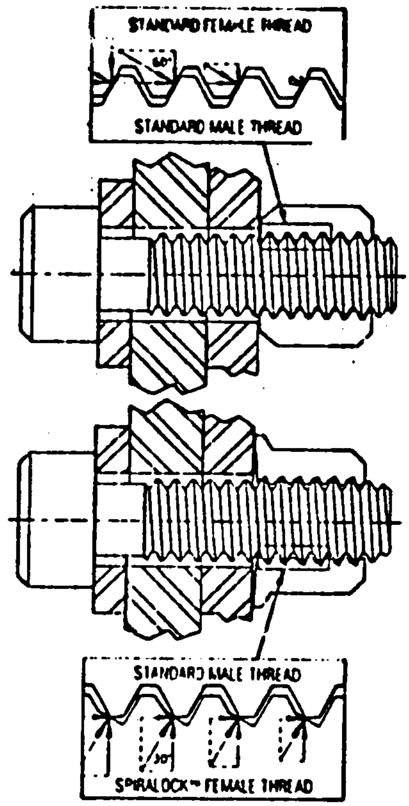


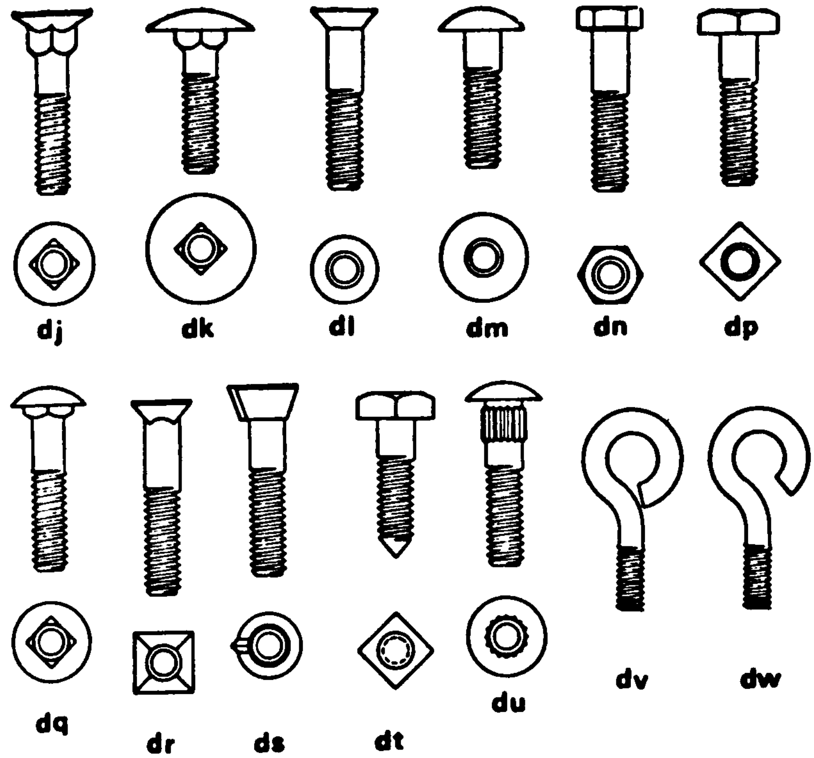
Figure 5.12. Spiral Lock female threads locking system. The 30 degrees wedge rampcut provides thread contact force at 60 degrees from the bolt axes.

Source: Spiralock system, Detroit tool industries, warren, MI.

"One Piece Simultaneous Fastener (OPSF) like bolts and nuts. If the fastener has two pieces preassembled and completes the fastening operation individually , then it is a "Two Piece Complete Fastener (TPCF) like Huckbolt, push-in rivnut, or pin drive rivet.

Nuts and bolts as threaded fasteners provides flexibility and have distinct advantages. One of the most important features about the threaded fasteners is their availability in different sizes, materials, and head styles. Their installation is relatively easy with manual or power tools. Threaded fasteners like bolts are easily removed or replaced when maintenance is required.

To select a bolt or other threaded fasteners, it is important to consider the need for hole preparation, number of threads, type of nut and washer, locking features, tooling, and head type. A bolt featuring different design requirements and considerations for ease of assembly is prefered for automation. Some of the selected bolts (Figure 5.13) and common nuts (Figure 5.14) are shown in next page. The major difference between these bolts is their head configuration. Carriage bolt and hex bolt are commonly used in industries. Other head designs and shapes also facilitate assembly. For example, ribbed neck carriage bolt features locking action by incorporating ribs which prevent rotation of fastener or its loosening.



dj–Countersunk head square neck carriage bolt.

dk–Step bolt.

dl–Countersunk bolt.

dm–Round head bolt.

dn–Hex cap bolt.

dp–Square head bolt.

dq–Round head short square neck carriage bolt.

dr–Square countersunk head plow bolt.

ds–Round countersunk heavy key head plow bolt.

dt–Joint bolt.

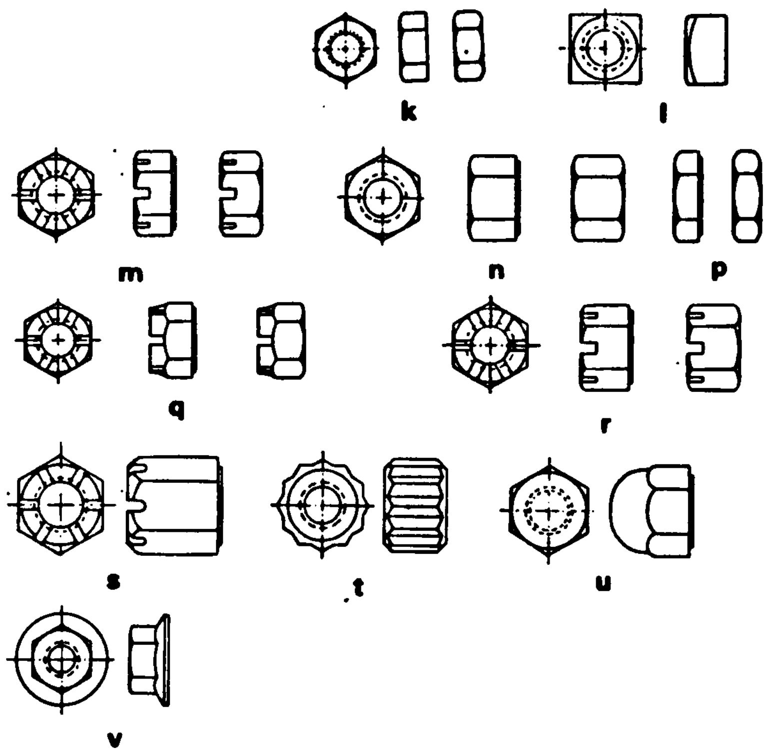
du–Round head ribbed neck carriage bolt.

dv–Closed eye bolt.

dw–Open eye bolt.

Figure 5.13. Common bolts and head configurations.

Source: Schwarz, O., Grafstein, P., "Pictorial handbook of technical devices," Chemical publishing Inc., NY, 1971.



k–Machine screw nut.
l–Regular square nut.
m–Hex slotted nut.
n–Hex thick nut.
p–Hex jam nut.
q–Hex castle nut.
r–Hex thick slotted nut.
s–High slotted nut.
t–12 point nut.
u–Cap (Acorn) nut.
v–Hex flange nut.

Figure 5.14. Common nuts.

Source: Schwarz, O., "Pictorial handbook of mechanical devices," 1971.

5.6 Washers

Washers are paired with screws, bolts, or nuts to complete the fastening. Their primary usage is to lock the fastener in place against rotation and prevent leakage or loosening. Lock washers are available as Internal tooth, External tooth, External internal tooth, Helical, and beveled.

The sheared edges of tooth washers bite into the work and the spring action further insures the security and stability of locking feature. They are also used to distribute the clamping force of the fastener to prevent damage being done to the metal or work piece. Washers are rotational symmetric parts and are relatively easy to feed or to assemble. Most lock washers do not resist insertion on the assembly line. Lockwashers with external teeth can cause feeding problem as they might tangle to each other. Also if they are fed through a tube, the friction caused by teeth can obstruct the smooth flow of parts to the assembly line. Therefore it is recommended to use lockwashers with internal teeth if possible. Many types of screws or nuts have a built in washer or recessed head. The cost and complexity of manufacturing recessed head fasteners has been the primary reason for the use of washers separately. Also recessed head screws or nuts are not easily fed or oriented by the conventional feeders. A nut with washer attached is not an alpha symmetry part anymore.

Washers are either inserted simultaneously with the other fasteners or are separately fed into the system. Therefore assembly or feeding of a washer is considered to be an intermediate step in joining two parts. The name of

"One Piece simultaneous" fastener is assigned to washers to clearly define some of their characteristic. The main purpose of assigning technical names to a group of fasteners is to help designers to better understand mechanical and assemblability behavior of their selected parts.

Washers with asymmetric feature should not be selected for automation. Asymmetric fasteners must be either avoided on the assembly line or their asymmetric feature must be utilized to improve feeding and orienting. Feeding mechanisms for parts which do not have rotational symmetry are complicated and expensive.

Helically coiled spring lock washer easily tangles if the gap or the opening is relatively larger in compare to the size of the wire used to manufacture or draw it. Any part or fastener which tangles easily during the feeding or orienting steps is not a suitable one for use on an assembly line.

Plastic washers are used mostly to seal or prevent corrosion. They do not pose many difficulties for assembly, but care must be taken for selection of the type of plastic used. Some plastics tend to deform or become sticky in a hot environment like an assembly line. Washers with a plastic ring permanently bounded to them share some common problems of feeding with plastic washers. Conical washers are not alpha symmetric and should be faced up or down as they are assembled. It is wise to choose washers which are both alpha and beta symmetric.

For a screw - washer assembly (Figure A.4) it is recommended to use vertically up fastening operation as gravity facilitates holding the parts together. If a washer is placed on top of the work or on a nut, care must be taken to insure the stability of the washer until the screwing operation begins. The teeth in a toothed washer facilitate alignment by providing more friction between the metal and the washer. Some of the commonly used washers are shown on next page (Figure 5.15).

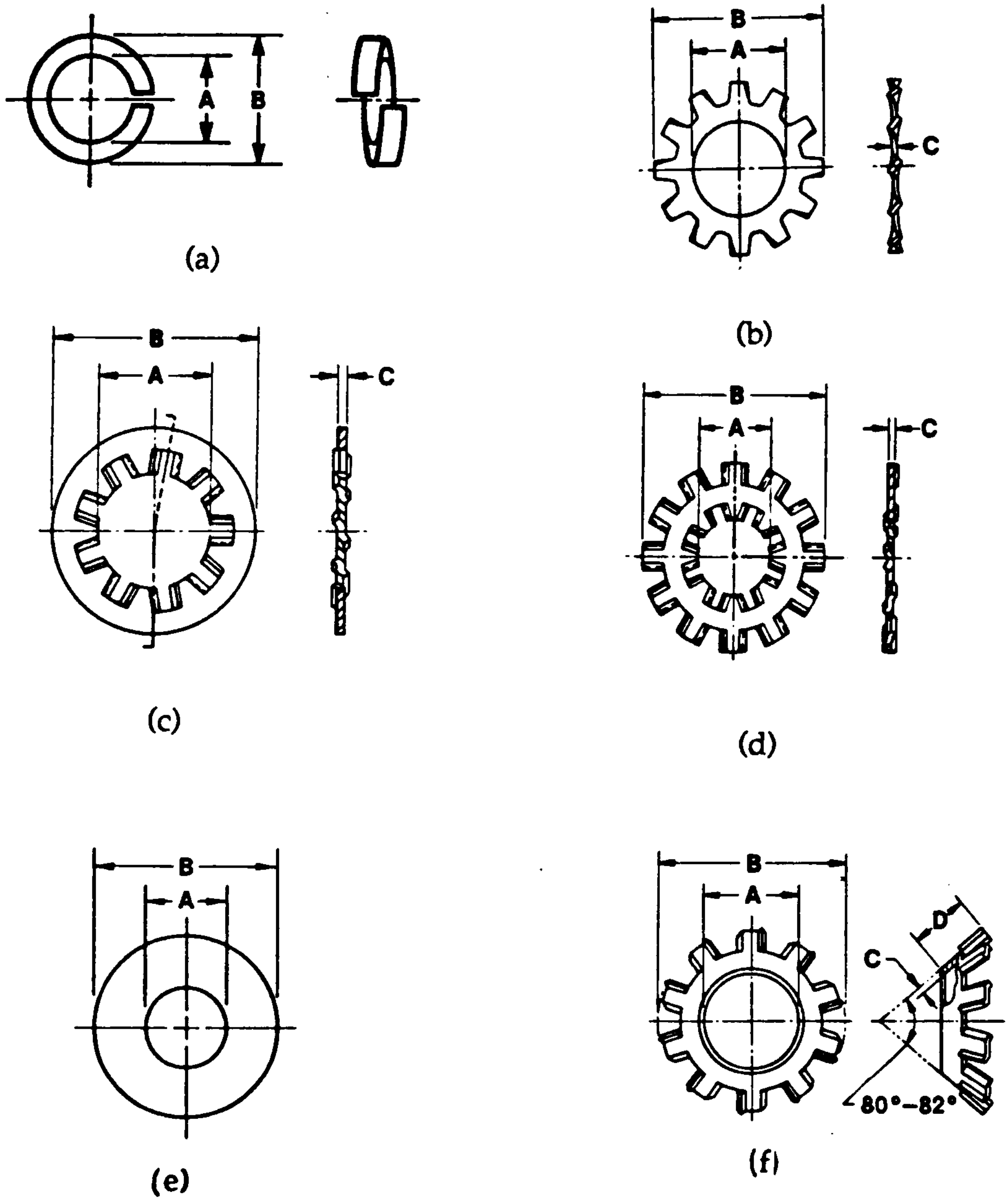


Figure 5.15. Lock washers. a) Helical spring. b) External tooth. c) Internal tooth. d) External-Internal. e) Plain. f) Countersunk.

Source: Industrial Fasteners Institute, "Fasteners Standard," Ohio.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The code for FSFA is simply a string of letters where each one represents the grade for one of the 21 major categories identified for selecting an efficient fastening method. A separate flow chart for every section or category is obtained and letter grades are assigned. The grade letter of "A" is the highest for any selection.

6.1 Why FSFA?

Factories of future represent flexible automation lines where new technologies make possible product changeover and quick setups. Machines are able to deal with various products and fixtures are designed to handle different shapes of parts. Assembly tools are minimized as the DFA principle is applied. Designers will choose a few standard assembly systems and machines to produce parts and products. Software for flexible systems are able to control an entire line or work cell for frequent changeovers. Grippers are prepared for different fasteners in few seconds. What needs to be done and how its is going to be accomplished is controlled by computers.

The FSFA coding system provides the exact type of information that Flexible Assembly Systems (FAS) need. For each fastener involved in the assembly line, machines are automatically setup and readied based on the information received from the FSFA library. The alpha - numeric code also compares different fasteners and chooses the most efficient one for automation. FSFA facilitates the screening process by listing the fasteners which match the design requirements. For instance, if the engineer is looking for a suitable method of joining two plastic parts which should not feature threaded fasteners, computers with the aid of FSFA select the best fastener which meets the design requirements.

The advantages of the coding system can be listed as: 1) Codes and scores can be used to compare and rank various fastening methods. 2) Designers can input the desired method of fastening and select the one method that matches the required features. 3) Flexible Assembly Systems can benefit from the coding system as each string of letters commands the assembly machines and controls their setups and tooling configuration.

6.2 Outline for FSFA

The outline for 21 major categories is listed below and the grades are shown in **bold** letters.

1. Fastener symmetry:

A--> Full symmetry

B--> Alpha symmetry

Beta symmetry

C--> Symmetry

D--> 60 degrees symmetry

E--> 90 degrees symmetry

F--> 180 degrees symmetry

G--> Beta asymmetry

2. Hole preparation:

Drilling not required

A--> Molded hole already prepared

B--> Self drilling

C--> Piercing or pressing

D--> Ultrasonic

Drilling required

No need for threading

E--> Needs no threaded hole

F--> Forms it s own thread

G--> Threading required

3. Completion of fastening:

A--> One fastener completes the joining like screws, rivets

One fastener does not complete the joining

B--> One is installed separately. More than one needed to join parts

C--> Two or more fasteners are installed simultaneously

4. Quickness:

Very fast

A--> snap

B--> press

C--> pull like riveting

Fast

D–> 1/4 turn

E–> 1/2 turn

F–> few turns. Less than 5

G–> more turn or threads

Slow

H–> Like waiting for material to solidify.

I–> Many fasteners in a joint

5. Locking the fastener:

Locking action not required

A–> parts provide locking action

B–> assembly is self locking

locking action is required

The nature of fastener provides the locking action by

C–> Permanent joining like rivets, ultrasonic inserts

D–> Press or snap fit

E–> Special screw thread ramp angle

F–> Waved or deformed threads

G–> Knurled surfaces

H–> Tight fit with more locking than loose fit

Fastener feature locking action by:

I–> recessed head or built in washer

J–> Plastic pellets. prevailing torque

K–> Keys to lock

Does not feature locking action

Can add locking action

L--> Chemical locking

M--> Toothed or spring washer

Can not add locking action

N--> Not enough tolerance

O--> Can not find a suitable method

6. Features for handling and orienting and alignment:

A--> Chamfered holes , round corners, grooves,center of gravity.

B--> External asymmetry features enhance feeding, orienting, fastening

C--> Internal asymmetry feature complicate assembly

D--> Fastener sticks, tangles, or has troublesome geometry

7. Head selection and tool engagement:

Not a threaded fastener. push or pull motion

A--> Grooves, edges, and friction facilitate pulling pushing

B--> No special feature to facilitate push. pull or press

Threaded fastener. Turning or tool rotation required

C--> Socket head, Internal tooling

D--> Hex head, better grip

E--> Phillips head, cam out effect

F--> Grooved head

G--> No head. Tool must be threaded into the fastener

8. Insertion, and fastening:

In same work station or by same tooling

A--> Same tool motion or direction

B--> Different tool motion or direction

Insertion separate from fastening, different tooling

C--> Same tool motion or direction

D--> Different tool motion or direction

9. Fastening steps and methods:

One step fastening

A--> Snap together

B--> Push or pull

C--> Press. High friction stay to gether

D--> Thread

Two step fastening

E--> Threading and pressing or pulling, like thread rivet

F--> Threading and tapping

10. Work access or fastening direction:

A--> From top

B--> From bottom

C--> from side

D--> From both top and bottom

E--> Complicated access. Access is problem

11. Tooling:

Hard automation possible

Tooling not special

A--> Very simple tooling. Push or pull

B--> Simple. Threading

Tooling is special

C--> Use of heat or ultrasonic

D--> Need die at other side of work

E--> Hostile tooling. Shock produced not suitable for robotic

Robotic assembly only because:

F--> Difficult to orient for hard automation

G--> Complicated movements required

H--> Extreme precision required

12. Part geometry and size:

A--> L/D ratio Facilitates handling

B--> L/D ratio does not facilitate handling

C--> L/D ratio complicates handling

D--> Fastener too small for handling

E--> Fastener too large for handling

13. Excessive material:

A--> Excessive material not formed.

Excessive material formed

B--> Rivet pin to be discarded

Chips formed

Chipping not a problem because

C--> Chip is negligible

D--> Chip is out of way. Through hole

E--> Chips must be removed

14. Work material deformation:

A--> Work not deformed

Work deformed

B--> Temporary

Permanent due to:

C--> Drilling

D--> Melting

E--> Piercing

15. Fastener deformation:

Fastener not deformed

A--> Reusable

B--> Not reusable

Fastener deformed

Temporary deformation

C--> Reusable

D--> Not reusable

E--> Permanent deformation

16. Disassembly:

A--> Frequent disassembly

B--> Rare disassembly

C--> Never disassemble

17. Work material and suitability:

A--> Fastener suitable for both plastics and metals

Only plastics. Corrosion and rust protective, electric conductivity

B--> soft

C--> Hard

Only metals. Use in high temp. or pressure environment

D--> Brittle

E--> soft

F--> Only composites

18. Fastener pickup:

A--> No pickup. Feed directly to the tooling

Pickup required. No direct feeding to the tools

B--> Suitable for vacuum pickup

C--> Magnetic pickup

D--> Facilitates gripping

19. Feeder selection:

A--> Magazines or bands to feed parts

B--> Vibratory bowl feeder

C--> Hopper feeder

20. Work preparation:

A--> Along with feeding , insertion, and fastening or an integral part of it

B--> Must be separated from the rest of operation

21. Second fastener selection:

A--> Not required. Fastening is completed by one fastener

Required like insert that need machine screw for joining

B--> Similar tooling and feed machines used

C--> Different tooling and feed machines used

6.3 FSFA coding system

To obtain a code, simply pick a fastener, review the outline and the flowcharts for the 21 major categories, (Figure 6.1) and determine the possibility of changing your selection or revising the design or work material for a more feasible assembly operation. For each fastener an identification code and a relative score is found by the FSFA. The code gives all the necessary information about the chosen assembly method and the involved elements.

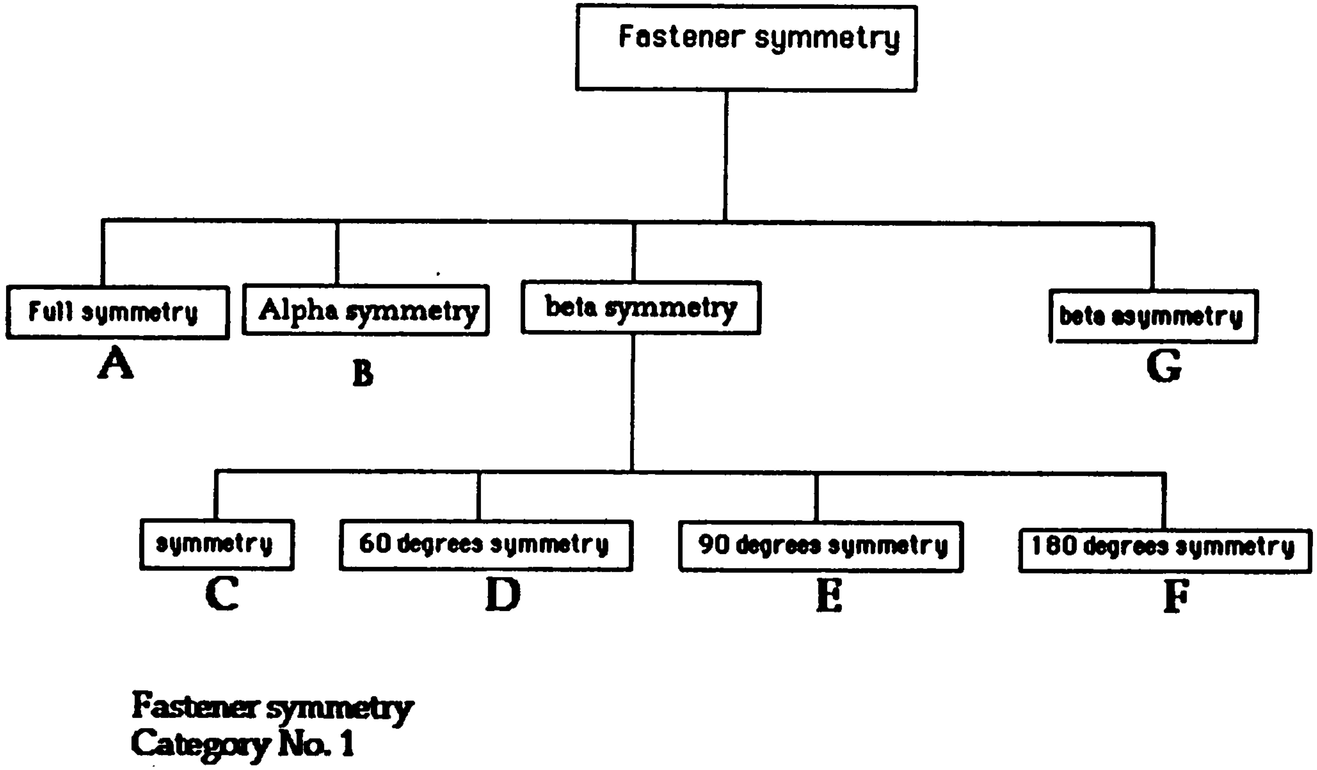


Figure 6.1. Major categories for FSFA.

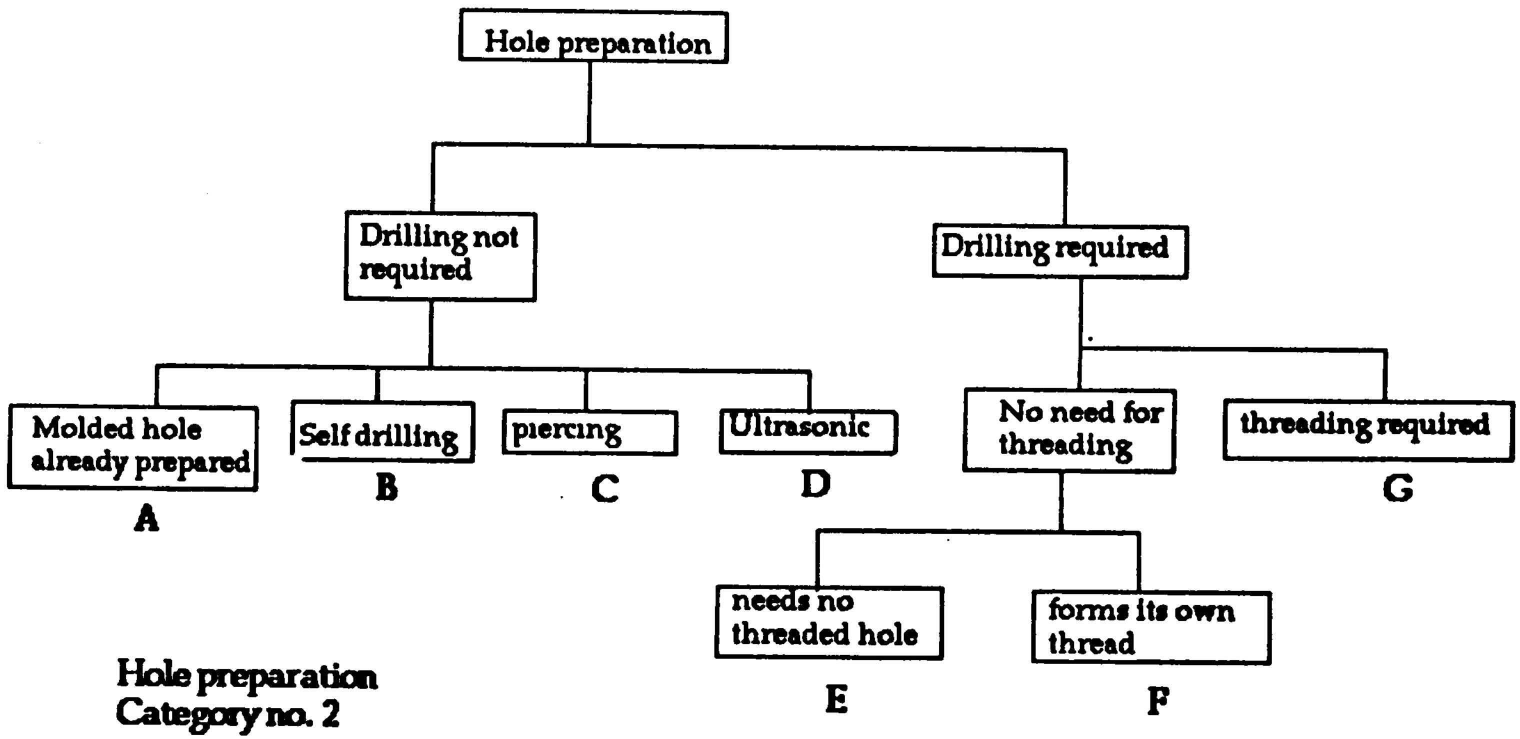


Figure 6.1. (Continued)

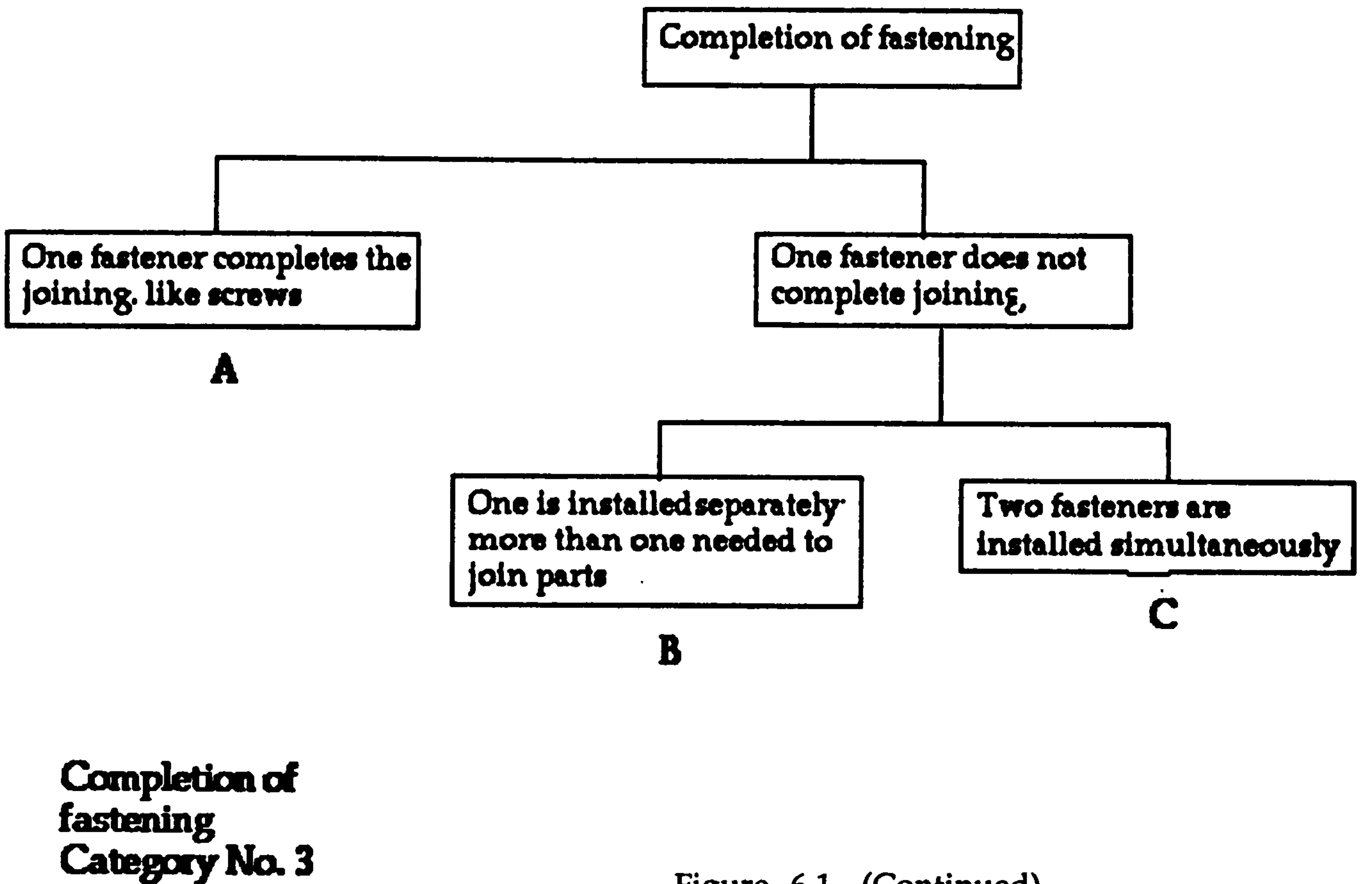


Figure 6.1. (Continued)

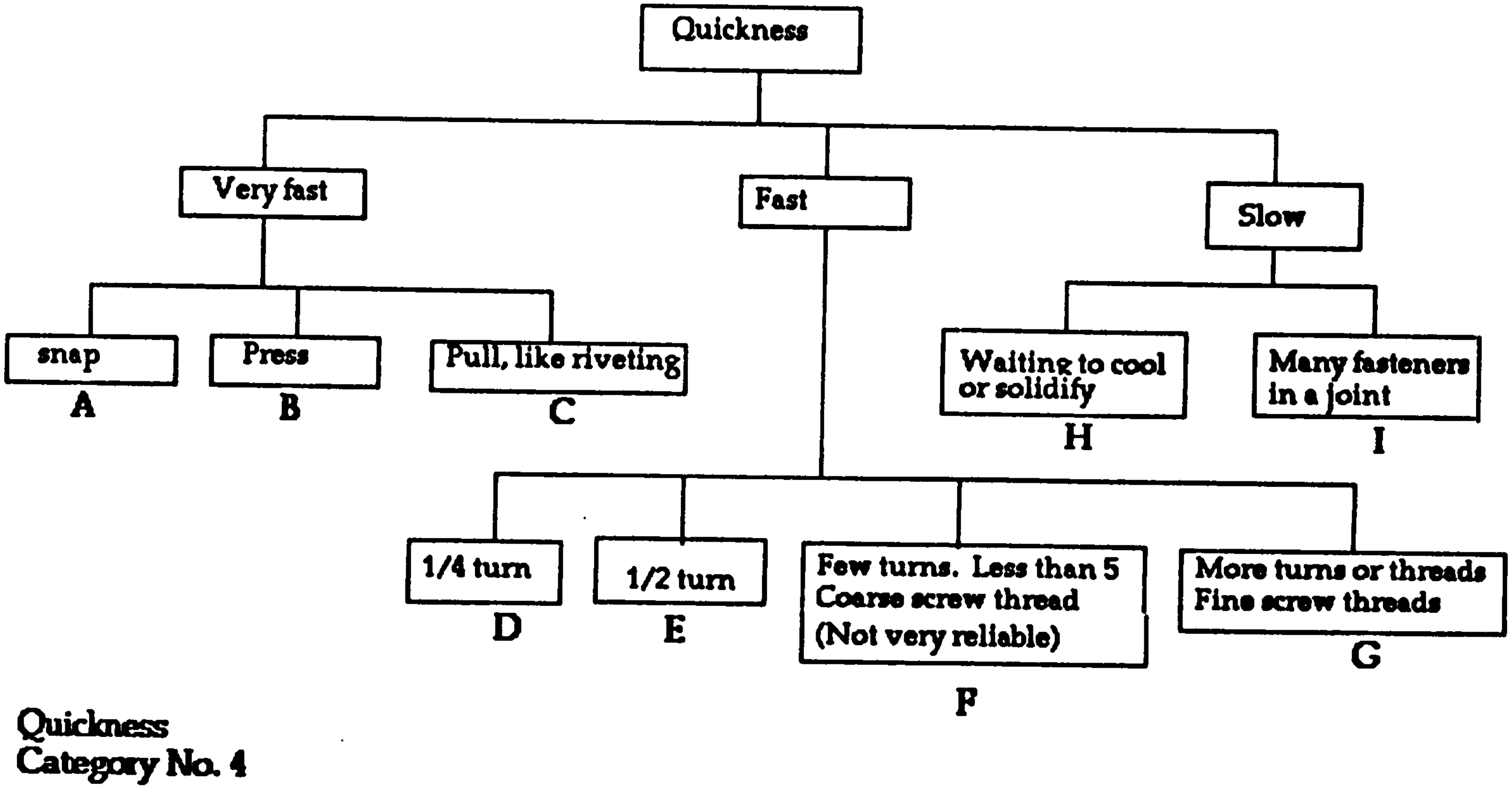


Figure 6.1. (Continued)

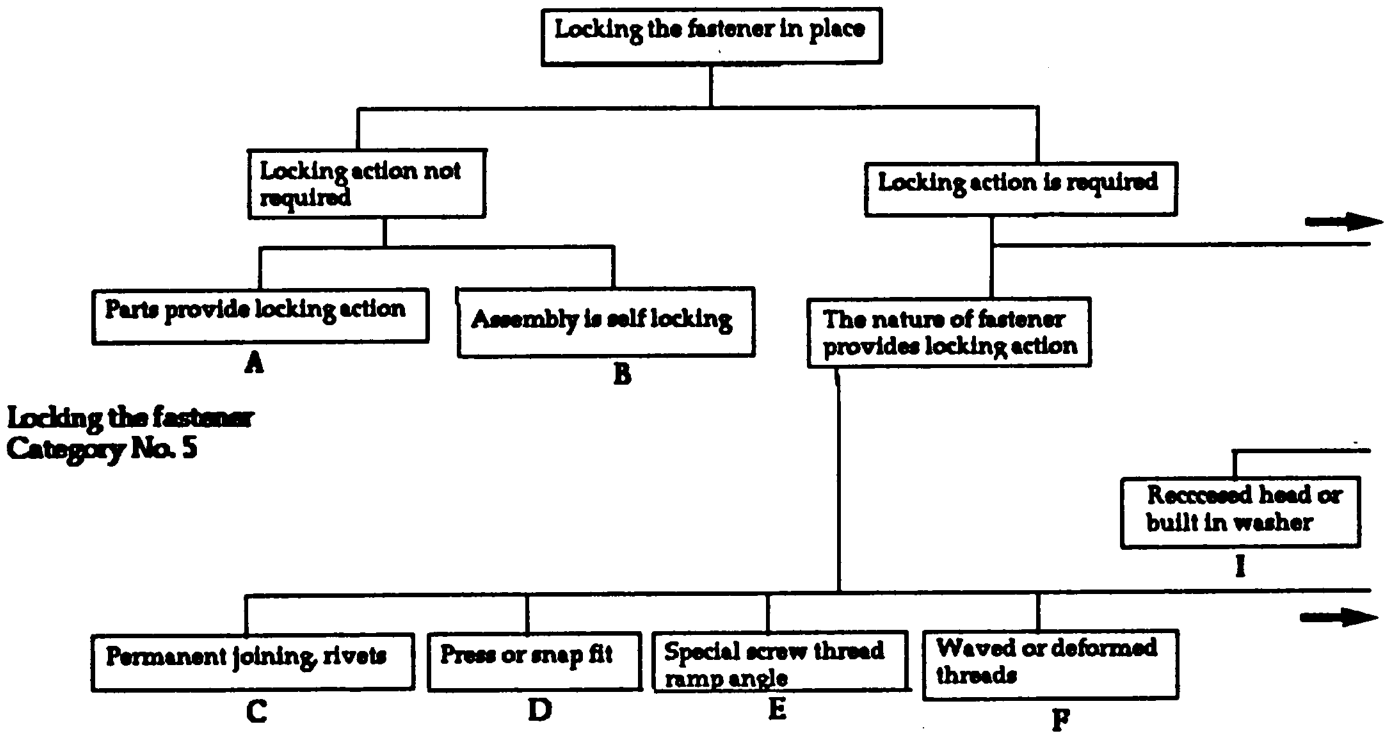


Figure 6.1. (Continued)

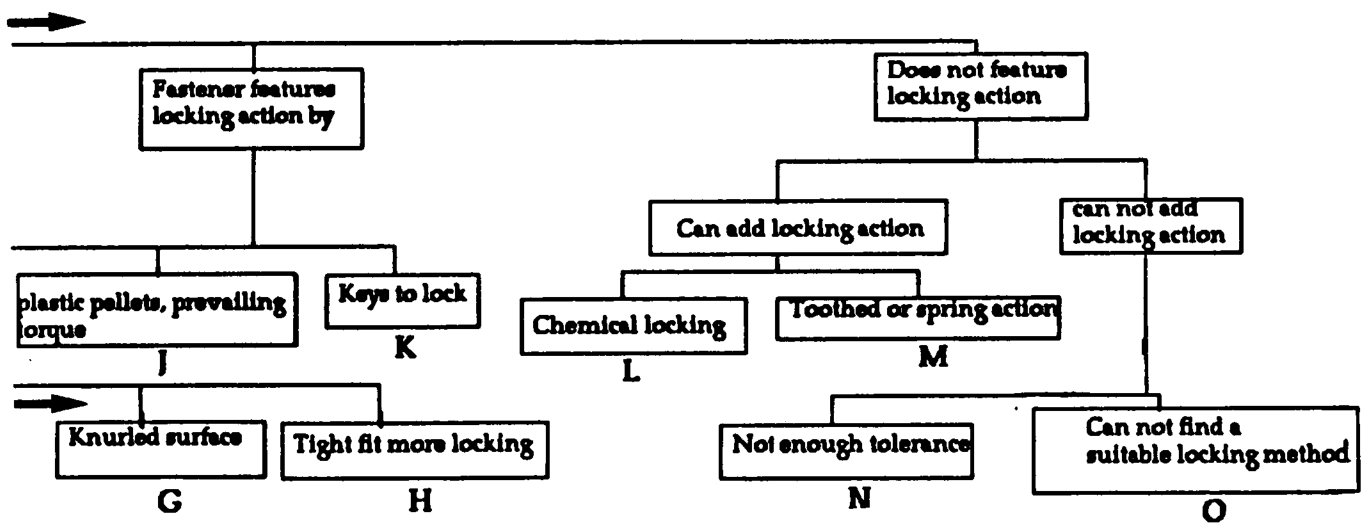
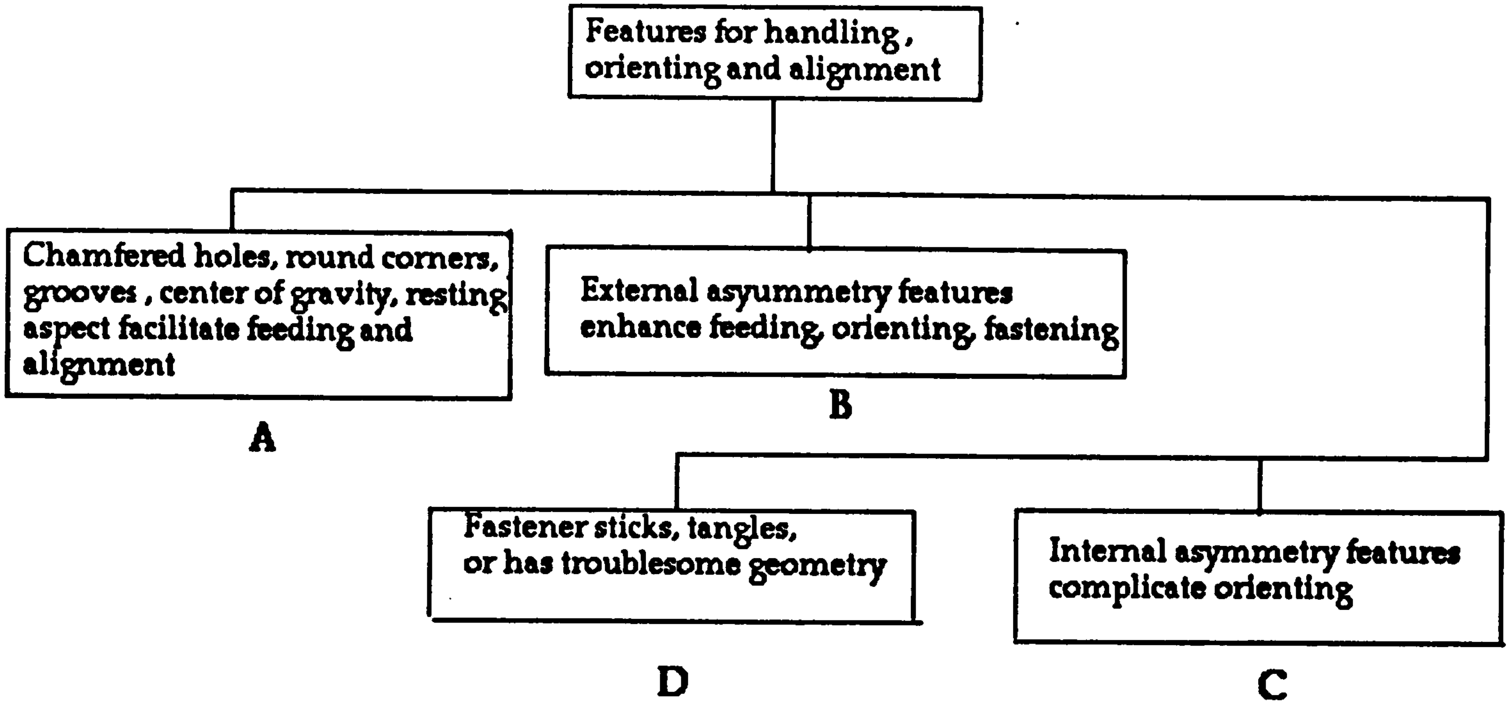


Figure 6.1. (Continued)



Features for feeding orienting and alignment Category No. 6

Figure 6.1. (Continued)

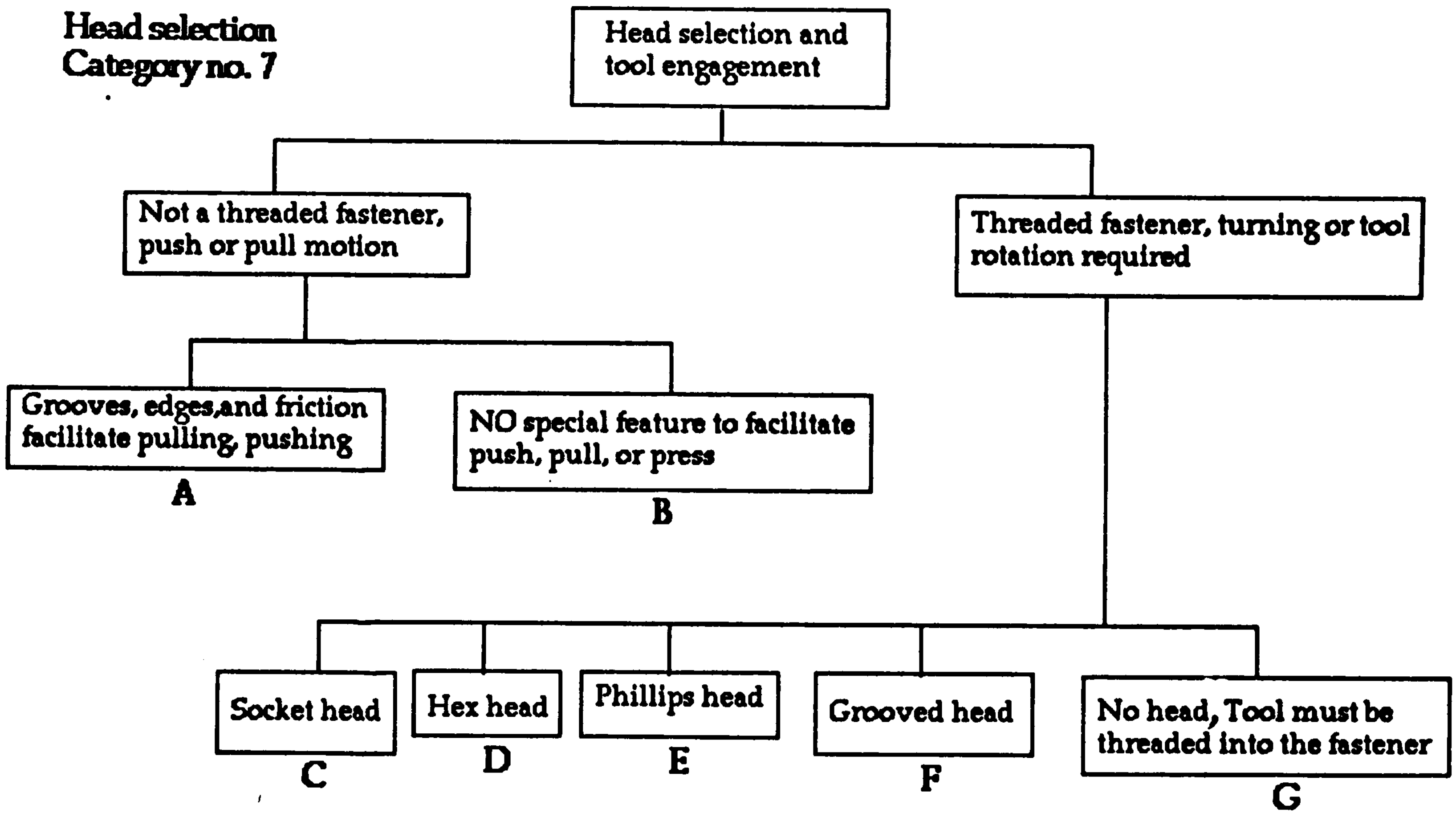
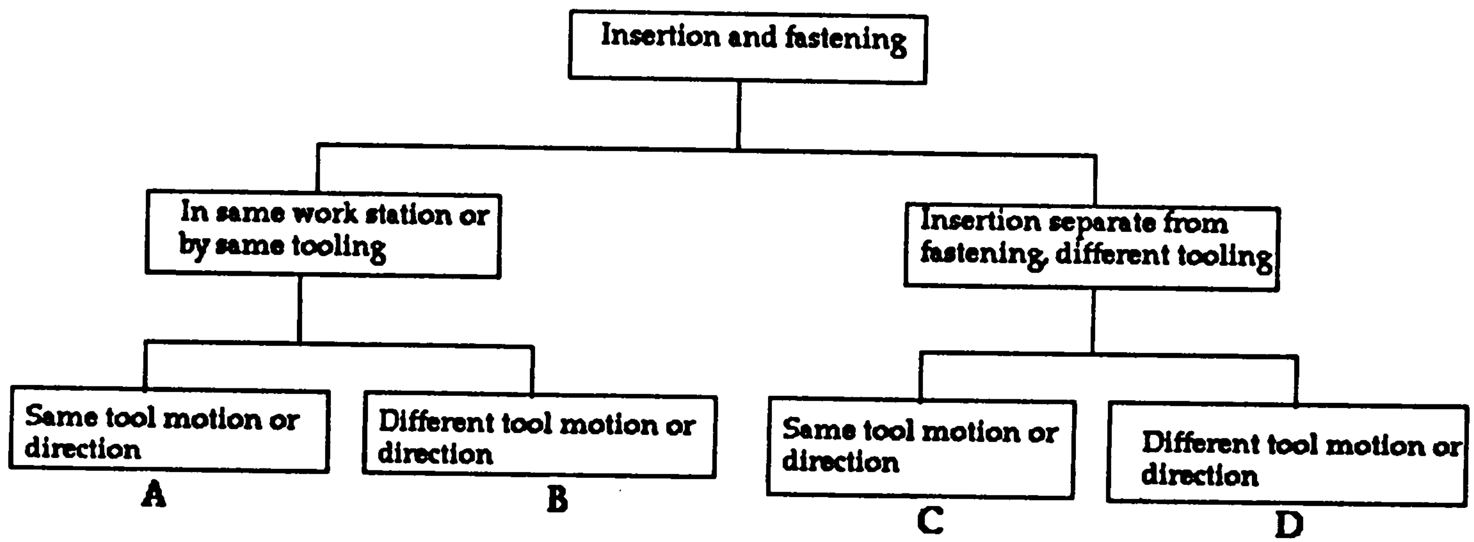


Figure 6.1. (Continued)



Insertion and fastening
Category No. 8

Figure 6.1. (Continued)

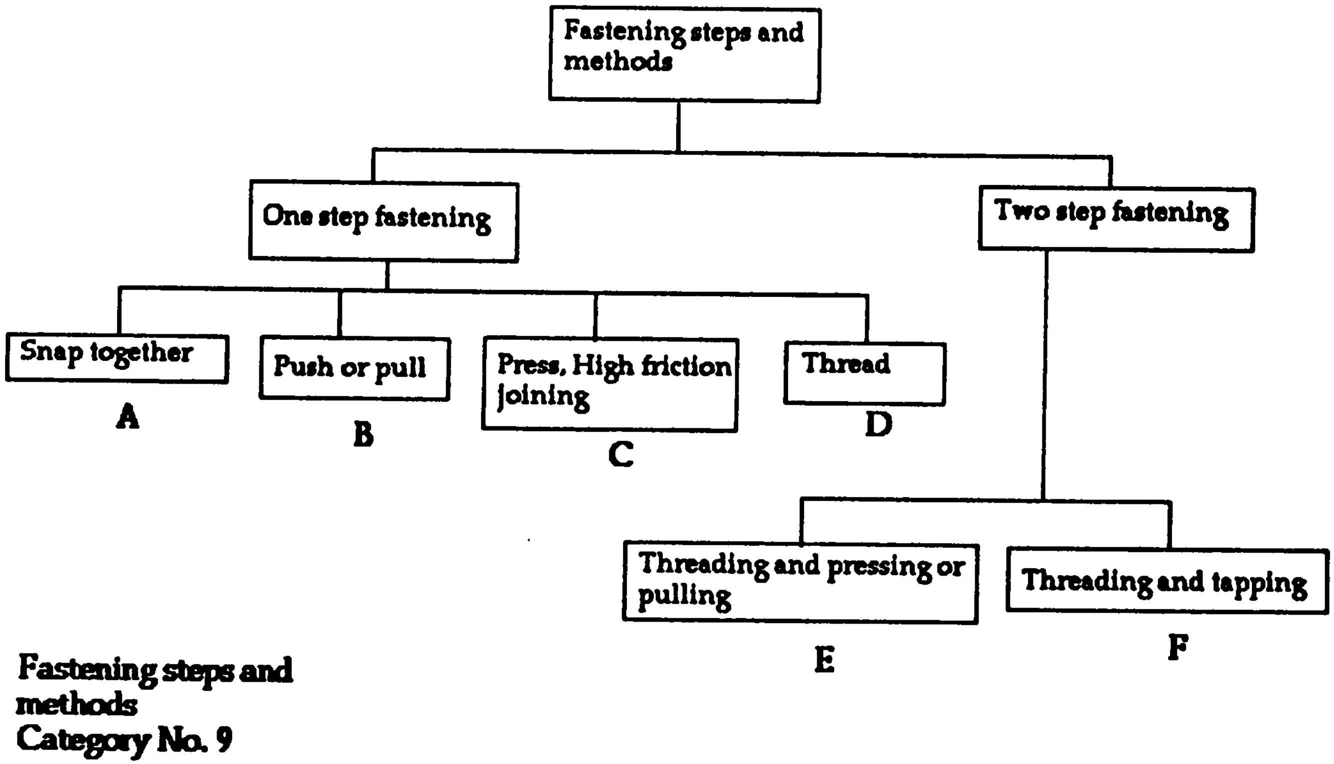


Figure 6.1. (Continued)

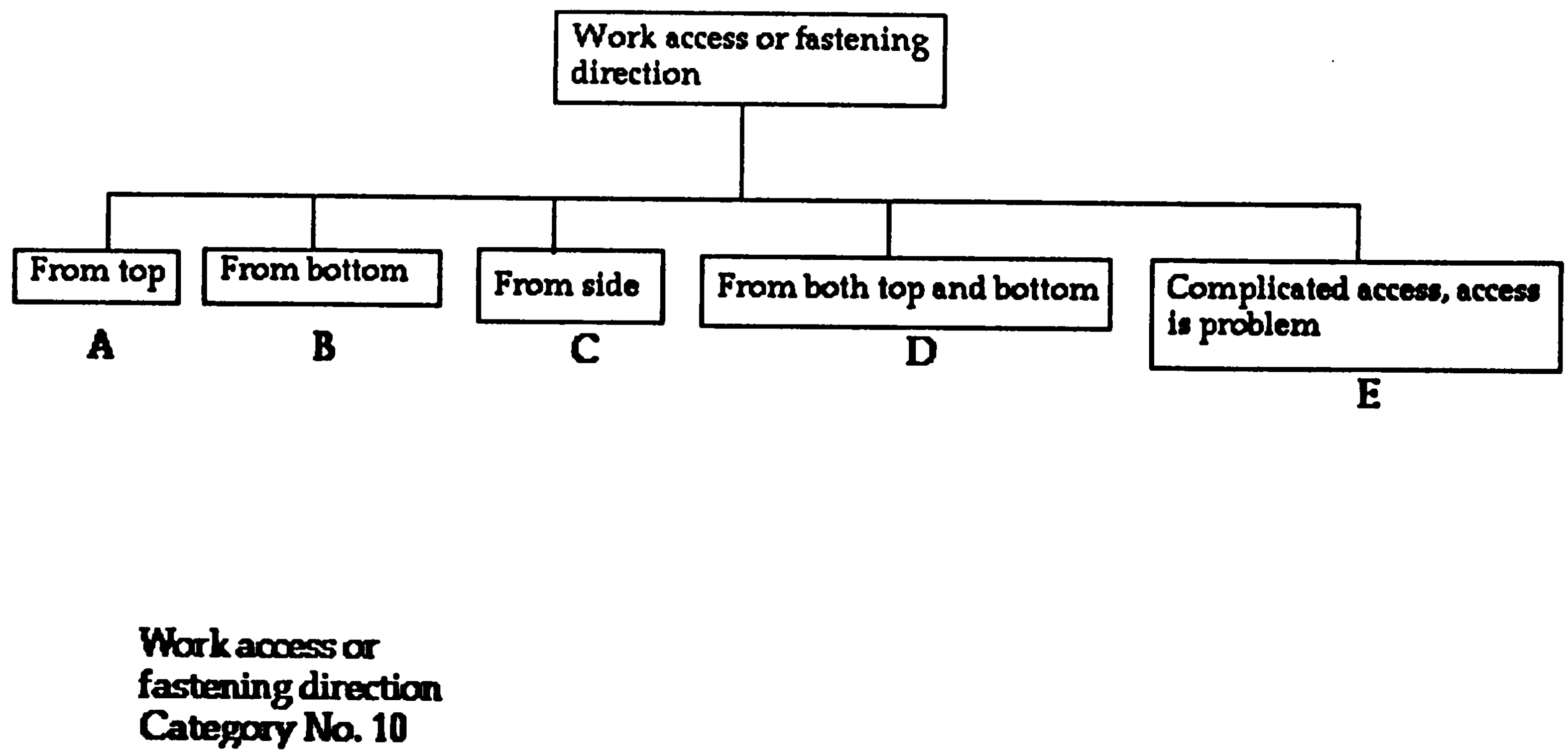


Figure 6.1. (Continued)

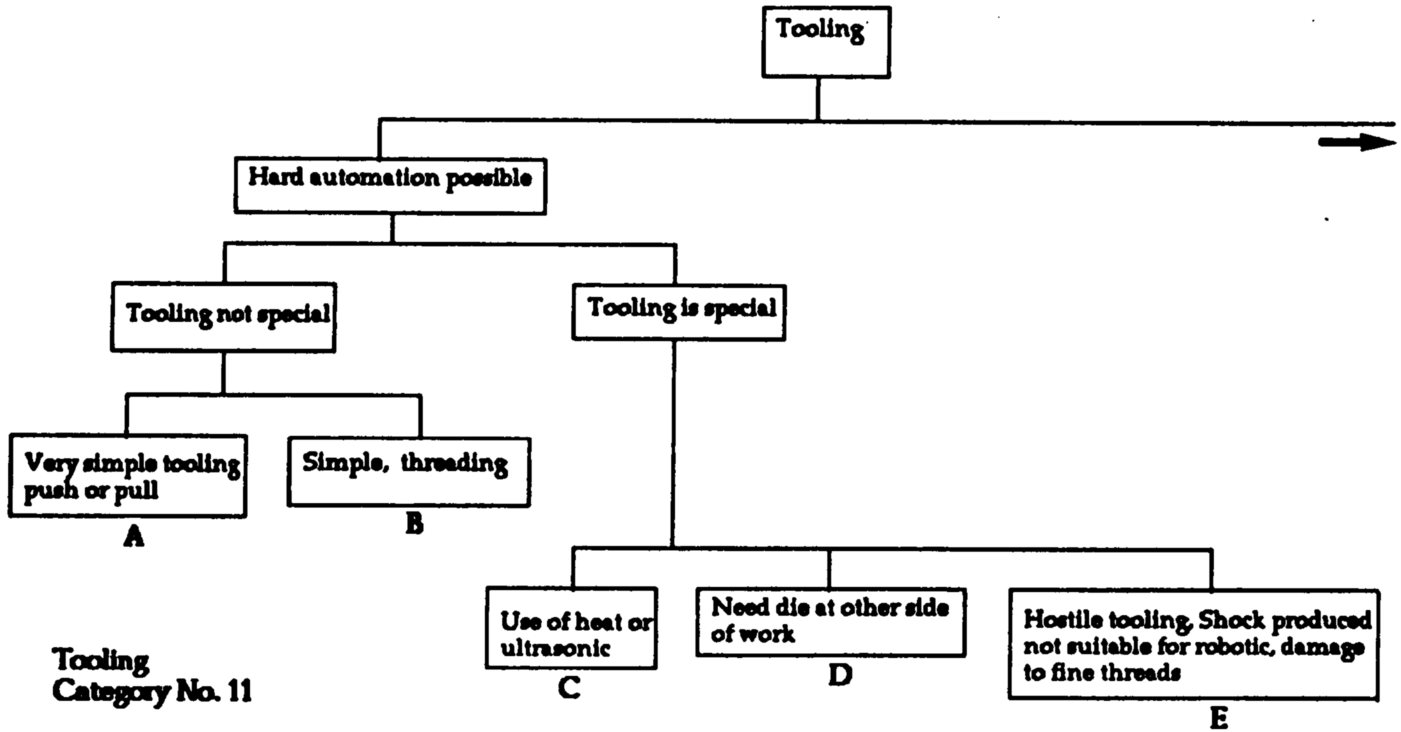


Figure 6.1. (Continued)

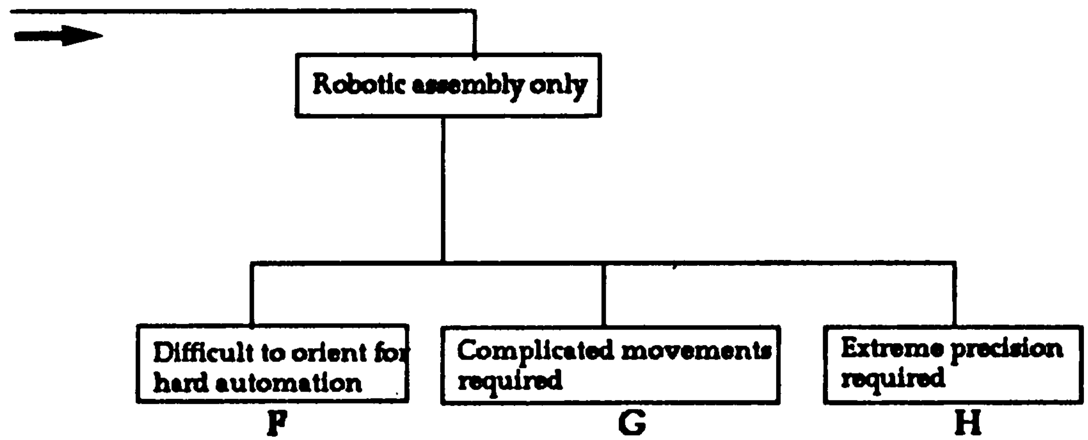
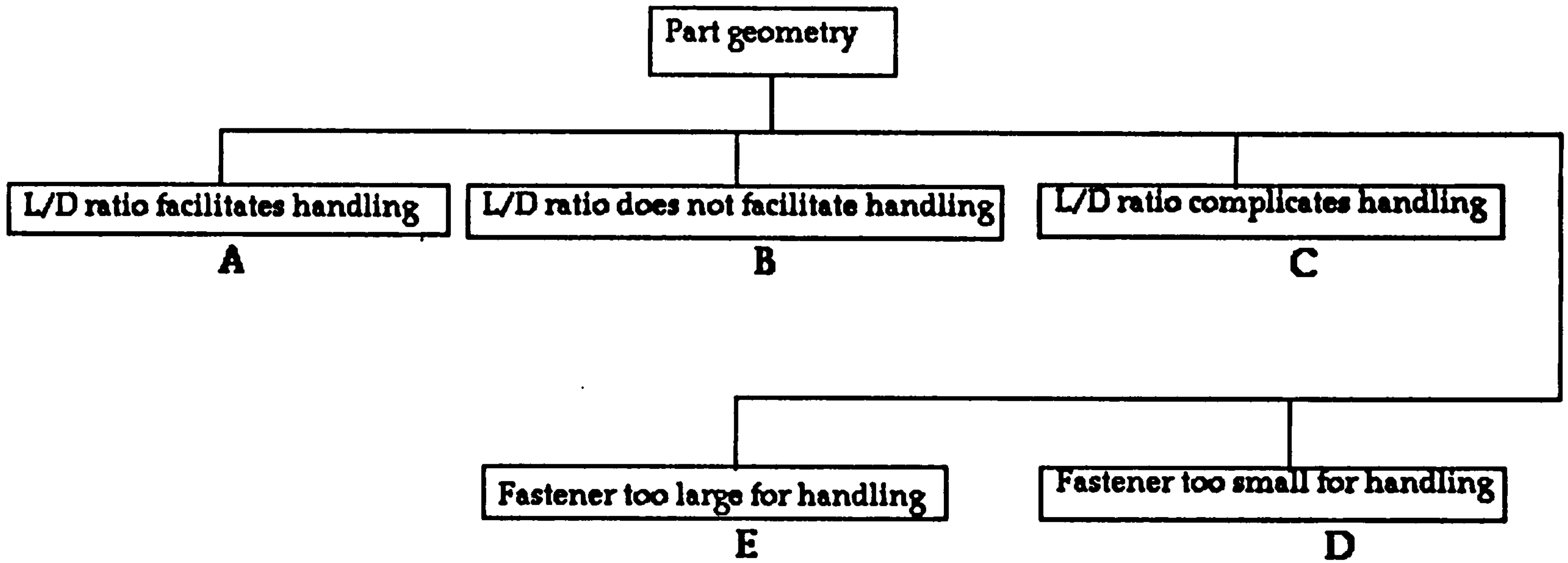


Figure 6.1. (Continued)



Part geometry
Category No. 12

Figure 6.1. (Continued)

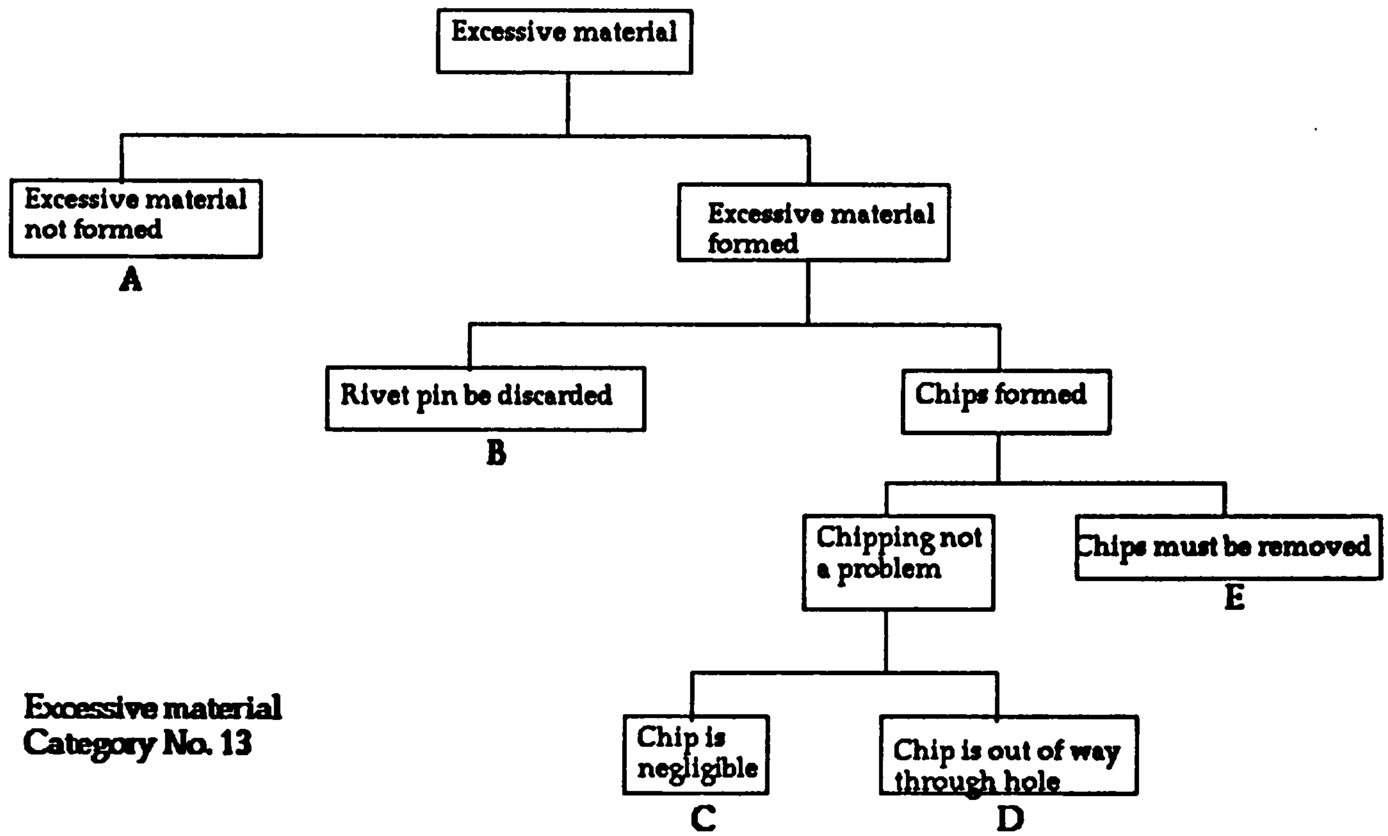
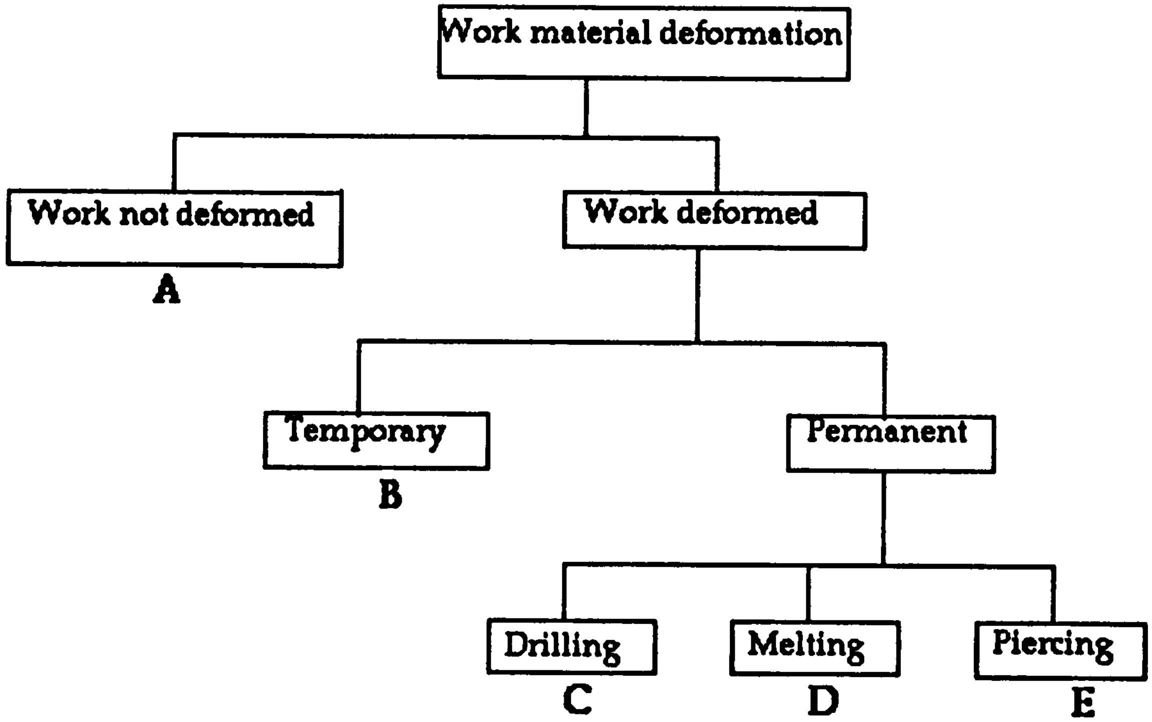
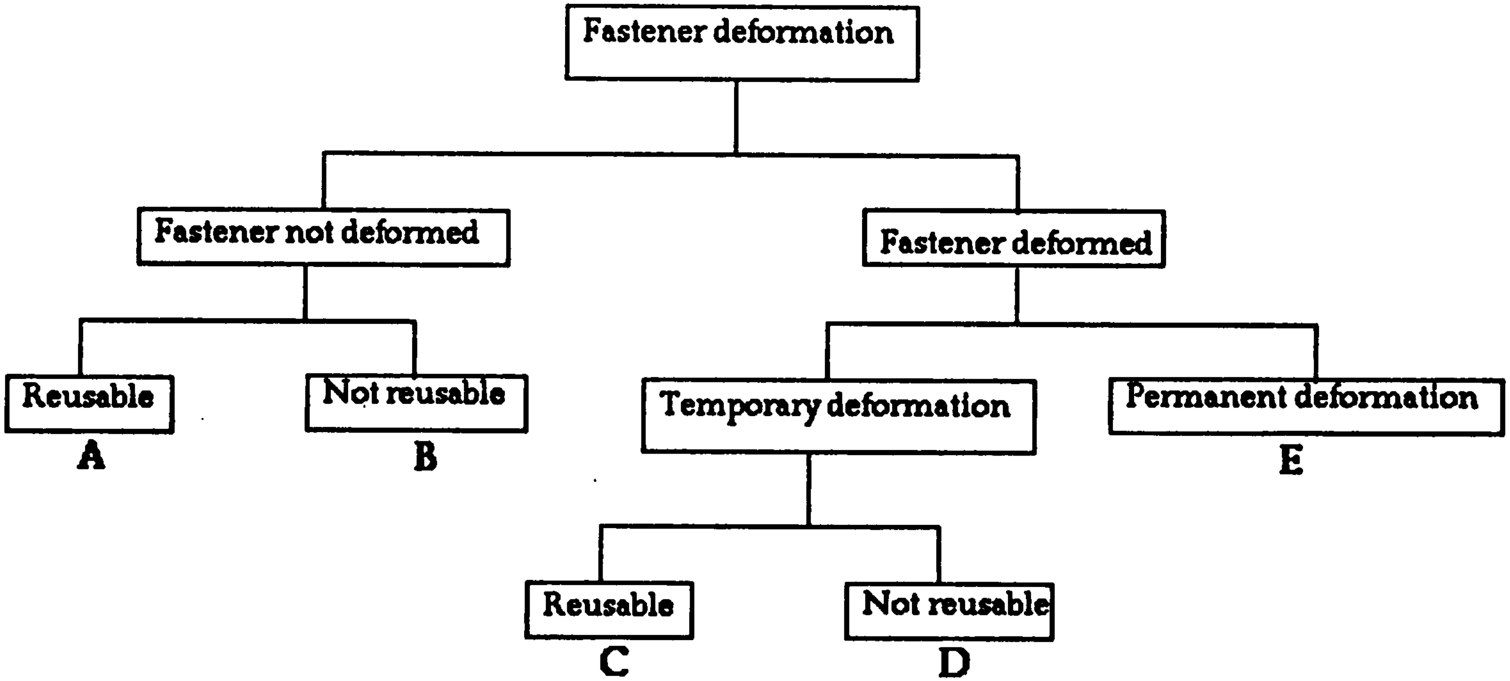


Figure 6.1. (Continued)



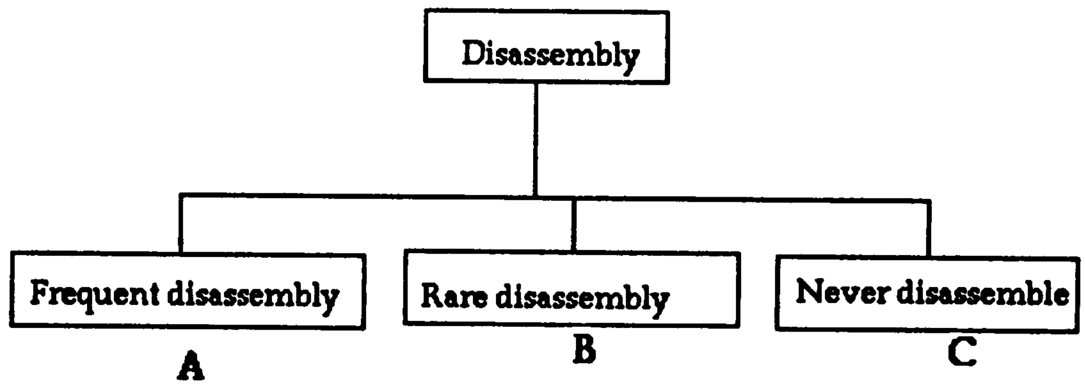
Work material deformation Category No. 14

Figure 6.1. (Continued)



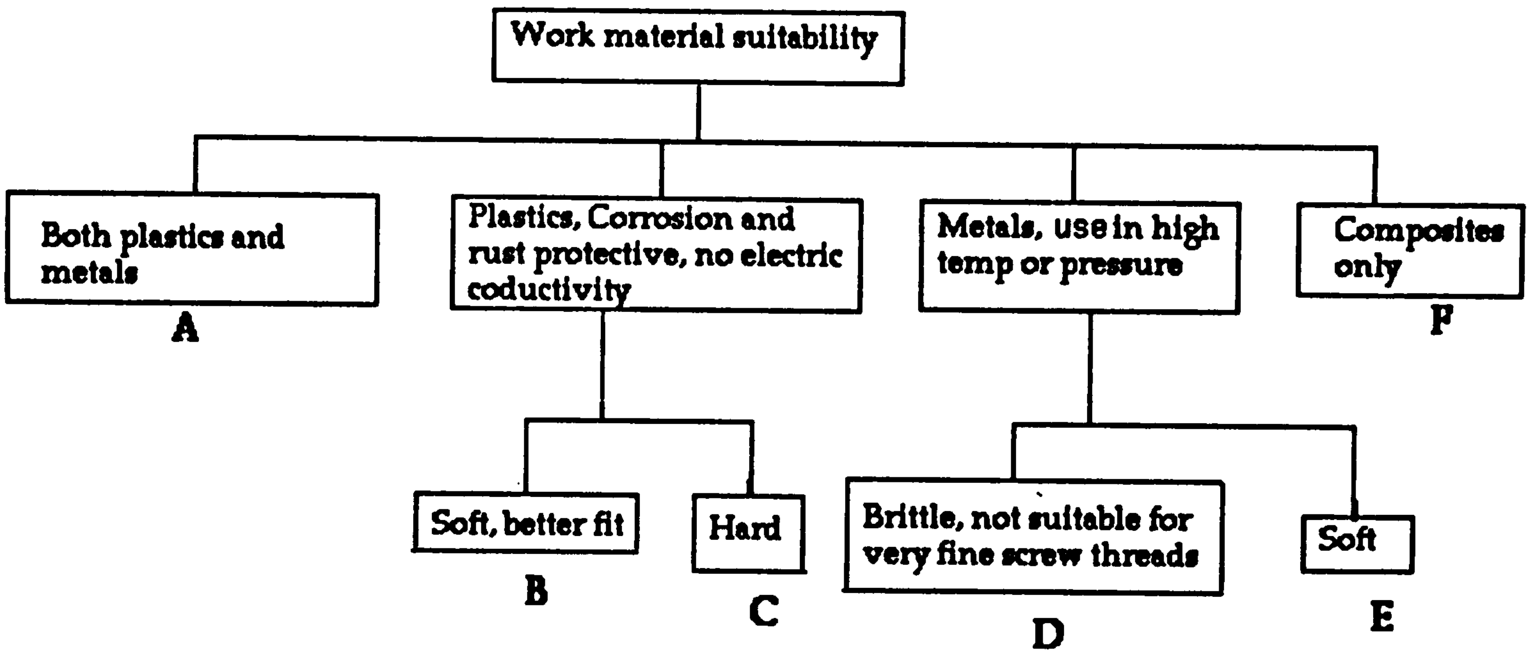
Fastener deformation
Category No. 15

Figure 6.1. (Continued)



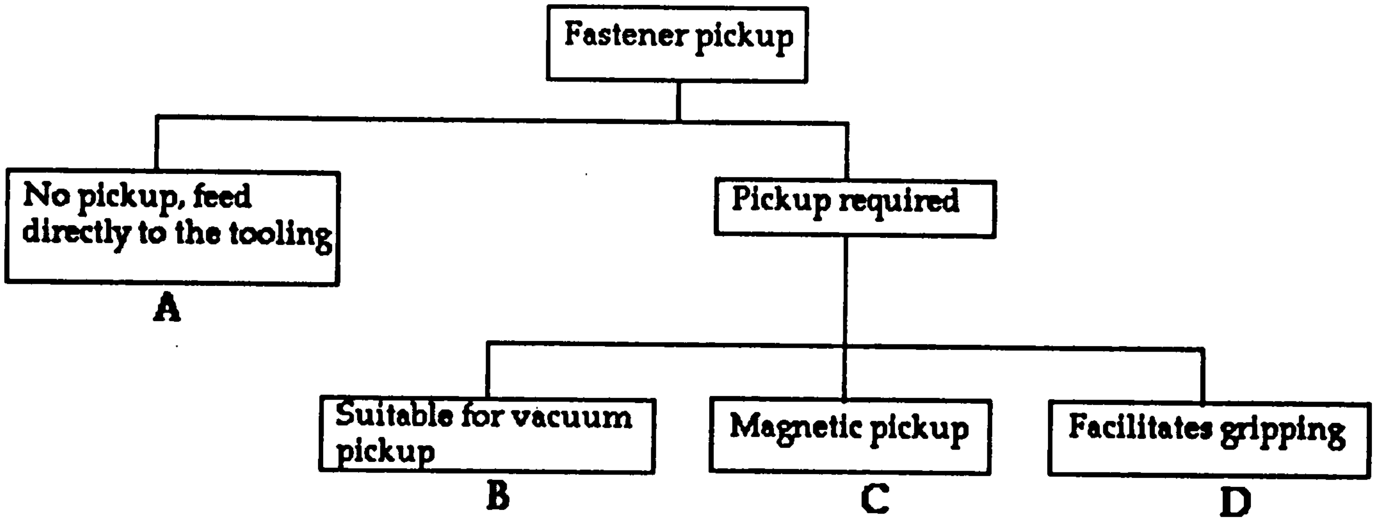
Disassembly
Category No. 16

Figure 6.1. (Continued)



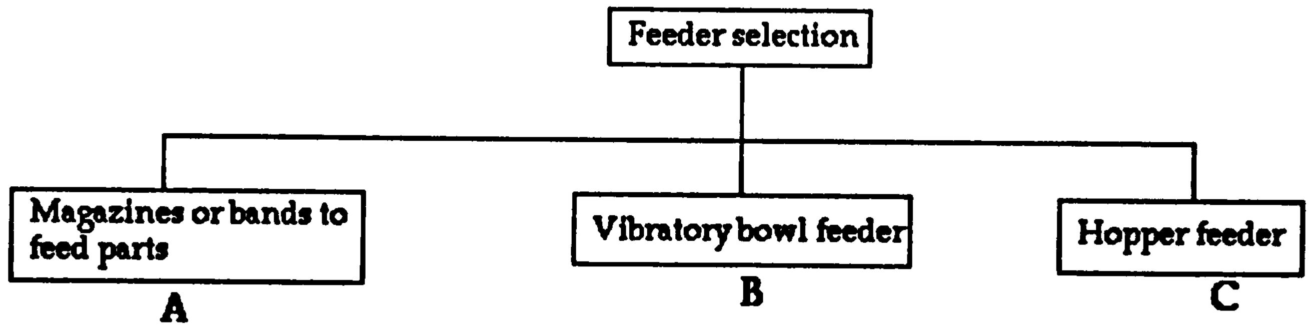
Work material and suitability
Category No. 17

Figure 6.1. (Continued)



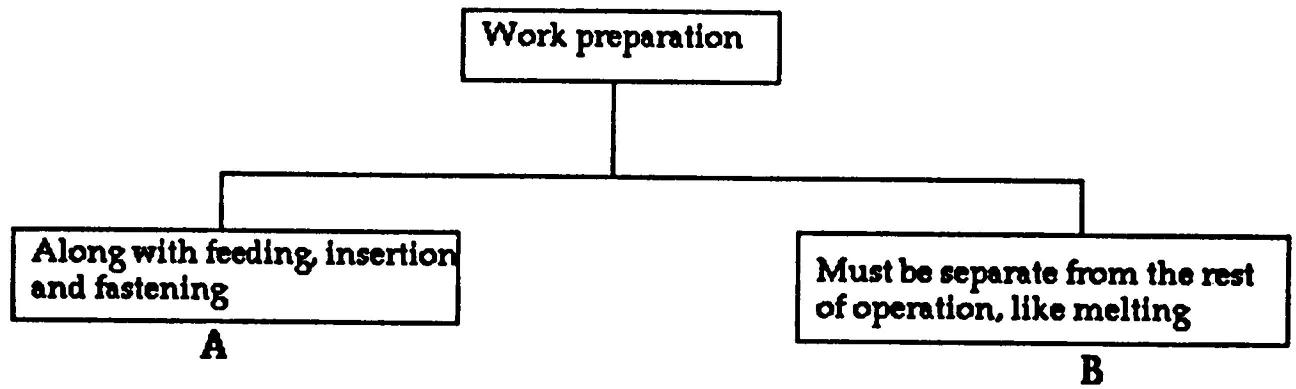
Fastener pickup
Category No. 18

Figure 6.1. (Continued)



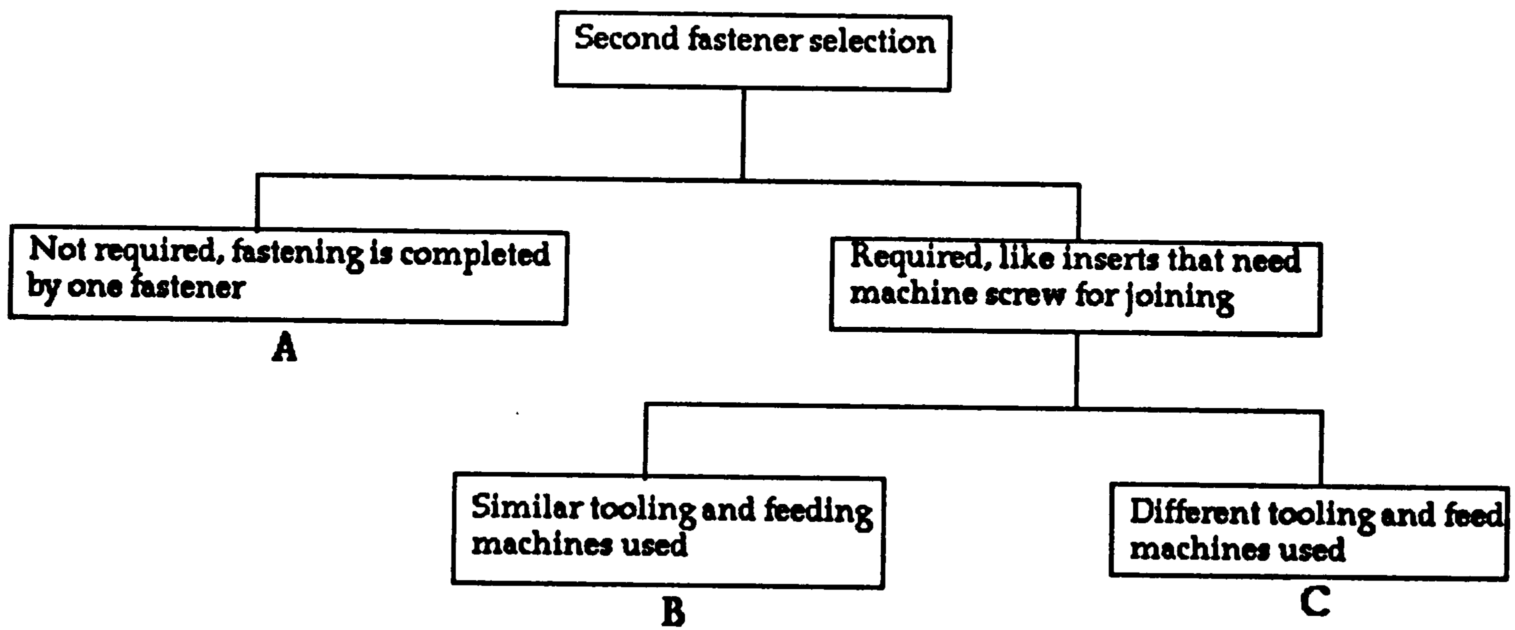
Feeder selection
Category No. 19

Figure 6.1. (Continued)



Work preparation
Category No. 20

Figure 6.1. (Continued)



Second fastener selection
Category No. 21

Figure 6.1. (Continued)

To demonstrate the use of FSFA, a "Self drilling screw" is picked and the 21 major categories are analyzed:

code 1C for beta symmetry

code 2B for self drilling

code 3A for one fastener joins the parts

code 4F for few turns needed to fasten

code 5E special screw thread ramp angle for locking action

code 6A center of gravity will help handling

code 7E phillips screw head

code 8A assembly from one side

code 9D threading

code 10A work access from top

code 11B simple tooling required

code 12A L/d ratio facilitates handling

code 13E chips must be removed after the completion of assembly

code 14C work material is deformed due to drilling

code 15A fastener is not deformed and can be reused

code 16B rare disassembly

code 17A Suitable for both plastics and soft metals

code 18A fastener can be feed directly to the tooling

code 19b vibratory feeder are used to feed

code 20A work is prepared along with feeding, insertion, and assembly

code 21A joining does not require another fastener

The final code for a self drilling screw with the above characteristics is:

1C2C3A4F5E6C7E8A9D10A11B12A13E14C15A16C17B18A19B20A21A

If the numbers are eliminated, the code will be as:

CCAFECEADABAECACBABAA

6.4 Points

To further improve the coding system, points are assigned to each grade. The letter grade "A" has the highest point of 10.0 , while the other letter grades are equally incremented and are less than 10.0 The increments are determined after dividing 10 by the quantity of the letter grades in each category. The following example demonstrates the pointing procedure:

The first category for "Fastener symmetry" has a total number of 7 grades from "A" to "G". Knowing that the point value for "A" is 10, the increment is found after dividing 10 by the number of grades.

In first category:

The increment is: 10./7.=1.43

The point value for "A" = 10.0, "B" = 8.57, "C" = 7.14, "D" = 5.71, "E" = 4.29, "F" = 2.86, "G" = 1.43

6.5 Importance Factor

Each category is assigned a multiplier called the Importance Factor. This Factor increases the effect of the some critical issues on fastener selection. For instance, the role of "Fastener symmetry" is far more essential than the role of "Work material deformation", therefore its involvement in giving a correct score must be emphasized.

Importance Factor can be changed according to the needs and the type of assembly systems. Author defines three major groups as "Extremely important", "Very Important", and "Important", where each is assigned the factor of 3.0, 2.0, 1.0 respectively.

Importance Factor of 3.0 for:

Category #1: Fastener Symmetry

#2: Hole preparation

#3: Completion of fastening

#4: Quickness

#5: Locking the fastener

#7: Head selection and tool engagement

#9: Fastening steps and methods

#10: Work access or fastening direction

#21: Second fastener selection

Importance Factor of 2.0 for:

Category #6: Features for orienting and alignment

#8: Insertion and fastening

#11: Tooling

#12: Part geometry

#13: Excessive material

#16: Disassembly

Importance Factor of 1.0 for:

Category #14: Work material deformation

#15: Fastener deformation

#17: Material suitability

#18:Fastener pickup

#19: Feeder selection

#20: Work preparation

After the grades for different categories are determined and the points are assigned, the Importance Factor is multiplied by the points and the results are added to get the final score for the fastener. For instance, by analyzing the self drilling screw, a grade of "C" is assigned to the "Fastener symmetry" section. Multiplying the Importance Factor of 3.0 by the point value of 7.14:

Adjusted point= 7.14 x 3.0 --> 21.42

After adding all the points, the score for the self drilling screw is calculated as: 348.

6.6 Test data for selected fasteners

To prove the accuracy of the FSFA , a number of selected fasteners from different major groups were analyzed and the results were compared. A user friendly computer code, written in BASIC language, aides the selection process by providing speed, accuracy, and flexibility. Every time a fastener is analyzed, the data are recorded in a file which can be retrieved or revised. Importance Factor and grades can be changed or modified in order to fit the requirements of different fastening systems. The stored data can be used by other designers as a library of information for coding and scoring purposes. The listing and the run of the program are included in the Appendix (C). The calculated scores for selected fasteners are shown below, for comparison.

Snap ins

Code: CAAADAAAAAAAAAAACAAAA

Score: 432

Self drilling screw :

Code:CBAFEAEADABAECABAABAA

Score: 348

Tapping screw:

Code: CFAGLAEADABAECABAABAA

Score: 313

Machine Screw:

Code: CGAGLAEADABAECAAEABAA

Score: 309

Hex bolt:

Code: CECGLADADABADCAADABAC

Score: 288

Carriage bolt

Code: CECGLAGADABADCAADABAC

Score: 271

Drive pin Rivet

Code:CEACCAAABAAAAAECDAAAA

Score: 382

Compression rivet

Code:CCABCAAACAAAAEECCAAAA

Score: 383

Pull through rivet

Code: CEACCAABBAAABCECDAAAA

Score: 369

Press in insert

Code: CEBBGAAACAABDEBCBABAC

Score: 325

Self drilling insert

Code: CFBFFAGADABBECBBAABAC

Score: 284

Key insert

Code:CGBGKDGAFABBDCAAEABAC

Score: 248

The above data is graphically illustrated as bar chart (Figure 6.2). Sources for fastener drawings are included in chapter 5, under the corresponding sections.

The codes and the scores provide valuable information to the designer who is searching for a suitable joining method. Chapters 3, 4 and specially 5 analyze in depth the path taken to develop and construct the FSFA. It is very important to remember that fasteners are only partially effecting the code and the final score. Designer's choice on ways to handle, assemble, or add extra features to the fastening operation plays a crucial role for obtaining the final results.

By studying the data listed above, it is obvious that Snap ins have the highest score since they are eliminating or facilitating various assembly and fastening steps. These fasteners also feature better design for assembly and easier handling and orienting characteristics. Self drilling screw and self drilling insert score relatively higher than other members of their groups. Obviously this is due to the elimination of hole preparation and other major issues. Key inserts score lower than other fasteners since the tapping of the keys is an additional step for assembly. These inserts also feature fine screw threads which are undesirable in the fast pace of automation. Press in inserts have a high score because of their simple installation and hole preparation. Even though some inserts received relatively better grades, it is

Comparison chart for the FSFA scores of selected fasteners

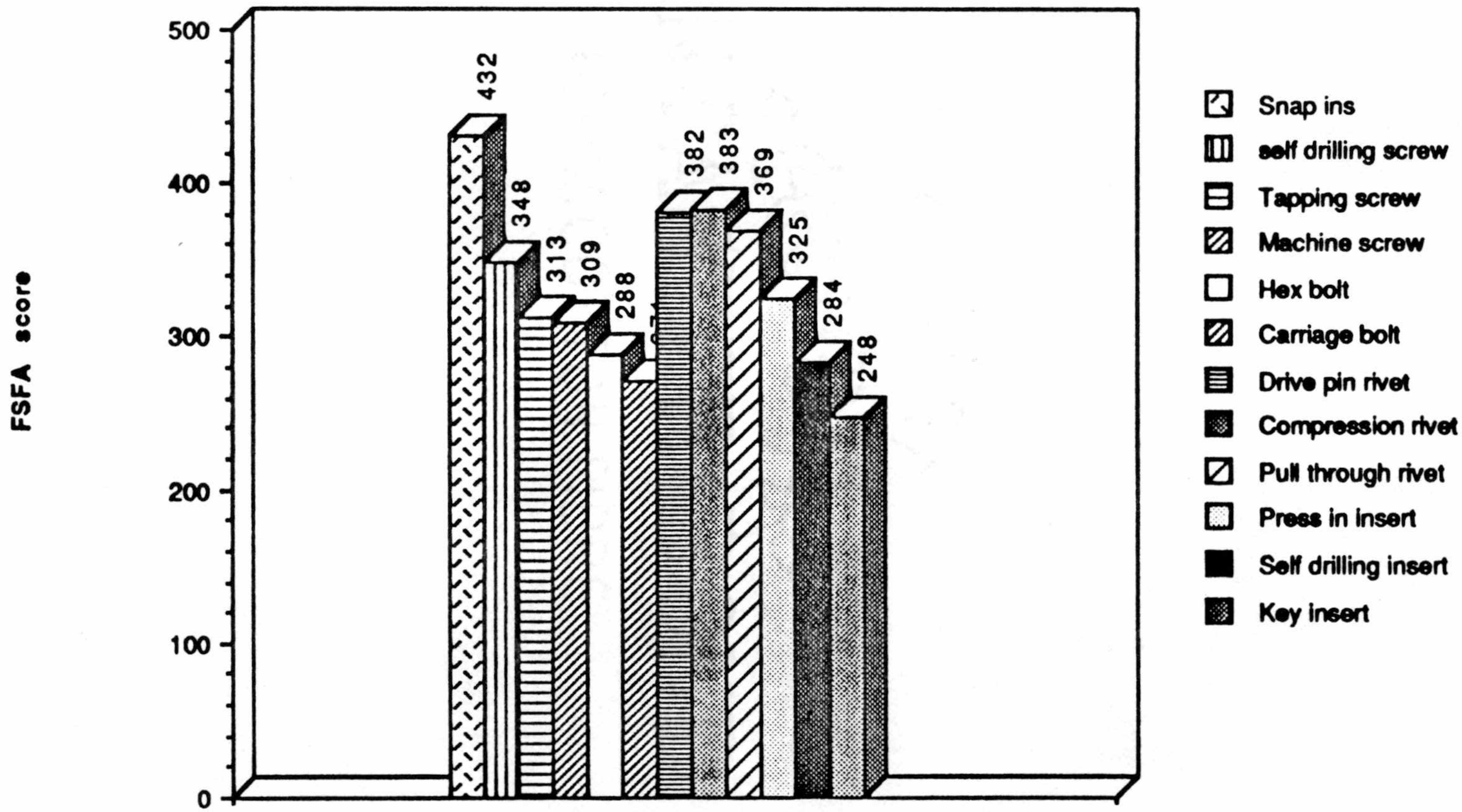


Figure 6.2. Comparison chart for selected fasteners.

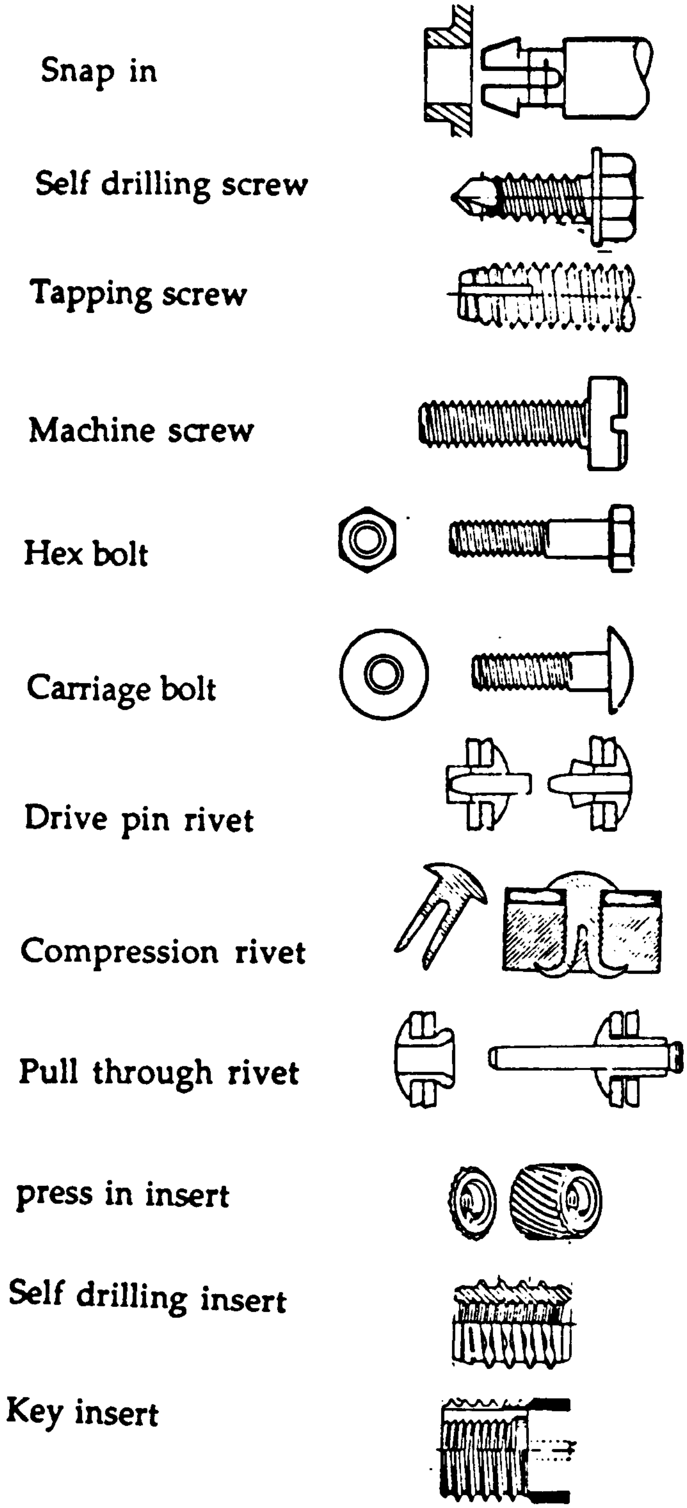


Figure 6.2. (Continued)

Comparison chart for the FSFA score of screws and bolts

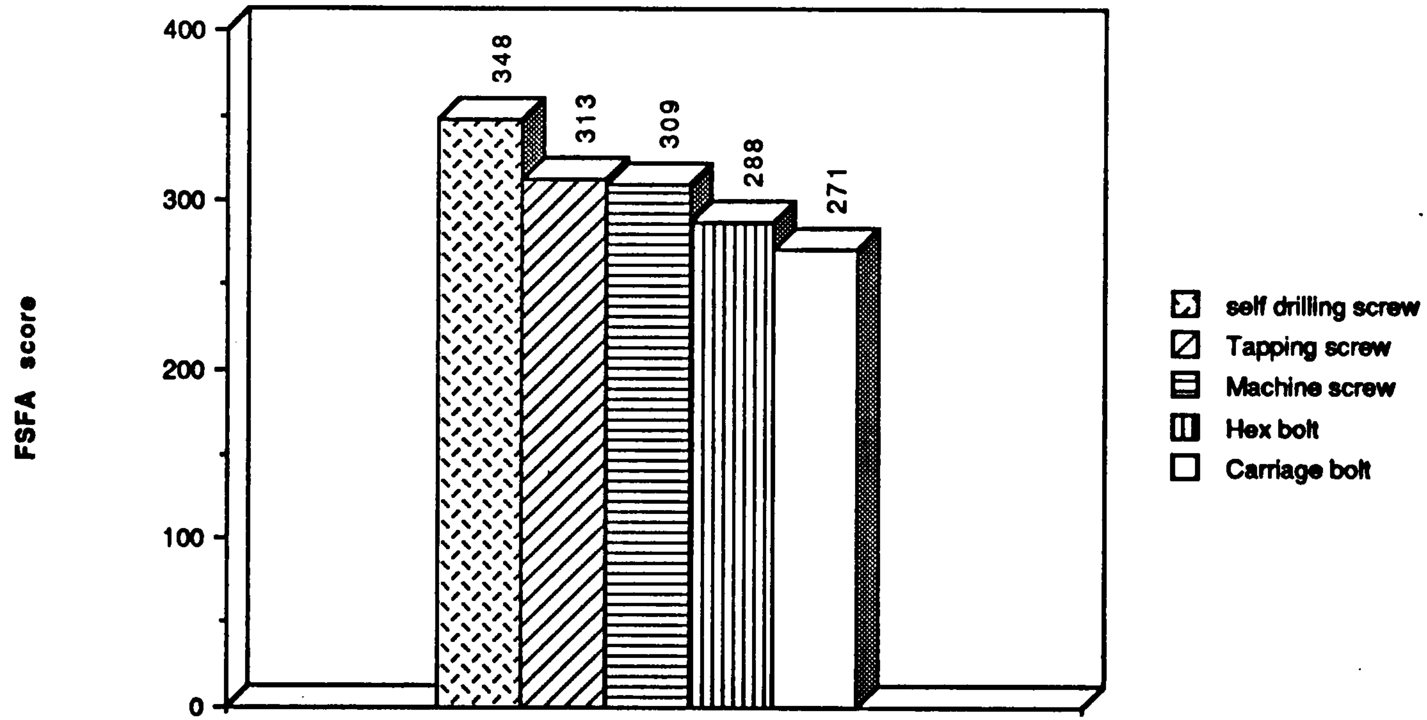


Figure 6.2. (Continued)

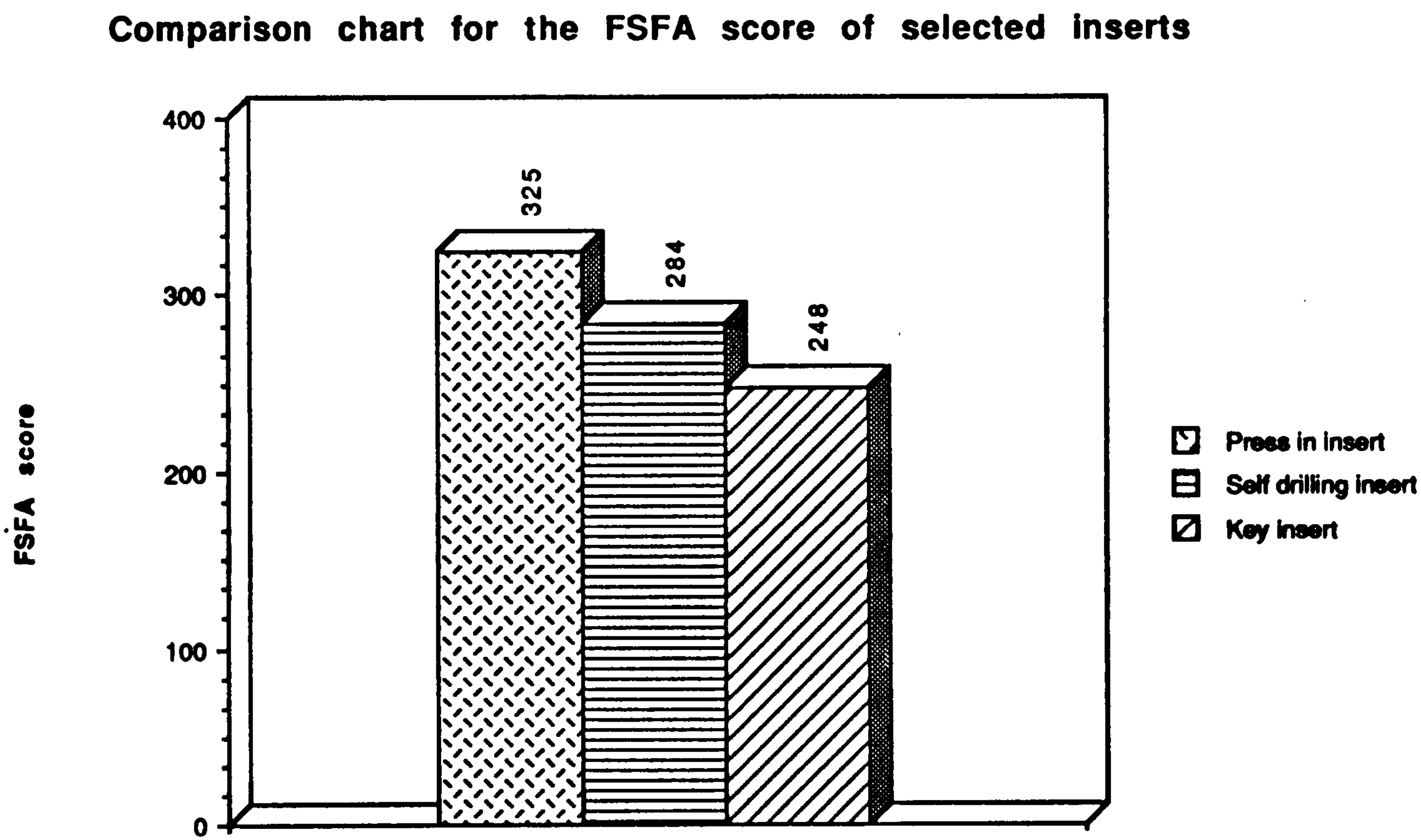


Figure 6.2. (Continued)

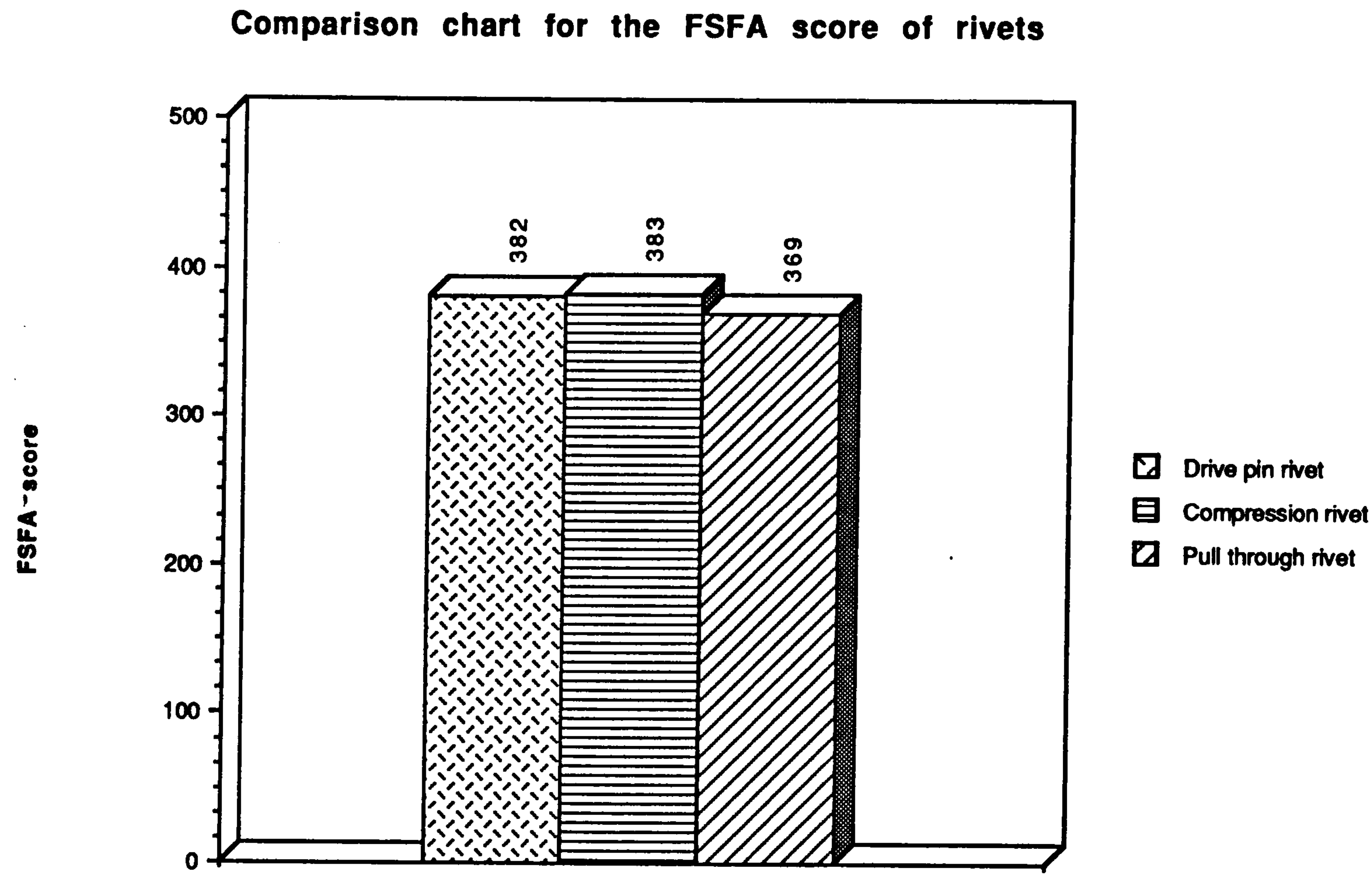


Figure 6.2. (Continued)

important to recognize the fact that inserts must be paired with another fasteners in order to complete the joining process.

A hex bolt is prefered to a carriage bolt as it features better tool engagement and handling characteristic. Bolts scored less than screws and rivets since they require two hand assembly or more than one AFM. The drive pin rivet is more suitable for automation than other two members of its group. The simple and uniform motion of the riveter eases fastening and installation sequence.

Finally, the author believes that the best method to improve assembly is either eliminate it all together or to design fasteners and automatic joining methods which have the FSFA code of:
AAAAAAAAAAAAAAAAAAAAA.

6.7 Future work

First, plastics are finding their way into the construction of many electronic or mechanical assemblies. One piece molded parts which feature hinges, latches, and cantilevers eliminate major steps in assembly. The author believes that, improvements in the design of snap ins and molded plastic parts will provide important results on enhancing the efficiency of fastening operations.

Second, development of computer software as a central command unit for controlling the fastening operation with the aid of FSFA is a valuable tool in designing fully automated assembly cells. The program not only controls the tool motion and the type of gripper, but also enables engineers to select or screen fasteners during the initial design stages.

LIST OF REFERENCES

LIST OF REFERENCES

[1] Lee, G., "Tips on selecting fasteners for plastics," Assembly Engineering, pp. 32-34, March, 1987.

[2] Boothroyd, G., Dewhurst, P. "Design For Assembly: selecting the right method," Machine Design, pp. 94-97, November, 1983.

[3] Wilson, C., Kennedy, M., "Some essential elements of superior product development," The University of Tennessee Mechanical Engineering, April, 1989.

[4] Boothroyd, G., Poli, C., and Murch, L. " Feeding and orienting techniques for small parts," Handbook, Department of Mechanical Engineering, University of Massachusetts 01002.

[5] Teicholz, E., Orr, J. "Computer Integrated Manufacturing handbook," Mcgraw hill, 1987.

[6] Yousofian, Z., "Effects of part symmetry on manual assembly times, "Journal of Manufacturing Systems, Volume 2, pp. 189-195.

[7] Watson, G., Theis, E., Janek, R., "Mechanical equipment Design For Simplicity," AT&T Technical Journal, pp. 14-27, May/June, 1990.

[8] Lane, J. D., "Automated Assembly," Society of Manufacturing Engineers, Dearborn, Michigan, 1986.

[9] Boothroyd, G., Dewhurst, P. "Design For Assembly: Automatic Assembly," Machine Design, pp. 87-92, January, 1984.

[10] Schuch, L., "DFA promises and delivers," Assembly engineering, pp. 18-21, May, 1989.

[11] Gatenby, D., Foo, G., "Design for X (DFX): Key to competitive, profitable products," AT &T Technical Journal, pp. 2-12, May 1990.

[12] Zorowski, C., "PDM- a Product Assemblability Merit analysis tool," The American Society of Mechanical Engineering, pp. 1-6, October, 1986.

[13] Freeman, B. "Design for Flexible Assembly," Assembly Engineering, P. 28, July, 1988.

[14] Boothroyd, G. , Dewhurst, P. "Product design- Key to a successful robotic assembly," Assembly Engineering, pp. 90-93, September, 1986.

[15] Boothroyd, G., Knight, W., "Fundamentals of machining and machine tools," Second edition, Marcel Decker, Newyork, NY, 1989.

[16] Claycombe, W.W. "Automation," Notes from class lecture, University of Tennessee, Knoxville, 1989.

[17] Rembold, U., "Information control problem in manufacturing technology, " Pergamon press, Newyork, NY, 1980.

[18] Parmley, R., "Standard handbook of fastening and joining," Mcgrawhill, Second edition, 1989.

[19] Boothroyd, G., Poli, C., and Murch, L. "Feeding and Orienting Techniques for small parts," Technical paper. Society of Manufacturing Engineers, 1975.

[20] Dunton, R. "Threaded inserts for solving assembly problems," Assembly Engineering, pp. 30-36, April, 1980.

[21] Blake, A., "What every engineer should know about threaded fasteners,"Marcel Decker, New york, 1986.

[22] Graves, B., "Taking the guesswork out of press and snap fits," Assembly Engineering, pp. 20-22, February and March, 1975.

[23] Industrial Fasteners Institute, "Metric Fastrener Standards," Industrial Fasteners Institute, Cleveland, Ohio, 1976.

[24] Schuhc, L., "Plastic fasteners, please," Assembly Engineering, May, 1989.

[25] Waterbury, R. "Applying Design For Assembly principles," Assembly Engineering, March, 1986.

[26] Trilling, J., "How special fasteners improve a product," Machine Design, pp. 102-105, May 6, 1976.

[27] Rajan, A., Segal, M., "Assigning components to robotic workcells for electronic assembly," AT &T Technical Journal, May/June, 1989.

[28] Camloc Fasteners, Catalog, Hasbrouck, NJ, 1990.

[29] Southco Fasteners, Catalog, Concordville, PA, 1989.

[30] TRW Fasteners Division, Catalog, Cambridge, MA, 1990.

[31] BF Goodrich, "Rivnut-Plusnut design guide," Catalog, Akron, Oh, 1986.

[32] Schwatz, W., "Threaded Fasteners Live," Assembly Engineering, November, 1989.

[33] Chow, W., "Snap fit design," Mechanical Engineering,", July, 1977.

[34] Groover, M., Zimmers, E., "CAD/CAM," Prentice hall Inc. Englewood, NJ, 1984.

[35] Rathmill, K., "Robotic Assembly," IFS Publication Inc., Kempton, UK, 1985.

[36] Schwarz, O. B., Grafstein, P., "Pictorial handbook of technical devices,"Chemical publishing Co, Inc., Newyork, NY, 1971.

[37] Laughner, V. H., "Handbook of fastening and joining of metal parts, "Mcgrawhill book company, Inc., Newyork, NY, 1956.

[38] Industrial Fasteners Institute, "Fasteners Standard," Industrial fasteners Institute, Sixth Edition, Cleveland, Ohio.

[39] Dzus corp., Catalog, West Islip, NY, 1989.

[40] Tridair Inserts Corp., Catalog, Torrance, CA., 1990.

[41] Assembly Engineering Magazine,"Assembly Automation and Fasteners, "Assembly Engineering, July, 1990.

[42] Edwards, C., "Seven mechanical fasteners speed assembly of thermoplastics," Materials Engineering, pp. 24-27, December, 1974.

[43] Arden Fasteners, Catalog, Lavergne, TN, 1989.

[44] Phillips Corp., Catalog, Chippewa falls, Wisconsin, 1990.

[45] ACME Corp., Fastener Catalog, Briston, CT, 1990.

[46] Huck Corp., Catalog, Irvine, CA, 1988.

[47] Boothroyd, G, "Product design for assembly," BDI, Inc, RI, 1987.

APPENDIXES

APPENDIX A:

FASTENERS AND STANDARDS

The following is directly quoted from "Metric Fasteners Standards" [23].

Fastener--A fastener is a mechanical device for holding two or more bodies in definite positions with respect to each other.

Mechanical Properties--Mechanical properties are those properties which involve a relationship between strain and stress. Hardness, proof load, yield strength and ultimate tensile strength are examples of mechanical properties.

Physical properties--Physical properties are the properties defining the basic characteristics of the material or fastener.

Proof load--Aproof load is as specified test load which a fastener must withstand without any indication of significant deformation or failure.

Proof test--A proof test is any specified test required for a fastener to indicate that it is suitable for the purpose intended.

Quality denotes the suitability of a fastener for the purpose for which it is intended.Quality should not be confused with precision or workmanship as it is possible that precision parts of good workmanship and finish can be of poor quality if they fail to perform the function for which they are intended. Also for countless applications, good quality parts do not require precision or fine finish in order to serve satisfactory.

Special Fastener--A special fastener is a fastener which differs in any respect from recognized standards.

Shear fastener--A shear fastener is a fastener whose primary function is to resist forces which tend to shear it.

Standard fastener-- A standard fastener is a fastener which conforms in all respect to recognized standards.

Tension fastener-- A tension fastener is a fastener whose primary function is to resist forces which tend to elongate it.

Threaded fastener-- A threaded fastener is a a fastener a portion of which has some form of screw thread.

Bearing surface-- The bearing surface is the supporting locating surface of a fastener with respect to the part which it fastens(mates). The loading of a fastener is usually through the bearing surface.

Blank-- A blank is a fastener in some intermediate stage of manufacturing

Body-- The body of a threaded fastener is the unthreaded portion of the shank.

Externally relieved body--An externally relieved body is a body on which the diameter of the entire body or a portion thereof is reduced to less than the rolled thread blank size of the thread.

Collar--A collar is a raised ring or flange of material on the head or shank of a fastener.

Fillet--A fillet is the concave junction at two intersecting surfaces of fastener.

Fin--Afin is a form of key under the head of a fastener which serves to keep the fastener from turning during assembly and use.

Head--The head of a fastener is the enlarged shape preformed on one end of a headed fastener to provide a bearing surface.

Recessed head-- A recessed head is a head having a specially formed indentation or recess centered in its top surface. Three common forms of recess heads are cross recess, clutch recess and square recess.

Slotted Head-- A slotted head is a head having a slot centered across its top surface.

Button Head-- A button head as applied to threaded fasteners has a low top surface with a large flat bearing surface.

Flat Head--The flat head has a flat top surface and a conical bearing surface with head angle of nominally 90 degrees.

Flat trim head--Flat trim head has a smaller head diameter and lower head height than the standard flat head.

Headless--A headless threaded fastener is a fastener having a slot, recess or socket in one end.

Hex Head-- The hex head has a flat or indented top surface, six flat sides and a flat bearing surface.

Hex Washer Head--The hex washer head is a washer head upon which a hex head is formed.

Oval Head-- The oval head has a rounded top surface and a conical bearing surface with head angle of nominally 90 degrees

Oval Trim Head-- The oval trim head has a smaller head diameter and lower head height than the standard oval head with a controlled radius at the junction of the top and the conical bearing surface.

Pan Head--The pan head has a flat bearing surface and a flat tp surface rounding into a cylindrical side surface. On recessed pan heads, the top surface is semi-elliptical, rounding into a cylindrical side surface.

Round Countersunk Head--The round countersunk head is a circular head having a flat top surface and conical bearing surface.

Round Head-- The round head has a semi-elliptical top surface and a flat bearing surface.

Round Washer Head--The round washer head is a washer head upon which a round head is formed.

Socket Head--The socket head has a flat chamfered top surface with smooth or knurled cylindrical side surface and a flat bearing surface. A hexagon or spline (formerly known as fluted) socket is usually formed in the center of the top surface.

Square countersunk head--The square countersunk head is a square head having a flat top surface and pyramidal bearing surface.

Square head--The square head has a flat top surface, four flat sides and a flat bearing surface. Square heads on set screws have a rounded top surface and may have an underhead construction tapered or radiused directly into body.

T-Head--The T-Head is an oblong shaped head, having a rounded top surface, flat sides and a flat bearing surface.

Twelve Spline Head--The twelve Spline head has a flat or indented top surface, a vertical sided twelve involute spline configuration around the head perimeter, a circular flange at the bottom of the head, and a flat-to-concave bearing surface.

Washer Head--A washer head is a head having a circular collar with a large flat bearing surface upon which various other head styles are integrally super-imposed.

Wrenching Head--A wrenching head is a head having provision for driving or holding by means of a wrench. "External wrenching" designates the application of a wrench externally to the sides of the head. "Internal wrenching" designates the application of a wrench internally to a socket, the sides of which are parallel to the fasteners axis.

Lug-- A lug is a form of key under the head of a fastener to keep the fastener from turning during the assembly and use.

Neck-- Neck is used to define : (1) a specialized form of the body of fasteners near the head to perform a definite function, such as preventing rotation, etc.; and (2) a reduced diameter of a portion of the shank of a fastener which is required for design or manufacturing reasons. Various neck styles are described and illustrated below.

Fin Neck-- A fin neck is a style of neck consisting of two or more fins under and integral with the head.

Ribbed Neck-- A ribbed neck is a style of neck consisting of longitudial ribs around the shank adjacent to the underside of the head.

Point-- The point of a fastener is the configuration of the end of the shank of a headed fastener or of each of a headless fastener. Point of fastener fall into the general categories described and illustrated below.

Gimlet point-- A gimlet point is threaded cone point usually having a point angle of 45 to 50 degrees. It is used on thread forming screws such as type "AB" tapping crews, wood screws, lab screws, etc.

Pilot point-- A point is cylindrical point having a diameter somewhat smaller than the shank diameter. It is designed to facilitate the alignment and stating of such fasteners as drive screws and groove pins into holes at assembly.

Rib-- Ribs are small edges of material usually formed longitudially around the shank.

Shank-- Shank is the portion of the head fastener which lies between the head and the extreme point.

Thread-- A thread is a ridge of uniform section in the form of a helix on the external or internal surface of a cylinder. This is known as a straight or parallel thread to distinguish it from a taper thread formed on a cone or frustum of a cone.

Washer face-- A washer face is a circular boss on the bearing surface of a bolt or nut.

Allowance-- An allowance is an ontentional difference between the maximum material limits of mating parts. It is the minimum clearance (positive allowance) between such parts.

Body diameter-- The body diameter is the diameter of the body of a threaded fastener.

Fit-- Fit is the general term used to signify the range of tightness which may result from the application of a single combination of allowance and tolerances in the design of mating parts.

Head Angle--The head angle is the included angle of the bearing surface of the head.

Head diameter-- The head diameter is the diameter at the largest periphery of the head.

Length-- The length of a headed fastener is the distance from the intersection of the largest diameter of the head with the bearing surface to the extreme point measured in aline parallel to the axis of the fastener. Exceptions: The length of a shoulder screw and a socket head shoulder screw is the length of the shoulder. The length of a headless fastener is the distance from one extreme point to the other, measured in a line parallel to the axis of the fastener.

Point Angle-- The point angle is the included angle of the point.

Recess Depth-- The recess depth is the distance measured parallel to the fastener axis from the intersection of the head surface with the maximum diameter of the recess to the bottom of the recess.

Recess Diameter-- The recess diameter is the diameter measured in a plane perpendicular to the axis of the fastener over the intersection of the outermost extremities of the recess with the head surface.

Recess Width-- The recess width is the distance measured in a plane perpendicular t axis of the fastener across the intersection of the sides or wings of the recess with the head surface.

Shank Diameter--The shank diameter is the diameter of shank of an unthreaded fastener. The diameter of the unthreaded portion of a threaded shank is termed the body diameter.

Shank length-- Shank length is the length of the shank, measured parallel to the axis of the fastener.

Slot Depth-- The slot depth on a headed fastener is the distance measured parallel to the axis of the fastener from the highest part of the head to the intersection of the bottom of the slot with the head or bearing surface. The slot depth on a nut or headless fastener is the distance measured parallel to the fastener axis from the top surface to the extreme bottom of the slot.

Slot width-- Slot width is the distance measured in a plane perpendicular to the axis of the fastener over the intersection of the sides of the slot with the head surface of a headed fastener or top surface of a nut.

Total Thread-- The total thread includes the complete or effective thread and the incomplete thread.

Tolerance-- A tolerance is the total permissible variation of a size. The tolerance is the difference between the limits of size.

Broaching-- Broaching is the process of removing metal by pushing or pulling a cutting tool, called a broach, along the surface.

Chip-- A chip is a small fragment of metal removed from a surface by cutting with a tool.

Cut thread-- A cut thread is a thread produced by removing material from the surface with a form cutting tool.

Drilling-- Drilling is the process of forming holes by means of specialized cutting tools called drills.

Ground thread-- A ground thread is a thread finished on the flanks by a grinding operation.

Knurling-- Knurling is the process of producing a roughed surface by means of a specialized forming tool called knurl.

Machining-- Machining is the process of forming the surface by cutting away material.

Rolled threads-- A rolled thread is a thread produced by action of a form tool which when pressed into the surface of a blank displaces the material radially.

Slotting-- Slotting is the process of forming or cutting slots in a fastener during either the primary or secondary operation.

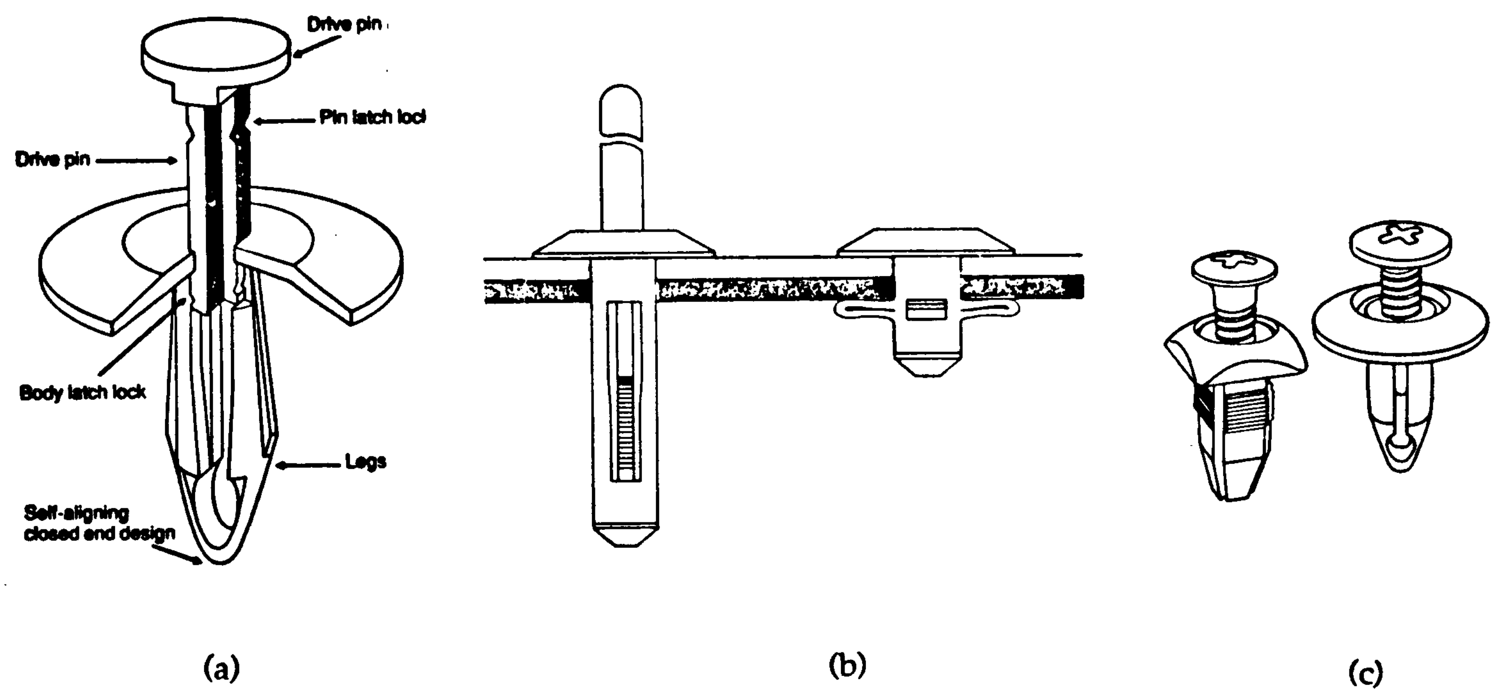


Figure A.1. Special plastic blind rivets. a) Push rivets. b) Expansion plastic rivet. c) Screw rivet.

Source: Phillips Corp., Catalog, 1990.

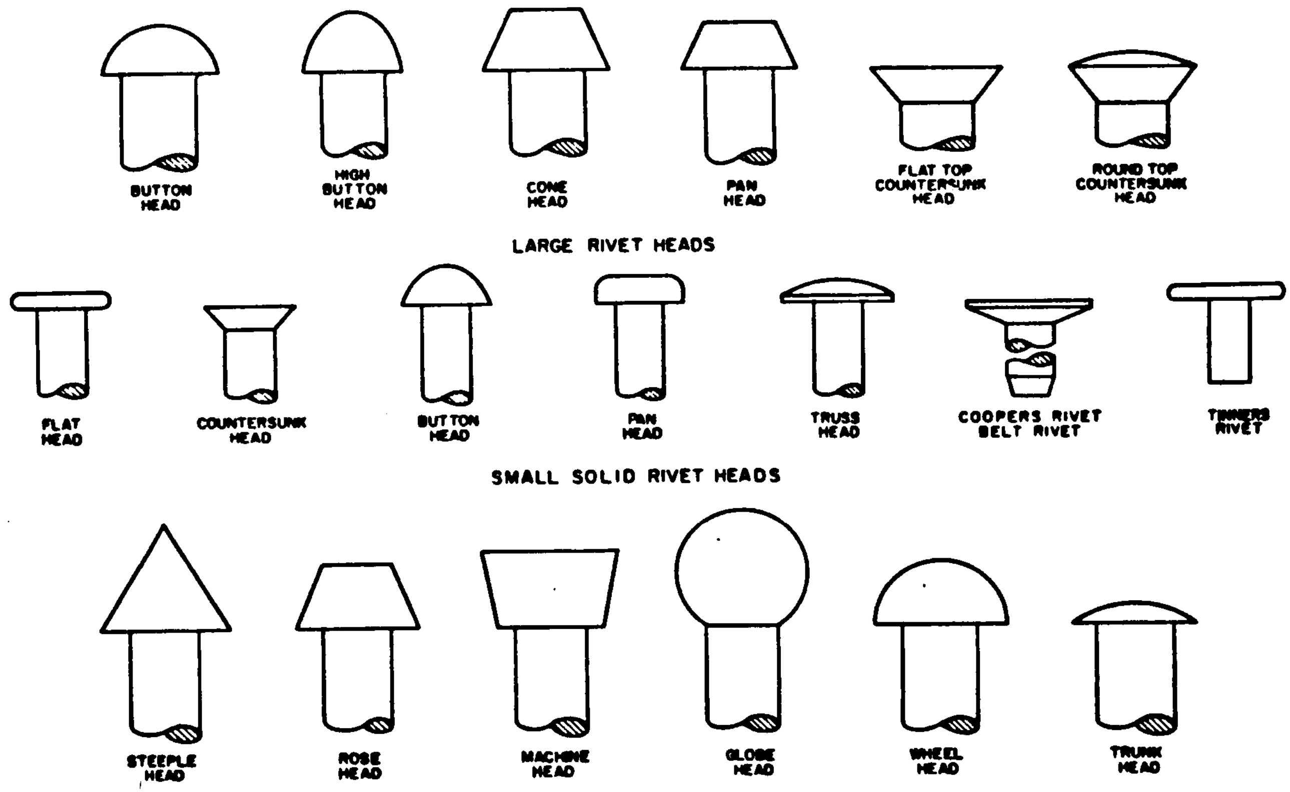


Figure A.2. Various rivet heads.

Source: Laughner, V., "Handbook of fastening of metal parts," 1956.

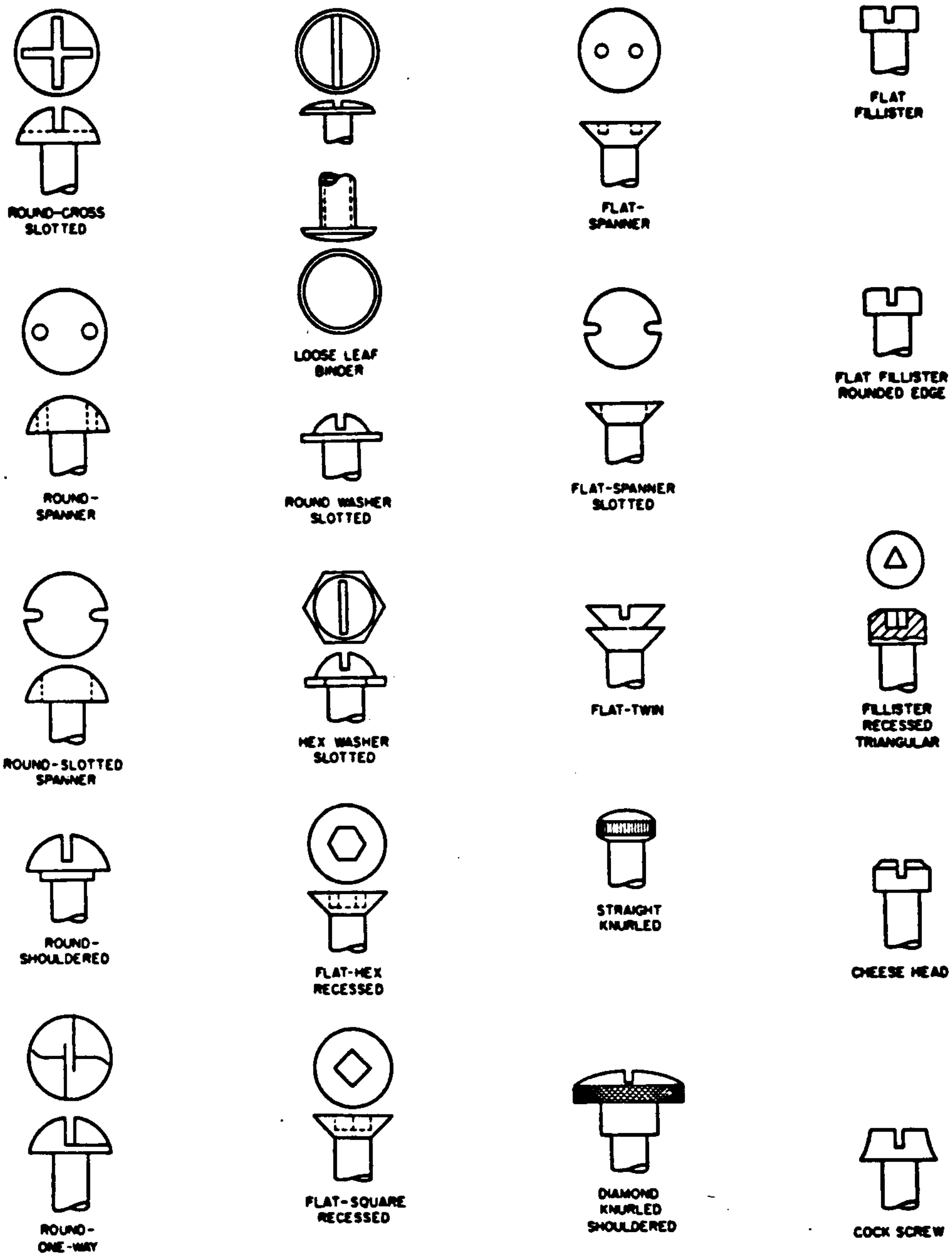


Figure A.3. Special type screw heads.

Source: Laughner, V., "Handbook of fastening of metal parts," 1956.

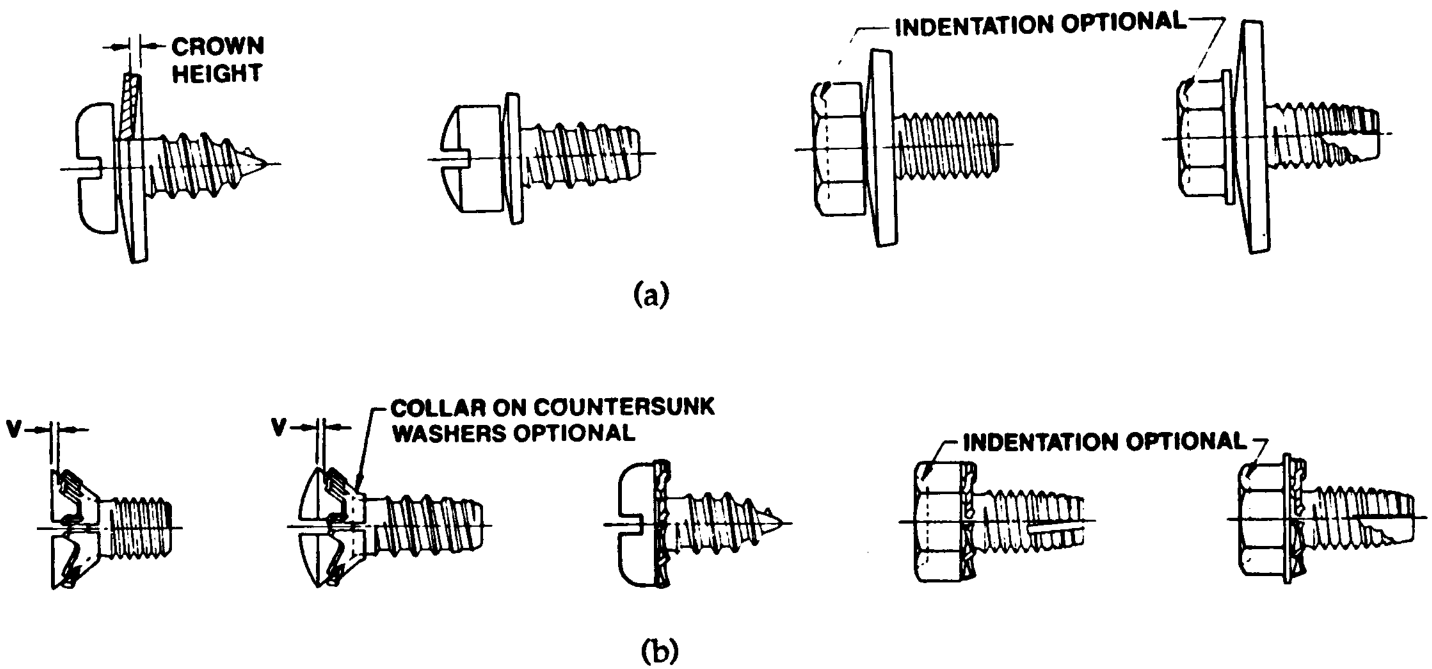
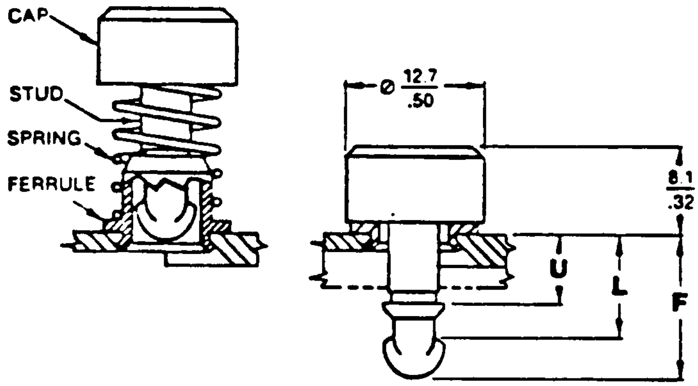
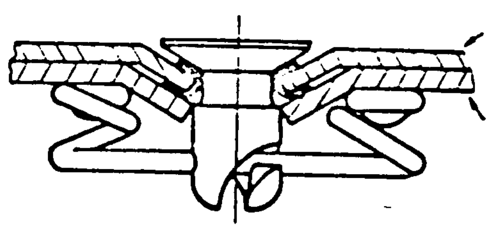


Figure A.4. Screw lock washer assembly. a) Conical spring washer sems.
b) External tooth lock washer sems.

Source: Industrial Fasteners Institute, "Fasteners Standard."



(a)



(b)

Figure A.5. Panel fasteners. a) Captive screw 1/4 turn. b) **1/4 turn.**

Sources: a) Southco Fastener, Catalog, 1989.
b) DZUS Corp., Catalog, 1989.

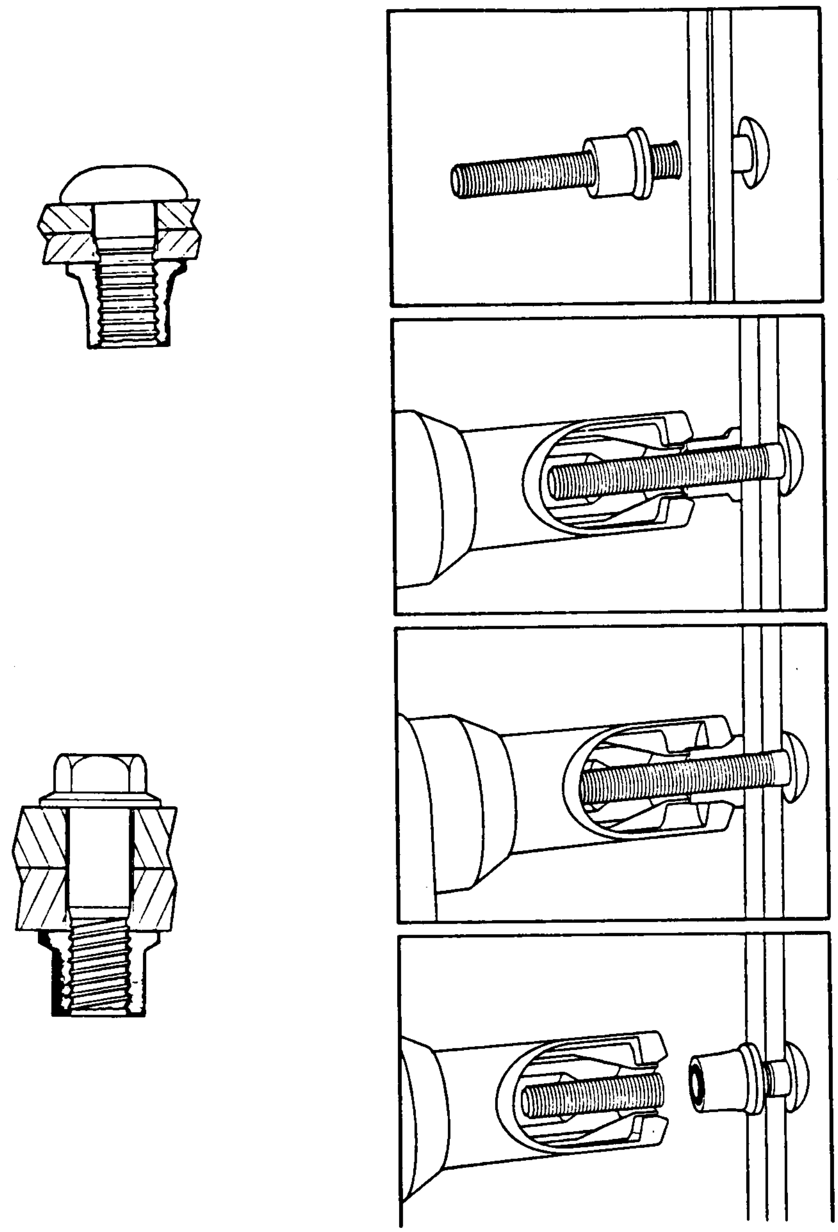


Figure A.6. Huckbolt two way access installation sequence.

Source: Huck corp., Catalog, 1988.

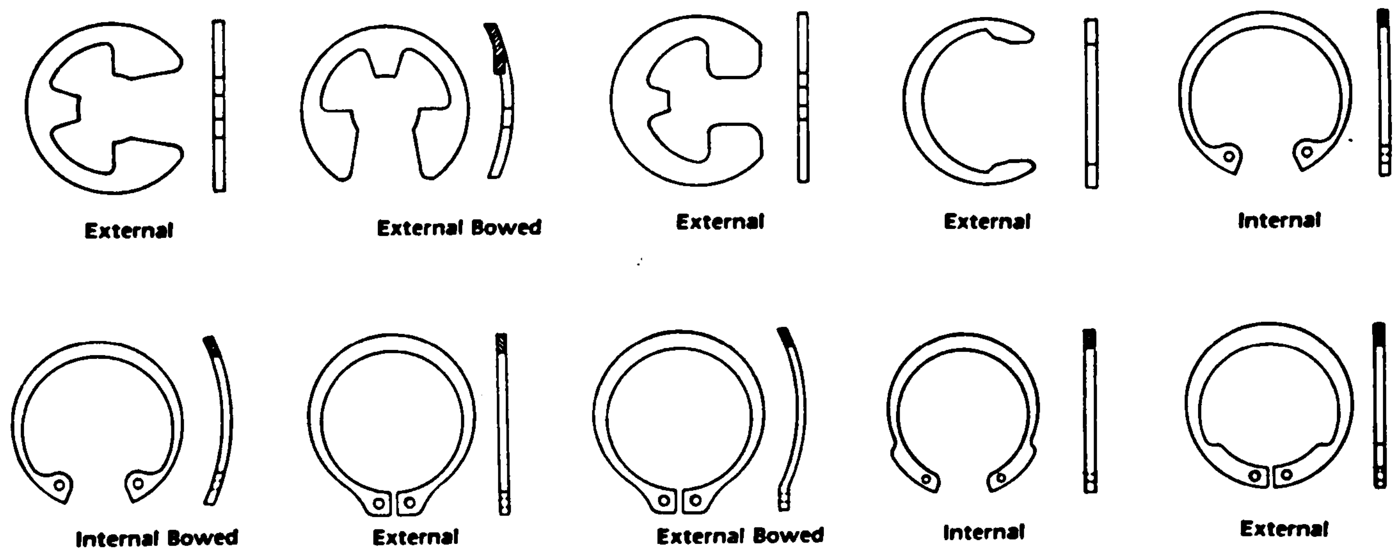


Figure A.7. Industrial retaining rings.

Source: Arden fasteners, Catalog, 1989.

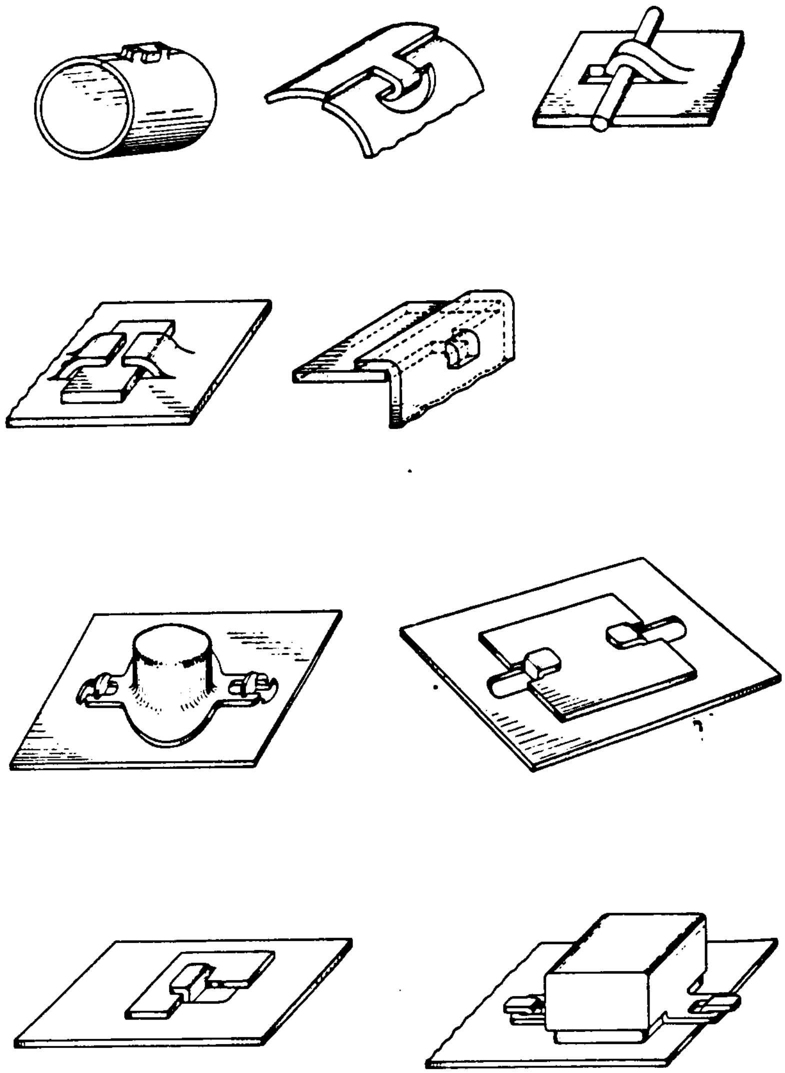
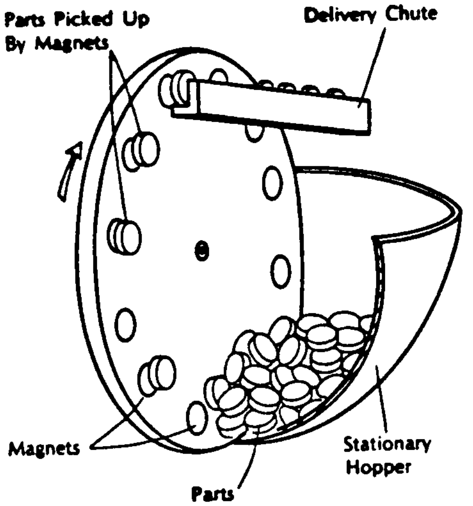


Figure A.8. Other joining methods.

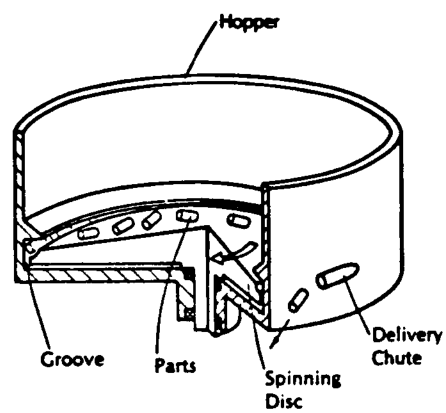
Source: Laughner, V., "Handbook of fastening of metal parts," 1956.

APPENDIX B:

FEEDING MACHINES AND ORIENTING DEVICES



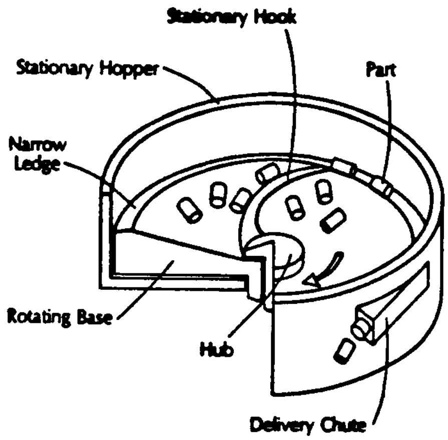
MAGNETIC DISC HOPPER FEEDER



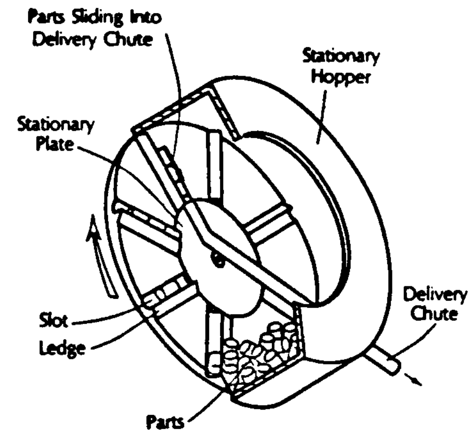
CENTRIFUGAL HOPPER FEEDER

Figure B.1. Various Hopper feeders.

Source: Boothroyd, G., "Handbook of feeding and orienting techniques."



STATIONARY HOOK HOPPER FEEDER



ROTARY DISC HOPPER FEEDER

Figure B.1. (Continued)

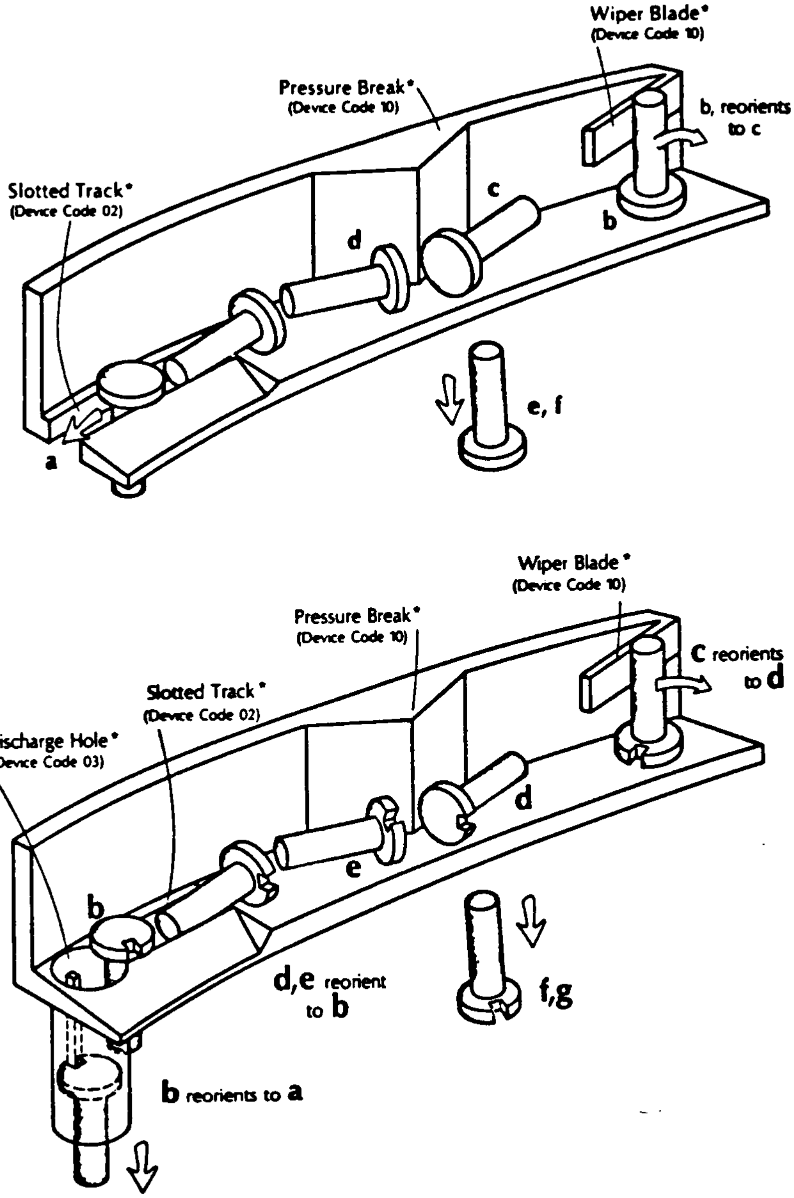
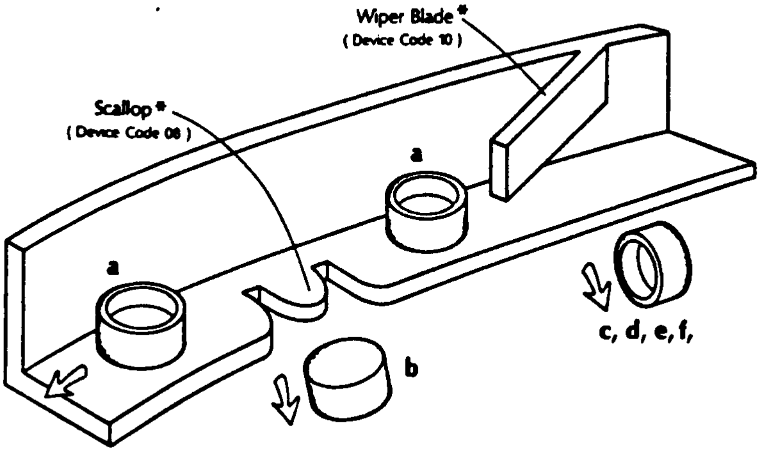


Figure B.2. Various part orienting devices.

Source: Boothroyd, G., "Handbook of feeding and orienting."



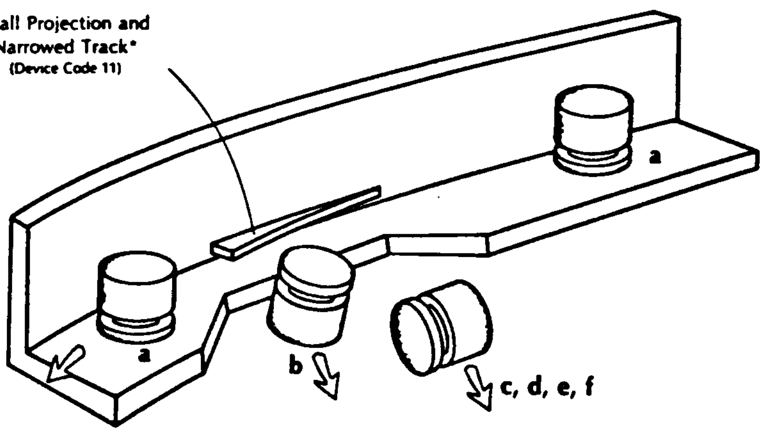
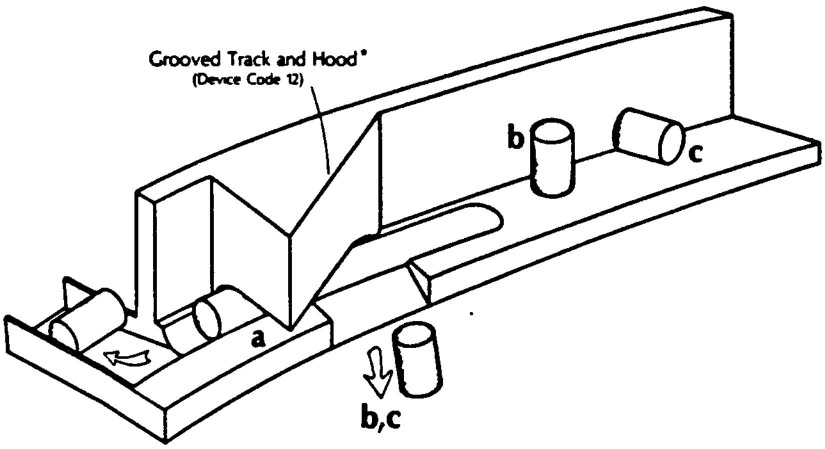


Figure B.2. (Continued)



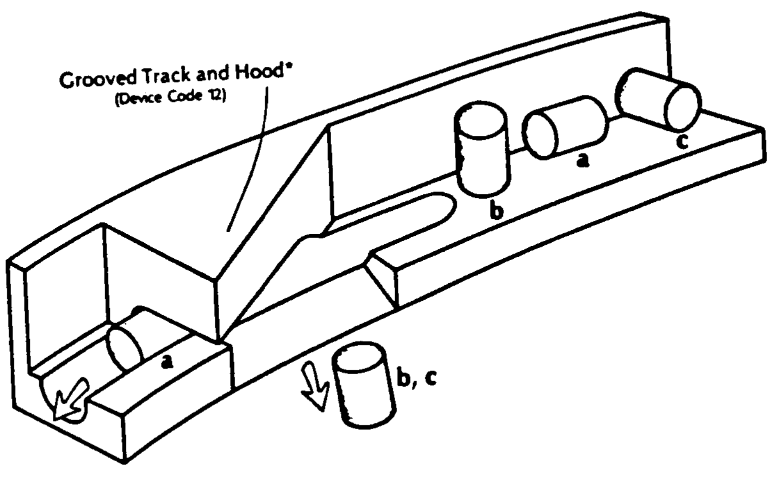


Figure B.2. (Continued)

APPENDIX C:

COMPUTER PROGRAM

```
RUN
 PLEASE ANSWER ALL THE QUESTIONS IN CAPITAL LETTER

                    WELCOME TO THE FSFA

 TO OPERATE THIS PROGRAM YOU MUST HAVE THE GRADES
 FOR ALL THE 21 CATEGORIES READY. THE GRADES CAN BE
 OBTAINED BY REVIEWING THE FLOW CHARTS INCLUDED IN
 CHAPTER SIX OF THE REPORT. SOME SELECTED FASTENERS
 HAVE BEEN EXAMINED AND THE DATA ARE STORED IN THE
 DISK. IF YOU WOULD LIKE TO EXAMIN OR MAKE ANY CHANGES
 ON THESE DATA, SIMPLY ANSWER THE QUESTIONS AS YOU RUN
 THE PROGRAM. SINCE THE INPUT DATA ARE CONVERTED TO
 ASCII CODES, UPPER CASE LETTERS SHOULD BE USED.

 PRESS ANY KEY TO START...
REVIEW AN EXISTING FILE? (Y/N) :N
TYPE THE NAME OF THE FASTENER(8 LETTERS MAX): DEMO

ENTER THE GRADE FOR NO.  1  CATEGORY: ? A
ENTER THE GRADE FOR NO.  2  CATEGORY: ? A
ENTER THE GRADE FOR NO.  3  CATEGORY: ? A
ENTER THE GRADE FOR NO.  4  CATEGORY: ? A
ENTER THE GRADE FOR NO.  5  CATEGORY: ? A
ENTER THE GRADE FOR NO.  6  CATEGORY: ? A
ENTER THE GRADE FOR NO.  7  CATEGORY: ? A
ENTER THE GRADE FOR NO.  8  CATEGORY: ? B
ENTER THE GRADE FOR NO.  9  CATEGORY: ? B
ENTER THE GRADE FOR NO.  10  CATEGORY: ? B
ENTER THE GRADE FOR NO.  11  CATEGORY: ? B
ENTER THE GRADE FOR NO.  12  CATEGORY: ? B
ENTER THE GRADE FOR NO.  13  CATEGORY: ? B
ENTER THE GRADE FOR NO.  14  CATEGORY: ? B
ENTER THE GRADE FOR NO.  15  CATEGORY: ? B
ENTER THE GRADE FOR NO.  16  CATEGORY: ? B
ENTER THE GRADE FOR NO.  17  CATEGORY: ? A
ENTER THE GRADE FOR NO.  18  CATEGORY: ? A
ENTER THE GRADE FOR NO.  19  CATEGORY: ? A
ENTER THE GRADE FOR NO.  20  CATEGORY: ? A
ENTER THE GRADE FOR NO.  21  CATEGORY: ? A

 PRESS ANY KEY TO SEE THE TABLE OF RESULTS.....
```

CATEGORY	GRADE	IMPORTANCE	POINT
1	A	3	10
2	A	3	10
3	A	3	10
4	A	3	10
5	A	3	10
6	A	2	10
7	A	3	10
8	B	2	7.5
9	B	3	8.333333
10	B	3	8
11	B	2	8.75
12	B	2	8
13	B	2	8
14	B	1	8
15	B	1	8
16	B	2	6.666667
17	A	1	10
18	A	1	10
19	A	1	10
20	A	1	10
21	A	3	10

PRESS ANY KEY TO SEE THE REST OF THE RESULTS.....

FOR A DEMO FASTENER THE CODE IS:
AAAAAAABBBBBBBBBAAAAAA
THE TOTAL QUALITY POINT FOR DEMO IS: 412.8334
DO YOU WANT TO STORE THESE DATA ? (Y/N): Y
SAVE IT UNDER A DIFFERENT NAME ? (Y/N) :N
DO YOU WANT TO CONTINUE ? (Y/N) :N
Ok
LIST

```
RUN
 PLEASE ANSWER ALL THE QUESTIONS IN CAPITAL LETTER

                  WELCOME TO THE FSFA

 TO OPERATE THIS PROGRAM YOU MUST HAVE THE GRADES
 FOR ALL THE 21 CATEGORIES READY. THE GRADES CAN BE
 OBTAINED BY REVIEWING THE FLOW CHARTS INCLUDED IN
 CHAPTER SIX OF THE REPORT. SOME SELECTED FASTENERS
 HAVE BEEN EXAMINED AND THE DATA ARE STORED IN THE
 DISK. IF YOU WOULD LIKE TO EXAMIN OR MAKE ANY CHANGES
 ON THESE DATA, SIMPLY ANSWER THE QUESTIONS AS YOU RUN
 THE PROGRAM. SINCE THE INPUT DATA ARE CONVERTED TO
 ASCII CODES, UPPER CASE LETTERS SHOULD BE USED.

 PRESS ANY KEY TO START...


REVIEW AN EXISTING FILE? (Y/N) :Y
 FIND THE FILE  YOU WANT TO RETRIEVE:

A:\
FSFA    .BAS    SNAP            DIGIT1  .BAS    DIGITSTR.BAS
RECTRAP .BAS    ULTRASON        DIGIT2  .BAS    DIGIT   .BAS
PRESSINS        BEFEB27 .WK1    BEAPR9  .WK1    CASTINSE
SCREWTAP        SCREWMAC        SELFINSE        KEYINSER
HEXBOLT         BOLTCARI        RIVETPUL        RIVETPIN
RIVTCOMP        SCRWDRIL
 1359360 Bytes free

TYPE THE FILE NAME:SCRWDRIL


PRESS ANY KEY TO SEE THE TABLE OF RESULTS....
```

CATEGORY	GRADE	IMPORTANCE	POINT
1	C	3	7.142857
2	B	3	8.571428
3	A	3	10
4	F	3	4.444444
5	E	3	7.333333
6	A	2	10
7	E	3	4.285714
8	A	2	10
9	D	3	5
10	A	3	10
11	B	2	8.75
12	A	2	10
13	E	2	2
14	C	1	6
15	A	1	10
16	B	2	6.666667
17	A	1	10
18	A	1	10
19	B	1	6.666667
20	A	1	10
21	A	3	10

PRESS ANY KEY TO SEE THE REST OF THE RESULTS....

THE TOTAL QUALITY POINT FOR SCRWDRIL IS: 347.8333
THE CODE FOR SCRWDRIL IS:
CBAFEAEADABAECABAABAA
DO YOU WANT TO CHANGE ANY ENTRY ?
Y

ENTER THE CATEGORY NO.:20
TYPE THE NEW GRADE: B
TYPE THE IMPORTANCE FACTOR: 4

PRESS ANY KEY TO SEE THE TABLE OF RESULTS.....

CATEGORY	GRADE	IMPORTANCE	POINT
1	C	3	7.142857
2	B	3	8.571428
3	A	3	10
4	F	3	4.444444
5	E	3	7.333333
6	A	2	10
7	E	3	4.285714
8	A	2	10
9	D	3	5
10	A	3	10
11	B	2	8.75
12	A	2	10
13	E	2	2
14	C	1	6
15	A	1	10
16	B	2	6.666667
17	A	1	10
18	A	1	10
19	B	1	6.666667
20	B	4	5
21	A	3	10

PRESS ANY KEY TO SEE THE REST OF THE RESULTS.....

FOR A SCRWDRIL FASTENER THE CODE IS:
CBAFEAEADABAECABAABBA
THE TOTAL QUALITY POINT FOR SCRWDRIL IS: 357.8333
DO YOU WANT TO STORE THESE DATA ? (Y/N): N
Ok

```
10 '---------------------------------------------------------------
20 'PROGRAM TO FIND THE FSFA CODE FOR FASTENERS
30 'BY: KHOSROW ARABI-ESFAHANI
40 'MAY 1991
50 '---------------------------------------------------------------
60 ' L$           LETTER GRADE FOR EACH CATEGORY
70 ' P            POINT FOR EACH GRADE
80 ' M            ASCI CODE DIFFERENCE FOR EACH GRADE
90 ' N            NUMBER OF GRADES IN EACH CATEGORY
100 ' IM           IMPORTANCE FACTOR
110 ' I            LOOP COUNTER
120 '---------------------------------------------------------------
130 '
140 CLS
150 CLEAR
160 KEY OFF
170 DIM P(21),L$(21),M(21),N(21),IM(21)
180 '
190 '******************** INPUT DATA  ***************************
200 '
210 DATA 7,7,3,9,15,4,7,4,6,5,8,5,5,5,5,3,6,4,3,2,3
220 DATA 3,3,3,3,3,2,3,2,3,3,2,2,2,1,1,2,1,1,1,1,3
230 FOR I=1 TO 21
240   READ N(I)
250 NEXT
260 FOR I=1 TO 21
270   READ IM(I)
280 NEXT
290 '
300 '******************** INSTRUCTION FOR USERS ****************
310 '
320 PRINT" PLEASE ANSWER ALL THE QUESTIONS IN CAPITAL LETTER"
330 PRINT
340 PRINT"                    WELCOME TO THE FSFA         "
350 PRINT
360 PRINT" TO OPERATE THIS PROGRAM YOU MUST HAVE THE GRADES"
370 PRINT" FOR ALL THE 21 CATEGORIES READY. THE GRADES CAN BE"
380 PRINT" OBTAINED BY REVIEWING THE FLOW CHARTS INCLUDED IN "
390 PRINT" CHAPTER SIX OF THE REPORT. SOME SELECTED FASTENERS"
400 PRINT" HAVE BEEN EXAMINED AND THE DATA ARE STORED IN THE "
410 PRINT" DISK. IF YOU WOULD LIKE TO EXAMIN OR MAKE ANY CHANGES"
420 PRINT" ON THESE DATA, SIMPLY ANSWER THE QUESTIONS AS YOU RUN"
430 PRINT" THE PROGRAM. SINCE THE INPUT DATA ARE CONVERTED TO "
440 PRINT" ASCII CODES, UPPER CASE LETTERS SHOULD BE USED. "
450 PRINT
460 '
470 '******************* STARTUP MENU ***************************
480 '
490 PRINT" PRESS ANY KEY TO START..."
500 WHILE INKEY$="":WEND
510 CLS
520 INPUT"REVIEW AN EXISTING FILE? (Y/N) :",Y3$
530 CLS
540 IF Y3$="Y"  THEN GOTO 1070
550 INPUT"TYPE THE NAME OF THE FASTENER(8 LETTERS MAX): ",NAM$
560 PRINT
```

```
580 '************************ CALCULATION **********************
590 '
600 FOR I=1 TO 21
610   PRINT"ENTER THE GRADE FOR NO. ";I;" CATEGORY: ";
620   INPUT L$(I)
630   M(I)=ASC(L$(I))-65
640   P(I)= 10-M(I)*(10/N(I))
650   IF Y2$="Y"  THEN 670
660 NEXT
670 PRINT
680 '
690 '************************ OUTPUT AND RESULTS **************
700 '
710 PRINT" PRESS ANY KEY TO SEE THE TABLE OF RESULTS....."
720 WHILE INKEY$="":WEND
730 PRINT"CATEGORY  GRADE       IMPORTANCE       POINT    "
740 FOR I=1 TO 21
750   PRINT I,L$(I),IM(I),P(I)
760 NEXT
770 PRINT"PRESS ANY KEY TO SEE THE REST OF THE RESULTS....."
780 WHILE INKEY$="":WEND
790 PRINT
800 PRINT "FOR A ";NAM$;" FASTENER THE CODE IS:"
810 SUM=0
820 FOR I=1 TO 21
830       SUM=P(I)*IM(I)+SUM
840 PRINT L$(I);
850 NEXT
860 PRINT " "
870 PRINT"THE TOTAL QUALITY POINT FOR ";NAM$;" IS:",SUM
880 '
890 '**************** OPTION MENU FOR SAVING THE DATA**********
900 '
910 INPUT"DO YOU WANT TO STORE THESE DATA ? (Y/N): ",Y$
920 IF Y$="Y" THEN 930 ELSE END
930 INPUT" SAVE IT UNDER A DIFFERENT NAME ? (Y/N) :",Y4$
940 IF Y4$="Y" THEN INPUT"TYPE THE NEW FILE NAME: ",NAM$
950 OPEN NAM$ FOR OUTPUT AS #1
960 FOR I=1 TO 21
970   PRINT #1,P(I),IM(I),L$(I)
980 NEXT
990 PRINT #1,SUM
1000 PRINT #1,NAM$
1010 CLOSE
1020 '
```

```
1030 '********************* RETRIEVE AN EXISTING FILE*************
1040 '
1050 INPUT" DO YOU WANT TO CONTINUE ? (Y/N) :",Y5$
1060 IF Y5$="Y" THEN 140 ELSE END
1070 CLS:PRINT " FIND THE FILE  YOU WANT TO RETRIEVE:"
1080 PRINT
1090 FILES
1100 INPUT"TYPE THE FILE NAME:",NAM$
1110 CLS
1120 OPEN NAM$ FOR INPUT AS #1
1130 PRINT"PRESS ANY KEY TO SEE THE TABLE OF RESULTS...."
1140 WHILE INKEY$="":WEND
1150 PRINT"CATEGORY  GRADE      IMPORTANCE      POINT  "
1160 FOR I=1 TO 21
1170   INPUT #1,P(I),IM(I),L$(I)
1180   PRINT  I,L$(I),IM(I),P(I)
1190 NEXT
1200 INPUT #1,SUM
1210 PRINT"PRESS ANY KEY TO SEE THE REST OF THE RESULTS...."
1220 WHILE INKEY$="":WEND
1230 PRINT "THE TOTAL QUALITY POINT FOR ";NAM$;" IS: ",SUM
1240 PRINT "THE CODE FOR ";NAM$;" IS: "
1250 FOR I=1 TO 21
1260   PRINT L$(I);
1270 NEXT
1280 PRINT" "
1290 CLOSE
1300 '
1310 '**************** CHANGING OR MODIFYING THE DATA *********
1320 '
1330 INPUT"DO YOU WANT TO CHANGE ANY ENTRY ? ",Y2$
1340 IF Y2$="Y" THEN INPUT" ENTER THE CATEGORY NO.:",I ELSE END
1350 INPUT" TYPE THE NEW GRADE: ",L$(I)
1360 INPUT" TYPE THE IMPORTANCE FACTOR: ",IM(I)
1370 GOTO 630
```

VITA

Khosrow Arabi-Esfahani was born in Tehran-Iran on May 7, 1964. He attended the Sheshom Bahman elementary school where he started an education program which has lasted almost twenty years. He was later accepted to Alborz and Razi high school majoring in science. His interest in technology encouraged him to pursue higher education in the Europe and the United States. In September, 1983, he entered the Dekalb Community College in Atlanta, GA. He later transferred to the engineering program at the University of Tennessee, Knoxville. In May, 1988, he received his Bachelor of Science degree with honors, majoring in Mechanical Engineering, from the University of Tennessee. In fall of that same year he entered the graduate program of his department and in May, 1991, a Master of Science degree with the thesis title of: "Fastener Selection For Assembly" was awarded to him.

The author is a member of the National Engineering honor society, TAU BETA PI, and PI TAU SIGMA. He is also a certified Engineer in Training from the state of Tennessee. Mr. Arabi-Esfahani is currently teaching computer laboratory at the University of Tennessee. The author is hoping to use his engineering knowledge for enhancement of human welfare.