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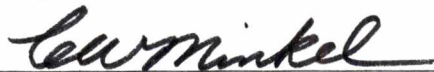


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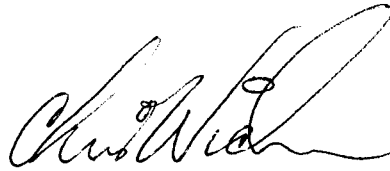
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**Evolution of a Product: Development of a Force Reaction Device for the Input
Cord on Solid Body Stringed Electric Musical Instruments**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Thomas Christopher Widner

December 1993

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DEDICATION

This thesis is dedicated to my mother and father

Anne Craig Widner

and

T. C. Widner, Jr.

Through their unending love, they have given me invaluable opportunities.

They are, without a doubt, the best parents in the world. I will forever be grateful.

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My associates at the University of Tennessee Department of Mechanical and Aerospace Engineering have made this a truly enjoyable experience. This list is incomplete, but I do have a deadline: thanks to Scott Hale & Dean Edwards (my partners in crime), Bart Ideker, Kunle Harrison, and Tim Wyrick. Special thanks to Mike Kennedy, Joel Lenoir, and Mark Holdaway for going out of their way to help get this thing right. Other thanks to: Dennis Higdon, Janine Jennings, Linda Stooksbury, Jackie Hurst, Peter Lowe, George Bean, Larry Cruze, Mark Burton, and the miracle workers in the departmental machine shop.

Finally, I must also thank my family; without their support, the pursuit of this degree would have indeed been impossible. Specifically, I would like to thank my brother and sister and their families; their interests both initiated the idea for this work and motivated me throughout the project. A *million* thanks to Josie Taylor, whose love and support were unending.

ABSTRACT

This purpose of this thesis was to perform an investigation of the design and development process required to bring a potential product from concept to production. The specific product to be developed was a force reaction device to be installed on solid body electric musical instruments such as electric guitars and basses. In addition to reacting forces subjected upon the instrument cord, the device was to continually protect the surface finish of the instrument by keeping the cord and the instrument body from coming into contact with one another. The development process included such areas as determination of the design requirements for the device (i.e. Product Design Specification), generation of conceptual designs for the device, formal selection of a conceptual design, development of the concept into a working prototype, and testing of the prototype. All of these aspects of the development process were fully investigated and completed. A few areas, due to the time limitations of this work, were simply outlined for future work. These areas included mass production of the device and marketing considerations.

The prototype for the designed device was found to fulfill all of the design requirements listed in the Product Design Specification. The device was found to be easily attachable to any typical instrument. Once the device was installed and the cord was inserted, the device successfully secured the cord and prevented any movement of the input jack during the subjection of force. The arrangement of the device was also found to continually prevent any contact between the cord and the instrument finish.

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LIST OF SYMBOLS

Greek

<i>Symbol</i>	<i>Explanation/Definition</i>
β	additional "wedge" angle added to the clamping device for added mechanical advantage
δ_i	deflection of a member in the 'i'-direction
δ_x	deflection of a member in the x-direction
Δ	total deflection of clamping ring
γ	angle on model of clamping device between ring face and vertical
μ	coefficient of friction
θ	polar coordinate of integration in analysis using Castigliano's Theorem
$d\theta$	differential length of integration in analysis using Castigliano's Theorem

Standard

<i>Symbol</i>	<i>Explanation/Definition</i>
A	cross-sectional area of clamping ring face
c	distance from inner ring wall to line of force
dS	differential length of integration in general form of Castigliano's Theorem
E	modulus of elasticity
F_i	insertion force required to place cord in clamping ring
g	gap at inner radius of clamping ring
G	shearing modulus

LIST OF SYMBOLS (continued)

<i>Symbol</i>	<i>Explanation/Definition</i>
GAP	gap at outer radius of clamping ring
GL	grip length of a quick release pin
I	area moment of inertia
J	polar moment of inertia
k	shear correction factor
K_c	spring rate of instrument cord
K_{eq}	equivalent spring rate of the cord/clamping device model in the x-direction
K_p	spring rate of the clamping device in the x-direction
M	internal moment in clamping device model at the plane of cut
N	internal normal force in clamping device model at the plane of cut
P	applied force on each face of the clamping ring model
P_i	applied force in the 'i'-direction
r	inner radius of clamping ring
R	distance from center of clamping ring to line of force (1st two models)
t	wall thickness of the clamping ring
T	internal torque in clamping device model at the plane of cut
T_1	tension in instrument cord due to pulling force
T_2	tension in portion of instrument cord that is inside clamping device
T_3	tension in instrument cord on the input jack side of the clamping device
V	internal shear force in clamping device model at the plane of cut

LIST OF SYMBOLS (continued)

Computer Code Variables

<i>Symbol</i>	<i>Explanation/Definition</i>
A	area of cross section of ring cut at angle theta
B	wedge angle added to provide mechanical advantage
BB	B expressed as a fraction of π radians
C	distance from inner surface of ring to line of action of forces
DC	diameter of instrument cord
DELTA	required deflection of ring
DMDPX	partial derivative of M expression with respect to the x-component of the input force on the ring face
DNDPX	partial derivative of NN expression with respect to the x-component of the input force on the ring face
DS	differential length of ring section
DVDPX	partial derivative of V expression with respect to the x-component of the input force on the ring face
E	modulus of elasticity of ring material
FI	one half the required insertion force needed to place the cord in the clamping ring
FINS	the total required insertion force needed to place the cord in the clamping ring
G	shearing modulus of ring material
GAMMA	angle between insertion force and the face of the holding ring
II	area moment of inertia of ring section cut at angle theta

LIST OF SYMBOLS (continued)

<i>Symbol</i>	<i>Explanation Definition</i>
KC	spring rate of instrument cord perpendicular to major axis
KEQ	equivalent spring rate of the cord/clamping device model in the x-direction
KK	shear correction factor
KP	spring rate of the clamping ring in direction of deflection
M	internal moment in clamping device model at the plane of cut
MU	coefficient of friction
NN	internal normal force in clamping device model at the plane of cut
P	dummy variable for component of force on clamping device face
R	inner radius of clamping device
T	angle of integration, θ
THICK	wall thickness of ring
V	internal shearing force in clamping device model at the plane of cut

CHAPTER 1

INTRODUCTION

1.1 Background

Performing musicians are faced not only with displaying their talents to the listening audience but also with maintaining their equipment in working order. The expense of quality musical equipment is continuously increasing due to both the improving technology of the field and the increasing value of "vintage" (i.e. old) technology that is no longer available. For example, the purchase price of new technology guitars increases for the simple reason of reimbursing the research and design. Likewise, the value of vintage guitars increases due to the inherent qualities that these discontinued instruments possess. Older instruments have been reproduced to the exact dimension, but these replicas simply do not produce the same effects to the discriminating musician's ear. Due to this, older guitars have become more valuable with age and some have even become collector's items. The point is that guitars are not just a piece of equipment to the guitarist; they are an *investment*.

The direct reason that these instruments are so costly is that they are the tools that the musician wants and *demand*s for use in his/her music. For the most part, these instruments are bought for the sole purpose of *use*. And, due to the aforementioned initial expense and increasing value of these instruments, the musicians would like to preserve

them such that they can use them for their entire careers. A specific aspect of the upkeep of an electric guitar is the emphasis for this thesis. One must keep in mind that the inherent "personality" of each guitar is dependent upon its the *original* components (i.e. electrical and mechanical components, etc.). The increasing value of vintage instruments shows that musicians are *not* satisfied with replacement parts; therefore, the importance of maintaining all original components is crucial.

1.2 The need for the device

During live musical performance, the musician depends upon the equipment to function properly such that his performance may proceed smoothly. If one component of the equipment fails, even the most proficient of musicians cannot continue the performance as desired. In fact, sometimes the show actually comes to a halt. The electric guitar itself is dependent upon numerous other pieces of gear (i.e. signal processing units, amplifiers, monitors, etc.) but none of these can function without the proper functioning of the guitar. The signal from the guitar is usually transmitted via a cable to the subsequent gear. If the continuity of this cable is broken, then the guitarist has *absolutely no output* coming from the instrument.

Although this problem may seem simple to avoid, it is not. Guitarists have continually been unable to keep their instruments "plugged in" since the inception of electric guitars. It seems simple to keep a headphone type input jack plugged into a guitar, but this is definitely not the case. Since electric guitarists generally perform

standing up, they tend to step on the cord and *unplug the instrument in the middle of a performance!!!* This problem has happened at least once to every guitarist. This problem is so common that all electric guitarists run the cord between the shoulder strap and the guitar in an effort to eliminate the problem. However, this is not an effective solution for two specific reasons. First, when the cable is arranged in this manner, the guitar's finish is quickly worn off (the original finish is another irreplaceable item). Second, in rare cases, the cord is pulled so abruptly that it causes the shoulder strap to come loose and the guitar to fall to the ground! These problems are generally more costly to the guitarist than the original cost of the instrument. Moreover, the female jack on the guitar can be damaged and even ruined by repeated jerks on the cord. The elimination of this specific problem is a goal this investigation.

An informal survey of numerous guitarists revealed a unanimous response: All of the musicians questioned said that they would buy the device that would solve this problem if it could do so without permanently altering the instrument. Moreover, since most guitarists own more than one guitar, it is conceivable that they would buy more than one (one for each instrument used frequently in performance).

1.3. Problem Statement

In order to clarify the specific aspects of the problem, the arrangement of the guitar cord, input jack, shoulder strap, and strap button on a typical guitar is shown in Figure 1.1. The signal input jack is generally directed toward the ground when the



Figure 1.1 Standard Guitar Configuration

guitar is in playing position. In an effort to alleviate our specific problem, some guitars have a jack directed parallel to the ground. This is also ineffective because a jerk on the cord deflects the jack and eventually ruins it. The working musician's "solution" to the problem is shown in Figure 1.2. Notice that the cord is placed between the shoulder strap and the guitar such that the strap button might provide a place of reaction for a jerk on the cord. As mentioned before, this both ruins the guitar's finish and increases the risk of unfastening the strap and subsequently causing the guitar to fall.

It is desired that a device be designed to provide force reaction from any jerks on the cable, while keeping the cable away from the finish of the guitar.

1.4. Scope of project

The scope and objective of this thesis involve a full investigation of the design and development process to bring a potential product from concept to production. For the purpose of this thesis work, the development of a working prototype will be completed in full. This will include investigations into such areas as product definition, concept selection, critical dimensions, etc. The chosen conceptual design will be fully developed and a prototyping process will be used for evaluation of the design. Specific aspects of the design such as aesthetic factors, manufacturing methods, etc., will be thoroughly addressed.

Secondly, the work which cannot be completed within the time limits of this work will be fully described and discussed. Topics of discussion will include items such as



Figure 1.2 Current "Solution" to Problem

specific parameters of mass production, marketing considerations, etc. The topics within these discussions are to be fully implemented upon completion of this work. Estimated time schedules for all future work will be included in the discussions.

CHAPTER 2

DESIGN REQUIREMENTS

2.1 Investigation for Product Definition

The initial phase of the design process for this device involved compiling a list of design requirements for the force reaction device. Since the author is a musician, many of the features needed to yield a superior product were apparent. However, in an effort to discover some design features that might have been overlooked, this investigation was discussed with several other musicians. As anticipated, there were a few aspects which were overlooked concerning the design requirements. In fact, one of the features that was discussed could have easily been a fatal flaw in the design if overlooked. This stresses the point that more than one person's viewpoint should be utilized in the product definition stage of the design process. The following is a summarization and discussion of the finalized list of design requirements for the device.

Any design requirement that, if not addressed during the design process, would deem the product undesirable by any potential consumer is considered a primary design requirement. These requirements should be of utmost importance in uncovering the product definition and limitations; these requirements must be met in order to make the product functional. The secondary design requirements, if met, deem the product more desirable than if the product only meets the primary design requirements.

2.2 Primary Design Requirements

(1) The device must not permanently alter the instrument in any fashion. It must be kept in mind that one of the main goals of the development of this force reaction device is to aid in keeping the instrument in its original condition (i.e. as it was at the time of purchase). Any permanent alteration of the instrument would defeat the purpose of the device completely.

(2) The device must react any sudden jerks on the input cord and completely protect the wiring in the input jack. This states one of the two main specific objectives of the device. If the input cord is stepped on or jerked in any fashion during the performance, the device should isolate the input jack of the instrument from any resulting forces. Damage to the input jack of the instrument requires replacement of the wiring or even the input jack itself. This seemingly small repair can (and does) affect the overall character of the instrument's sound; the most important aspect of the original condition of the instrument is the original "tone" (i.e. sound). It is for this very important reason that the input jack must be protected from this type of damage.

(3) The surface finish of the instrument must be protected from the input cord. This states the other of the main specific objectives of the force reaction device. In order to keep the instrument in its original condition, the surface finish of the instrument must be maintained. One of the main causes of surface wear on the instrument is continual surface contact between the instrument body and the input cord. Therefore, the force reaction device should sufficiently keep the cord and instrument body from

coming into contact with one another.

(4) The device should be sufficiently small as to not affect the overall tonal quality of the instrument. Since the tone of the instrument is of great importance to the musician, any adverse effects to the sound of the instrument would prove to be a fatal design flaw.

(5) The playability of the instrument and the performance of the musician must not be inhibited by the device. Any discomfort or awkwardness brought on by the addition of this device to the instrument would deem the device undesirable by the consumer.

(6) The instrument must still fit in the carrying case¹. The carrying cases for the musical instruments under consideration are made to securely enclose the instrument and protect it from any damage during transportation. That is, the carrying cases are fitted to the shape of the instrument. The device must not in any way pose problems in fitting the instrument into the carrying case; such a design flaw would deem the product completely undesirable. Therefore, the device must be (a) either sufficiently small such that, when attached, the instrument still fits in the carrying case or (b) easily and very quickly removable.

¹This design requirement was discovered through a discussion with another musician. It was completely overlooked initially.

2.3 Secondary Design Requirements

(1) The device must be easily attachable to the instrument. Simplicity of attachment is desirable such that all potential customers can use the device. Not all customers can afford to pay a technician to install the device for them.

(2) The design of the device must be adaptable such that different brands and style of instruments can be accommodated. It is desirable that one design be an effective product for all instruments which could benefit from the device. However, if this is not feasible then it is desired that minimal changes need be made to a basic design to encompass use on different brands and styles of instruments.

(3) The input cord must be easily secured with the device. For the device to be desirable, it must be easy to use. Since a musical performance can be a somewhat hectic situation in itself, the use of the device needs to be as simple as possible as to not add any difficulty to the situation. For example, if a musician breaks a string on the instrument in the middle of a song, the instrument must immediately be swapped with another. Since the same input cord is to be used on the "new" guitar, it must be easily removed and attached to the device on the "new" guitar. It should also be kept in mind that the environment of a musical performance is generally void of bright light; therefore, the device should be easy to use in a somewhat darkened environment.

(4) The purchase price of the force reaction device should be as low as is feasible to make a reasonable profit. Although this statement seems to be obvious, there are several reasons why the purchase price should be as low as possible. The main

reason does not involve "marketing strategy" or competition with a similar product. The main reason that this is desirable is because most musicians own several instruments. Since a single musician may use more than one instrument on a regular basis, more than one of the device would be needed. If the purchase of two or more of the devices is not feasible for the average salaried musician due to a high purchase price, then they (the musicians) might decide that they might as well do without the device altogether. For this reason an estimated sale price of 25 dollars or less is desirable for the device.

Another possible means of making the device affordable for those who might need more than one could be a modular design. That is, perhaps the means of attachment for the device could be sold separately as well as with the device. Therefore the musician could buy as many attachments as needed for the number of instruments owned; this would allow all of the musician's instruments to be accommodating of one device. Also, for this to be feasible, the requirement that the device must be easily attachable to the instrument is reinforced (i.e. secondary design requirement (1)).

(5) Both the locking and non-locking types of guitar straps must be accommodated by the device. Figures 2.1 and 2.2 show locking and non-locking type guitar straps, respectively. Since both types of guitar straps are highly used in musical performance, both types of the straps must be accommodated by the device. The type of strap used by the musician is simply a personal preference. It is desired that a single design be accommodating of both types of straps, rather than the design and manufacture of a device for each type of guitar strap.

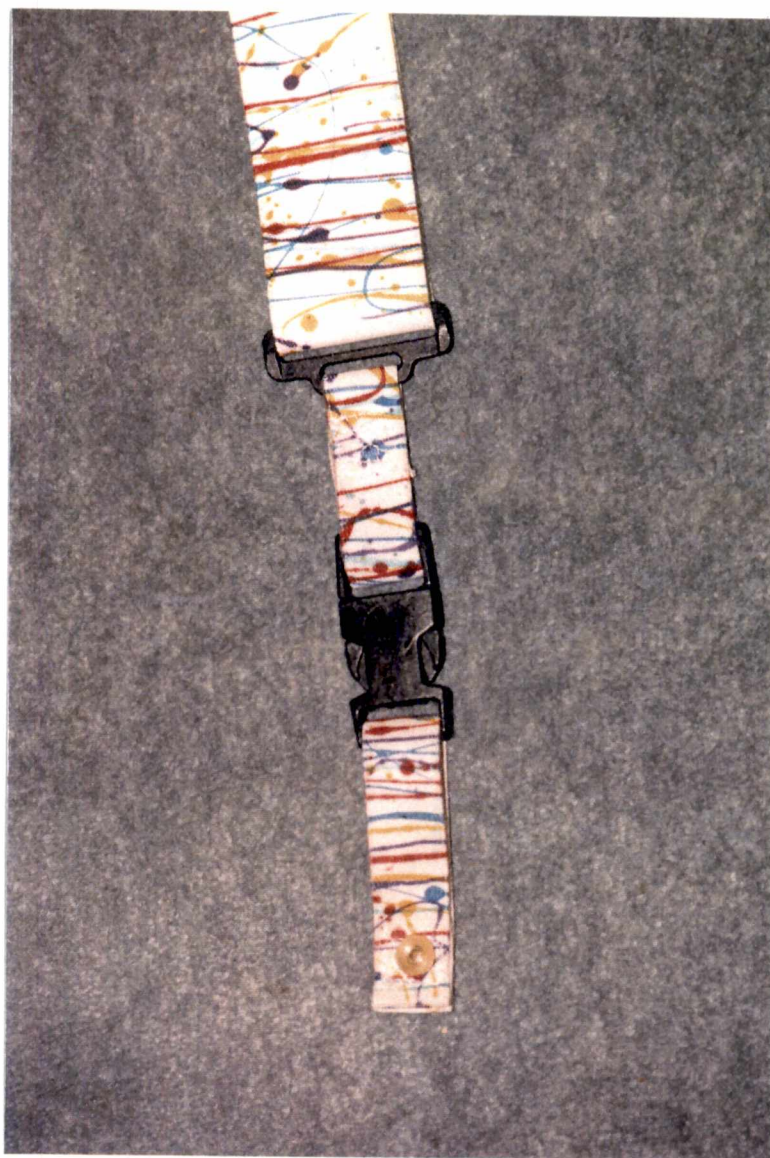


Figure 2.1 Locking Type Guitar Strap

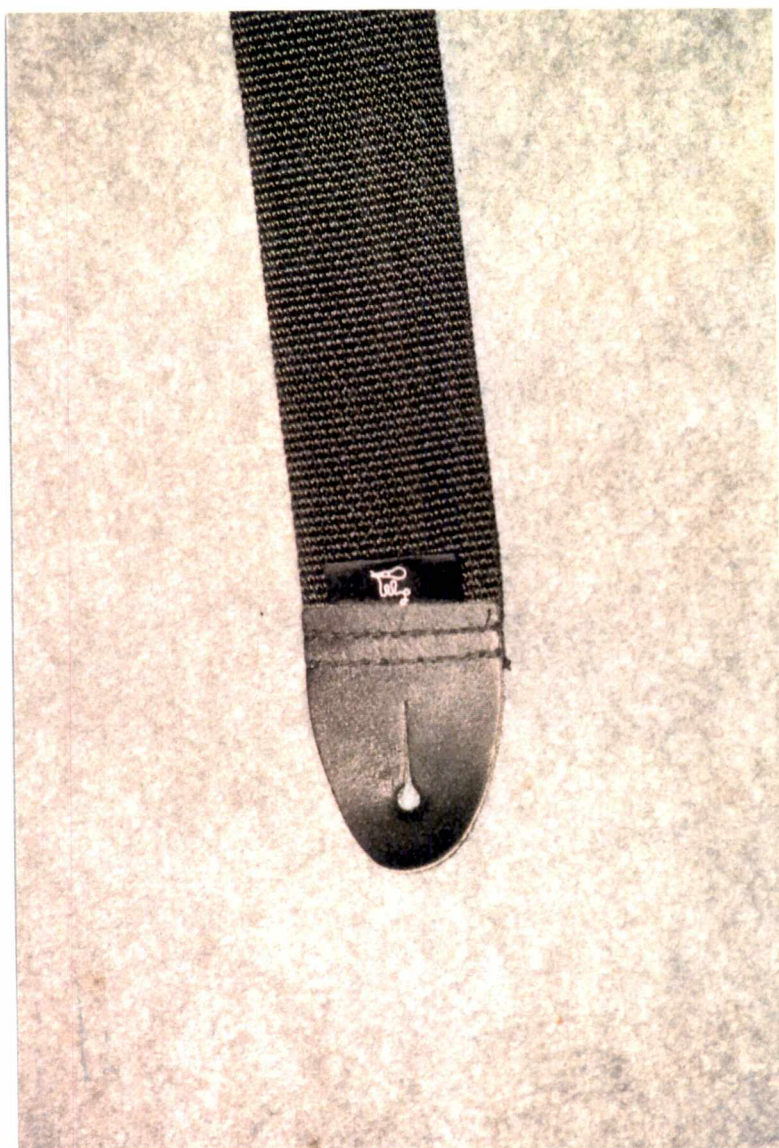


Figure 2.2 Regular ("Non-Locking") Type Guitar Strap

(6) **The appearance of the device should be neat and unobtrusive to the appearance of the instrument itself.** It is essential that the device not look like an "engineering contraption" to the consumer. It does not matter how well the device functions if it takes away from the appearance of the instrument. Instrument appearance is one of the factors the device is to maintain. The aesthetic factors of the design need to be fully addressed if the device is to be desirable.

The meeting of all of the above design requirements, both primary and secondary, is essential to make the product a functional *and* potentially desirable product. The design of the device should strongly encompass the primary design criteria in order to be *functional*. The secondary design requirements should be met in order to make the product *potentially desirable* by the consumer.

CHAPTER 3

CONCEPTUAL DESIGNS

3.1 Method of Attachment of Force Reaction Device to Instrument

The first primary design requirement states: "The device must not permanently alter the instrument in any fashion". This statement requires that the device be attached in a manner that is not in any way harmful to the instrument itself. After investigation into the possible means of attaching the device, it was concluded that the attachment could be achieved in one of two fashions:

(1) **The device could be attached to the instrument strap.** Since the cost of an instrument strap is much less than that of the instrument itself, the device could be designed such that it attaches to the strap; this would alleviate any attachment or permanent alteration to the instrument.

(2) **The device could be rigidly attached to the instrument at one of the locations of the strap buttons.** Figure 3.1 shows the location of the strap buttons on a typical instrument. The "front" strap button is located on the left "horn" of the instrument. The "rear" strap button is located at the center of the base of the instrument body. In the figure, the buttons are seen at the left and right extremes of the photograph. By using one of these locations, the instrument would not be permanently altered in any way. The strap buttons are held in position by a standard screw common to all types and brands of



Figure 3.1 Typical Instrument Showing Strap Button Locations

instruments. If the device could be attached by means of the same (or a similarly threaded) screw, then the attachment would meet the design requirement.

Possibility (1) was rejected for several reasons. First, an attachment to the guitar strap depends upon the strap and its connection to the instrument. In order for the force reaction to be effective, it must be assured that the instrument strap in use be firmly attached to the instrument. If the strap is *not* firmly attached to the instrument, then the possibility of a sudden jerk on the cord causing the strap to dislodge exists. This is one of the major problems that this design is supposed to eliminate. Therefore, an effective design in this manner requires a locking-type instrument strap. Since it is not wise to depend upon the consumer to continually use other components which are best suited for this product, the design would need to include the design of a guitar strap. This is not only out of the desired scope for the project, it is also an unwise undertaking. Even if the design was made to be part of an instrument strap, who is to say that the strap would be a desirable product? Being a musician, the author would not want the product because it requires the purchase of another strap. Since the personal preferences of the consuming public are of such a wide spectrum, it would be all but impossible to meet all tastes with a new product in this manner. Numerous aesthetic designs would need to be made in an attempt to meet all the personal tastes of the consumer. And, if those aesthetic preferences for the instrument strap were not met in some fashion, a consumer who could use the product would *decline to purchase*. It seems that it would be quite impossible to promote a new product in this manner. For these reasons, the attachment of the device to the instrument by means of the strap button screw was deemed the only feasible choice.

As seen in Figure 3.1, the strap buttons on a typical instrument are located at the front and rear of the instrument body. Since the strap button at the rear of the instrument is much closer to the cord input jack, this location was chosen for device attachment.

Primary design requirement (6) states: "The instrument must still fit in the carrying case". Since it was chosen to attach the device at the location of the rear strap button, the device must either be extremely small or easily removable. The form fitted carrying case has a very small area allotted to the accommodation of the strap buttons. Figure 3.2 shows an instrument in the carrying case. It can be concluded that the device cannot be made small enough to fit in this small space. Therefore, the device must be easily attachable and removable. To meet this requirement, a concept consisting of a male / female configuration was chosen. As long as the receptacle (i.e. female portion of configuration) is sufficiently small enough to fit in the space allotted to the rear strap button in the carrying case, it (the receptacle) may be rigidly attached to the instrument by means of the strap button screw. The use of the arrangement should not require any tools for attachment and removal of the device. That is, the receptacle should accept the male portion of the arrangement and the device without the use of tools of any kind.

The device, once attached through the use of the male/female arrangement, should be secure and basically motionless throughout the performance of the musician. Several concepts were considered for the specific means of attachment. These included (1) a quick release pin and receptacle arrangement, (2) a quarter-turn or half-turn screw and receptacle arrangement, and (3) a snap-fit arrangement.

After evaluation, the snap-fit arrangement was discarded due to concerns of



Figure 3.2 Typical Instrument in Carrying Case

accidental release of the device. If used, the snap fit would need to be very strong indeed to assure that no accidental releases take place. If the snap-fit arrangement was designed as such, then it would be difficult to remove the device when desired. Difficulty in removal does not meet the primary design requirement (6b).

Figure 3.3 shows an alternate configuration snap-fit that would, if properly designed, securely hold the device in place under all reasonable conditions. After the snap-fit ring is in place, a small cylindrical piece can be inserted through the center of the snap-fit ring in order to assure that it cannot come loose during performance. Although this design would work properly, it also was discarded for two reasons. First, the extra piece is not desirable since, if it is lost, the entire configuration would not work properly. It is desirable for this reason that there be as few integral pieces as possible. The second reason that this concept was discarded was concerned with manufacturing considerations. Use of this type of arrangement would require fabrication of a separate injection mold. Since the tooling expense for injection molding is very expensive, this would most likely raise the purchase price of the device to an undesirable level.

The other two concepts, on the other hand, could most likely be purchased. It is always wise to use existing parts whenever possible. It is almost always more expensive to fabricate a piece than it is to buy it. Of the two remaining concepts, the quick release pin arrangement is most desirable simply because it may be attached and removed more quickly than the quarter-turn (or half-turn) screw arrangement. For this reason, the quarter-turn screw arrangement concept was discarded.

Figure 3.4 shows the quick release pin and receptacle concept. The quick release

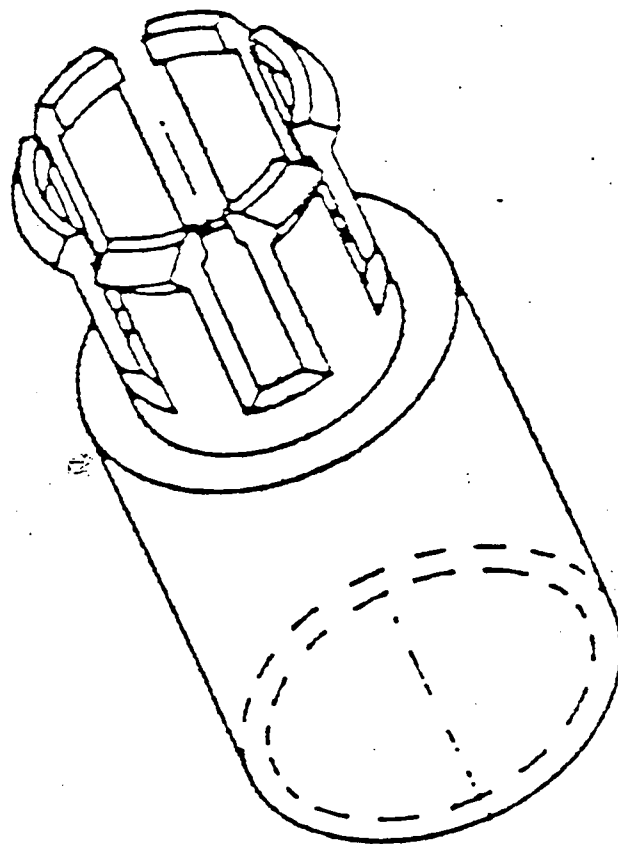


Figure 3.3 Sketch of Snap Fit Configuration Concept

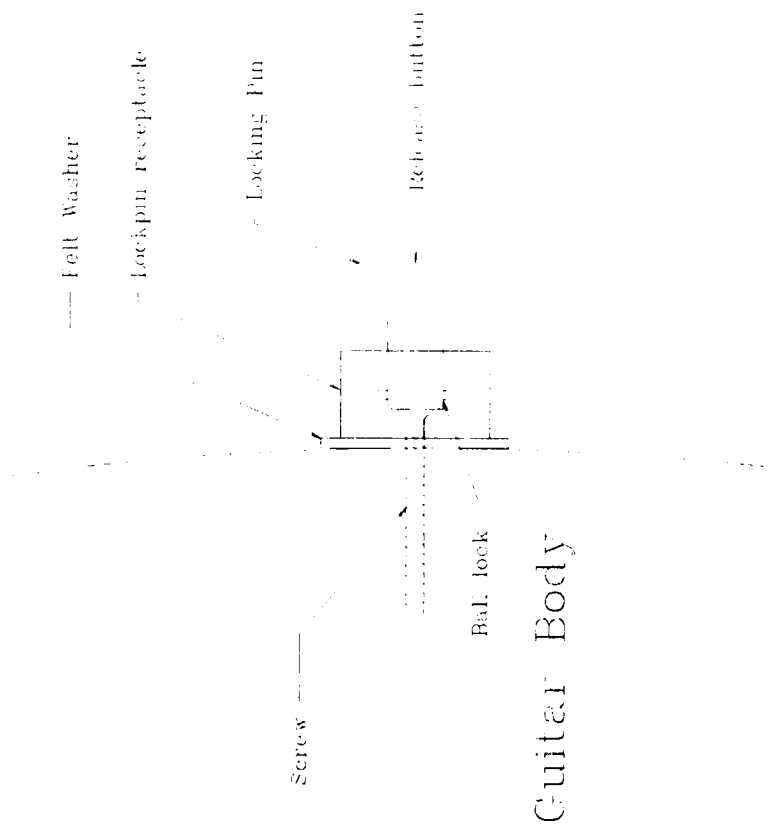


Figure 3.4 Quick Release Pin And Receptacle Concept

pin should be of the push button locking variety. That is, removal of the quick release pin requires that the button on the pin be pushed. This aspect of the design eliminates any chances of accidental release of the pin and attached device. When investigating the specifics of the quick release pin and receptacle arrangement, two primary design requirements must be recognized and satisfied. Primary design requirement (4) states: "The device must be sufficiently small as to not affect the overall tonal quality of the instrument". Also important is primary design requirement (5): "The playability of the instrument must not be inhibited by the device". These two statements dictate that the device and means of attachment be as small as possible. Therefore, the quick release pin must have a short grip length. Figure 3.5 shows a typical quick release pin with grip length GL. This also is important due to the requirement of fitting the instrument into the carrying case. Therefore, the grip length of the quick release pin must be less than approximately one quarter of an inch.

3.2 Force Reaction Device

The force reaction device must continually protect both the instrument's input jack and surface finish from any damage that the input cord might cause. In other words, to protect the input jack, the device must restrain the input cord from any type of motion at the point of the jack. In order to protect the surface finish, the device must keep the input cord away from the body of the instrument. These two statements are short summaries of primary design requirements (2) and (3).

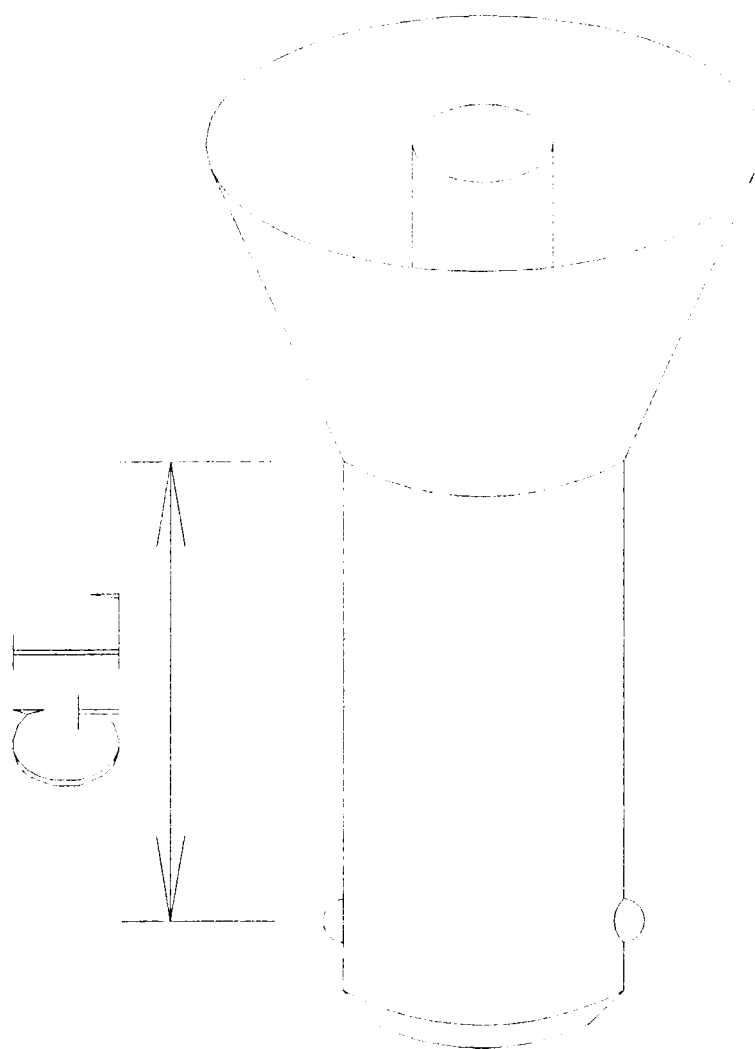


Figure 3.5 Typical Quick Release Pin with Grip Length GL

A few of the secondary design requirements are also important at this stage in the design. Secondary design requirement (3) states: "The input cord must be easily secured with the device". Likewise, the input cord should be easily removable from the device. Since the environment of use will most likely be somewhat darkened, the use should not require the aid of precise vision. Secondary design requirement (6) states: "The appearance of the device should be neat and unobtrusive to the appearance of the instrument itself". In other words, the device should look like a product and not like a "gadget". It should not in any way take away (or add to) the appearance of the instrument. This reinforces the need to keep the device as small as possible. A requirement which is important but has not been officially addressed is concerned with the condition of the input cord. The device should not harm the cord during use. In other words, the restraint of the input cord by the device should not induce damage to the condition of the cord.

Several concepts were considered for the force reaction device. When evaluating the different concepts, two important questions were asked for each design: (a) How well will it work? and (b) Does it look like a contraption? If the answers to these questions were not fairly convincing, then the idea was discarded. After investigating several ideas, two conceptual designs seemed most promising. The two ideas were very different but both had positive attributes.

3.2a First Conceptual Design for the Force Reaction Device

The first conceptual design originated from concerns with the cord slipping through the device. It was desired to prevent the cord from moving in the device in any fashion. Somehow, a device was needed that would tighten its grip if the cord began to move. It was this thought that made the concept for the first design come to mind. The concept will be referred to as the "Chinese Handcuffs" concept. Chinese finger handcuffs are a novelty item that are used for amusement. When a finger is inserted into each end of the finger handcuffs, it becomes immediately obvious that the fingers are stuck. If the "prisoner" tries to pull the fingers out of the device, the grip becomes even tighter. The principle seemed ideal for this application. A discussion with Dr. Frank Speckhart of the Mechanical and Aerospace Engineering department at UTK clarified the principles behind the concept. Figure 3.6 shows a schematic of the basic principle behind the Chinese finger handcuffs. This schematic is a representation of how the principle might be used to advantage in this application. Notice that a horizontal pull on the cord in either direction causes the opening on the side of the pull to become smaller; this greatly increases the "grip" of the device. This should eliminate any motion on the side of the input jack. Although the original concept seemed very promising, a lot of modification would be needed to meet the design requirements. First, this arrangement seemed to pose potential damage to the surface of the instrument cord. When the "grip" tightens on the cord, the outer surface would most likely become damaged. This was the first drawback noticed. Secondly, the complexity of the arrangement brought forth concerns with manufacturing

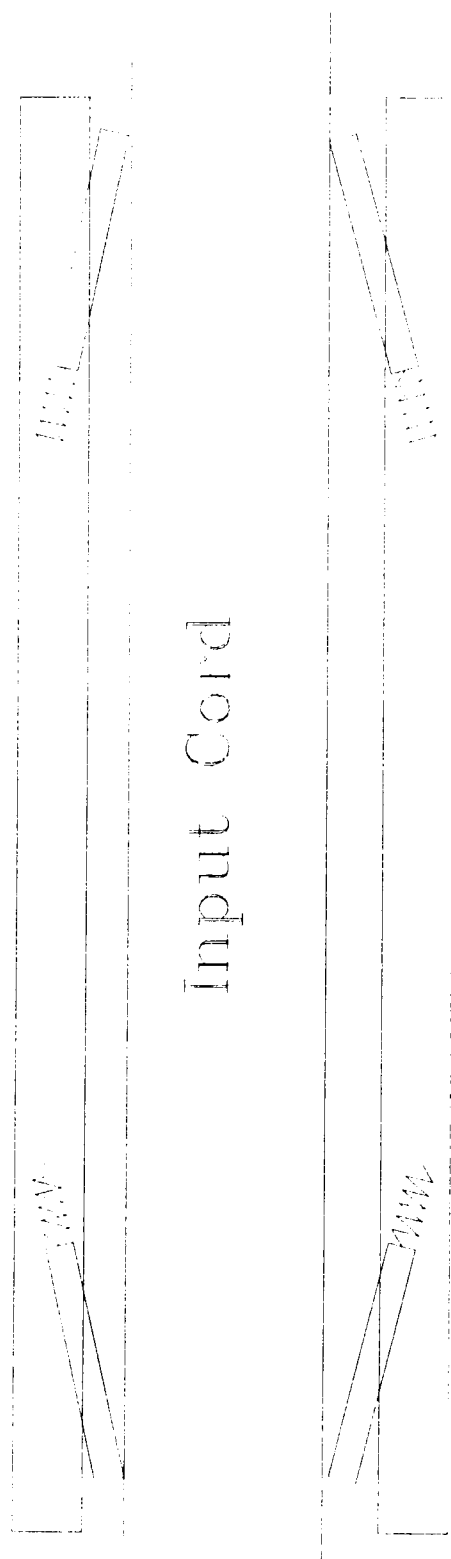


Figure 3.6 Schematic of Chinese Handcuffs Principle

and purchase price. If the Chinese handcuff principle could be used with a similar but somewhat more simple arrangement, then the concept would have more of a chance to meet all of the pertinent design requirements. Figure 3.7 (a) shows a much more simple variation of the Chinese handcuffs principle as applied to this situation. Shown in the figure is a cross-section of the arrangement. The cord runs through the device as before. The simplification has to do with the inner portion of the arrangement. Instead of spring fastened inner pieces, the arrangement is aligned with a soft, high-coefficient-of-friction plastic. Figure 3.7 (b) demonstrates the tightening effect as achieved by this arrangement. When the cord is pulled on either end, the soft, inner layer of plastic begins to group together at the end of the arrangement on the side of the pull. This increases the grip of the device in a similar manner to the first arrangement. Since this idea was much less complex than the initial idea, it seemed much more likely that the concept was feasible.

Once the first concept for the general means of holding the cord was developed, the conceptual design was further investigated to determine just how the cord was to be inserted and removed from the "clamping" device. The cylindrical shape of the clamping portion of the device would have to be somehow opened such that the instrument cord could be inserted. The reason for this is due to the fact that the cover on the end of the cord is approximately $\frac{3}{8}$ of an inch in diameter. This is where the cord is soldered to the jack. Because of this increase in diameter, the cord could not be "threaded" through the device. For this reason, it was decided that the clamping device would be split into two portions for insertion of the cord. These two portions could be hinged together and a snap-fit could be used to hold the arrangement shut. At this point it was obvious that

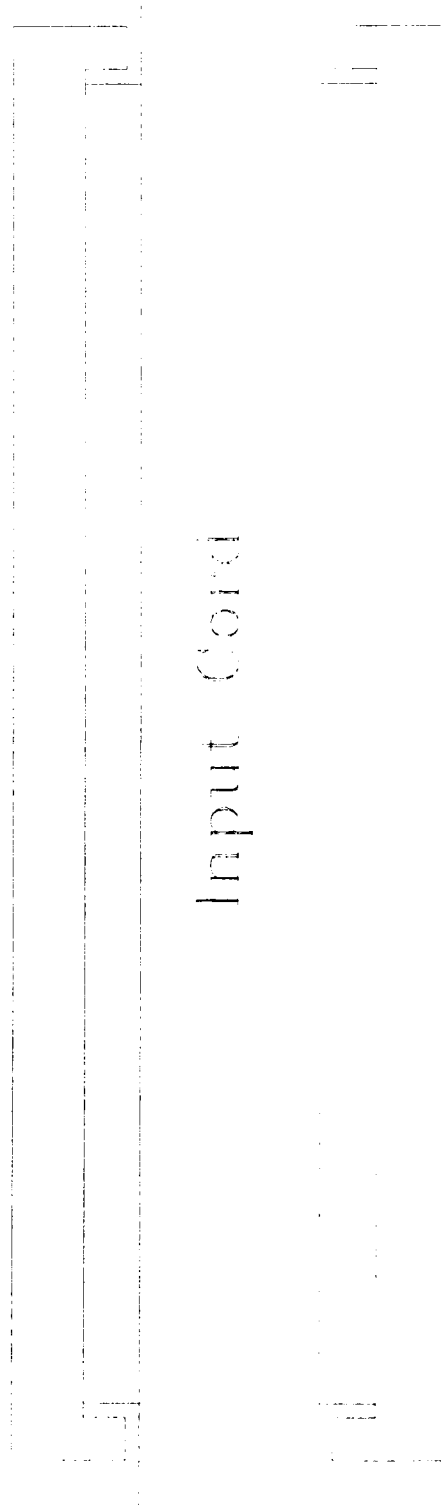


Figure 3.7 (a) Variation of Chinese Handcuffs Principle

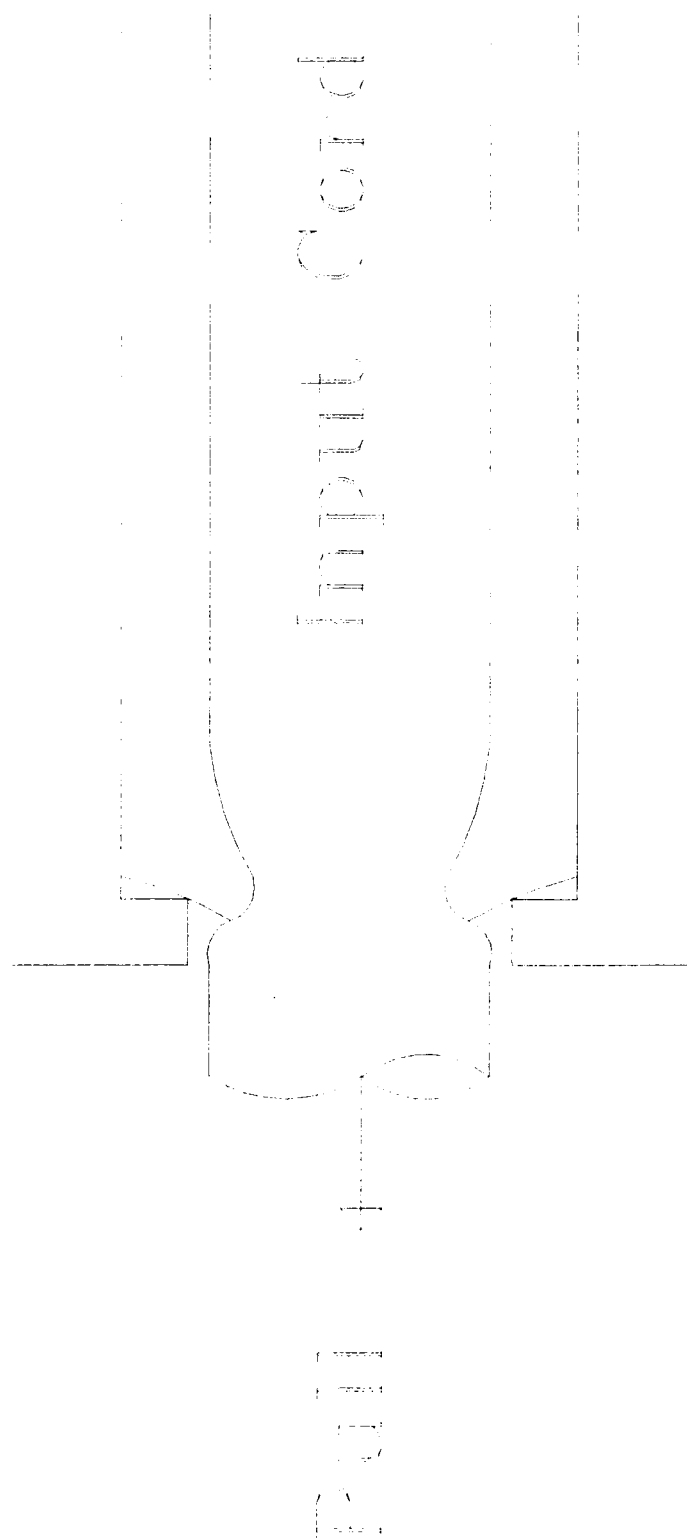


Figure 3.7 (continued) (b) Demonstration of Tightening Effect

the only feasible means of mass producing an arrangement of this fashion was injection molding.

A point of investigation arose concerning the specifics of the clamping device. First, a decision needed to be made as to where exactly the clamping device would open. Also, the type of hinge best fitted for the application would need to be determined. Figure 3.8 demonstrates a few possibilities. In (a) of the figure, the device is split into two halves along the horizontal diameter. This possibility was discarded due to concerns of a downward force on the cord causing the device to accidentally open. In (b) of the figure, the device is split into two halves along the vertical diameter. This possibility was also discarded due to concerns with accidental opening of the device. This arrangement also seemed too dependent upon the strength of the hinge. In an effort to provide more strength against a downward jerk on the cord, the arrangement in (c) of the figure was considered. This arrangement is also split into halves along the major diameter as in (a) with one major difference. The connection link to the instrument is part of the lower half and not the upper half as in (a). This small change allows the downward force to be reacted at the point of connection to the instrument (i.e. at the quick release pin arrangement). Still, a few concerns with the placement of the hinge needed to be addressed. The hinge could be placed at either the front or back side of the arrangement as shown in Figure 3.8 (c). At this point it was realized that the best way to split the clamping device would be to split it into portions of $2/3$ and $1/3$. This concept is shown in Figure 3.9 (a). With this arrangement, the hinge does not play a role in the force reaction; it simply connects the two pieces together. Also, the entire arrangement can be

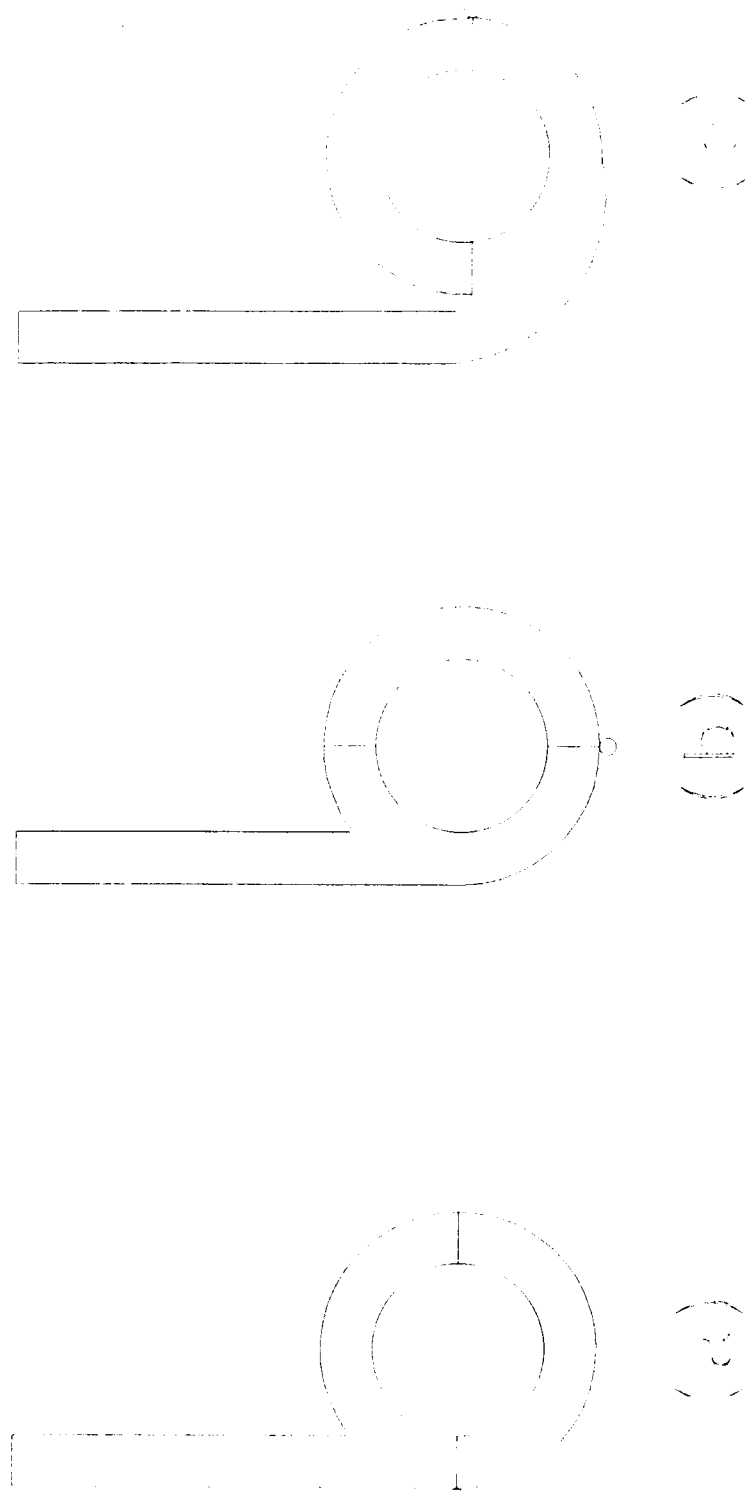


Figure 3.8 Various Concepts for Splitting of Clamping Device

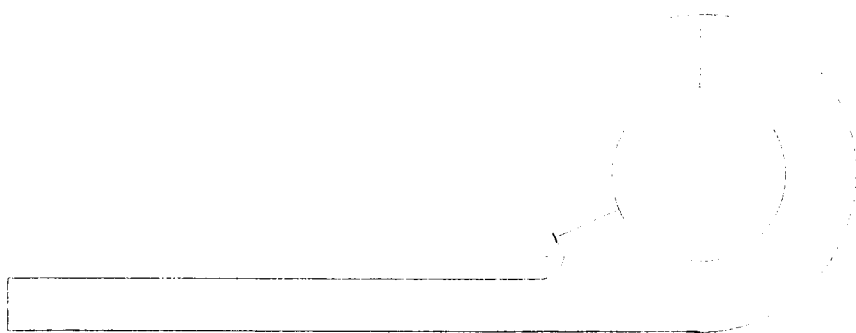
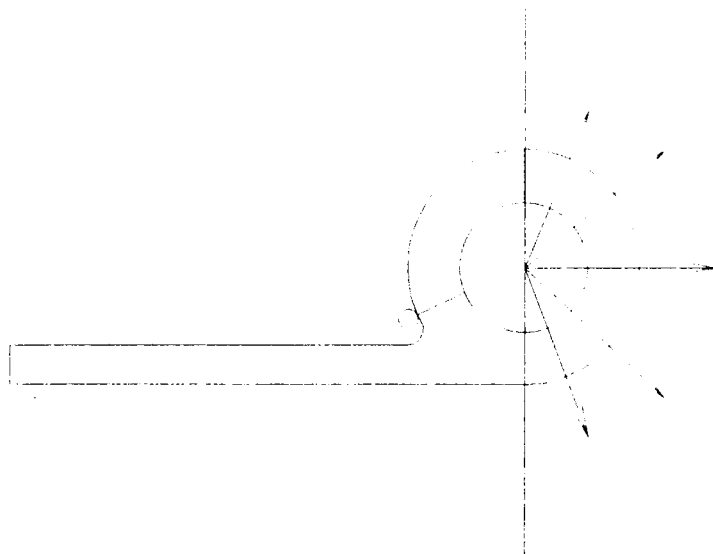


Figure 3.9 (a) Choice of Split for Clamping Device (Concept #1)

moved closer to the instrument body with this configuration. It must also be noted that all possible directions of the forces on the cord are below the horizontal diameter of the clamping device. This is demonstrated in (b) of Figure 3.9. The worst case scenario put the force in direct line with the horizontal diameter; this is all but impossible since the cause of any forces in the cord comes from stepping on the cord by one of the feet of the performing musician.

The only other decision that needed to be made for this basic concept was the type of hinge to be used. Recalling that the method of fabrication would be injection molding, it was considered to use an appropriate material such that an integral hinge could be molded into the clamping device. An example of an integral hinge (i.e a hinge that is molded into the part) is a standard video cassette case. The only feasible material that will yield an integral hinge with a satisfactory life (i.e. resistant to cyclic or fatigue failure) is a polypropylene (PP) resin. This idea was discarded due to concerns that the hinge would not be able to support the compression of the soft inner plastic over the input cord. For this reason, the simplest concept for the hinge would be the use of a small pin to hinge the two parts together. This would require two separate injection molds and a secondary operation to insert the pin. The complexity of this concept was becoming a concern at this point. However, the final conceptual design for the first idea is shown in Figure 3.10.



Directions of Pulling Force

Figure 3.9 (continued) (b) Some Possible Directions of the Pulling Force

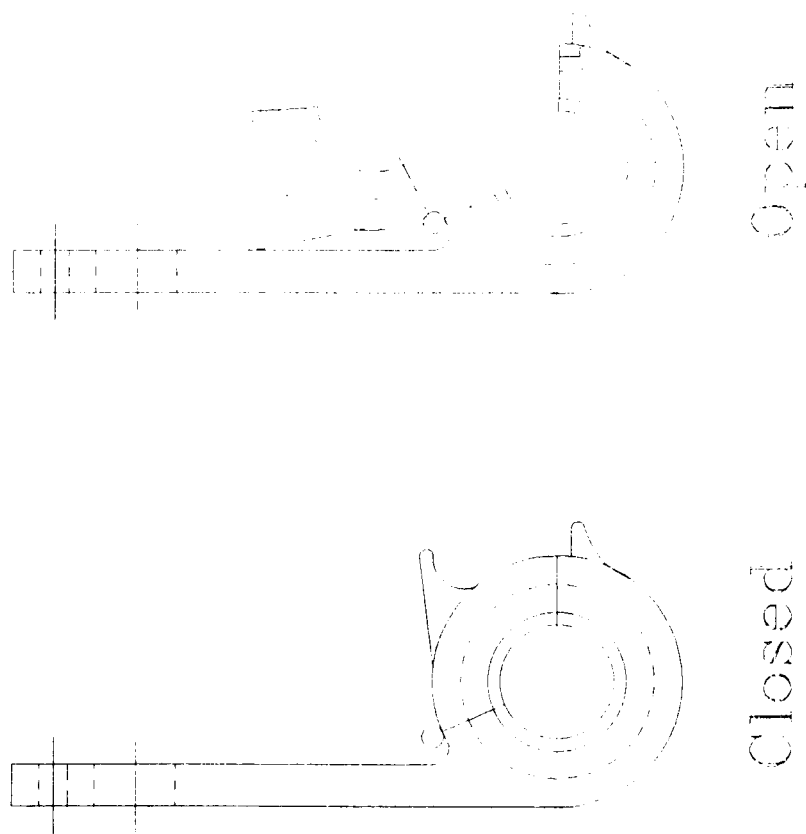


Figure 3.10 Sketch of Final Conceptual Design For Concept #1

3.2b Second Conceptual Design for the Force Reaction Device

The second conceptual design arose from concerns with the complexity of the first concept. Although simplifications had been made, it still seemed that the manufacturing expense of the injection molding process alone was enough to raise the purchase price of the device to an undesirable level. Also, with the conclusion that the line of action of the jerk forces would always be below the diameter, it was questioned as to whether the soft inner plastic was really an essential component of the design. To investigate this aspect, a few simple calculations were performed using the following equation:

$$\frac{T_A}{T_B} = e^{\mu\theta}$$

T_A and T_B represent tensions at two different points in the instrument cord as it is wrapped around an angle θ . The variable μ represents the coefficient of friction between the cord and the surface with which it is in contact. This equation can be applied to this application using Figure 3.11. The figure shows a sketch of the front view of the first conceptual design along with a schematic of the arrangement of the forces on the cord. Referring to the figure, the following equation relates the tension just inside the clamping device, T_2 , to the tension caused by a sudden jerk of the cord, T_1 :

$$\frac{T_1}{T_2} = e^{\mu\theta_1}$$

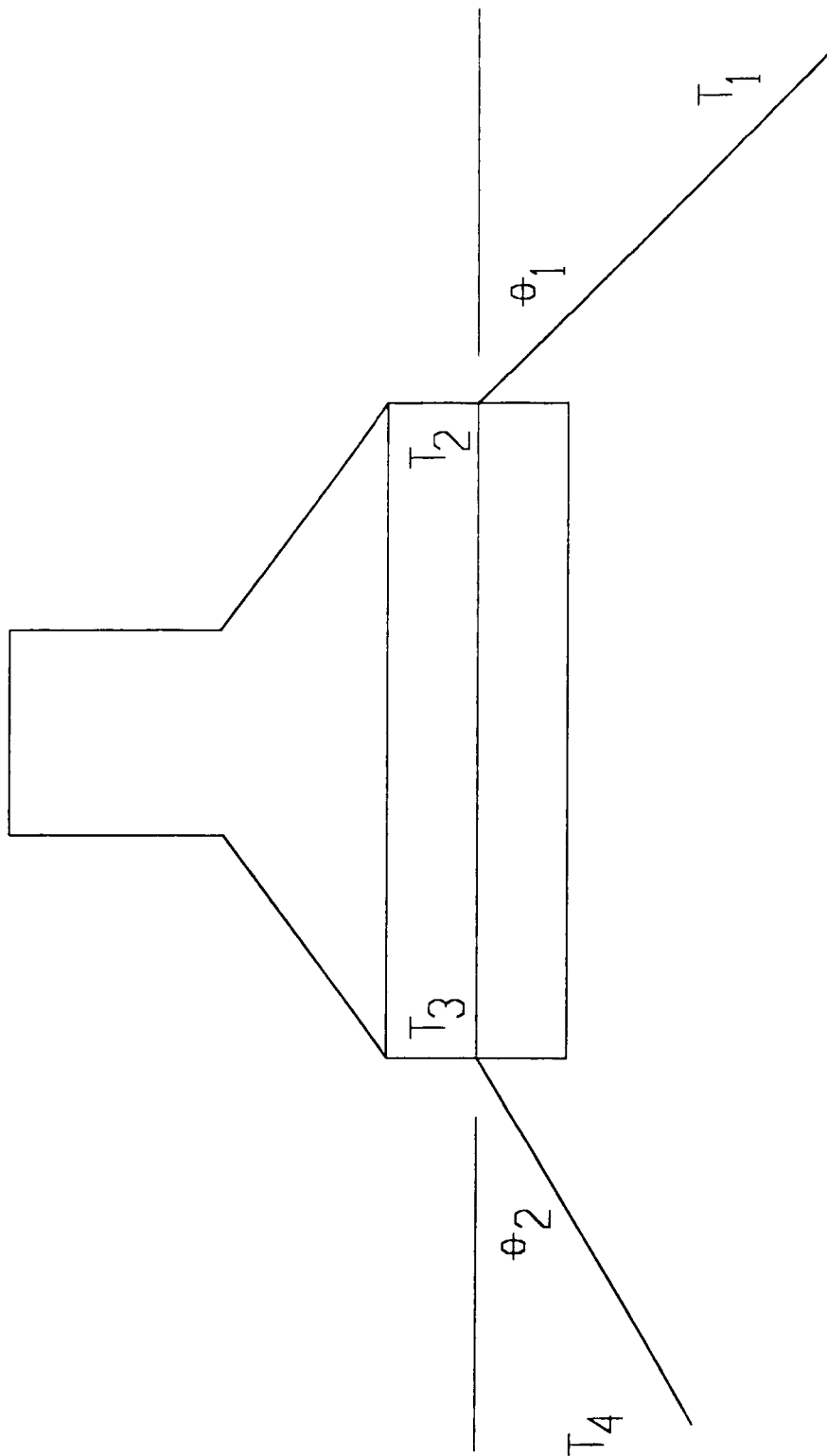


Figure 3.11 Investigation of Forces

where θ_1 is the angle between the two forces. The tension on in the cord just inside the other side of the clamping device, T_3 , can be found with the following equation:

$$T_3 = T_2 - \mu PA.$$

The variable P represents the pressure exerted onto the cord by the clamping device, and the variable A represents the area of contact between the cord and the clamping device. Finally, the tension on the portion of the cord on the input jack side of the clamping device can be found by once again using the initial equation...

$$\frac{T_3}{T_4} = e^{\mu\theta_2}.$$

It can be concluded from these calculations that $T_4 \ll T_1$. To demonstrate this, a sample calculation can be performed. Assuming $T_1 = 10$ lbs, $\mu = 0.5$, $\mu PA = 1$ lb, and $\theta_1 = \theta_2 = 60^\circ$, the value for T_4 is found to be approximately 2.9 lbs. From this, it can be seen that the soft inner plastic is not an essential element of the conceptual design.

The expense of injection molding initiated an investigation into designing a device which could be made by a less expensive means of fabrication. The method which seemed most feasible for a plastic part was an extrusion process. The use of extrusion requires a uniform cross-sectional profile. As discussed earlier, if the cord is to be completely enclosed within the clamping device, the device must be split in some fashion such that the cord may be inserted. Since this could not be fabricated using extrusion,

it was questioned as to whether or not the cord needed to be completely enclosed. Upon examination, it was realized that the upper portion of the device that is hinged to the lower portion only provides a slight increase in the inner surface area that is in contact with the cord. Therefore, it only offers a very slight increase in the frictional force provided by the clamping device. Due to this fact, this aspect was also concluded to not be an essential component of the design.

Even though the theory was convincingly stating that the upper portion was not needed, it seemed appropriate to build a basic prototype to demonstrate that the cord only needed to be partially enclosed in order to be held securely. This was an important factor; if this was true, then the part could be fabricated by means of extrusion. As a crude means of investigating the situation, a length of 0.5 inch diameter polyvinylchloride (PVC) rod was purchased and machined to the specifications shown in Figure 3.12. A 0.25 inch diameter hole was drilled through the center of a two inch long segment of the rod. A 90° segment was cut out of the cross-section of the piece. Once the piece was received, it was found that there was not significant gap available in order to insert the 0.25 inch diameter cord. Also, the rigidity of the PVC was too high to allow the gap to be flexed open for insertion of the cord. A simple calculation showed that the gap on the inside wall was approximately $\pi/16$ inches (approximately 1/5 of an inch). The gap was gradually increased by use of a file until the cord could be inserted. The required gap was determined with calipers. (note: the gap can still be less than 1/4 inch; the outer surface of the cord is a soft and slightly compressible elastomer). Once the cord was inserted, it was found that the theory had indeed been correct. Any reasonable force not

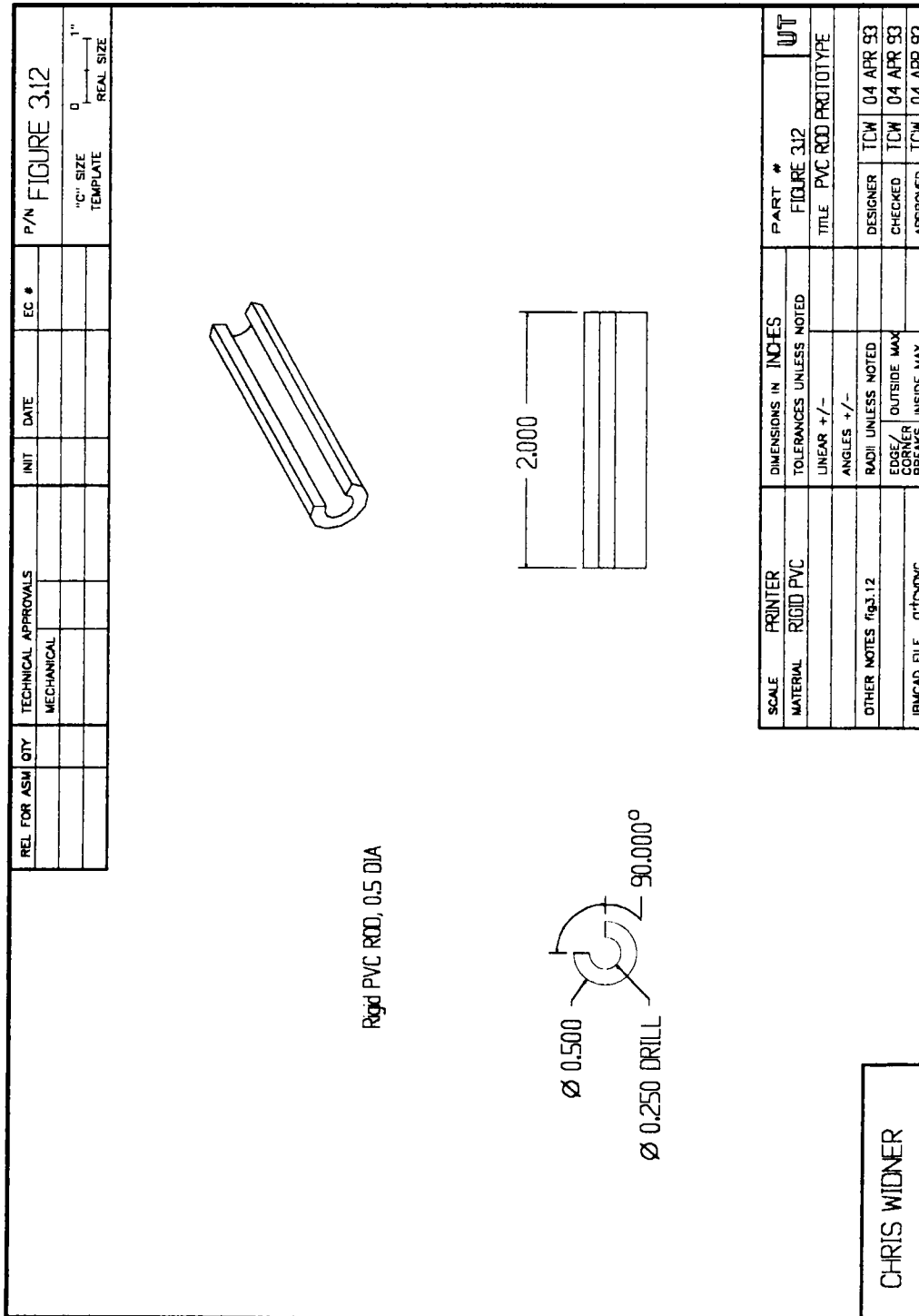


Figure 3.12 PVC Rod Machining Specifications

directly in line with the axis of the rod does not cause the cord to slip whatsoever. It can be concluded from this that the second conceptual design can be an extruded part. Figure 3.13 shows a sketch of the extrusion profile (i.e. cross-section) of the second conceptual design.

This conceptual design will obviously require a secondary manufacturing operation. Once the profile has been extruded, a machining process will be needed in order to finish the clamping device. This will include a machining process to cut the part out, and a drilling operation to drill the hole for the quick release pin. Figure 3.14 shows a sketch of the front view of the second conceptual design after the secondary operation.

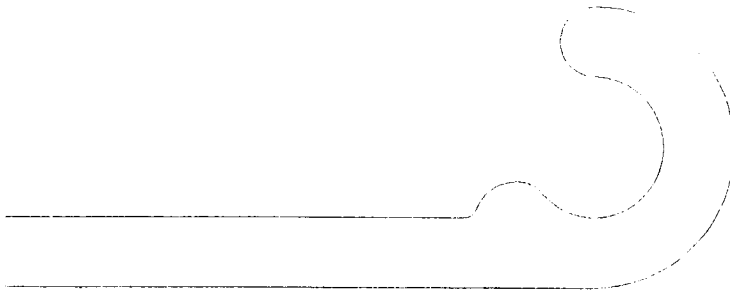


Figure 3.13 Conceptual Extrusion Profile
(Concept #2)

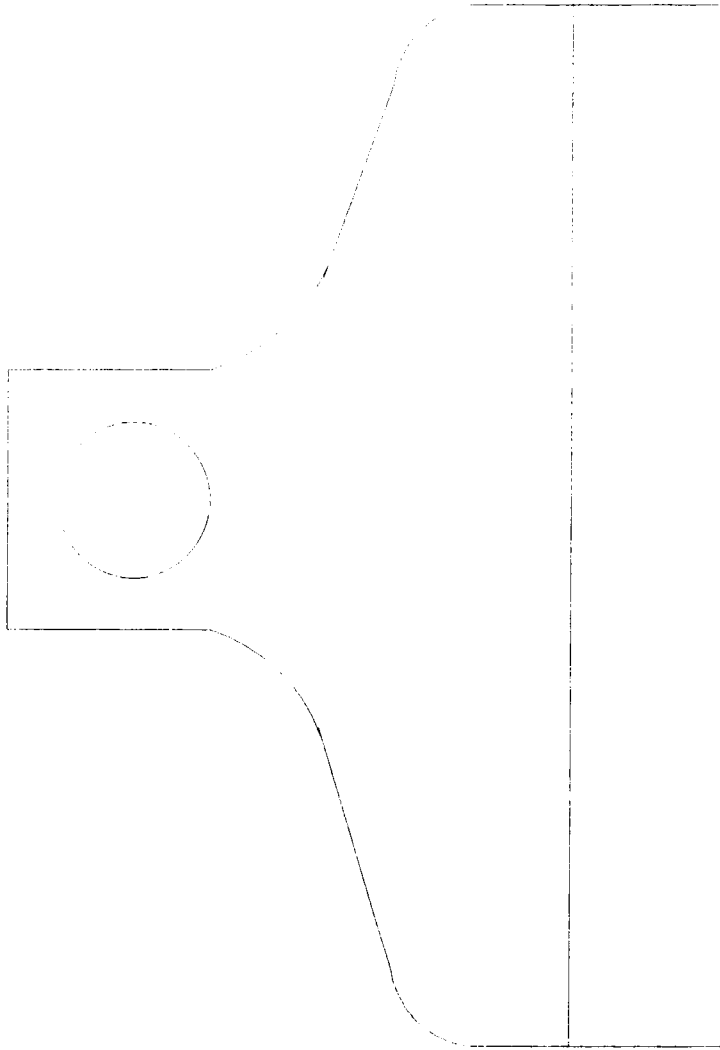


Figure 3.14 Front View of Concept #2

CHAPTER 4

FORMAL SELECTION OF CONCEPTUAL DESIGN

4.1 Overview

At this point, two major conceptual designs have been introduced. As an aid to assure the correct selection of the best conceptual design, a formal concept evaluation was used. Each of the design requirements, both primary and secondary, were addressed for each conceptual design. The evaluation process is of a nature as described by Stuart Pugh in his book Total Design. Once all of the design requirements have been addressed, the results of the evaluation should verify which conceptual design is most likely to successfully meet the design criteria and hold the inherent qualities and aspects which are proposed to yield a potentially successful product.

4.2 The Concept Evaluation Process

The evaluation process, for this study, was divided into two sections. The sections are comprised of evaluations of the conceptual designs as they pertain to (a) the primary design requirements, and (b) the secondary design requirements. For each of the evaluations, a matrix is arranged to provide a visual representation of the comparison between each of the conceptual designs; each of the conceptual designs are compared

concerning the satisfaction of the design criteria. The matrix is arranged in the form of a table. The headings of the columns designate each of the conceptual designs. The first column (or row headings) designate each of the design requirements.

The comparison of the conceptual designs are denoted by symbols which describe how well the design criteria is met for each of the concepts. If a concept better meets a design requirement than the other concept, then this is noted with the symbol of "+". Conversely, if a concept does not meet a design requirement as well as another concept, then this is denoted with a symbol of "-". If the concepts do not differ significantly as to how well the design requirement is met (or if there is any doubt as to which concept is better), then this is denoted with the symbol "S" meaning "SAME". In both of the evaluation tables, the last three rows are summations of the results.

It should be noted that the comparisons serve only as a means to guide the designer to the best conceptual design. Pugh stresses that "Under no circumstances should the results (i.e. the +'s, -'s, and S's) be considered absolute..."; therefore, the results should not be summed algebraically.

In an effort to re-emphasize that the primary design requirements are of utmost importance, the evaluation of the performance of the conceptual designs against the *primary* design criteria is assumed to carry twice the importance of the *secondary* design requirements and thus is given a weighting factor of 2. In other words, the primary design requirements are assumed to be at least *twice* as important as the secondary design requirements. When the results of the two evaluations are investigated, a result in the *primary* design requirement evaluation will be considered *at least equivalent to two*

similar results in the *secondary* design requirement investigation. It is re-emphasized that this tactic serves only as a *reminder* to the designer as to the importance of the primary design requirements; the results should *not* be considered absolute.

4.3 Concept Evaluation : Primary Design Requirements

Table 4.1 illustrates the results of the concept evaluation against the primary design requirements. The table shows that the two conceptual designs are very similar in their meeting of the primary design requirements, with one exception. Primary Design Requirement (2) states: "The device must react any sudden jerks on the input cord and completely protect the wiring in the input jack". When the two conceptual designs are compared for this design requirement, the first conceptual design, which is based on the Chinese handcuff principle, better reacts sudden jerk forces with a line of action along the axis of the cylindrical portion of the clamping device. The two conceptual designs behave similarly for all other lines of action of the jerk force. As investigated during the development of the second conceptual design, (i.e. the design for extrusion), the line of action of the jerk force is *not* generally along the axis of the clamping device. In other words, the probability of a situation occurring in which the first conceptual design will provide a better reaction of the jerk force is *very* small. This was kept in mind as the results were noticed. However, at this point, the results will stand with the advantage given to the first conceptual design. The symbol "2+" serves as a reminder that the primary design requirements are of utmost importance.

Table 4.1 Concept Evaluation Matrix: Primary Design Requirements

Criteria	Concept #1	Concept #2
Alteration to instrument	S	S
Reaction of Jerk Forces	2+	2-
Protection of Finish	S	S
Size of Device	S	S
Affects Playability?	S	S
Accommodation of Case	S	S
Σ "+"	2	0
Σ "-"	0	2
Σ "S"	5	5

4.4 Concept Evaluation: Secondary Design Requirements

Table 4.2 illustrates the results of the concept evaluation against the secondary design requirements. The conceptual designs are similar with respect to secondary design requirements (1), (2), and (5). The differences between the two conceptual designs are discussed as follows:

Secondary design requirement (3) states: "The input cord must be easily secured with the device". The extrusion design better meets this design requirement in that there are no latches to open. With the first concept, a snap-fit cylindrical "hatch" must be opened for the cord to be inserted. Because of the sometimes inherent darkness of a musical performance environment, this is of concern.

Secondary design requirement (4) states: "The purchase price of the force reaction device should be as low as is feasible to make a reasonable profit". The extrusion design carries great advantage over the Chinese handcuff design when this design criterion is addressed. Since the Chinese handcuff design requires injection molding as the means of fabrication, the manufacturing cost, due mostly to the initial investment in tooling, greatly exceeds that of the extrusion design. This significant increase in tooling expense would no doubt force the required purchase price of the device to an undesirable level. For this reason, *the extrusion design is significantly advantageous in meeting this particular criterion.*

Secondary design requirement (6) states: "The appearance of the device should be neat and unobtrusive to the appearance of the instrument itself". Due to the small size

Table 4.2 Concept Evaluation Matrix: Secondary Design Requirements

Criteria	Concept #1	Concept #2
Attachment to instrument	S	S
Adaptable Design	S	S
Ease of Securing Cord	-	+
Posed Purchase Price	-	+
Compatible to Both Types of Straps	S	S
Unobtrusive Appearance	-	+
Σ "+"	0	3
Σ "-"	3	0
Σ "S"	3	3

of the entire device relative to the instrument for both conceptual designs, neither of the concepts would be overly obtrusive to the overall appearance of an instrument. However, since the two conceptual designs are being compared to each other, it seems that the extrusion design has a more compact and simplistic appearance than the injection molded design. The simple aspect of the extrusion design seems to draw less attention to the eye; therefore, it is less likely to draw attention from the appearance of the instrument.

4.5 Final Selection of Conceptual Design

The results of the two concept evaluations show that the extrusion design seems to be the best overall conceptual design for this project. Although the extrusion design was "outranked" in the primary design requirements evaluation, it was discussed that the situation in which the extrusion design should be outperformed occurs only very rarely, if ever. The evaluation for the secondary design requirements was dominated by the extrusion design. The most significant area in which the extrusion design was advantageous was concerned with the potential purchase price of the device. The tooling expense inherent to the injection molded design made it undoubtedly much more costly to manufacture. The effects of this on the potential purchase price yielded the extrusion design much more favorable. It is interesting to note that the majority of the extra manufacturing cost for the first conceptual design is dedicated to the performance of the clamping device in the *very rare situation* of a jerk force in line with the axis of the clamping device cylinder. Since the occurrence of this event is very rare, designing for

this situation is basically a wasted effort and a wasted investment in the more expensive tooling. For these reasons, the extrusion concept was chosen as the final conceptual design.

It is probably apparent that this evaluation did not directly yield an absolute answer as to which was the best of the two conceptual designs. The assignment of a weighting factor for the primary design requirements was used to remind the designer that these aspects of the product specification were imperative to the proper function of the product. When evaluating the results of the two matrices, it can be seen that the second conceptual design had one more "+" than the first concept. A question that might be asked is: "What if a weighting factor of 4 was chosen for the primary design requirements?". This would have made the first conceptual design "favorable" as seen from the evaluation results; the first concept would have had one more "+" than the second concept. This re-emphasizes the point that these results should in no way be considered absolute. This is merely an organized method of assisting the concept selection process. That is, these results are used to *initiate* the concept selection. The final selection of the conceptual design by a design team should only be done after careful and repeated examinations of how well each concept meets the product design specification. The matrices can be a powerful tool for initiating this process.

CHAPTER 5

PROGRESSION OF THE DESIGN

5.1 Overview

With the conceptual design selected and frozen, attention could be focused upon the initiation of the specifics of the design. The basic dimensions of the clamping device along with the holding pin and receptacle were determined. A formal search for purchasing a feasible quick release pin was made. In an effort to gain a fresh and outside opinion on the clamping device, both an industrial designer and a manufacturing advisor were consulted. The recommendations made by both of these individuals proved to be most insightful toward the realization of moving the clamping device design toward a robust and appealing potential design component. The manufacturing advisor in particular offered great insight as to a first estimate of the cost of mass production of the clamping device. All of the above tasks are discussed in detail in this chapter.

5.2 Basic Dimensions for the Force Reaction Device

In order to work further upon the chosen conceptual design, the layout of the basic dimensions for the force reaction device needed to be estimated. The majority of these dimensions will remain unchanged throughout the design process. However, the critical dimensions (namely the gap in the clamping device) are to be analytically determined

according to (i.e. as a function of) the chosen material for manufacturing.

The quick release pin and receptacle were the first parts to be sized. The strap button on a standard instrument is attached with a 1.25 inch, #8 screw. The head size of the screw is $\frac{3}{16}$ of an inch (dimensions are approximate). The most important dimensions on the screw concerning the quick release pin receptacle are the maximum diameter of the screw and the size of the head of the screw. The screw is to be used to hold the receptacle in place. Therefore, a hole in the back of the receptacle will allow for the insertion of the screw and attachment to the instrument. The chosen dimensions for the receptacle for compatibility with the screw are 0.150 inches for the screw hole, and 0.275 inches for the inner diameter. Figure 5.1 shows a dimensioned sketch of the receptacle.

The clamping device should be dimensioned as small as is feasibly possible. Several of the design requirements demand this action. One consideration is the effect of the device on the instrument; this is stated in secondary design requirement (6): "The appearance of the device should be neat and unobtrusive to the appearance of the instrument itself". Reinforcing the requirement that the clamping device be relatively small is provided by two of the even more imperative primary design requirements. Primary design requirement (4) states: "The device should be sufficiently small as to not affect the overall tonal quality of the instrument itself". Since an increase in total mass on the instrument will affect the overall tone of the instrument, the device should be as small as possible. Primary design requirement (5) states: The appearance of the playability of the instrument and the performance of the musician must not be inhibited

by the device"--- another reinforcement for keeping the device as small as possible. For these reasons, the clamping device dimensions were set to basically "fit" the area of the instrument to which the device is to be attached. Most solid body instruments have a body thickness of approximately 2.00 inches; this number does vary, but this estimate is on the high side. The basic dimension for the base of the clamping device is chosen to be 1.75 inches such that the device will fit neatly within the thickness face of the instrument. For the overwhelming majority of instruments, this dimension will prevent any "overhang" of the device over the edge of the body, preventing any probability of the device aggravating the motion and performance of the musician. To appeal to the eye, the height of the device is chosen to be of the same magnitude as the width (base). The basic dimension for height is also initially chosen to be 1.75 inches. The thickness of the clamping device at the point of attachment is chosen to be 0.125 inches; this dimension is small enough to be unobtrusive but large enough to ensure that the device will have sufficient strength to withstand the forces exerted onto the cord. The holding portion of the device is tentatively set to also have a thickness of 0.125 inches, although this dimension may be decreased in order to reduce the amount of force required for insertion of the cord. A relatively stiff material such as polyvinylchloride (PVC) could allow the thickness of this portion to be reduced. The estimated range of thickness for this portion of the device is 0.0625 to 0.125 inches. Figure 5.2 shows a dimensioned sketch of the clamping device as predicted at this point in the design process.

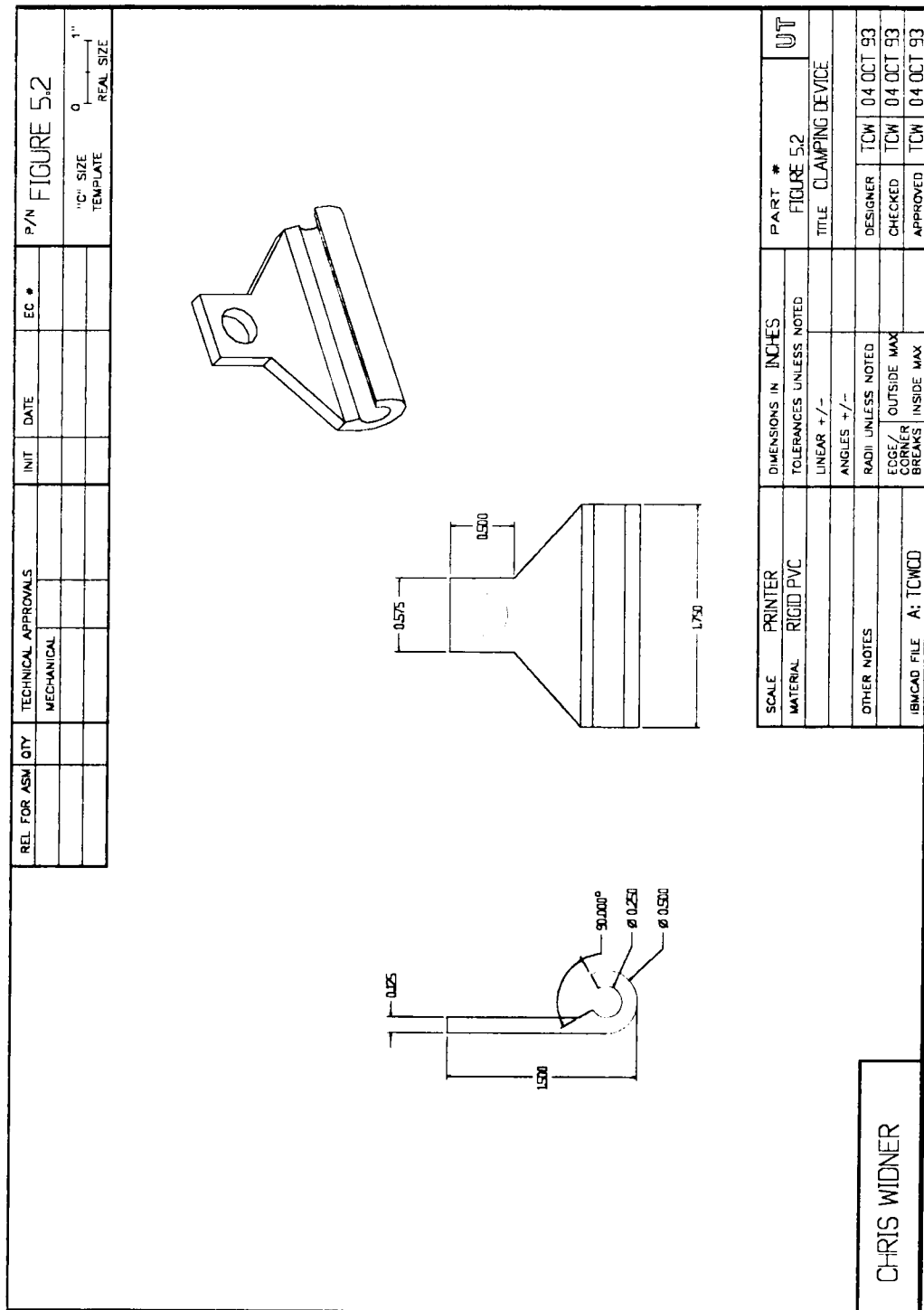


Figure 5.2 Dimensioned Sketch of Clamping Device (Preliminary Design)

5.3 Vendor Search for the Quick Release Pin Arrangement

In an attempt to keep the overall manufacturing cost of the force reaction device at a minimum, it is always wise to use existing parts whenever possible. For this reason, a search was performed for a vendor which could supply a quick release pin and receptacle compatible to this design. The quick release pin needed is of the push-button variety; that is, the pin will not release until the button is pushed. As mentioned in Chapter 3, the most important aspect of the quick release pin concerning compatibility with this design is the grip length of the pin. The grip length of the quick release pin must be less than 0.25 inches and it is preferred that this dimension be approximately 0.125 inches. This is required such that the instrument will still fit in the carrying case; the receptacle, which will house the quick release pin and the head of the screw that attaches the receptacle to the instrument, is continually attached to the instrument. The entire arrangement (i.e both the quick release pin and receptacle) should be as low in cost as possible in order to meet the goal purchase price for the product: less than \$25.00.

When searching through several vendor catalogs (consisting mostly of tooling companies), it was quickly discovered that most quick release pins are manufactured for much more demanding conditions. The majority of quick release pins available are made for such tasks as holding together machine components. Furthermore, all the quick release pins that were initially found had a minimum grip length of 0.75 inches; this is far too large for this design. Another discouraging factor was the purchase prices of the items: the minimum price found for the pin alone was around \$7.00. This is far too

expensive for the needs of this design.

At this point it seemed that the only feasible means of using a quick release pin for this project was to design one specifically to meet the design requirements. This was discouraging to say the least; the overall tooling cost for the project would undoubtedly be greatly increased. Just before this design work was undertaken, a discovery was made.

When talking with a close friend, a discovery was made that completely changed the course of this aspect of the design. A use for a quick release pin and receptacle can be found on a variety of key chains. This device is generally called a "key separator". These key chains generally consist of two key rings that are attached by a quick release pin and receptacle arrangement. This allows the owner to easily separate the two key rings whenever desired. Valet parking at a restaurant, for example, would be an instance where only the ignition key would need to be given to the parking attendant; this arrangement of the key chain allows the owner to separate the keys for this purpose. My associate had just such a key chain. Upon closer inspection, I found that the quick release pin arrangement satisfied all of the dimensional requirements for the design. The arrangement included the receptacle, which had an inner diameter of 0.275 inches, and a hole of 0.150 inches. The quick release pin had a grip length of 0.125 inches. All of these dimensions were *perfectly* compatible to the design dimensions. An inquiry was made concerning the cost of this key ring. The key separator belonging to my associate was a *free* gift at Engineer's Day on UTK campus from the IBM booth. There was also a pin flashlight on the key chain as part of the gift. This flashlight had the IBM logo embossed on the cover. Since this item was being given away, the cost of the item must

have been very low (at least lower than the earlier estimate of \$7.00 each).

This discovery initiated a new search for the quick release pin arrangement. Instead of searching tooling company catalogs, the arrangement was sought through marketing/advertising companies; the logo on the flashlight led the search in this direction. Upon meeting with an advertising firm in Knoxville, a database was used to find the exact key chain. Several days later, a bid was received from the advertising firm: 500 of the key chains could be bought for 80 cents each. Higher quantities of purchase would lower the individual cost by a few cents each.

It is remarkable to note that this "chance" discovery reduced the purchase price of the quick release pin arrangement by almost a factor of 10. Also, the savings versus designing a new arrangement specifically for this design is undoubtedly just as significant. It should be noted from this event that a designer should never close any doors concerning resources; undoubtedly, the best resources are often where they are *least* expected.

5.4 Conference with an Industrial Designer

Concerning the aesthetic factors of the clamping device, a conference was held with an industrial designer: Peter Lowe of Cimulate, Co. There are many advantages to meeting with an industrial designer at this point in the design process:

(1) A new perspective on the project is offered. Working for an extended period of time on a project can cause the engineer to become so focused upon the work

that new ideas are often never realized. This form of "tunnel vision" can be broken by a meeting such as this. An industrial designer is not an engineer; he/she deals more with the non-engineering aspects of the design work. If the technical side of a product design becomes almost overwhelming, an industrial designer can help to the engineer regain focus and realize that the end goal is indeed a product - not a numerical code or a stringent technical analysis.

(2) Aesthetic factors that can be overlooked by the engineer are a main focus of an industrial designer. Often, after a cumbersome technical analysis, the scale drawing of a part or product as it comes off of the desk of an engineer is anything but appealing to the eye. The engineer tends to think in terms such as "A thickness of xx.xx is needed here in order to provide a factor of safety of.....". In other words, the part will, from the engineer's point of view, look the way it does because of its function. The industrial designer can take a drawing of a part and work with the engineer to make it more appealing to the eye without degrading the structural quality of the part. The amazing fact is how *quickly* this process can take place.

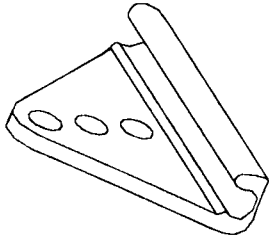
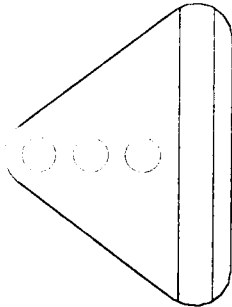
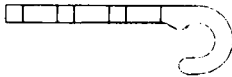
(3) Questions that may likely be asked by the consumer are often asked by the industrial designer. Anyone unfamiliar with a project will undoubtedly ask questions. It is doubly advantageous that a meeting of this type can bring out questions about the product that may have been overlooked. If this is the case, it is not too late in the design process to make appropriate changes. It is important to note that, if the conceptual design is indeed robust, these changes will be minor and will not require a change in the chosen (and hopefully frozen) concept.

(4) The experience of the designer offers invaluable insight to both the current and future projects. All designers with any "history" have had their share of good and bad experiences. The sharing of "war stories" can provide great help and insight towards design characteristics to "shoot for" and "avoid at all costs". With special respect to aesthetic factors, an industrial designer can point out, on any given product (present or past), aspects of the design that will appeal to or disappoint the consumer.

In all honesty, the advantages of meeting with an industrial designer were immediately obvious at the time of the meeting. However, within less than an hour of talking with Mr. Lowe, several extremely beneficial bits of advice were offered. In fact, the author was amazed at the quantity and quality of the advice offered. Upon entering Mr. Lowe's office, a CAD sketch of the clamping device as it had been designed was presented. A photocopy was made of the drawing, and the product was discussed. Through a series of simple questions, Lowe began to understand (within minutes) the basis for the need and function of the product. Lowe began to smooth the rough edges of the drawing while continually asking questions. Changes that could alter the structural quality of the part were avoided. Figure 5.3 shows a new sketch of the part with Lowe's recommended aesthetic changes.

All of the changes that were made were concerned with only the aesthetic factors of the design. All of the corners were rounded, and the part was given a triangular shape. The introduction of the additional holes were also only for appearance. These few changes were found to be exciting; This rejuvenated the work. It is apparent that this new appearance for the clamping device would never arise from any form of technical

REL FOR ASM		QTY	TECHNICAL APPROVALS		INIT	DATE	EC #	P/N TCW CD	

SCALE	NONE	DIMENSIONS IN INCHES		PART #	UT
MATERIAL	RIGID PVC	TOLERANCES UNLESS NOTED		TCW CD	
		LINEAR +/-		TITLE NEW PROFILE	
		ANGLES +/-			
OTHER NOTES	RADIO UNLESS NOTED				
	EDGE/ CORNER BREAKS				
IBMCAD FILE	A:TCW3D	INSIDE MAX		DESIGNER	TCW 10 JUN 93
		OUTSIDE MAX		CHECKED	TCW 10 JUN 93
				APPROVED	TCW 10 JUN 93

CHRIS WIDNER

Figure 5.3 Sketch of Clamping Device with Lowe's Recommended Changes (Preliminary Design Concept)

analysis. The part still can perform its function, but now it has an appearance that is appealing to the eye. In other words, the part now has "function and *form*". A meeting such as this is both an imperative and enjoyable experience.

5.5 Conference with a Manufacturing Firm

Once the changes from the meeting with the industrial designer had been made, some initial advice concerning manufacturing was needed. Specifically, Dr. E.S. Clark, Professor of Material Science Engineering at UTK, discussed the fact that special precaution must be taken when designing a die for extrusion such that the critical dimensions of the part will stay within the desired tolerance ranges. The most critical dimension on the clamping device is the gap wherein the cord is inserted. Since this gap is to be less than the diameter of the cord, a certain force will be required to deflect the device (and the cord) and allow the cord to be inserted into place. The insertion force is dependent upon the available gap and the properties of the material. It is desired to set an approximate value for insertion force and use the resulting gap (depending upon the chosen material) as an integral part of the design. For the purpose of a conference with a manufacturing firm, a reasonable value was assumed for the gap such that a scale drawing could be made. Mark Burton, an engineer with the Vinylex Corporation, was contacted by phone; the basis of the design was explained. After the discussion, a scale drawing and cover letter were sent to Vinylex by FAX.

The response of Vinylex consisted of several comments. First, the tolerance was estimated as $\pm .010$ inches on the critical gap and inner radius dimensions of the device. Vinylex warned that it may be fairly difficult to punch out the front shape of the device due to the material thickness. It was also warned that punching a hole other than a standard size could be expensive since this would require the manufacture of a custom punch. The other comments were concerned with material selection; for this design, the engineers at Vinylex were favoring the same material of which the prototype had been made: rigid polyvinylchloride (PVC). This was due mostly to the specified hardness and material property ranges. The comments were concerned with environment temperature, light, conditions etc.-- none of which were a problem for this design.

Assuming that a standard rigid PVC was suitable, the tooling costs were estimated as follows:

EXTRUSION TOOLING: \$1200.00

FABRICATION TOOLING: \$3500.00

Table 5.1 shows the estimate from Vinylex of the manufacturing cost for the clamping device. This estimate shows that, if Vinylex is chosen as the company for manufacturing, an initial investment of \$4700.00 will be required for tooling. Above that, for a minimum release of 15,000 pieces, the cost per clamping device will be approximately 8 cents each.

Table 5.1 Manufacturing Cost for the Clamping Device

(VINYLEX Estimate)

MINIMUM RELEASE	PRICE PER THOUSAND PIECES
15,000	\$79.71
30,000	\$59.71
60,000	\$51.37
120,000	\$48.87
240,000	\$47.62
480,000	\$47.00

TOTAL INITIAL INVESTMENT: \$5,895.65

Although the dimensions were only estimated in the drawing sent to Vinylex, the only dimensions subject to major change are the gap and the thickness of the ring. If the sale price is approximately \$20.00, the initial investment would be recovered (simple payback) after a sale of approximately 300 pieces. The estimated price of \$20.00 includes the \$0.80 cents for the quick release pin and receptacle. Packaging, shipping, etc. for the device had not been considered at this point. Figure 5.4 shows the scaled and dimensioned drawing of the clamping device that was rendered by Vinylex to account for the flow properties of PVC. Mr. Burton also stated that the Vinylex engineering department would be glad to assist in the designing of the extrusion die if it was decided to manufacture the part elsewhere.

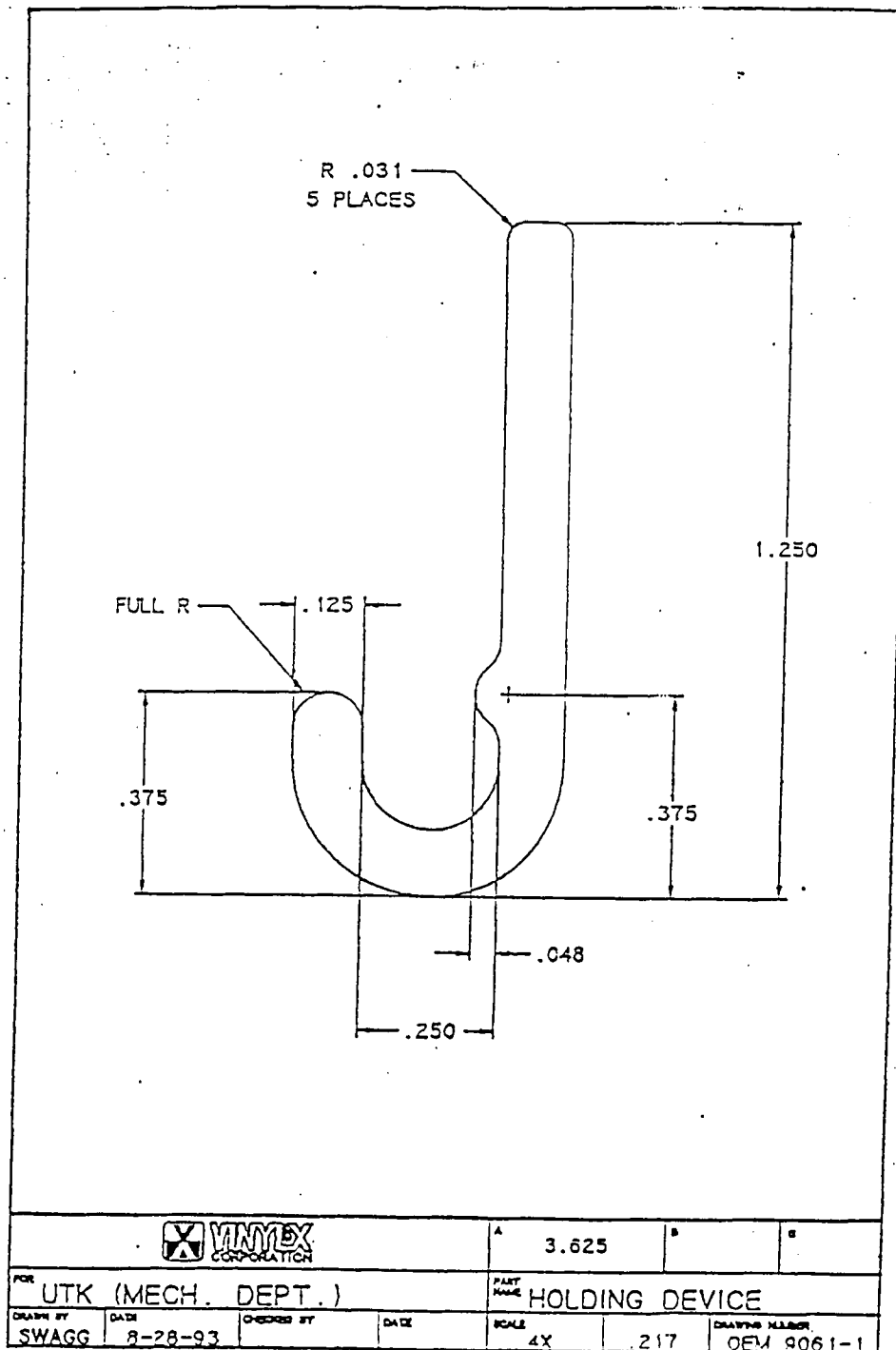


Figure 5.4 Scaled and Dimensioned Sketch of Clamping

Device as Rendered by Vinylex, Corporation

CHAPTER 6

PROTOTYPING OF THE FORCE REACTION DEVICE

6.1 Overview of Analysis: Insertion Force vs. Available Ring Gap

The insertion of the instrument cord into the "snap-fit" clamping device requires a certain amount of force. This insertion force is used to deflect the sides of the clamping device such that the device opens. The required amount of insertion force is dependent upon many factors. These factors include the geometry of the system (i.e. the sizes and orientations of the clamping device and instrument cord) and the material properties of each member. One very important factor in this arrangement is the available gap in the clamping device as compared to the diameter of the cord. This relationship between these two quantities along with the material properties of each member defines the amount of force required to insert the cord into the device. For example, if a certain value of insertion force is desired (say, for instance, 15 lbs), a clamping device which is made of a low modulus material will be easily deflected and allow for a much "tighter" gap. On the other hand, if a higher modulus material is used, the gap must be increased such that the insertion force will not exceed the desired value. Therefore, a relationship between the insertion force and available gap should be determined as a function of the system geometry and the material properties. Once this relationship is developed, the selection of the material for manufacture can be augmented and used to best benefit the device.

Also, if other factors lead the design toward a certain material for the clamping device, the geometry may be properly adjusted such that the insertion force remains with desirable bounds.

The relationship between the insertion force and the available gap was developed by using Castigliano's theorem. This theorem was chosen for its simplicity in finding deflections of members in various directions. Castigliano's theorem can be used to find the deflection in the direction of any applied force P_i . To find this deflection, Castigliano's theorem is written as follows [Seely, 1948]:

$$\delta_i = \int \left[\left(\frac{N}{EA} \right) \left(\frac{\partial N}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{kV}{GA} \right) \left(\frac{\partial V}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{M}{EI} \right) \left(\frac{\partial M}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{T}{GJ} \right) \left(\frac{\partial T}{\partial P_i} \right) dS \right]$$

where "i" represents the direction of the force P_i . For the problem at hand, the properties of the member (both physical and geometric) are constant. Also, the forces and moments can all be expressed in terms of the constant force 'P' which is applied onto the faces of the member. These variables can therefore be moved outside the integral, leaving an expression in terms of the force 'P' and the coordinate of integration. This expression can be integrated in closed form to find the deflection of the member in the desired direction.

The analysis was performed in three parts. First, the model was reduced to its most simple form by neglecting the effects of friction. Next, the effects of friction on the relationship between the required insertion force and the available gap were determined. Finally, the addition of a wedge angle β was analyzed to investigate the related mechanical advantage. When this wedge angle is added to the ring of the clamping

device, the force 'P' on the face of the ring is directed more towards the direction of desired deflection. Also, the resistive force provided by friction is directed in a direction further away from the direction of the desired deflection. The analysis demonstrates these observations.

For the most simple case (i.e. neglecting friction), the deflection equation becomes the following upon integration...

$$\delta_x = \frac{kPR}{GA}(2 + \sqrt{2}) + \frac{PR^3}{4EI}(3 + 2\sqrt{2}).$$

Due to the orientation of the model, this deflection represents **one half** of the total deflection of the clamping device. The model is oriented such that the x-direction corresponds to the desired direction of deflection. Next, using equivalent spring rates for the clamping device and the instrument cord, the insertion force can be directly related to the insertion force. Since spring rate is the ratio of force to deflection, the equivalent spring rate of the clamping device, K_p , can be found directly from the above deflection equation...

$$K_p = \frac{P}{\delta_x} = \frac{1}{\left[\frac{kR}{2GA}(2 + \sqrt{2}) + \frac{R^3}{4EI}(3 + 2\sqrt{2}) \right]}.$$

The spring rate of the instrument cord can be determined experimentally by generating a force vs. deflection curve in the range of deflection under consideration. Since the two

equivalent springs are "connected" in series, the equivalent spring rate for the system, K_{eq} , can be directly calculated from the equation...

$$K_{eq} = \frac{K_c K_p}{K_c + K_p}$$

where K_c is the spring rate of the instrument cord. Finally, by a summation of forces on the system, the expression showing a relationship between insertion force and available gap is obtained...

$$F_i = K_{eq} \Delta \tan \gamma$$

where, for the model arrangement used in this analysis, $\gamma = \pi - \theta$, and Δ = the total deflection of the clamping device in the x-direction. A detailed discussion of this analysis can be found in Appendix 1.

When the effects of friction are considered in the analysis, the equation for insertion force becomes...

$$F_i = \frac{K_{eq} \Delta (\sin \gamma + \mu \cos \gamma)}{(\cos \gamma - \mu \sin \gamma)}$$

where μ = the coefficient of friction. It should be noticed that the friction force does indeed increase the required amount of insertion force by trying to keep the clamping device shut. The existence of friction both increases the numerator and decreases the denominator of the expression for insertion force. Also notice that the above relation

reduces to the earlier expression for F_1 when $\mu = 0$. A detailed discussion of this analysis can be found in Appendix 2.

When an additional wedge angle β is added to the model, the expressions that are to be integrated become somewhat more complex. Due to this, a program was written such that the integral could be numerically integrated. The results of the investigation were summarized graphically such that the relationships could be analyzed easily. It was found, as expected, that the addition of the additional angle did reduce the required force for insertion. This effect increased with increasing β ; the limiting factor concerns geometry. The outside edge of the opening must be greater than the diameter of the cord such that the cord may be inserted. A detailed discussion of this analysis can be found in Appendix 3; the program listing for this investigation can be found in Appendix 4, and the graphical results of the analysis can be found in Appendix 5.

6.2 Selection of the Profiles for the Prototype

After completion of the analysis for the clamping device concerning the available gap and the additional angle β , the profile for the prototype was selected. The chosen material for the prototype was once again selected as rigid PVC. The angle β was chosen to be as large as possible such that the cord could still be inserted; this maximizes the acquired mechanical advantage for cord insertion. The equation limiting the range of the angle β is derived and discussed in Appendix 3. In order to keep the profile as continuous as possible, the effective angle β was put entirely on the curved side of the profile. This

allows the side of the clamping device on the side closest to the instrument to be of a continuous linear profile down to the point where the cord is to be placed. This profile is more advantageous because warpage during an extrusion process is less likely to occur for a more continuous profile.

The available gap at the top of the clamping device was chosen to be approximately 0.22 inches. This coincides with the desired amount of force required to insert the cord into the device. The graphical results of the analysis were used to verify this selection of gap. Figure 6.1 shows a dimensioned sketch of the part as it was prototyped.

6.3 CNC Machining of the Prototype

The prototypes for the clamping device were made with a Computer-Numerically-Controlled (CNC) milling machine. The basic process for making parts with this machine involves three steps. First, a full scale CAD drawing of the part must be completed. Secondly, the drawing must be converted into a machine path for the CNC mill. This process involves taking the scaled drawing into a conversion program in which the desired machining parameters (i.e. cutter sizes, rotation speeds, feed rates, etc.) and cutting paths can be specified. Once the cutting paths have been specified, a new program (called the part program) is both written and saved by the computer in the form of a text file. The milling program offers two types of path simulations such that the program validity can be verified. The third and final step involves taking the part program to the CNC mill

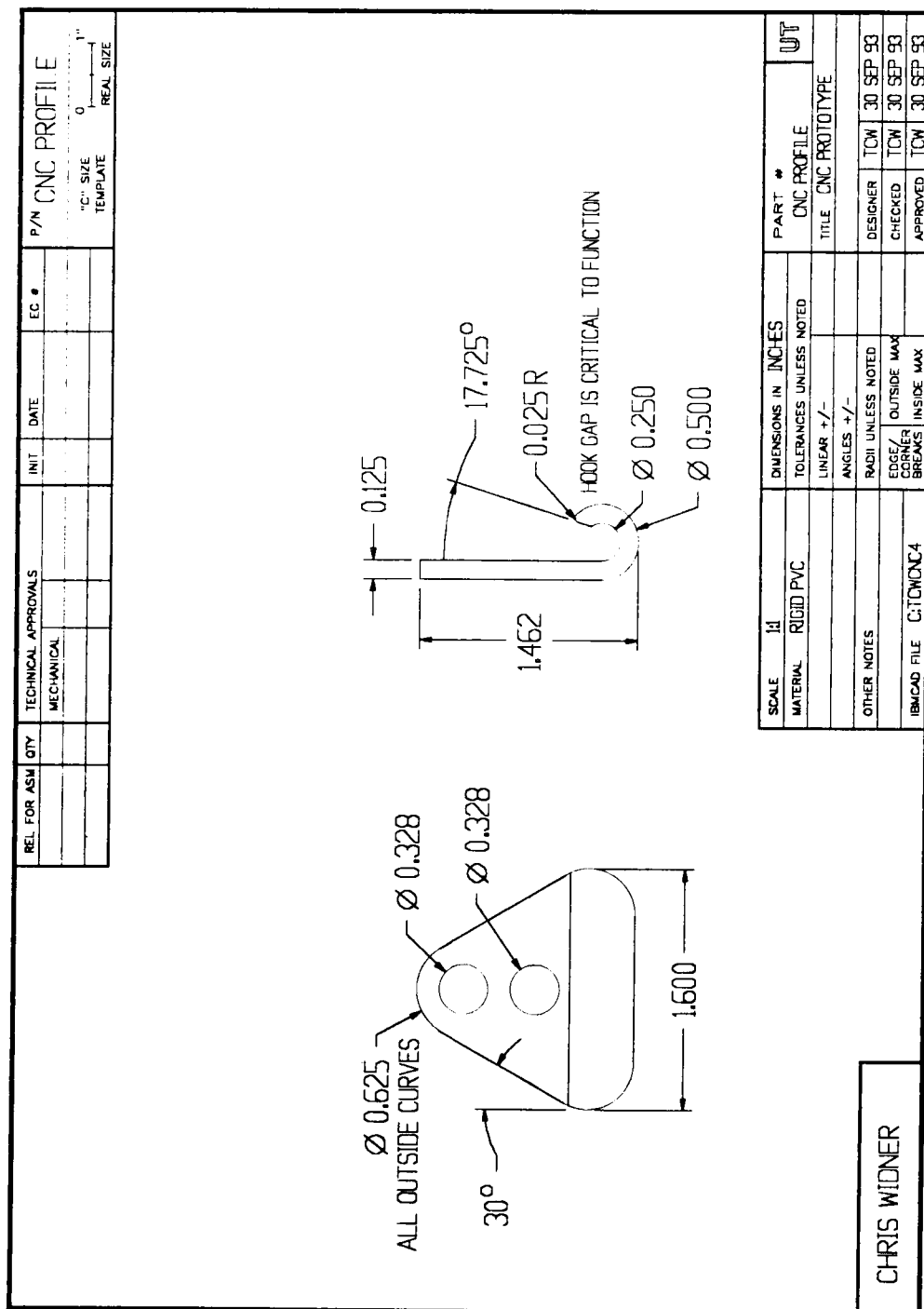


Figure 6.1 Dimensioned Sketch of Clamping Device as Prototyped

and actually cutting the part.

The milling paths used for the prototyping of the clamping device were somewhat unusual due to the relatively small size of the part. The first view of the device that needed to be machined was the side view. This view of the part coincides with the profile that is to be extruded in mass production. The depth of cut for this profile (as seen in the front view in Figure 6.1) required an extra long cutter. That is, if this profile was to be cut with a single cutter, then the cutter would need a flute length (or length of cut) of two inches. It should also be noticed that the diameter of the cutter must be less than 0.25 inches such that the gap at the top of the clamping portion of the device could be cut. Upon searching for a sufficient cutter, it was discovered that a cutter of this proportion could not be purchased. Such a small diameter cutter was not available with a flute length of 2 inches. However, a 3/16 or 1/8 inch diameter cutter with a flute length of one inch was available. If this length cutter is used, the extrusion profile would need to be cut in two portions. The 1/8 inch diameter, 1 inch flute length cutter was chosen. First, the profile was cut to a depth of 1 inch. Then, the reverse (or mirror image) of the first profile was cut from the other side of the part to a depth of 1 inch such that the desired shape was obtained with a total cut depth of slightly less than 2 inches. In order for this to be done, a jig was needed for the cutting of the "mirrored" profile. The jig was used to hold the part after the first machining process such that the "mirrored" profile could be cut. Figure 6.2 shows a sketch of the jig. After the cutting of the first profile, the material block was inverted and the first profile was inserted into the jig and pinned such that it was held into place. Then, the cutting path for the second profile was used

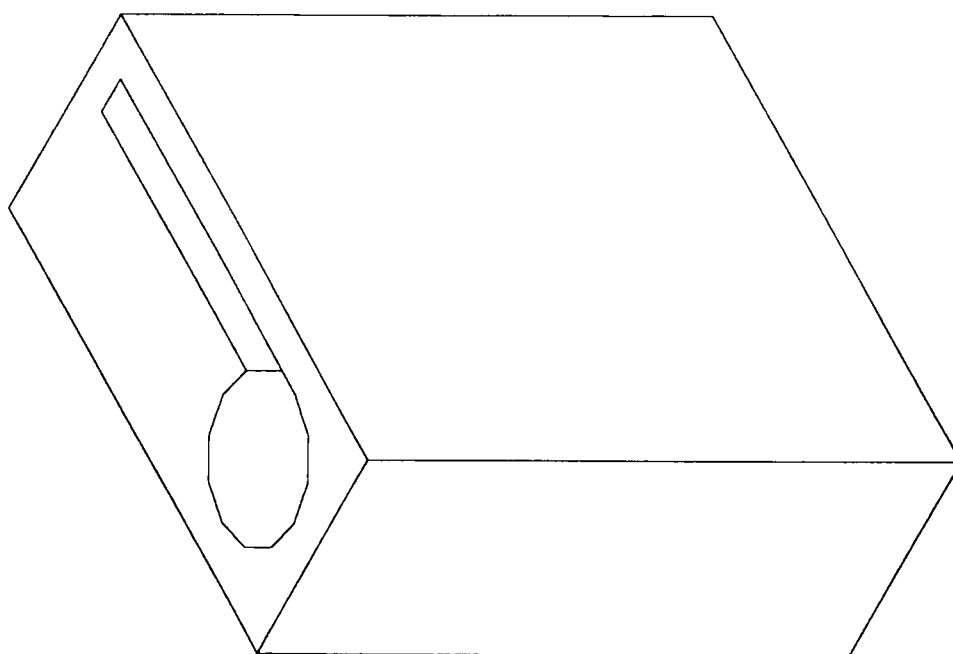


Figure 6.2 Sketch of Jig Used in Prototyping of Clamping Device

to complete the cutting of the extrusion profile.

Next, the front view of the device had to be cut. The holes shown in the front view of the part in Figure 6.1 were cut first. The part was pinned to the cutting table at locations that would not damage the appearance of the final part. After the holes were machined, the part was then pinned in these holes also; this was needed since the first two pins would not be able to hold the part once the outside profile was cut. This is demonstrated in Figure 6.3. The outside profile was cut with a larger diameter cutter (1/2 inch) such that the cutting time would be decreased. The part was completed after the cutting of the outside profile.

It should be noted that although use of the CNC milling machine is indeed a form of *rapid prototyping*, it is by no means a fast enough process for mass production. Although the first profile is to be extruded in mass production, the second profile (i.e. the front view of the part) will require a secondary manufacturing process. From this experience, it was reassured that milling is not a feasible possibility for this secondary operation. It is far too time consuming to be considered. The mass production considerations for the product are discussed in Chapter 7.

6.4 Informal "In-House" Testing of the Prototype

Upon completion of the prototype of the clamping device, the entire force reaction device prototype was completed. Testing of the prototype should be considered from two different viewpoints. First, there is the evaluation of how well the device works, simply

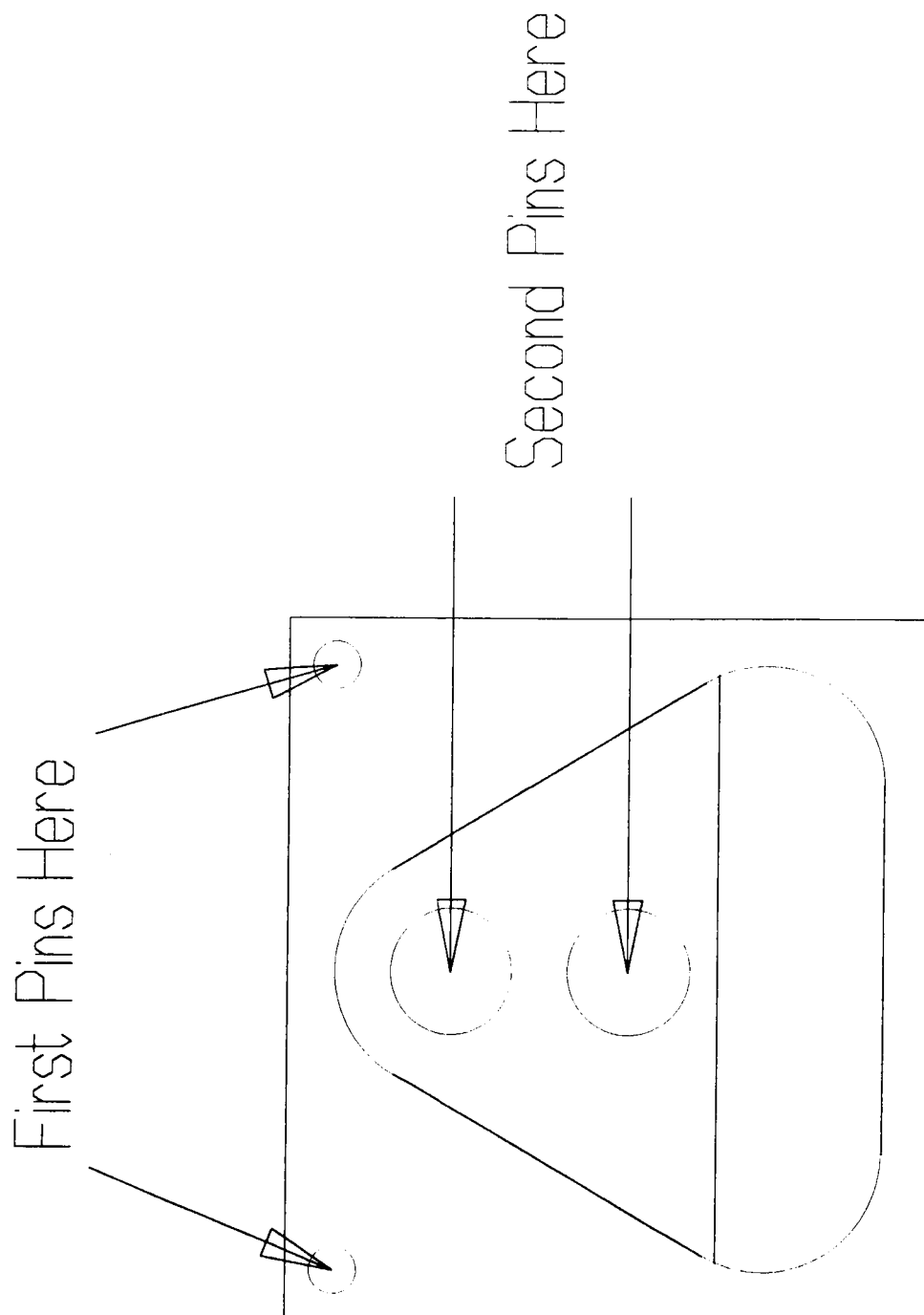


Figure 6.3 Sketch Showing Positions of Holding Pins for CNC Milling of Front View of Clamping Device

from a function point of view. From my standpoint, this involves evaluating the device as to how well it meets the design requirements. One of the most important aspects to be considered is evaluation of how well the device secures the instrument cord. All of the other design requirements should be addressed similarly by the designer. Additionally, however, the testing of the device should also involve field testing; that is, the device should be given to a few performing musicians on a trial basis such that it may be used within the environment for which it was designed. This is critical for gaining some "outside" input as to how well the device meets the needs of the consumer. Aspects such as ease of attachment, ease of use, etc. can be directly addressed by the "testing" musician. It must be kept in mind that the viewpoint of the designer towards ease of use, etc., could be somewhat different than that of a typical customer, since the designer has become "intimately" familiar with the product through extensive work. A few new viewpoints on the performance of the device should determine if all of the key points were addressed during the design of the product.

Concerning the evaluation of the device, it was immediately attached it to a block of wood and simply "tried out". It was found that the cord inserted into the clamping device much more easily than it did into the PVC rod "prototype". As predicted, this is mainly due to the additional mechanical advantage provided by the aforementioned wedge angle, β . Since the prototype had to be machined from two sides, there was a slight (i.e. small but visible) misalignment between the two profiles at the center of the part. This misalignment did cause the required insertion force to be slightly greater at the center of the part. This was noticed simply by "feel", not by rigorous testing. Once the cord was

inserted into the clamping device, the assembly was completed by attaching the device to the block of wood by means of the quick release pin and receptacle arrangement. At this point, the effectiveness of the force reaction device as to how well it secured the cord was evaluated. It was found that the device held the cord firmly when the cord was jerked toward the ground by an "accidental" step on the cord. The portion of the cord on the "jack" side of the device (i.e. opposite of the jerk force) did not move from its seated position in the clamping device. It was even surprising as to how well the device held the cord against jerk forces along the axis of the clamping device; even though this cannot occur in actual use, it was interesting to see how the device would react. The cord would eventually move if this "in-line" force was continually applied; however, a sudden jerk barely moved the cord at all. By use of a spring scale, typical jerk forces were estimated to not usually (if ever) exceed 25 pounds; greater forces were intentionally applied during my evaluation. The prototype performed as hoped and expected during the "informal" testing.

In an effort to gain a few other opinions concerning the performance of the device, it was given (unassembled) to a few other graduate students for evaluation. Once the purpose of the device was explained, evaluations similar to those of the author were performed. Along with standard instrument cords, any 0.25 inch diameter cord that could be found were used. All who tried out the device concluded that the cord was properly secured; in fact, it did not move at all from its seated position.

Next, the device was "installed" onto several personal instruments of the author. It was found that the device was easily used with both types of guitar straps (i.e. both the

locking and non-locking variety). The force reaction by the device was even more impressive when used on an actual instrument. Having become accustomed over the years to the way the instrument reacts to an accidental step on the cord, the benefits of the device were obvious. Without the addition of the device, the instrument moves toward the direction of the force. With the device attached, however, the movement of the instrument is drastically reduced; in fact, awkward amounts of force had to be used such that the instrument would move as it did before. The magnitude of this difference can only truly be realized if experienced.

6.5 Future Field Testing of the Force Reaction Device Prototypes

Further "performance" testing of the device should be done by typical working musicians. Once the work for this thesis has been completed, it is planned to fabricate several more prototypes such that they can be distributed them to a few musicians for evaluation. This type of "field testing" is imperative before beginning the mass production of the device. The field testing of the force reaction device will be done in the Spring of 1994.

CHAPTER 7

MASS PRODUCTION CONSIDERATIONS

7.1 Overview

This chapter is concerned with the mass production considerations of the force reaction device. The chapter consists of two separate discussions. The first discussion addresses the considerations for the quick release pin and receptacle arrangement. The second discussion addresses the considerations for mass production of the clamping device. These considerations could be investigated, but not implemented, during the course of this thesis work. Implementation of the first production of the force reaction device is planned to take place in 1994.

7.2 Quick Release Pin and Receptacle Arrangement

The quick release pin and receptacle as used in the prototype can be purchased in bulk quantity. They were found through Metro Marketing, an advertising company in Knoxville, TN. The quick release pin and receptacle as found are the main components of a small, simple, device called a "key separator". Figure 7.1 shows a photograph of the key separator that is compatible with this design. The advertising company that was dealt with had catalogs within a computer database. Numerous variations of this type of device



Figure 7.1 Photograph of Compatible "Key Separator"

are available for purchase. It was discovered that the size and geometry of these key separators was of wide variance; in fact, none of the initial devices that were found would work for this project. Even with the aid of the companies database, it took almost an hour of tedious searching to find the exact key separator that was compatible with this design. Once a key separator of the correct size and proportion was found, it was noticed that most of these devices were to be embossed with a company name, logo, etc. This "feature" increased the price of the device by over a factor of two. It was somewhat difficult to find a device which was available without this added feature. Upon finding the device that was needed, the advertising company called to determine a price and minimum quantity of purchase. It was determined that the device could be obtained at a price of 80 cents each for a minimum purchase of 500 items. The price decreased slightly for greater quantities of purchase. As compared to the minimum price of approximately 7-8 dollars found in tooling catalogs for the quick release pin alone, the cost was reduced by approximately a factor of 10. Also, the receptacle would have needed to be manufactured.

This key separator is manufactured in China; it is realized that, in buying the device from the advertising company, a profit margin for two additional companies is being provided within the purchase price; these companies are the supplier (i.e. importing company) and the advertising firm. Additional sources have been obtained which could possibly import the device directly from the manufacturer in China. The possibility of obtaining the device without the two key rings will also be investigated. These key rings are not needed for this design and would simply be a waste of money. Perhaps through

further searching and negotiations, the investment needed for the quick release pin and receptacle arrangement can be further reduced. The current estimate can be used as an upper bound on the required investment for this portion of the design.

7.3 Clamping Device

The design of the clamping device has been developed for a relatively low cost manufacturing method in mind: extrusion. The extrusion can be used to obtain the side view of the clamping device. Since extrusion simply yields a constant cross section length of plastic, a secondary manufacturing process will be required in order to obtain the front view of the part. Earlier, in Chapter 5, a conference with a manufacturing firm (i.e. Vinylex Corporation) discussed the possibility of using a stamping process to obtain the front view. The relative tooling costs were estimated for the extrusion and stamping operations as \$1200.00 and \$3500.00, respectively. The magnitude of the investment required to pay for the stamping tooling initiated an investigation into other possible secondary operations. That is, the first few productions could be significantly less expensive if a less expensive secondary process is chosen. Although another process might not yield a production rate equivalent to the stamping tooling, it might be sufficient for the first few productions. That is, a lower production rate could be sufficient until the magnitude of consumer demand is properly estimated through test marketing. If or when the demand exceeds the capability of a low production rate manufacturing method, a higher production operation can be adopted if available funding is sufficient. The

marketing considerations for the product are outlined in Chapter 8.

The initial secondary operations under consideration for fabrication of the front view of the clamping device are *template routing* and *drilling*. Once the extrusion profile has been fabricated, the profiles can be cut to an appropriate length for the secondary operations. First, the holes in the front view can be drilled. These holes can be used to locate the part in an appropriate jig such that the routing process can be used to finish the part. A sketch of the concept for the routing jig is shown in Figure 7.2. The desired router path can be machined into a metal plate. The two locating pins corresponding to the two holes in the front view of the part can also be pressed into the metal plate. Once the jig is completed and secured to the routing table, the entire secondary operation can be summarized as follows: (1) Cut the extrusion profile to the appropriate length (i.e. make the "blank" part); (2) Drill the two holes in the front view of the part with a drill press; (3) Place blank part into the jig using the two holes to locate the part; (4) Using the router, finish the part by cutting the outside geometry of the front view.

An appropriate router bit will consist of two key characteristics. First, the bit must have a depth offset (i.e. non-cutting face). This basically consists of a bearing at the bottom portion of the bit. The height of the bearing limits the depth of cut. The offset bearing is placed within the path channel and is used to move the router around the part through the desired path (see Figure 7.2). For this application, the routing jig will be arranged such that the part is elevated to a level just exceeding the lower limit of router cut. Also, a slight overhang of the part over the elevating plate in the jig will prevent any accidental contact between the jig and the router bit.

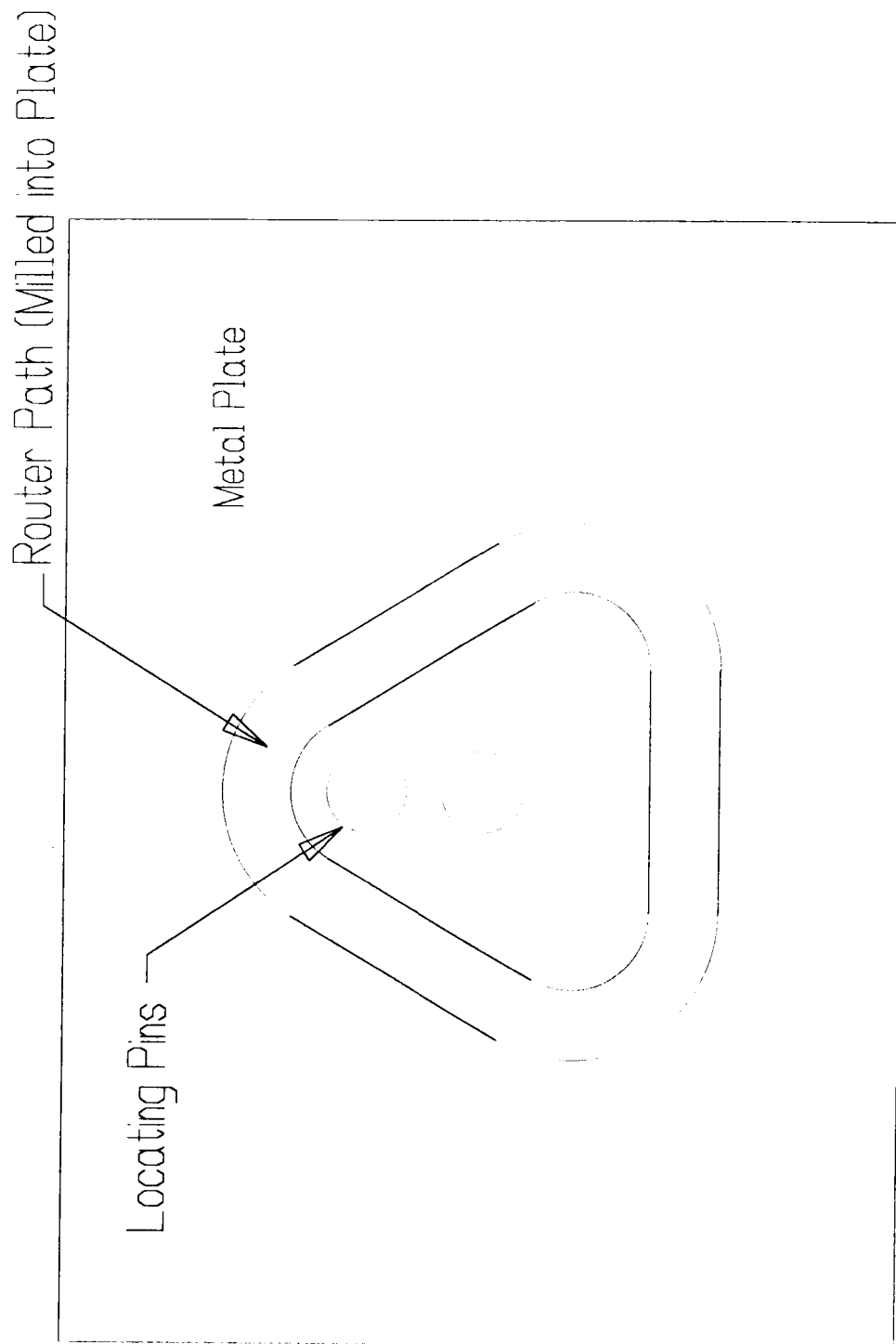


Figure 7.2 Sketch of Concept for Routing Jig

The tooling cost for the routing and drilling process will no doubt be considerably lower than that of the stamping tooling. This cost will simply consist of the machining cost of the jig and the cost of the router and drill bits. The trade-off, however, is the production rate that each secondary process can yield. Obviously, if the demand for the product eventually exceeds the production rate capability of the routing process, then a stamping operation will have to be adopted. The same considerations may eventually become important concerning the extrusion/stamping process versus injection molding. These factors should be investigated fully and integrated into the marketing strategy for the product. Once again, these topics are discussed in Chapter 8.

7.4 Conference with Another Manufacturing Firm

After the fabrication of the prototype for the force reaction device, a conference was held with a representative from another local fabrication company: Larry Cruze of Omega Plastics. The discussion was similar to that of the discussion with the other company, but was more informative due to the simple fact that a sample part was available for Mr. Cruze. While examining the part, Cruze discussed the adjustments that need to be made to the extrusion die design such that the part retains its desired geometry and critical dimensions. Of special concern was the available gap at the point where the cord is to be inserted. When extruding profiles with curved surfaces, special consideration must be taken to adjust the die design such that the cooling of the part does not induce warpage and cause the critical dimensions to fall outside the desired tolerances.

For example, when extruding a curved surface, the outside area of the curve cools more quickly than the inside curve; this is mostly due to the difference in the temperatures of the cooling fluid next to the part surfaces. On the outside of the part, the cooling fluid remains at a relatively low temperature and subsequently cools the surface of the part rather quickly. On the inside, however, the cooling fluid is almost completely surrounded by the warm part; this increases the average temperature of the cooling fluid and results in a lower rate of cooling. The differences in these two cooling rates cause the curved portion of the part to try to "close" upon itself. For this part, this phenomena would cause the available gap to be significantly decreased. This could be *critical* to the function of the part. If the cord will not insert into the device, the part is *useless*. This is compensated by an adjustment to the design of the die. The curved surface of the extrusion profile is altered such that the die profile shows an increased gap. The cooling of the part then closes the gap to a dimension within the tolerance range. Obviously, there is somewhat of an art to the designing of the extrusion die. Mr. Cruze assured that the die design would be adjusted until the desired dimensions were continually obtained.

7.5 Quality Control for the Extrusion Profile

The critical gap dimension of the clamping device must be checked to assure that no parts will be unusable if sent to the consumer. This is an issue of quality control. The manufacturing firm checks the critical dimensions of the profile at regular intervals. Also, the tolerances of the critical dimension will be set such that the tolerance range will lie

in an area which should not produce useless parts. That is, the tolerance range for the extrusion (e.g. ± 0.005 inches)² will be arranged such that the worst case dimension will still allow the gap to be sufficient to allow insertion of the cord. It was also stated that if any parts were found to fall outside the tolerance range, the defective parts could be returned such that the material could be recycled. At least in the first production, it seems feasible that the one critical dimension can be verified by 100% inspection. A simple gauge block could be used to speed up the inspection process. Similar methods of quality control can be used if a stamping process is used to fabricate the front view of the part.

7.6 Manufacturing Cost Estimate: Omega Plastics

The second estimate that was received for the manufacturing cost of the clamping device was obtained from Omega Plastics as follows:

EXTRUSION TOOLING: \$ 450.00

Table 7.1 shows the estimate from Omega Plastics of the manufacturing cost for the clamping device. This estimate shows that, if Omega Plastics is chosen as the company for manufacturing, an initial investment of \$450.00 will be required for extrusion tooling only. The cost of the extrusion profile will be \$400.00 per thousand feet

² This tolerance range is smaller than that quoted by Vinylex. Cruze stated that this can be achieved by reducing the flow rate of the plastic during the extrusion process. The tolerance range quoted by Vinylex is most likely for a maximum rate of flow.

TABLE 7.1 Manufacturing Cost of Clamping Device
(Omega Plastics Estimate)

Minimum Release	Cost per 1000 feet	Extrusion Cost per 1000 parts
5000 feet	\$400.00	\$58.34
10000 feet	\$320.00	\$46.67

for a minimum length of 5000 feet. The approximate extrusion cost per part (i.e. manufacturing cost) will be 6 cents each. This was calculated assuming that each part requires a 1.75 inch length of profile.

TOTAL INITIAL INVESTMENT FOR EXTRUSION: \$2450.00

CHAPTER 8

MARKETING CONSIDERATIONS

8.1 Overview

This chapter consists of the major marketing considerations that need to be addressed in order to enter the force reaction device into the market. The task of effectively converting a working prototype into a consumer product is challenging to say the least. Since this product is a *market driven product*, this task is of utmost importance to the product's success. The discussion of the marketing considerations within this thesis consists of two parts. First, the force reaction device is given a product name. The importance of the name of this product is discussed. Secondly, the steps that are to be taken in order to form a marketing strategy and eventually bring the product to market are discussed. Specifically, many distinct questions that must be addressed are outlined. A very large portion of the critical questions were found in The Product Development Guide: a software package written by Michael E. Kennedy and Dr. C.C. Wilson of the Superior Engineering Design Program at UTK. The marketing investigation for this product is to be initiated in the Spring of 1994.

8.2 Selection of a Product Name

The survival of a market driven product is solely dependent upon the interest of the consumer. In order to *gain* the interest of a consumer, steps must be taken to assure that the product becomes visible and *memorable* to those who might be interested. The first step in making a market driven product memorable is giving the product a name. A name may have little influence on the success of a *technology driven* product, but a name is essential to the success of a *market driven* product. For example, imagine if a computer company came out with a greatly improved microprocessor -- a unit that greatly exceeded all existing technology in performance. The name of this new unit would have little effect, if any, on its attractiveness and demand in the market. That is, this new product would be found desirable simply because of its performance and the *improvement in technology* that it has to offer. In other words, the marketing success of the microprocessor would be *technology driven*. On the other hand, imagine that another company developed a new type of soft drink. The success of the new product would depend considerably on how well the product is promoted and made visible to the general public. The success of the new beverage would be *market driven*. A unique name could be the key to the entire advertising campaign and, consequentially, the success of the product.

For this particular product, the force reaction device, the name should be chosen such that it aides the consumer in recognizing and remembering the product. A trademarked name can, in some cases, become such a powerful marketing tool that the

consuming public associates that name with all similar products that may evolve in the future. For example, do you wrap up leftover food in plastic wrap or "Saran Wrap"? Do you order a soda pop or a "Coke" with your hamburger at McDonald's? Do you treat a runny nose with a tissue or a "Kleenex"? There are many varieties of clear tape, but it is commonly referred to as "Scotch" tape. What is used to protect fragile items within boxes during shipment? The answer is foamed polystyrene, not "Styro-foam". These names have become so associated with their respective products that the name is commonly used for all similar products.

When choosing a product name, there are many factors which may be considered. Should the name be descriptive of the product? It may describe how the product looks (e.g. "U-bolt", computer "disk", etc.) or what the product does (e.g. "Liquid Wrench", "Off!" insect repellent, etc.) or even a combination of the two (e.g. "Slide-Rule", "Guitool", etc.). Other names may be associated with the manufacturer, as in a "Floyd Rose" tremelo system. The critical question to ask, especially for an innovative product, is "Is the name *memorable*?". It must somehow assist the customer in remembering the product and associating it with the benefits it can provide. The name can achieve this task by appealing to the consumer in various ways. It may appeal to rational thinking (i.e. "this product can be beneficial to *you*"), or emotions (i.e. clever or amusing names are generally memorable). All these factors must be considered. Which type of name is best for the product at hand?

It seems that the force reaction device is unique in two categories. First, the function of the device is relatively new; this should be represented in the name.

Secondly, the geometric shape of the device is somewhat unique. A name which encompasses this could provide another means of associating this particular product with the promotional campaign. The triangular shape of the device is reminiscent of the greek letter Delta (i.e. Δ). The function of the device is that it secures the cord to the instrument. Variations on the word "secure" could complete the name. Some possibilities are "Delta Clip", "Delta Clamp", "Delta Lock", etc. Spelling variations could also make the product more memorable (e.g. "Delta Klip", "Delta Klamp", "Delta Lok", etc.). All of these names are possibly suitable. In a design team effort, the name can be selected in an organized manner similar to that of the concept selection discussed in Chapter 4. Each of the names can be compared as to how well they meet the "requirements" of a name.

Once a potential name or list of potential names has been selected, the names can be accessed by another group (outside of the company) in order to estimate customer response. If desired, this should be done as far in advance as possible before the official release of the product such that the name may be modified if desired. Also, once the name or list of potential names has been selected, a trademark search must be performed such that any possible infringements may be avoided.

From this point within this thesis, the force reaction device will be referred to by the preferred name at this point -- "Delta-Lok". The initiation of the marketing investigation in the Spring of 1994 will involve a trademark search of this and other names before an official name is chosen. If no infringements are discovered, then the preferred name will be trademarked before the official market release of the product.

8.3 Acceptance of the Market to New Products

The presentation of new products can be quite difficult in some markets. Some markets are simply not accepting of new products; that is, some markets resist change and innovation. This is *not* the case with the music industry. This industry enjoys and encourages innovation. This fact can be demonstrated with numerous examples. Two simple products that have both sold in huge quantities have been presented into the market over the past few years. The list goes on and on, but these examples should clarify the disposition of the music industry.

EXAMPLE #1: When the strings are installed onto an instrument by the user, the strings must be wound several times around the tuning pegs. This involves a large number of revolutions of the tuning pegs with the fingers. After installing 2 or 3 strings, the user's hand quickly becomes somewhat fatigued. A very simple product called a "String Winder" was developed for this purpose. It is simply a crank that slips over the tuning knob and is used to quickly (and much more easily) revolve the tuning peg and tighten the string. It would not be a high estimate to say that 75% of *all* guitarists/bassists own a "String Winder". Millions have been sold. Retail Price: about \$5.00.

EXAMPLE #2: Also concerning the stringing of an instrument, several tools are needed during this task. Included in these are a screwdriver, wire cutter, allen wrenches, etc. A product which encased all of the common sizes of allen wrenches along with a wire cutter and two screwdrivers was developed to avoid the need to keep up with so many different items. The product was given the name "Guitool". Most every

guitarist/bassist that the author knows owns one of these. Retail Price: about \$25.00.

Many more examples could be given, but the trend is apparent. The music industry is accepting of simple products that can *meet a basic need*. The buyers of these products are of two completely different types, but both are compatible with the Delta-Lok. The first type of buyer is the kind of person who buys "all of the latest gadgets". This type of person is somewhat fanatical, but nonetheless falls into a category which could benefit this product. The author falls into the other type of category: a person who will buy a product if it meets a basic need. Since the Delta-Lok can help maintain the condition of the musician's equipment, it can *save* him/her money in the long run. This type of buyer uses more rational thought than impulse when buying a product. Therefore, in order to make a sale, the *value* of the Delta-Lok to the musician must *exceed* the price that is paid for it. A rational buyer will not purchase an item if they don't think that they are getting "the best end of the deal". The advertising of the Delta-Lok must convince the consumer that this is the case.

8.4 Test Marketing

Before the Delta-Lok is fully released into the market, the qualities of the device should be accessed by a test market. Initially, a few prototypes of the Delta-Lok should be given to a small number of working musicians for evaluation. Several questions should be thoroughly discussed with the "test users". Questions such as the following should be asked:

"How quickly was the value of the product apparent?"

"Does the product mean one of your *needs*?"

"Did you find the product easy to use?"

"Did the product work well? How well?"

"Would you change anything about the product?"

"Do you find the name appropriate? Is it easy to remember?"

Other questions such as color preferences, etc can be discussed. The results of these discussions should verify the design assumptions about the product. Also, these results can be used to determine the requirements for aspects such as assembly/use instructions, advertising, etc.

One particularly important question that must be asked of the "test users" is:

"Would you purchase this product?"

If this question is asked to a significant number of people, a rough estimate of the product demand can be made. Lacking more conclusive data, the following guidelines may be used to estimate the potential demand for the product [Kennedy, 1993]:

- estimate 90% of those saying "definitely would buy" actually will buy;
- estimate 40% of those saying "probably would buy" actually will buy;
- estimate 10% of those saying "might buy" actually will buy.

The estimated purchase price should be presented to the "test users" on the "high side" in order to keep this estimate of the demand conservative. This estimate can be used to

initiate the investigation of a marketing strategy.

8.5 Initial Investments

The first step in bringing the Delta-Lok to market is a gathering of funding such that the product may be started. For already established companies, the funding may be obtained within the firm if the potential of the product is demonstrated to those who make the decisions concerning new projects. A similar approach may be used to obtain funding for an independent project or the start-up of a new company. Prototypes of the new product can be presented and demonstrated to ignite interest in its development and release into the market. In this case, several prototypes could be given to working musicians, music store owners, etc. If the positive aspects of the product is quickly apparent to those who initially receive it, then it is likely that the product will have the same or greater affect on a consumer. Advertising, instruction manuals, etc. can also assist the consumer in realizing the benefits of the product. Especially with a relatively low investment (i.e. a few thousand dollars) project such as this, a large amount of capital is not needed. The money that is initially needed can come from within a small circle of associates, with little risk to each person. Demonstration of the potential of the product does not have to be as convincing for a low investment project as it does for a high investment project; therefore, funding can be easier to obtain. Several alternatives can be considered. The money may be borrowed from the bank, or from within the designer's family or friends. Caution should be taken as to not have too many investors; the future

profits will be split amongst them.

The minimum required initial funding could involve simply covering the expenses in such areas as manufacturing, packaging, tooling, etc. This can increase with the addition of trademark and patent searches/applications, additional advertising, etc. These factors should be fully addressed in a marketing strategy and the various options should be discussed with all potential investors.

8.6 Channels of Distribution

How is the Delta-Lok to be distributed in the market? Various channels may be used, but certain ones lend themselves to certain types of products. For the Delta-Lok, two channels are probably most advantageous. These are (1) mail order and (2) specialty (i.e. music) stores. The mail order option is advantageous because it can reach a very large number of people. There are several major guitar/bass publications which are printed worldwide on a monthly basis. All of these magazines include a "classified advertisements" section specifically for mail order products. This option is especially strategic in reaching consumers who do not live in highly populated areas. The music store option is strategic for reaching customers who "don't believe it until they see it". Admittedly, the author is a skeptic and almost always must "try out" a product before being convinced that it actually works. The music store owners also can help to promote the item. Often, the owners have built firm relationships with their customers. If the device convinces the store owner, then the product receives some "free advertising" by

word of mouth. The test marketing of the product can be done initially in just a few music stores; when proof of demand is established, then it will be more simple to convince additional stores that the product has the potential to sell.

The costs of both of the channels must be investigated and integrated accordingly into the marketing strategy. The initial promotion of the product could be kept somewhat small until the demand assumptions are verified. That is, the product advertisement could initially run in only *one or two* of the publications for mail order, and only two or three music stores in strategic locations might be used. Once the demand potential is realized, then additional channels (i.e. more magazines and stores) can be added with more confidence.

8.7 Pricing

Setting the price of the Delta-Lok is approached by considering several factors. First, it must be determined as to whether or not the market is price sensitive. A guideline for estimating this is presented in Table 8.1 [Kennedy, 1993]. As can be seen in the table, all characteristics consistent with this product show that the consumer will not be highly price sensitive. This is mostly due to the fact that the Delta-Lok will be a new, generally low-volume-of-purchase product. The table also demonstrates another question that must be addressed when pricing the product: what if a consumer wants to purchase the product in higher volume? The table suggests that customers expect a discount on unit price if higher volumes are purchased. For this reason, should the

TABLE 8.1 Price Sensitivity Guidelines

Characteristic	"More Price Sensitive"	"Less Price Sensitive"
Frequency of purchase	More frequent	Less frequent
Quantity purchased	Large quantities	Small quantities
Customer familiarity with the Product	Knows much about this and other products	Product never existed before: "new" item
Customer brand loyalty	Not loyal to brands	Prefers your brand
Customer excitement about product	Need product, but dislikes having to buy	Enjoys owning and using the product

product have two prices? That is, should there be a *volume discount*? It must be considered that the customers who do buy in higher volumes will most likely do so by mail order. When selling by mail order, the profit comes to the company, while selling in a music store allows some of the profit to go to that channel. For this reason, it seems that the relative prices between the two channels can be set such that a similar profit will come to the company through each channel. It should also be kept in mind that the additional costs due to packaging, shipping, etc., for a high volume purchase do not differ greatly from those of a small order. This should be noted when determining the magnitude of the volume discount.

A goal of the initial product design specification was to keep the purchase price of the device under \$25.00. It has now become apparent that this goal should not be difficult to meet. Also, since the market does not tend to be price sensitive for this type of purchase, the price can be set on the "high side" initially. It is always much easier to decrease a purchase price than it is to increase. The higher purchase price could determine the validity of the price sensitivity estimate, and in turn, even with a smaller number of sales, begin to return a majority of the initial investment.

A final discussion about pricing concerns future goals of the production of the Delta-Lok. The price can also be set in accordance to a specific set of goals concerning manufacturing methods. The chosen method for the initial production is extrusion with a secondary routing and drilling process. An improvement over the initial method (with a significant increase in tooling cost), is extrusion with a secondary stamping process. The maximum production capability (with *by far* the largest tooling cost) that would make

the part in one process is injection molding. Both of these "improved" manufacturing schemes would increase the production rate capability, and may, perhaps, even be *required* sometime in the future in order to meet product demand. Assuming though, that the only deciding factor is money, a price can be set for the cost per unit such that investment in the additional stamping tooling or conversion to an injection molding process would be justified after a approximate quantity sold. This pricing scheme investigation is demonstrated in Figure 8.1. The figure graphically represents the means of investigating how cost compares with the quantity of units sold. The three curves represent 3 different manufacturing methods. Each curve shows how much each of the units will cost the manufacturer if a certain quantity is expected to be purchased. For example, if it is expected to sell 1000 units, and the total cost of delivering (i.e. manufacturing, packaging, shipping, advertising, etc.) the product is \$3000, then the cost per unit to the manufacturer is \$3.00 each. The total cost is made up of a *fixed* cost (i.e. tooling, advertising, etc.) and a *variable* cost (i.e. material, manufacturing, packaging, etc.). As the names imply, the fixed costs do not change and the variable costs depend directly upon the number of units that are made and sold. The combination of these two costs gives the curves their respective shapes. A manufacturing scheme which requires little initial investment but has a low production capability yields a curve which quickly approaches a constant value of cost per unit. Other manufacturing schemes which, in turn, require higher initial investments but can yield much higher production rates are demonstrated by curves which take longer to approach a constant *but lower* value of cost per unit. The points where these curves intersect one another denote the minimum

Product Cost vs. Predicted Quantity Sold

(Concept Only: Does Not Apply to the Delta-Lok)

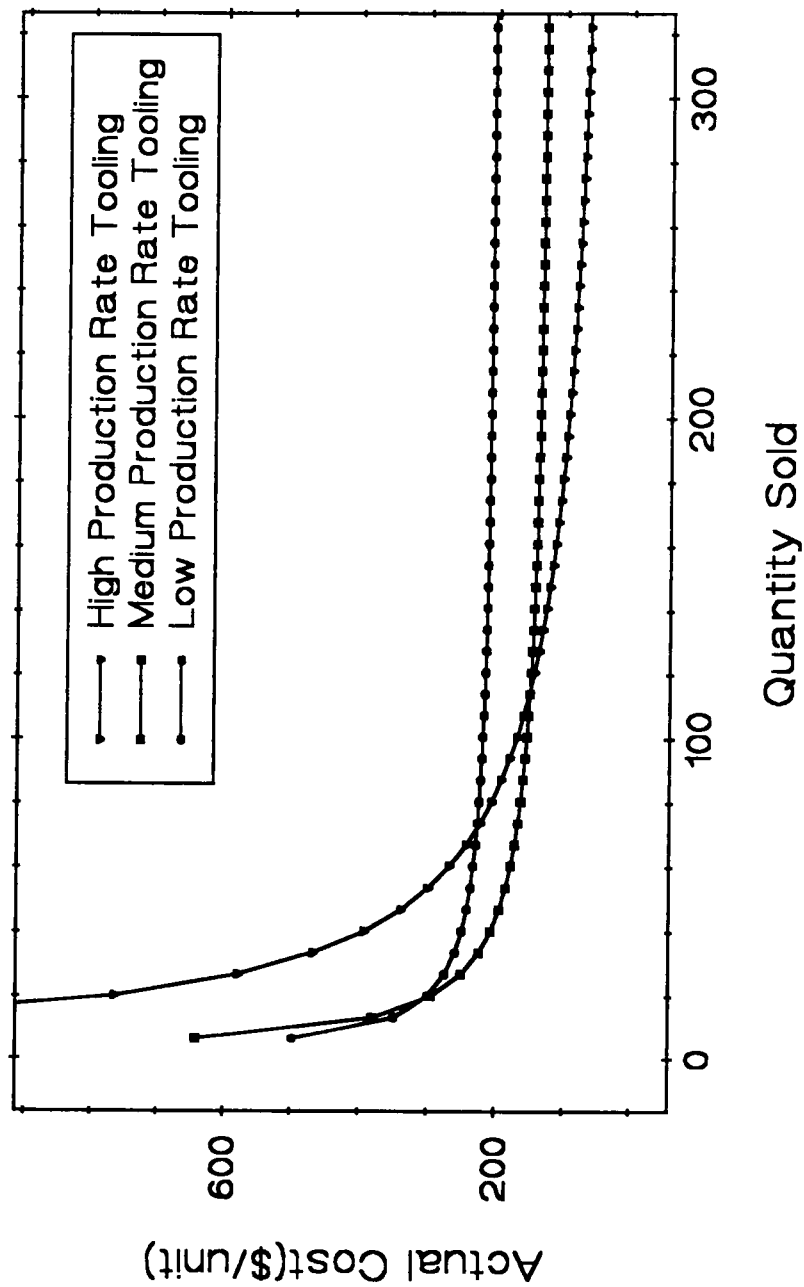


Figure 8.1 Unit Cost vs. Quantity Sold For Assisting Proper Setting of Price (Concept Illustration Only)

quantities of sale which could justify a new or improved method of manufacturing. If the time required to sell these quantities of units can be estimated, then this can be integrated into the marketing scheme and used to help determine a purchase price for the product.

8.8 Promotion/Advertising of the Product

It has already been briefly mentioned that the success of a market driven product is dependent on how well the product is promoted. What are the key points to promoting the Delta-Lok? The promotion of this product must be both convincing and memorable. Should the advertising of the Delta-Lok appeal more to emotional appeal or objective stimulation? As discussed before, consumers sensitive to both types of promotion could be potential buyers. Therefore, it seems that the promotion should appeal to both of these types of customers. For the more fanatical or emotional tempered consumer, the advertisements should be "clever" and "catchy". Also, for the objective or rational consumer, the positive attributes of the product should be *clearly* and *concisely* emphasized. That is, the advertisements should contain both an emotional and functional appeal. The name itself seems to do this. "Delta" is clever and memorable; "Lok" is demonstrative of the function of the product. From the initial test marketing of the Delta-Lok prototypes, the points which were not quite clear to the test users should be specifically addressed in the advertising campaign.

The most advantageous area for placing advertisements for the Delta-Lok is undoubtedly the major guitar/bass publications. Initially, the promotion can be encased into the mail order advertisement. Later, after the initial response to the product is received, more visible advertisements can be placed in the magazines. These publications greatly encourage innovation within the industry and are pleased to promote it. In fact, each of the publications have a section in each monthly issue dedicated to new products. In order to be considered for this section, the product must be sent to the publication for review. If the reviewer finds the product beneficial to the industry, then the product is photographed and reviewed within the "New Products" section. The information needed for contacting the companies is provided with the photograph and the review. This is done *at no cost to the manufacturer*. This form of free advertising could have a huge effect on the visibility of the product; this should be prepared for before this avenue is considered. It would be a *drastic* error to be published in the section and not have the capability to meet the sudden increase in production demand.

The amount of time required to develop (and subsequently test) the promotional materials for the Delta-Lok must be investigated during the initiation of the marketing strategy. In turn, this should be integrated into the estimated time schedule concerning release of the product.

8.9 Packaging

The documentation encased within the packaging of the Delta-Lok should be consistent with the promotional campaign. In fact, the packaging itself can provide another form of advertising for the product. A clever means of packaging the product can make the product more noticeable and, again, more memorable. The aspects of the product which make it unique can be re-emphasized through packaging. The name of the device should be *brilliantly* displayed. If the customer does not notice the product, there is no chance of a purchase. The logo for the name could be used cleverly to make the name even more memorable; perhaps the logo would depict the name Delta-Lok as "**DELTA-LOK**". The replacing of the letter 'a' with the greek symbol " Δ " provides yet another means of associating the shape with this product. The key points of the advertising campaign can be specifically re-emphasized directly on the front of the package. The major benefits of the product can be demonstrated to the consumer through perhaps just a few words. For example, underneath the logo, a small phrase such as "*Cord Locking System*" or "*Cord Locking Device*" can be emphasized. Does this quickly give the consumer an idea of what the product does (without prior knowledge of the advertisement)? If the logo and "catch phrase" simply sparks enough interest to pick up the package then it is effective. The details of the product can be summarized elsewhere on the package (perhaps on the back).

Other important aspects which must be included in the packaging of the product include assembly/use instructions, precautions, etc. These instructions are critical to

ensure that the product is used *properly*. It must be kept in mind that any product has a chance of failing if it is not used in the manner for which it was designed. A customer does not easily recognize their own misuse; that is, "If it breaks, then it was a piece of junk". For this exact reason, "design for misuse" can be advantageous. The assembly instructions should clearly explain how to attach the device to the instrument. Any special precautions that need to be made during assembly (e.g. assuring that the screw is fully tightened, placement of the felt washer under the receptacle, etc.) should be clearly noted. Also, there should be a clear set of instructions regarding use of the Delta-Lok. Instructions regarding the use of the product with both types of guitar straps should be clearly summarized. Needed precautions during use should also be clearly stated. One of the most important precautions during use is assuring that the quick release pin is fully inserted and locked into the receptacle.

The shaping of the packaging of the Delta-Lok can be used to effectively display the product. The triangular shape of the product lends itself to a hanging type package. The hanging package could be of the same shape as the product. It should now be apparent that the marketing of the product is quickly developing a theme. This is advantageous, because the theme of a marketing campaign can "make or break" a market driven product.

When considering the cost of the packaging, it should be remembered that the packaging could have a cost similar in magnitude to that of the product itself. However, a very simple package could be made effective using the aspects just discussed. The overall costs of packaging should be fully addressed in the marketing strategy.

8.10 Projected Competition

Once the Delta-Lok is released into the market, competition from other companies within the music industry is likely to occur. Many questions must be addressed in order to properly prepare for the competition. These questions include...

"How many competitors can be anticipated?"

"What strength will the competition have?"

"How quickly will the competition be able to respond?"

If it is anticipated that significant amounts of competition could appear since the product is innovative and potentially successful, then it is important to be prepared. Especially important is the protection of the product against duplication. Several steps can be taken to protect the product.

One relatively easy step that can be taken is the writing of a *Record of Invention*. This consists of summarizing the innovative features of the product in a short document. Once written, the inventor and a witness who understands the summary both sign and date the document. Then, by some means, the document is dated in an official manner. This document offers proof of when a concept was developed and project work was initiated. If, for instance, another company applies for and receives a patent for a similar device, the patent is not valid if proof of earlier work on the concept cannot be presented. The record of invention for the Delta-Lok can be found in Appendix 7.

Another important means of protecting the product is the application for a patent. In order for this to be done, a *patent search* must be performed. This is generally done

in conjunction with a qualified patent attorney. The two types of patent searches that could most likely be needed for the Delta-Lok are an *infringement* search and a *patentability* search. An infringement search is used to determine whether or not a product will infringe upon a patent not known to the company. A patentability search is used to determine whether or not a product is patentable. There are several different types of patents. Among these are device patents, process patents, and composition patents. If no patent for a similar product already exists, then a patent application can be written and submitted to the U.S. Patent Office. In order to receive a patent, the product must be deemed *novel, useful, and non-obvious*. If the Patent Office judges that this is the case, then a patent can be issued. If issued, the patent lasts for 17 years from the day it was issued.

Other means of protecting a product exist. Included in these are *design patents*. Although not as effective as a patent, this protects the ornamental design of the product. Any change in the appearance of a similar product will not infringe upon a design patent. Design Patents last for 3.5, 7, or 14 years. Trademarking can be used to protect a product name. Trademarks last for 20 years and are renewable.

It should be noted that there is a time limit on how long the company has to apply for a patent. The time limit states that the company has one full year after the official announcement of the product to the public to submit a patent application. In the case of the Delta-Lok, the official public announcement coincides with the publication of this thesis. This work is to be made available to the general public at the time of my graduation. Note should be taken that there is considerable expense involved with the

application of a patent. If a patent is desired, the magnitude of this expense should be investigated and integrated into the marketing strategy.

8.11 Some Final Remarks Concerning Marketing

It should be now be obvious that the marketing of a product is an extremely tedious and complex process. In order to market the product intelligently, many investigations must be performed. While the outline of questions discussed within this chapter is by no means complete, it provides a basis upon which a marketing strategy can be initiated. All of the discussed issues are to be investigated for the Delta Lok in Spring of 1994.

CHAPTER 9

DISCUSSION OF RESULTS

9.1 Overview

The objective of this thesis was to fully investigate the design and development that is required to bring a potential product from concept to production. While the majority of this development process was actually done, some aspects (such as mass production and marketing considerations) could not be completed within the time limits of this work. The results of this project will be discussed in two parts. First, the actual product as developed will be discussed. Secondly, a summary and conclusion of the development process will be presented.

9.2 The Product

The force reaction device, "Delta-Lok", was developed based on the extrusion concept chosen in Chapter 4. The device is attached to the instrument by means of a quick release pin and receptacle arrangement. The receptacle for the quick release pin is attached to the guitar by means of a standard strap button screw. Figure 9.1 shows the receptacle attached to a typical instrument.

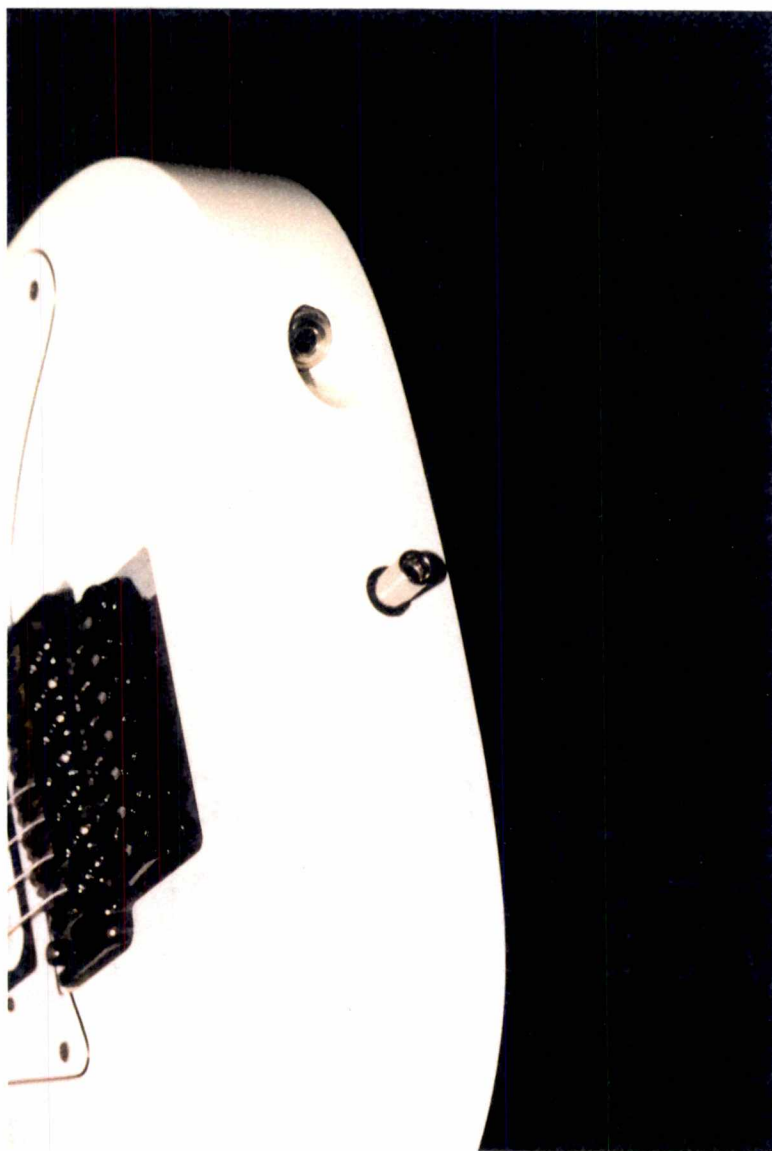


Figure 9.1 Receptacle Attached to a Typical Instrument

Both types of instrument straps (i.e. locking and non-locking) can be accommodated with this arrangement. Locking type straps are screwed directly into the instrument in the place of the strap button. Since this is the case, the rear portion of the locking type strap can be attached to the instrument directly underneath the receptacle. The receptacle is the only portion of the Delta-Lok arrangement that is continually attached to the instrument. Once the receptacle is in place, the clamping device can be attached to the instrument by means of the quick release pin. The cord may be inserted either before or after the clamping device is attached. The fully assembled Delta-Lok as used with a locking type strap is shown in Figure 9.2.

A non-locking type guitar strap is also compatible with the Delta-Lok. Once the receptacle is installed onto the instrument, the standard guitar strap can be placed over the receptacle. The strap is prevented from slipping off of the receptacle once the clamping device and quick release pin are attached to the instrument. Once again, the cord may be inserted into the clamping device either before or after the clamping device is attached. The fully assembled Delta-Lok as used with a non-locking strap is shown in Figure 9.3. It should also be noted that, if desired, a standard strap may be placed over the quick release pin body instead of the receptacle. However, this arrangement does not guarantee that the strap will remain in its desired position. In the assembly/use instructions for the device, it will be recommended that standard straps be placed behind the clamping device (i.e. over the receptacle).

In reference to the product design specification, all of the design requirements, both primary and secondary, are fully met with the current design of the Delta-Lok. The



Figure 9.2 Fully Assembled Delta-Lok As Used With a Locking Type Strap

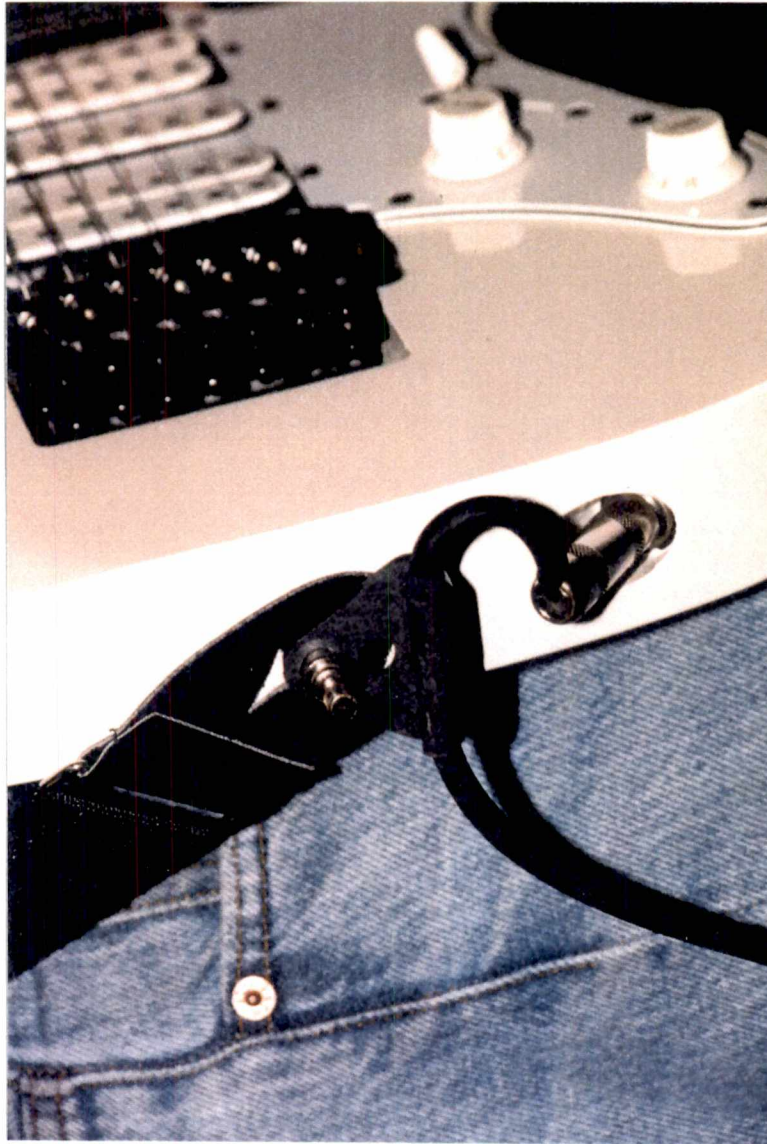


Figure 9.3 Fully Assembled Delta-Lok As Used With a Non-Locking Type Strap

major concerns, namely force reaction and surface finish protection, were fully satisfied by this design. The Delta-Lok prototype fully isolated the input jack side of the cord for all testing. The magnitude of the jerking force was estimated with a spring scale; the maximum force obtained during this process was slightly less than 20 lb. During the testing of the device, the arrangement was subjected to forces exceeding 20 pounds; it was found that the device did not release the cord *or even allow it to slip* under any of the subjected conditions.

The surface finish of the instrument is continually protected by the Delta-Lok. Any contact between the input cord and the instrument surface finish is prevented by the way that the device is arranged. Since the clamping device is offset from the instrument body by the receptacle, the cord and instrument body cannot come into contact under normal conditions.

Finally, the addition of the Delta-Lok to an instrument does not in any way inhibit the instrument from fitting into its carrying case. The only portion of the Delta-Lok arrangement that continually remains on the instrument is the receptacle. Since the size of the receptacle is of the same magnitude as a standard strap button, there is room in the carrying case to accommodate it. The satisfaction of all other design requirements primarily depends upon the size of the arrangement used. That is, the arrangement needed to be rather small in order to meet the majority of the rest of the design requirements. As can be seen from Figures 9.2 and 9.3, the Delta-Lok arrangement is very small and non-distracting to the use of the instrument. Overall, the design of the Delta-Lok, concerning the satisfaction of the Product Design Specification, seems to be

an overwhelming success.

9.3 The Development Process

The development process required to bring a product from concept to production is quite a formidable task. By no means could anyone learn everything in a short period of time. However, carrying out an investigation such as this is the one of the most efficient ways to learn. A personal concern for the project will increase the desire to be involved in all stages of the development process. In other words, since the idea for the product was the author's own, addressing all of the vital issues was a "personal" concern. Granted, some of the aspects of the design process are not a lot of fun; this fact, however, does not decrease their importance. A designer must be cautious not to neglect portions of the project that might not be as enjoyable as others. Even though they might not be as enjoyable to do, all aspects of the design demand a certain amount of time if they are to be done right. It was extremely beneficial to have the opportunity to work on a personal project; many of the small details might not have been addressed on a "standard academic project".

The development process be separated into several stages of work. This is rigorously done in the Superior Engineering Design Program's Product Development Guide. As a brief summary of the product development stages, they can be summarized in the author's own words as follows:

- (1) Identification of a Basic Need for a Product;
- (2) Development of the Product Design Specification (i.e. Design Requirements);
- (3) Development of Concepts for the Product;
- (4) Organized Selection and "Freezing" of Concept;
- (5) Full Development of Selected Concept (i.e. Analysis, etc.);
- (6) Prototyping of the Design;
- (7) Testing of the Prototypes;

Once the design specification has been fully satisfied, the following steps are used to bring the product to production...

- (8) Mass Production Considerations
- (9) Marketing Considerations

UNDER NO CIRCUMSTANCES should the above list be attacked sequentially. One of most important things to remember about product design is that all of the steps are important; in order to avoid a large number of "iterations", these aspects of product design are *all* kept in mind *continually*. The list is also only a summary. Certain projects will warrant other types of investigations; however, this *is* a *basic outline*.

Even though the entire basis of a thesis project is an *independent investigation*, the development of a product is most efficiently done in *small teams*. The members of design teams are most useful if each is a well rounded designer. The teams should not consist of "specialists". This project has gone a long way toward making the author a more well rounded engineer -- not a "Delta-Lok Specialist". The design "team" for this project consisted of both the professors within the thesis committee and the author's colleagues

at the Mechanical and Aerospace Engineering Department at the University of Tennessee, Knoxville. Without their generous help, this project could have never been completed.

CHAPTER 10

RECOMMENDATIONS

10.1 Quick Release Pin and Receptacle Arrangement

The initial estimate on the expense of purchasing the quick release pin and receptacle arrangement was obtained through a local advertising firm in Knoxville, TN. For the estimated price, the "key-separators" are to be obtained by the advertising company through a distributor which imports the devices into the United States from the manufacturer in China. The price of the arrangement can most likely be decreased if purchased either directly from the manufacturing company or a similar distributor. Also, since the two key rings are not needed for this design, the price could possibly be lowered somewhat if these were not included.

Also concerning this arrangement, since these key separators are generally used as a promotional item, company logos can be embossed upon the receptacle at an extra fee. This could be an advantageous addition to the overall appearance of the Delta-Lok. That is, since provisions for printing the name on the product have not yet been investigated, this could be a promising option.

Since this arrangement is not manufactured for engineering applications, some additional quality control and testing should be considered and performed before the product is packaged and shipped. With a small amount of analysis, the critical-to-function

dimensions can be ascertained and checked to assure that the device will work properly. Due to the relatively low manufacturing cost that has evolved for this product, it seems reasonable that 100% inspection of critical dimensions by a strategic means could be implemented. This investigation seems crucial for the assurance of proper functioning of all of the released products.

Although the size and proportion of the arrangement as purchased is sufficient for this design, it might eventually be advantageous to investigate the possibility of redesigning the arrangement specifically for this product. Since the part would be made upon a screw machine, tooling and manufacturing costs would be relatively low. The receptacle on the key separator is slightly longer than is necessary for use with the Delta-Lok. The extra length on the receptacle is provided to accommodate the key ring. Also, if the arrangement is to be redesigned, the quick release pin could be altered such that the push button is recessed (this is not required, but would reduce the overall length of the arrangement) and the body is shaped more similarly to that of a standard strap button. This would allow the user to place a standard (i.e. non-locking) guitar strap on either side of the clamping device without fear of accidental release. Once again, this is not a requirement, but it could be considered an *improvement*.

10.2 Clamping Device

One aspect that could be considered for the clamping device concerns the appearance of the device. The non-functional hole in the prototype could be of a

triangular shape similar to that of the outer profile. This would yet again reinforce the "delta" theme of the product. This change can only be feasibly made once the part is fabricated via an extrusion/stamping process or injection molding. If either of these production methods is eventually chosen for future productions of the Delta-Lok, then it would be a small task to make this minor change.

Of course, the cost of all possible changes should be investigated in order to determine whether or not the change is justified. Since all of these suggested changes are very minor (i.e. none of the changes affect the performance of the device), it would not be reasonable to invest a large amount of money into these changes. It may, however, be a feasible possibility to make a few of these minor changes on subsequent productions (or "new models") of the Delta-Lok.

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BIBLIOGRAPHY

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APPENDICES

APPENDIX 1

Detailed Discussion of Analysis:

Determination of Cord Insertion Force vs. Ring Gap

Case 1: Simplified Model: Neglection of Friction

A1.1 Objective

The insertion of the instrument cord into the "snap-fit" clamping device requires a certain amount of force. This force, termed hereafter as the insertion force, is a function of both the geometry of the clamping device and the properties of the chosen material. More specifically, the insertion force is dependent upon the available gap of the opening in the clamping device, the geometry of the clamping device (involving such parameters as area moment of inertia, cross-sectional area, etc.), and the physical properties of the chosen material (i.e. the modulus of elasticity, shear modulus, etc.). Therefore, the material and geometry of the clamping device must be chosen such that a desirable insertion force will result. The objective of this analysis is to start with a simple model of the clamping device, similar to that of the initial rough prototype of Figure 3.12, and derive a relationship between the insertion force and the available gap in the clamping device as a function of the geometry and material properties. This relationship is crucial to the setting of the design specifications, in that, the specifications of the geometry of the clamping device is dependent upon the material properties. For example, if a plastic of high modulus (and, thus, stiffness) is chosen as the material for manufacture, then the available gap must be greater than that of a plastic of less stiffness such that the force required for insertion is the same.

A1.2 Use of Castigliano's Theorem

Castigliano's Theorem is a useful method for finding the deflection of a member in a chosen direction. For example, the deflection δ_i of a member in the direction of a force P_i can be written as follows.

$$\delta_i = \int \left[\left(\frac{N}{EA} \right) \left(\frac{\partial N}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{kV}{GA} \right) \left(\frac{\partial V}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{M}{EI} \right) \left(\frac{\partial M}{\partial P_i} \right) dS \right] + \int \left[\left(\frac{T}{GJ} \right) \left(\frac{\partial T}{\partial P_i} \right) dS \right]$$

A dummy force may be added to the free body diagram of a member if the deflection is desired in a direction other than that of one of the forces in the system. The expressions resulting from the summations of forces, moments, and torques are not numerically affected by the dummy force since its numerical value is zero; however, the partial derivatives (i.e. changes of N , V , M , and T per unit change in the dummy force) are affected, resulting in an expression for the deflection of the member in the direction of the dummy force. This form of Castigliano's Theorem is useful due to its straightforward method of calculating deflections in various directions. Specifically for this case, it was desired to determine an expression for the change in gap of the clamping device as a function of the insertion force. Since the change in gap and the insertion force are in different directions, this theorem proved advantageous.

A1.3 Simple Model of Clamping Device

Figure A1.1(a) shows a sketch of a cord being inserted into a simple ring similar to the rough prototype of Figure 3.12. Figure A1.1(b) replaces the instrument cord with equivalent forces 'P' such that a free body diagram of the ring is obtained. Inspection of the ring reveals that the x-components of the equivalent forces 'P' will tend to open the ring symmetrically about a vertical plane which intersects the center of the ring. From this observation, the model can be further simplified as shown in Figure A1.1(c). Since the ring opens symmetrically, the intersection of the plane acts as a cantilever support; the ring does not deflect at this point. Therefore, the model can be divided into two identical parts; the resulting deflection from analysis of one of the parts will be one half of the total change in gap.

Figure A1.2(a) shows the cantilevered "split" model cut at an angle θ . Figure A1.2(b) shows the free body diagram of the cut section of the model. Friction is neglected for the first and most simple case for the purpose of illustrating the use of this method as applicable to this design.

Summation of Forces in the x and y directions lead to expressions for the shear force V and the normal force N at the plane of cut.

$$V = P \sin \theta$$

$$N = P \cos \theta$$

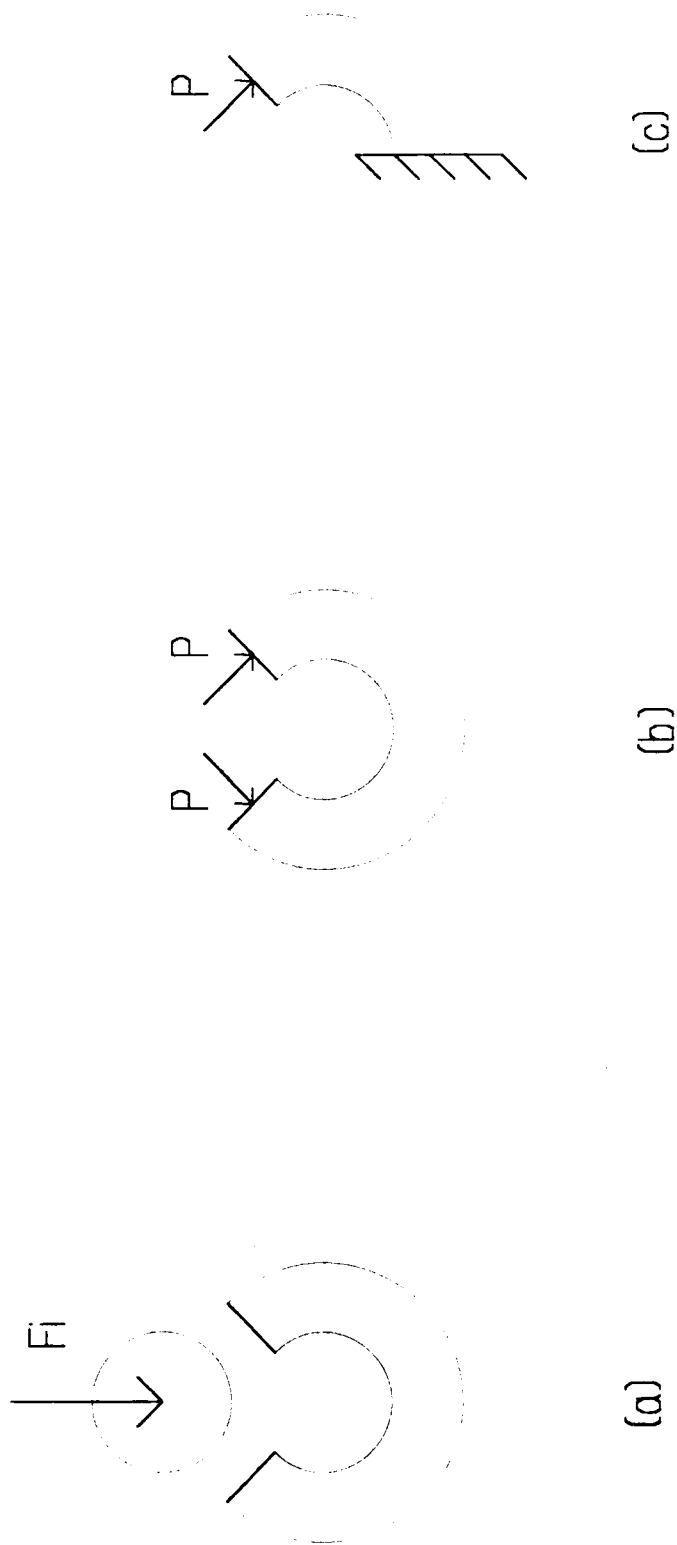


Figure A1.1 Initial Sketches: A Simple Model of the Clamping Device For Use With Castigliano's Theorem

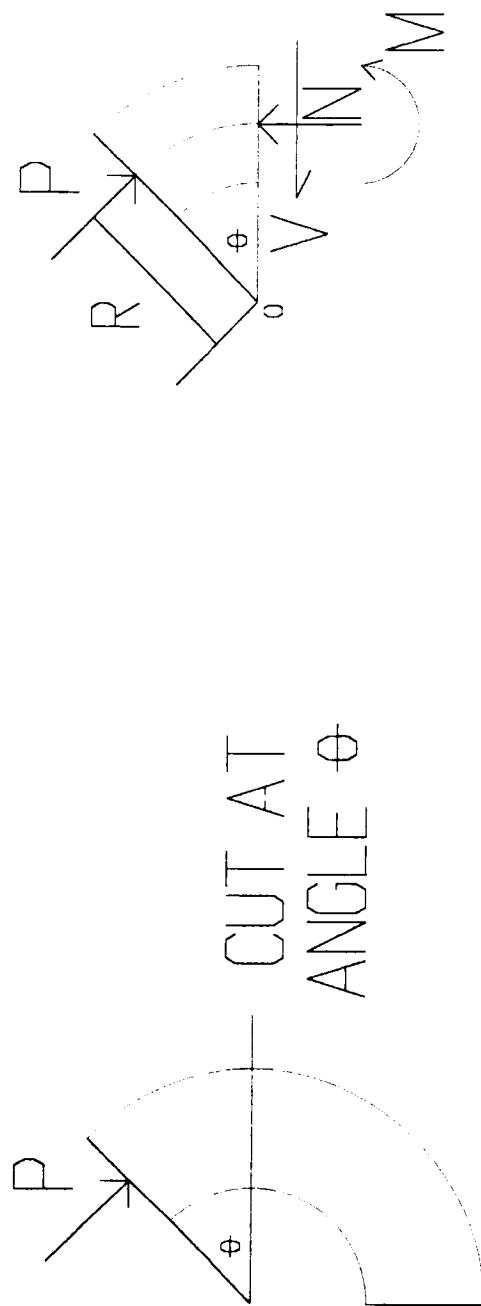


Figure A1.2 Schematic of Differential Element of Simple Model

Summation of Moments about the point 'O' gives a simple expression for the moment M .

$$M = PR - NR$$

Substituting the expression for N yields...

$$M = PR(1 - \cos \theta).$$

Since the desired deflection of the member is in the x -direction (for the schematic shown in Figure A1.2(a)), the partial derivatives should be taken with respect to the component of the force P in the x -direction. The expression for this component, P_x , is

$$P_x = P \cos \theta.$$

The partial derivatives of the expressions for V and N become

$$\frac{\partial V}{\partial P_x} = 1$$

$$\frac{\partial N}{\partial P_x} = 0.$$

An alternate expression for M containing P_x is found by using the x and y components of P and again summing moments:

$$M = PR(\cos^2 \theta - \cos \theta) + (P \sin \theta)(R \sin \theta).$$

The partial derivative of M with respect to P_x becomes...

$$\frac{\partial M}{\partial P_x} = R \sin \theta.$$

Since the partial derivative of N with respect to P_x is zero, the first integral in the deflection equation is eliminated. Noting that $dS = R d\theta$, and integrating between the limits of 0 and 0.75π , the expression for the deflection of the member in the x-direction becomes...

$$\delta_x = \frac{kPR}{GA} \int_0^{\frac{3\pi}{4}} \sin \theta d\theta + \frac{PR}{EI} \int_0^{\frac{3\pi}{4}} (1 - \cos \theta)(R \sin \theta)R d\theta.$$

Using the trigonometric identity $\sin 2\theta = 2\sin\theta\cos\theta$, this simplifies to...

$$\delta_x = \frac{kPR}{GA} \int_0^{\frac{3\pi}{4}} \sin \theta d\theta + \frac{PR^3}{EI} \left[\int_0^{\frac{3\pi}{4}} \sin \theta d\theta + \frac{1}{2} \int_{\frac{3\pi}{4}}^0 \sin 2\theta d\theta \right]$$

Integration yields...

$$\delta_x = \frac{kPR}{2GA} (2 + \sqrt{2}) + \frac{PR^3}{4EI} (3 + 2\sqrt{2}).$$

This is the expression for the deflection of the split model member neglecting friction, where A = the cross-sectional area of the rectangular face on which the force P

is applied. Likewise, I = the area moment of inertia of the same face. The expression represents **one half** of the deflection of the ring in Figure A1.1(b). Recall that the force P is not the insertion force; it is merely the force exerted by the cord on one side of the ring. However, with the geometry given, this expression relates the x -deflection to the force P .

Since the cord is not a rigid member, it will also deflect when being inserted into the clamping device. The expression for the change in gap must be modified to include the spring rate of the cord, K_c . The insertion of the cord can be modeled as two springs in series as shown in Figure A1.3. An expression for the spring rate in the x -direction, K_p , of the device can readily be found from the deflection equation; since K_p represents the ratio of force to deflection, the expression for K_p becomes...

$$K_p = \frac{P}{\delta_x} = \frac{1}{\left[\frac{kR}{2GA} (2 + \sqrt{2}) + \frac{R^3}{4EI} (3 + 2\sqrt{2}) \right]}$$

Since the springs are connected in series, the equivalent spring rate of the system in the x -direction, K_{eq} , is...

$$K_{eq} = \frac{K_c K_p}{K_c + K_p}$$

With the expression for K_{eq} known, an expression for the required insertion force, F_i , can be determined. Referring to the model in Figure A1.4 and recalling that δ_x

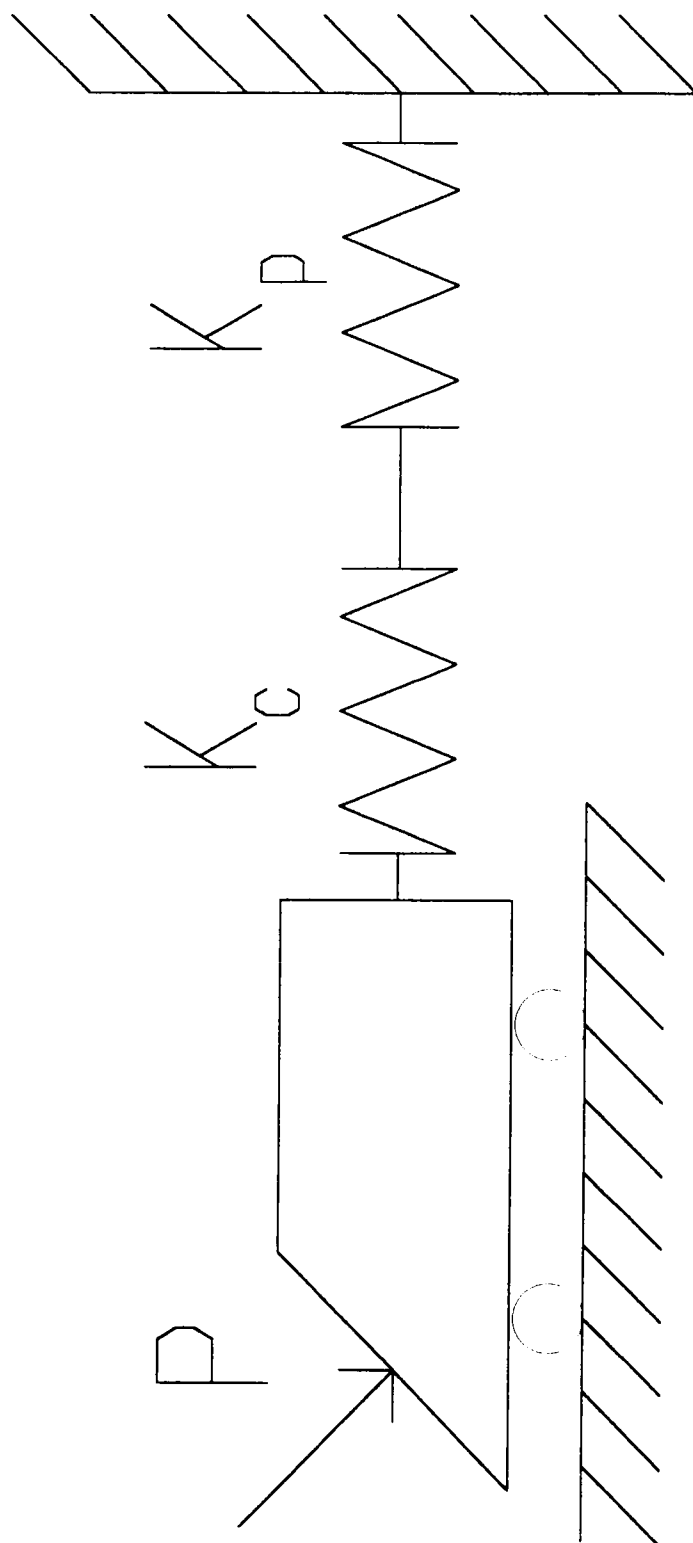


Figure A1.3 Model of System: Two Springs in Series

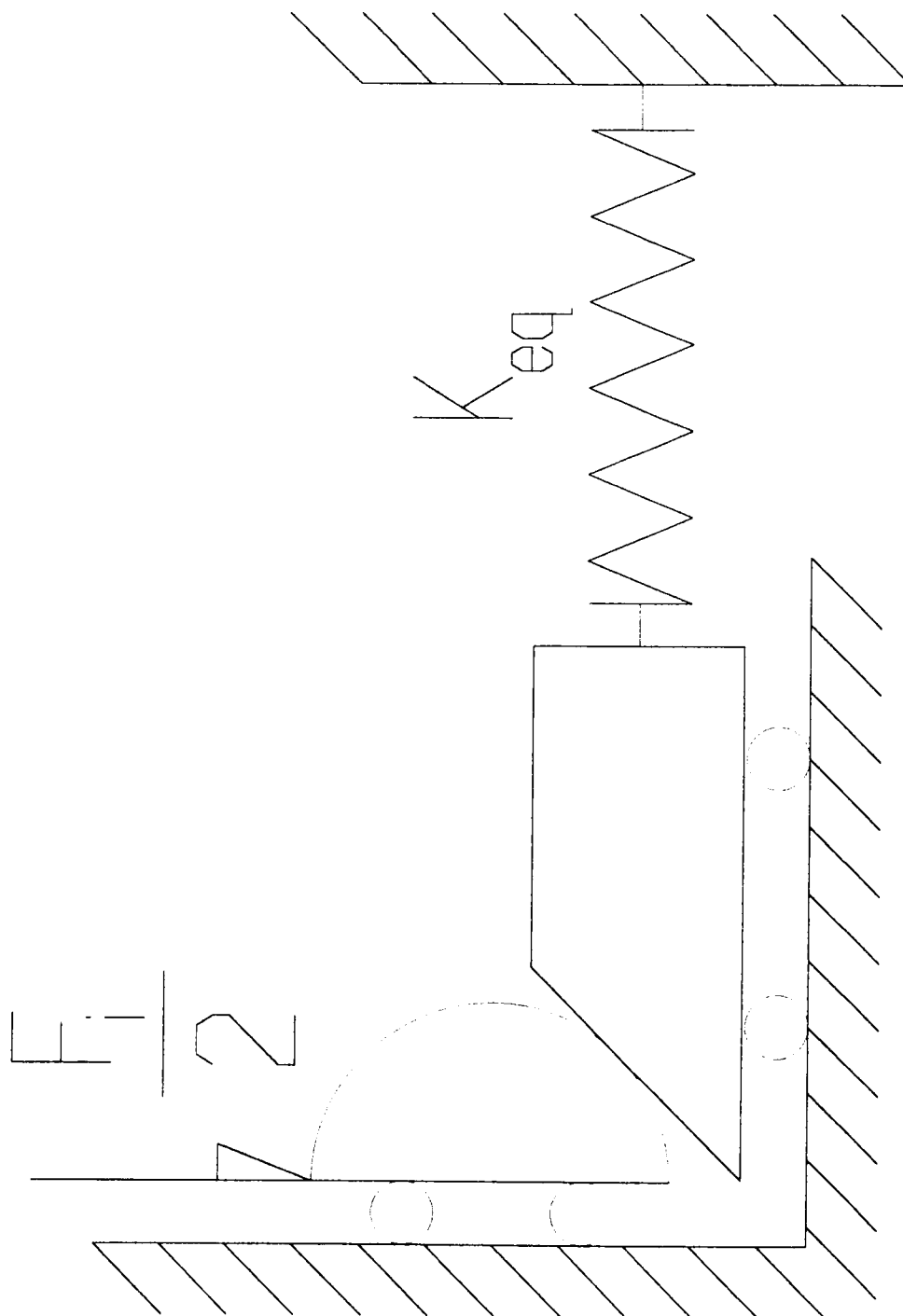


Figure A1.4 Schematic Relating Insertion Force vs. Deflection (no friction)

represents one half of the total deflection (or available gap), Δ , a summation of forces on the cord in the y-direction yields...

$$F_i = 2 P \sin \gamma$$

where $\gamma = \pi - \theta$. Similarly, a summation of forces in the x-direction on the model for the ring yields...

$$P = \frac{K_{eq} \Delta}{2 \cos \gamma}.$$

Combining the two equations yields the desired result: an expression for the insertion force as a function of the available gap:

$$F_i = K_{eq} \Delta \tan \gamma.$$

The only variable within the equation that must be determined experimentally is the spring rate of the cord K_c . This expression predicts the required exertion force for a given value of the available gap. In other words, if a material is to be chosen for the clamping device, this equation can be used to determine a range of gaps that will allow for a desirable insertion force for a given geometry. It should be noted that this equation does NOT consider the existence of an additional force due to friction, μP . Since this force opposes opening of the clamping device, it increases the required insertion force.

APPENDIX 2

Detailed Discussion of Analysis:

Determination of Cord Insertion Force vs. Ring Gap

Case 2: Addition of Friction Force onto Simple Model

A2.1 Objective

The objective of this analysis is to introduce a more complete model of the clamping device such that an expression for the required force for insertion may be found as a function of the geometry and material properties. Specifically, this more complete analysis accounts for the presence of friction force in the free body diagram of the same section of the ring cut at an angle θ . This new free body diagram is shown in Figure A2.1. The inclusion of this force is important to the accuracy of the analysis since this force opposes the opening of the ring. This increases the required insertion force. As mentioned for the simplified model, this analysis should provide legitimate support in the material selection and dimension specifications.

A2.2 Development of an expression for F_i vs. Δ : Friction Force Included..

Referring to Figure A2.1, summation of forces in the x and y-directions yield the expressions for V and N:

$$\begin{aligned}V &= P(\sin \theta - \mu \cos \theta) \\N &= P(\cos \theta + \mu \sin \theta)\end{aligned}$$

Similarly, summation of moments about 'O' yields an expression for M...

$$M = (P \sin \theta)R(\sin \theta - \mu) + PR(\cos^2 \theta - \cos \theta)$$

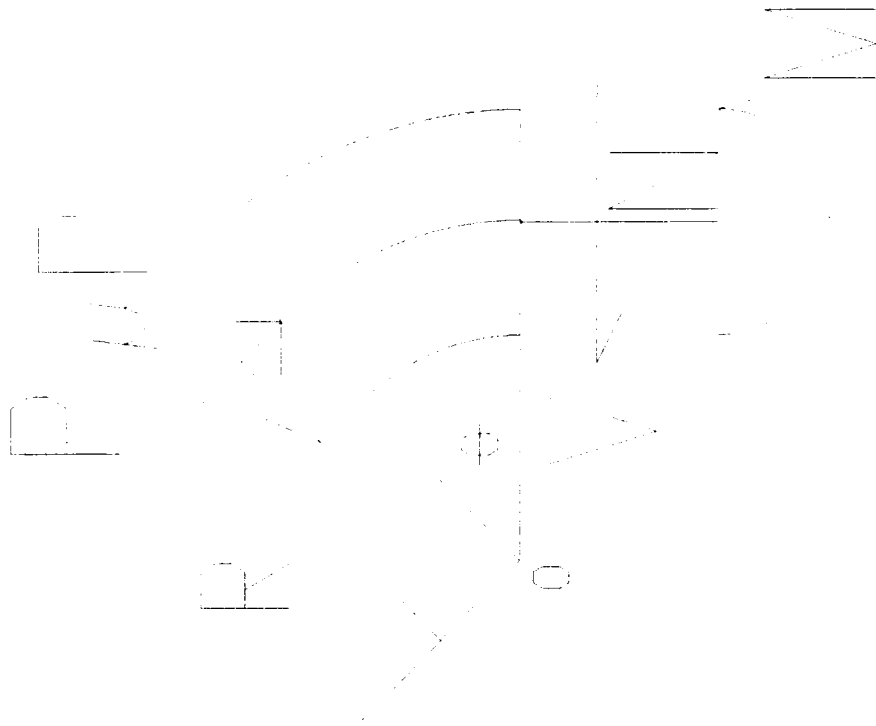


Figure A2.1 Schematic of Differential Element of Model (including friction)

Recalling that $P_x = P \sin \theta$, the partial derivatives of each of the above expressions with respect to P_x become...

$$\begin{aligned}\frac{\partial N}{\partial P_x} &= \mu \\ \frac{\partial V}{\partial P_x} &= 1 \\ \frac{\partial M}{\partial P_x} &= R(\sin \theta - \mu)\end{aligned}$$

Recalling that $dS = R d\theta$, the first integral in Castigliano's formula for deflection becomes...

$$\int_0^{\frac{3\pi}{4}} \frac{N}{EA} \left(\frac{\partial N}{\partial P_x} \right) dS = \int_0^{\frac{3\pi}{4}} \frac{P}{EA} (\cos \theta + \mu \sin \theta) (\mu) (R d\theta)$$

Similarly...

$$\begin{aligned}\int_0^{\frac{3\pi}{4}} \frac{kV}{GA} \left(\frac{\partial V}{\partial P_x} \right) dS &= \int_0^{\frac{3\pi}{4}} \frac{kP}{GA} (\sin \theta - \mu \cos \theta) (R d\theta) \\ \int_0^{\frac{3\pi}{4}} \frac{M}{EI} \left(\frac{\partial M}{\partial P_x} \right) dS &= \int_0^{\frac{3\pi}{4}} \frac{PR^3}{EI} (1 - \cos \theta - \mu \sin \theta) (\sin \theta - \mu) d\theta\end{aligned}$$

Upon integration, the first integral becomes...

$$\int_0^{\frac{3\pi}{4}} \frac{N}{EA} \left(\frac{\partial N}{\partial P_x} \right) dS = \frac{PR}{2EA} [\mu\sqrt{2} + \mu^2(2 + \sqrt{2})]$$

Integration of the second integral yields...

$$\int_0^{\frac{3\pi}{4}} \frac{kV}{GA} \left(\frac{\partial V}{\partial P_x} \right) dS = \frac{KPR}{2GA} [2 + \sqrt{2}(1 - \mu)]$$

Thirdly, the result of the third integral...

$$\int_0^{\frac{3\pi}{4}} \frac{M}{EI} \left(\frac{\partial M}{\partial P_x} \right) dS = \frac{PR^3}{EI} \left[\left(1 + \frac{\sqrt{2}}{2} \right) (1 + \mu^2) - \frac{\mu}{8} (9\pi + 2 - 4\sqrt{2}) - \frac{1}{4} \right]$$

As before, the summation of the three integrals yields the deflection of the member in the x-direction. Again, it is noted that due to the use of the "split model" this value of deflection is equivalent to **one half** of the total deflection (or change in gap) of the clamping device.

The expression for the spring rate of the member in the x-direction is found in the same manner as in the previous case, i.e...

$$K_p = \frac{P}{\delta_x}$$

The equivalent spring rate is likewise found in a similar manner to the previous case...

$$K_{eq} = \frac{K_c K_p}{K_c + K_p}$$

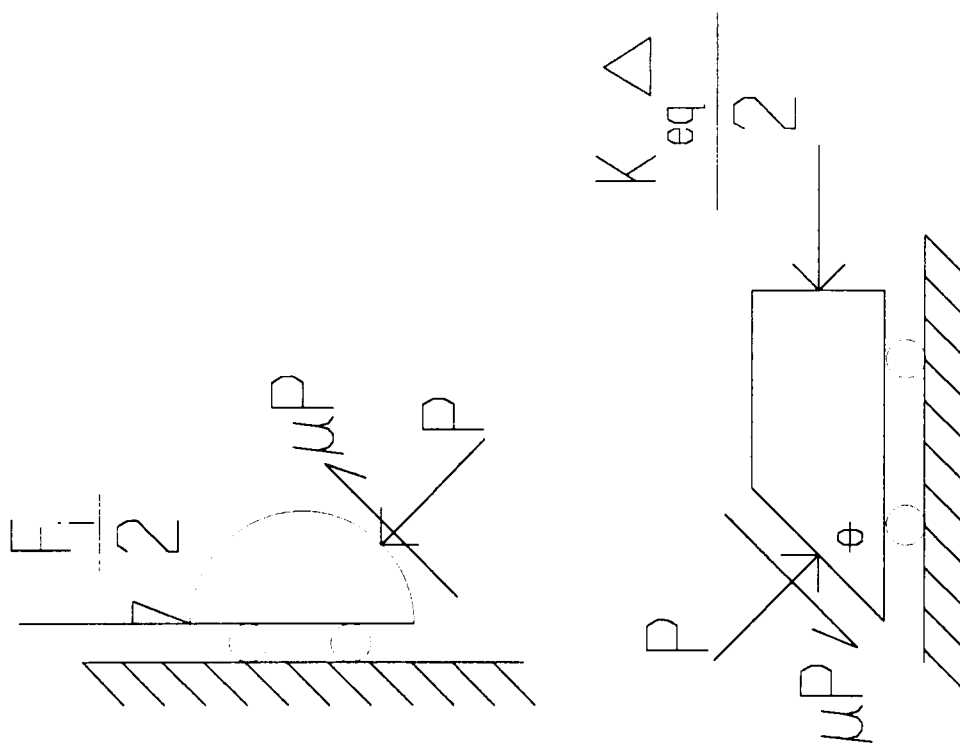


Figure A2.2 Schematic Relating Insertion Force vs. Deflection (including friction)

To determine the expression for the insertion force, F_i , refer to Figure A2.2. Summation of forces in the y-direction on the cord yields...

$$F_i = 2P(\sin \gamma + \mu \cos \gamma)$$

where $\gamma = \pi - \theta$. Summation of forces in the x-direction on the model for the ring yields...

$$P = \frac{K_{eq} \Delta}{2(\cos \gamma - \mu \sin \gamma)}$$

Combining the two equations yields the desired result of an expression for insertion force as a function of the available gap...

$$F_i = \frac{K_{eq} \Delta (\sin \gamma + \mu \cos \gamma)}{(\cos \gamma - \mu \sin \gamma)}$$

It should be noticed that when $\mu = 0$, this expression reduces to the exact expression for the earlier case. Once again, the only primary variable that must experimentally be determined is the spring rate of the cord, K_c . This expression aids the designer in selecting a material and geometry with respect to a desired insertion force in the same manner as the earlier expression. However, this expression can be expected to predict the deflection and insertion force much more accurately due to the additional consideration of the friction force μP .

The investigation of the relationship between F_i and Δ was continued with one final addition to the initial model. In an effort to provide some mechanical advantage for

insertion of the cord, an investigation as to the effects of an additional angle β was undertaken. This additional angle increases the x-component of the force P on the face of the clamping device.

APPENDIX 3

Detailed Discussion of Analysis

Determination of Cord Insertion Force vs. Ring Gap

Case 3: Addition of Angle β for Mechanical Advantage

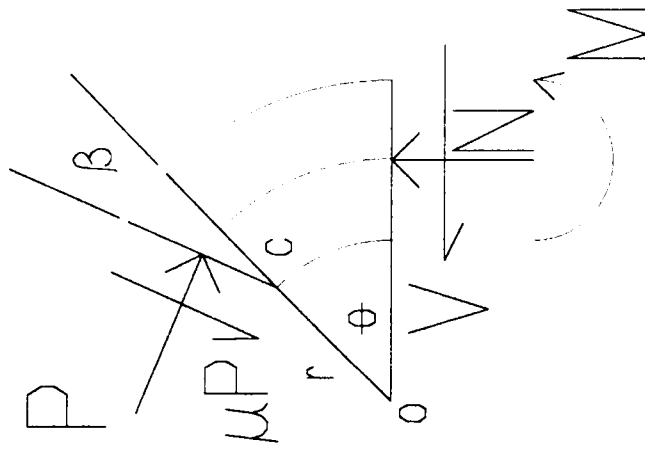
A3.1 Objective

The objective of this third and final investigation of determining a relationship between insertion force and the material and geometric properties of the clamping device is to evaluate the effectiveness of adding an additional angle β onto the face of the clamping device. This concept is shown on the now familiar "split model" in Figure A3.1. The addition of this angle provides some mechanical advantage towards the insertion of the cord into the clamping device. This additional angle increases the x-component of the force P ; the result is that a greater percentage of the insertion force is used in performing the desired task. That is, more of the insertion force is used to actually open up the clamping ring. In addition to the determining the effects of this additional angle, a relationship governing the feasible range of this angle is developed. As in the previous investigations, the end goal of this analysis is augmentation to the material and geometry selection process for the clamping device.

A3.2 Development of a Relationship between F_i and Δ : Addition of β .

Referring to Figure A3.1, summation of forces in the x and y-directions yield the expressions for V and N :

$$\begin{aligned}V &= P[\sin(\theta + \beta) - \mu \cos(\theta + \beta)] \\N &= P[\cos(\theta + \beta) + \mu \sin(\theta + \beta)]\end{aligned}$$



r = inner radius of ring

c = distance from inner radius to the line of force

Figure A3.1 Schematic of Differential Element of Model (including friction and β)

It should be noticed that the variable R has been replaced by the combination of ' r ' and ' c ' such that the moment arms for all forces can be calculated. Summation of moments about point ' O ' yields the expression for M :

$$M = P[\mu r \sin \beta + (r + c) - \{\cos(\theta + \beta) + \mu \sin(\theta + \beta)\}(r + c)]$$

Similar to the earlier case, the partial derivatives of V and N with respect to P_x can be determined. It should be noticed that, for this case, $P_x = P \sin(\theta + \beta)$. The partial derivatives of V and N become...

$$\frac{\partial V}{\partial P_x} = 1$$

$$\frac{\partial N}{\partial P_x} = \mu$$

The partial derivative of M with respect to P_x becomes...

$$\frac{\partial M}{\partial P_x} = r \sin \theta + [c - \mu(r + c)] \sin(\theta + \beta)$$

Noticing that $dS = (r + c)d\theta$, the first integral in the deflection equation becomes...

$$\int_0^{\frac{3\pi}{4}} \frac{N}{EA} \left(\frac{\partial N}{\partial P_x} \right) dS = \int_0^{\frac{3\pi}{4}} \frac{P}{EA} [\cos(\theta + \beta) + \mu \sin(\theta + \beta)] [\mu(r + c) d\theta]$$

The second integral in the deflection equation V becomes...

$$\int_0^{\frac{3\pi}{4}} \frac{kV}{GA} \left(\frac{\partial V}{\partial P_x} \right) dS = \int_0^{\frac{3\pi}{4}} \frac{kP}{GA} \{ \sin(\theta + \beta) - \mu \cos(\theta + \beta) \} (r + c) d\theta$$

Finally, the third integral in the deflection equation becomes...

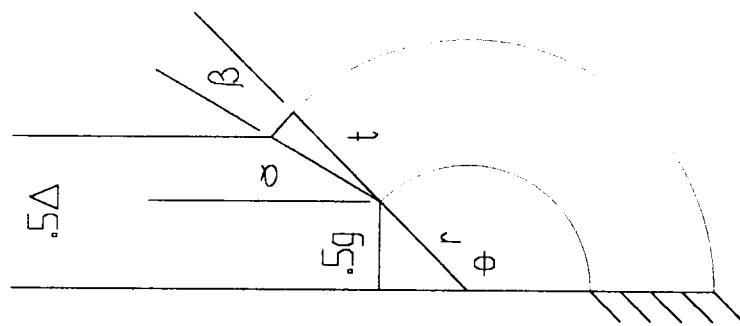
$$\int_0^{\frac{3\pi}{4}} \frac{M}{EI} \left(\frac{\partial M}{\partial P_x} \right) dS = \int_0^{\frac{3\pi}{4}} P \{ \mu r \sin \beta + [(r + c) - \mu \sin(\theta + \beta) + \cos(\theta + \beta)](r + c) \} \{ r \sin \theta + [c - \mu(r + c)] \sin(\theta + \beta) \} (r + c) d\theta$$

Due to the complexity of the integrals, a program was used to numerically solve these integrals. The program was further modified such that the material properties and the geometry of the clamping ring could be directly entered into the computer upon a prompt.

The relationship for the spring rate of the clamping device is found by a method identical to that the previous cases. It should be noticed that the expression for γ becomes $\gamma = \pi - \theta - \beta$.

From the collected data, plots were made of F_1 vs. Δ . The angle β was changed for various values of other properties. In order to determine the feasible range of the angle β , the sketch in Figure A3.2 was used. Denoting 'g' as the gap at the inner radius, the equation for 'g' becomes...

$$g = 2r \sin(\pi - \theta).$$



$$.5g = r \sin(\pi - \theta)$$

$$\alpha = \pi - \theta - \beta$$

Figure A3.2 Schematic for Developing Equation Limiting the Angle β

Since the distance between the two outermost points of the ring (denoted as GAP) must be greater than the diameter of the cord so that the cord can actually open the ring, the following equation limits the range of the angle β .

$$\beta \leq \theta - \pi - \sin^{-1}\left(\frac{GAP - g}{2t}\right)$$

where 't' is the wall thickness of the ring. If an angle β is chosen which does not satisfy this equation, then the cord cannot be inserted into the clamping device.

APPENDIX 4

Computer Code Printout

Analysis Using Castigliano's Theorem

Determination of Required Gap vs. Insertion Force for Chosen Material

```

CLS
REM save"INSERT.bas"
REM
REM *****
REM
REM Chris Widner. Department of Mechanical and Aerospace Engineering
REM University of Tennessee, Knoxville. 9/8/93
REM
REM *****
REM
REM This program calculates the amount of force required to insert a guitar
REM input cable into a plastic holding ring of length one inch.
REM
REM The calculation of deflection in this program is performed using
REM Castigliano's theorem. Since the curved member under consideration
REM is of constant cross section, the forces and geometric properties
REM of the ring (i.e. input force, tensile modulus, shear modulus, area
REM moment of inertia, etc...) are also constant and may be pulled outside
REM the integration. This results in an ordinary differential equation in
REM terms of the polar coordinate angle, theta (denoted as t in the program).
REM
REM The subroutine which integrates to find the deflection of the holding
REM ring is based upon a code written by Dr. F.H. Speckhart. This code uses
REM a 4th-order Runge-Kutta integration method to integrate systems of first
REM order ordinary differential equations.
REM
REM This program requires interactive input of several pertinent variables.
REM These variables mostly consist of the geometry and material properties
REM of the ring. An important variable that must be determined
REM by experimental methods is the spring rate of the guitar cord (KC).
REM
REM *****
REM
REM LIST OF VARIABLES
REM
REM T = angle of integration, theta
REM GAMMA = angle between insertion force and face of ring
REM R = Inner radius of holding ring
REM THICK = wall thickness of ring
REM C = distance from inner surface of ring to line of action of forces
REM E = Tensile Modulus of ring material
REM G = Shear Modulus of ring material
REM MU = Coefficient of Friction
REM BB = Angle of wedge (added to provide mechanical advantage for insertion)

```

```

REM B = BB as a fraction of PI radians
REM DC = Diameter of guitar cord
REM RGAP = Available gap between inter tips of ring
REM II = Area moment of inertia of ring section cut at angle theta
REM A = Area of cross section of ring cut at angle theta
REM KK = Shear Correction Factor (= 1.5 for rectangular section)
REM P = Dummy variable for component of force on ring face
REM DELTA = required deflection of ring
REM KC = Spring rate of guitar cord perpendicular to major axis
REM KP = Spring rate of holding ring in direction of deflection
REM
REM ----- VARIABLES INHERENT TO CASTIGLIANO'S THEOREM -----
REM
REM V = Shear force on section of ring cut at angle theta
REM NN = Normal force on section of ring cut at angle theta
REM M = Moment about center of ring on ring section cut at theta
REM DNDPX = Partial derivative of NN expression with respect to x-component
REM          of the input force on the ring face
REM DVDPX = Partial derivative of V expression with respect to x-component
REM          of the input force on the ring face
REM DMDPX = Partial derivative of M expression with respect to x-component
REM          of the input force on the ring face
REM DS = differential length of ring section
REM
REM *****
REM *****

```

$$PI = 4 * ATN(1)$$

```

DIM K(4, 80), Y(80), Z(80), YD(80)
FOR I = 1 TO 80: Y(I) = 0: NEXT I

```

```

REM *****
REM *****
REM Interactive input of ring constants
REM *****
REM *****

```

```

INPUT "Inner radius of ring (inches)"; R
INPUT "Wall thickness of ring (inches)"; thick
INPUT "Coefficient of Friction"; MU
INPUT "Tensile Modulus of Ring Material (psi)"; E
INPUT "Additional Angle Beta (fraction of PI radians)"; BB

```

```

GOTO 20
10 PRINT
REM *****
REM If the diameter of the cord is less than the available gap, then no
REM force is required for insertion of the cord into the ring.
REM *****

PRINT "Diameter of Cord must be greater than the ring gap  "
20 INPUT "Diameter of Cord (inches)"; DC
INPUT "Ring gap (inches)"; RGAP

REM *****
REM IF statement checks if the gap is less than the cord diameter
REM *****

IF DC <= RGAP THEN 10

REM *****
REM B expresses Beta as a fraction of PI radians
REM *****

B = BB * PI

REM *****
REM c = distance from inner surface of ring to line of forces on ring
REM *****

c = thick / 2

REM *****
REM II = Area Moment of inertia of ring for bending of differential area
REM *****

II = (thick ^ 3) / 12

REM *****
REM A = cross sectional area of ring section = 1 * ring thickness
REM *****

A = thick

REM *****
REM KK = Shear correction factor (1.5 for rectangular section)

```

```

REM *****
KK = 1.5

REM *****
REM G = shear modulus
REM *****

G = .4 * E

REM *****
REM P = dummy variable for component of force on ring surface
REM Numerical value is meaningless since end solution depends on spring rate
REM i.e. K = force/deflection; since deflection is a function of force,
REM the numerical value for P cancels out of the expression for K.
REM *****

P = 1

REM *****
REM This solution divides the problem into two parts: The ring is split at
REM the bottom and cantilevered at that point. For this reason, all spring
REM rates and deflections (including gaps) are divided by a factor of 2.
REM The final value for insertion force is corrected by multiplying by this
REM factor at the conclusion of the calculations
REM *****

REM *****
REM DC2 is the half of the diameter that is used for the "split" model
REM *****

DC2 = DC / 2

REM *****
REM RGAP2 is the half of the ring gap that is used for the "split" model
REM *****

RGAP2 = RGAP / 2

REM *****
REM DELTA is the required ring deflection for the "split" model. The actual
REM required deflection is twice this value.
REM *****

```

DELTA = DC2 - RGAP2

PRINT

PRINT "Coefficient of Friction = "; MU

PRINT "Wedge angle, beta ="; B; "radians"

PRINT "Ring Thickness = "; thick; "inches"

PRINT

'LPRINT "P = "; P; "lbs"

'LPRINT "Coefficient of Friction = "; mu

'LPRINT "Wedge angle, beta ="; B; "radians"

'LPRINT "Ring Thickness = "; thick; "inches"

'LPRINT

REM *****

REM Enter initial conditions if different than zero

Y(1) = 0

REM T9 = Maximum time

T9 = .75 * PI

REM T8 is equal to the print interval

T8 = .75 * PI

REM D1 = Increment of integration step size

D1 = T9 / 400

REM N = number of first order equations

N = 1

REM *****

T8 = T8 / D1

FOR I = 1 TO 80

Z(I) = Y(I)

NEXT I

T7 = 9.000001E+09

T = 0

GOTO 500

280 FOR J = 1 TO 4

ON J GOTO 430, 300, 350, 390

300 T = T + D1 * .5

FOR I = 1 TO N

Y(I) = K(1, I) * D1 * .5 + Z(I)

NEXT I

GOTO 430

350 FOR I = 1 TO N

```

    Y(I) = K(2, I) * D1 * .5 + Z(I)
    NEXT I
    GOTO 430
390 T = T + .5 * D1
    FOR I = 1 TO N
        Y(I) = K(3, I) * D1 + Z(I)
    NEXT I
430 GOSUB 620
    FOR JK = 1 TO N
        K(J, JK) = YD(JK): NEXT JK
    NEXT J
    FOR I = 1 TO N
        Z(I) = Z(I) + D1 * (K(1, I) + K(4, I) + 2 * (K(3, I) + K(2, I))) / 6
    NEXT I
500 FOR I = 1 TO N
    Y(I) = Z(I)
    NEXT I
    T7 = T7 + 1
    IF T7 <= T8 - .0002 THEN 600
    T7 = 0
    REM *****
    'PRINT USING "THETA = ##.### RADIANS  DGAP = ###.##### INCHES";
T; Y(1)
    PRINT "CALCULATING SPRING RATE OF HOLDING RING....."
    REM *****
600 IF T <= T9 THEN 280

REM *****
REM Deflection in x-direction has been calculated from subroutine
REM *****

REM *****
REM Spring Rate of Holding ring equals (input force--x)/(x-deflection)
REM *****

    KP = (P * SIN(T + B)) / Y(1)

    PRINT
    PRINT "EQUIVALENT SPRING RATE OF PIECE = "; KP; "lb/in"

REM *****
REM Interactive input of spring rate of guitar cord
REM *****

```

```

INPUT "Spring Rate of Guitar Cord (lb/in)"; KC

REM *****
REM KC2 = Guitar Cord Spring Rate for "Split" model
REM *****

    KC2 = KC / 2

REM *****
REM Calculation of Equivalent Spring Rate of system
REM (Addition of 2 springs in series)
REM *****

    KEQ = KC2 * KP / (KC2 + KP)

REM *****
REM GAMMA = angle between insertion force and face of holding ring
REM *****

    GAMMA = PI - T - B

REM *****
REM Calculation of required insertion force for "split" model
REM *****

    FI = (KEQ * DELTA * (SIN(GAMMA) + MU * COS(GAMMA))) / (2 *
(COS(GAMMA) - MU * SIN(GAMMA)))

REM *****
REM Correction of insertion force from "split" model to actual system
REM *****

    FINS = 2 * FI

PRINT
PRINT "REQUIRED FORCE FOR INSERTION ="; FINS; "lbs"
END

REM *****
620 REM Start of a subroutine containing N first order differential equations
REM Subroutine calculates the x-direction deflection of the holding ring
REM This deflection is used in conjunction with the input force P in
REM order to calculate the spring rate of the holding ring

```

REM *****

REM *****

REM Expression for shear force on ring section cut at angle theta

REM *****

$$V = P * \sin(T + B) - MU * P * \cos(T + B)$$

REM *****

REM Expression for normal force on ring section cut at angle theta

REM *****

$$NN = MU * P * \sin(T + B) + P * \cos(T + B)$$

REM *****

REM Expression for moment about center of ring on section cut at theta

REM *****

$$M = MU * P * R * \sin(B) + P * (R + c) - NN * (R + c)$$

REM *****

REM Partial derivative of NN expression with respect to force in x-direction

REM *****

$$DNDPX = MU$$

REM *****

REM Partial derivative of V expression with respect to force in x-direction

REM *****

$$DVDPX = 1$$

REM *****

REM Partial derivative of M expression with respect to force in x-direction

REM *****

$$DMDPX = R * \sin(T) + c * \sin(T + B) - MU * (R + c)$$

REM *****

REM Differential length of integral with respect to theta

REM

DS = (R + c)

NEA = NN / (E * A)

KVGA = (KK * V) / (G * A)

MEI = M / (E * II)

REM *****

REM Expression of Castigliano's theorem to integrated to find x-deflection

REM *****

YD(1) = (NEA * DNDPX + KVGA * DVDPX + MEI * DMDPX) * DS

RETURN

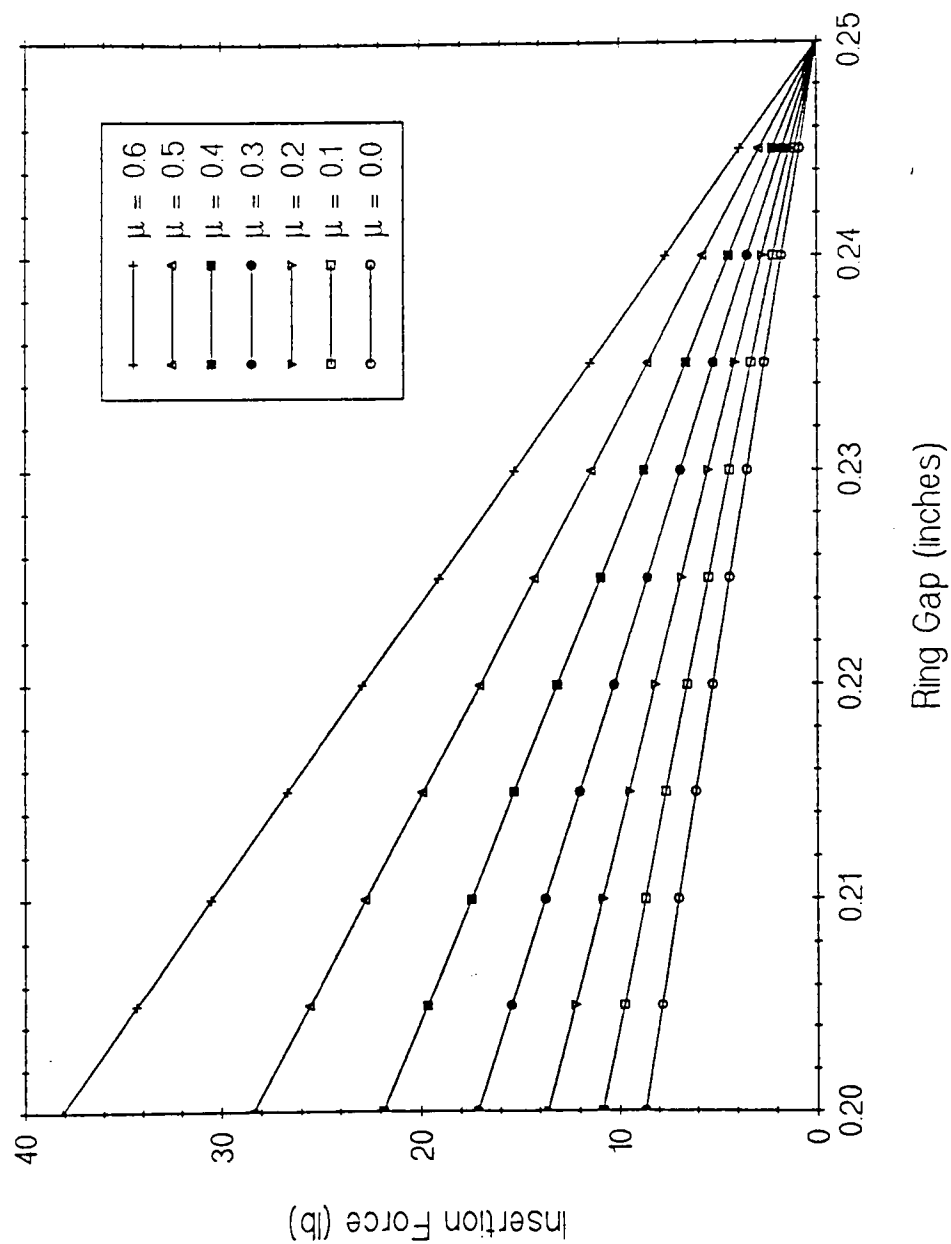
APPENDIX 5

Graphical Results of Analysis:

Investigation of Insertion Force vs. Available Gap

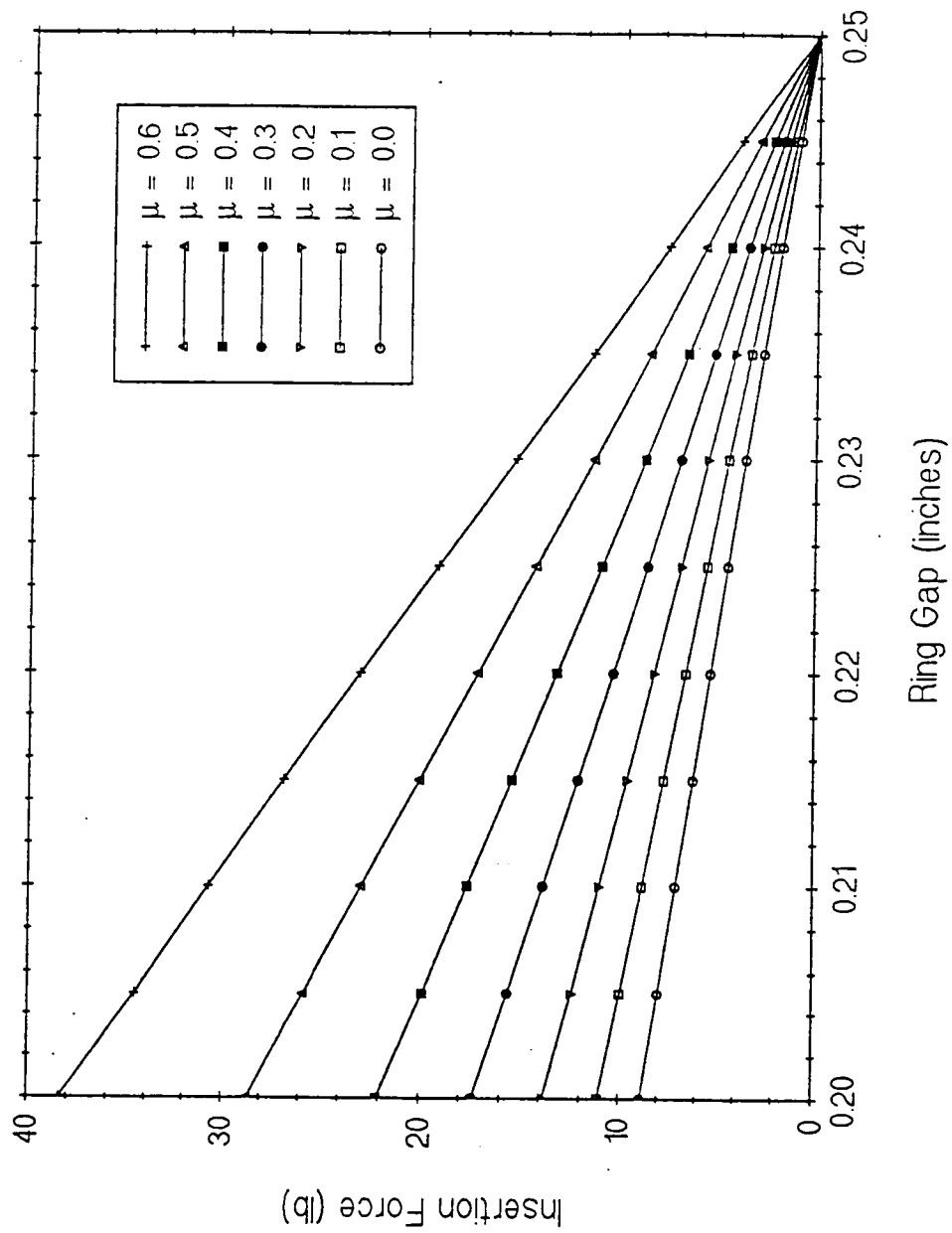
Insertion Force vs. Available Gap

$E = 250000 \text{ psi}$; $\beta = 0$



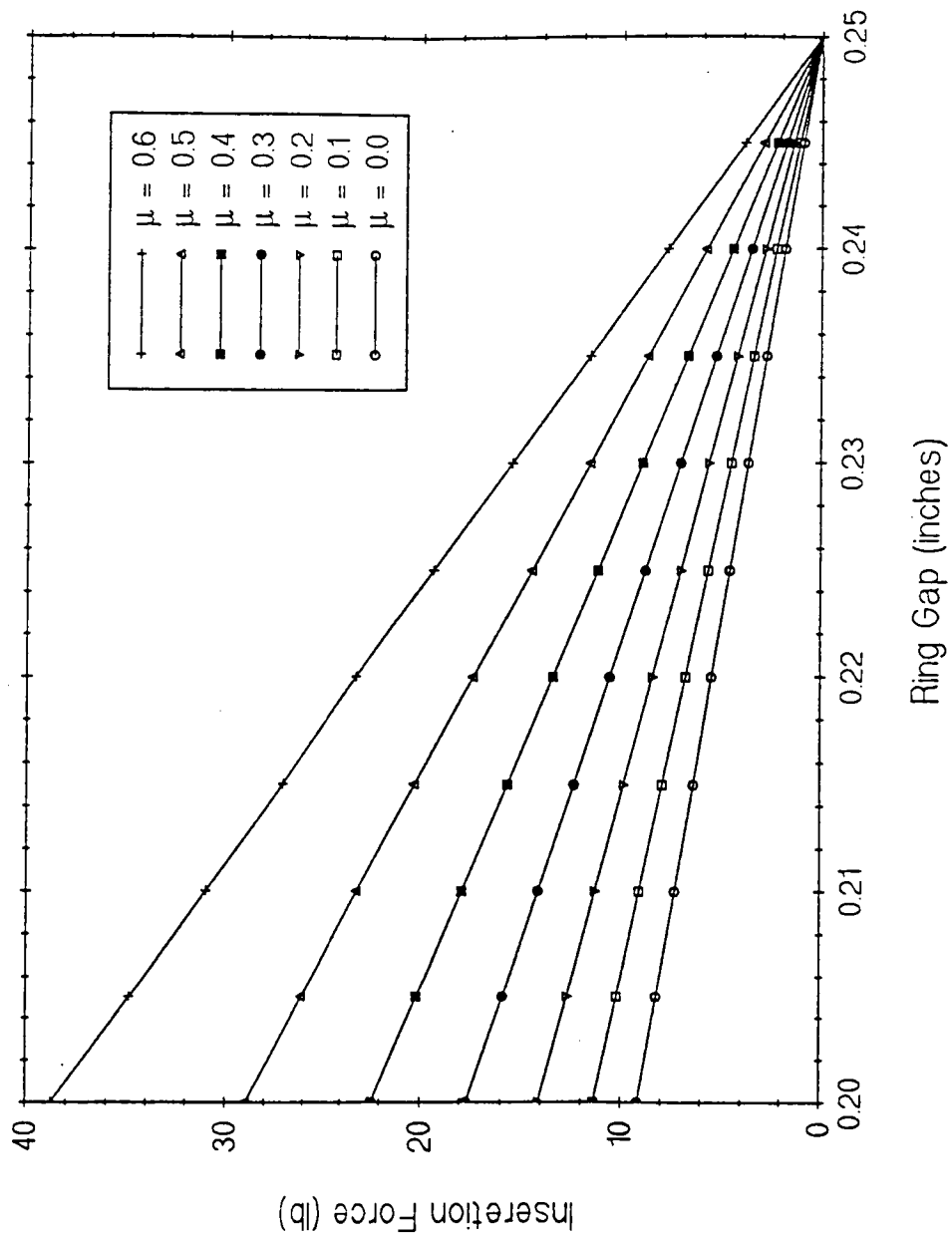
Insertion Force vs. Available Gap

$E = 300000 \text{ psi}; \beta = 0$



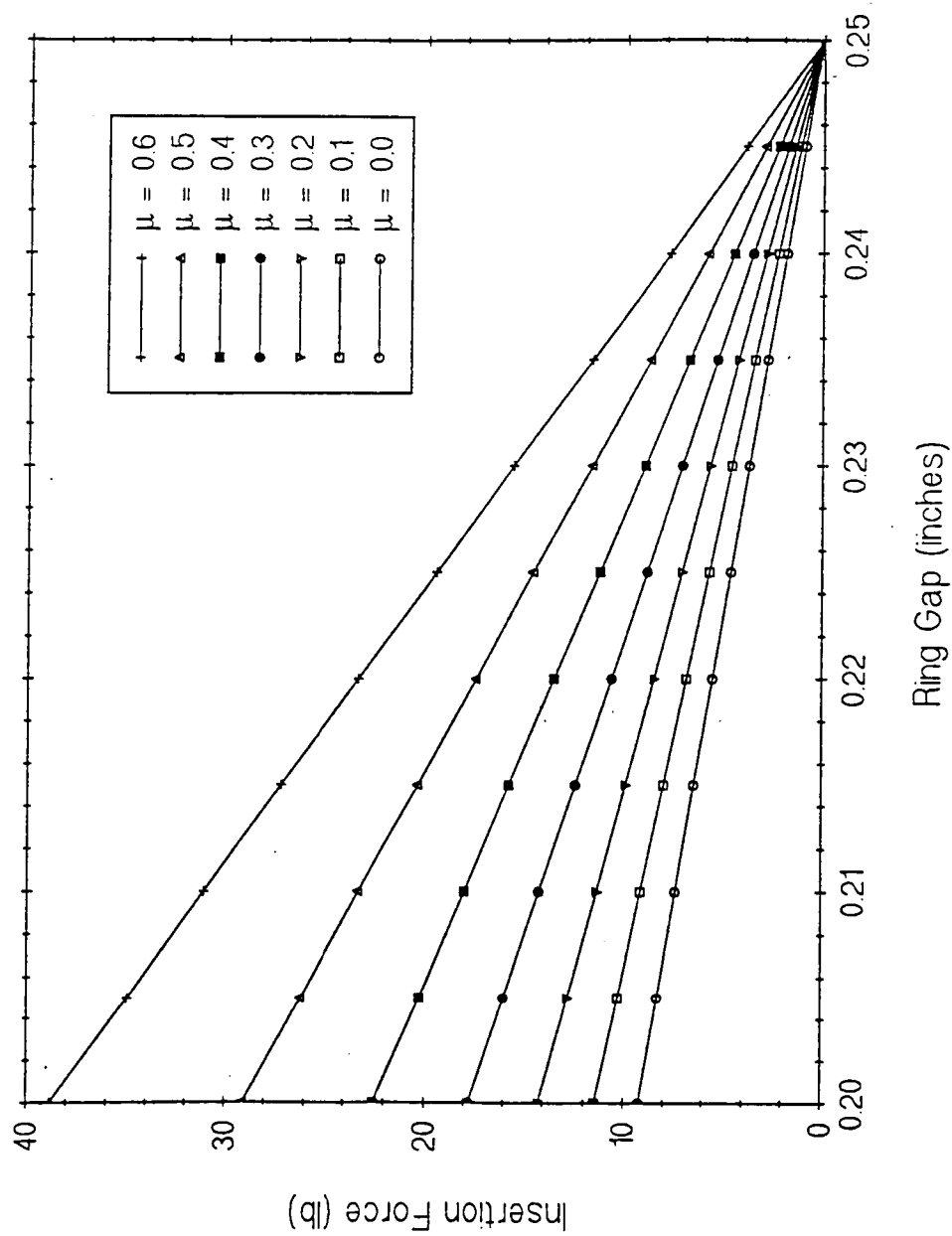
Insertion Force vs. Available Gap

$E = 400000 \text{ psi}; \beta = 0$



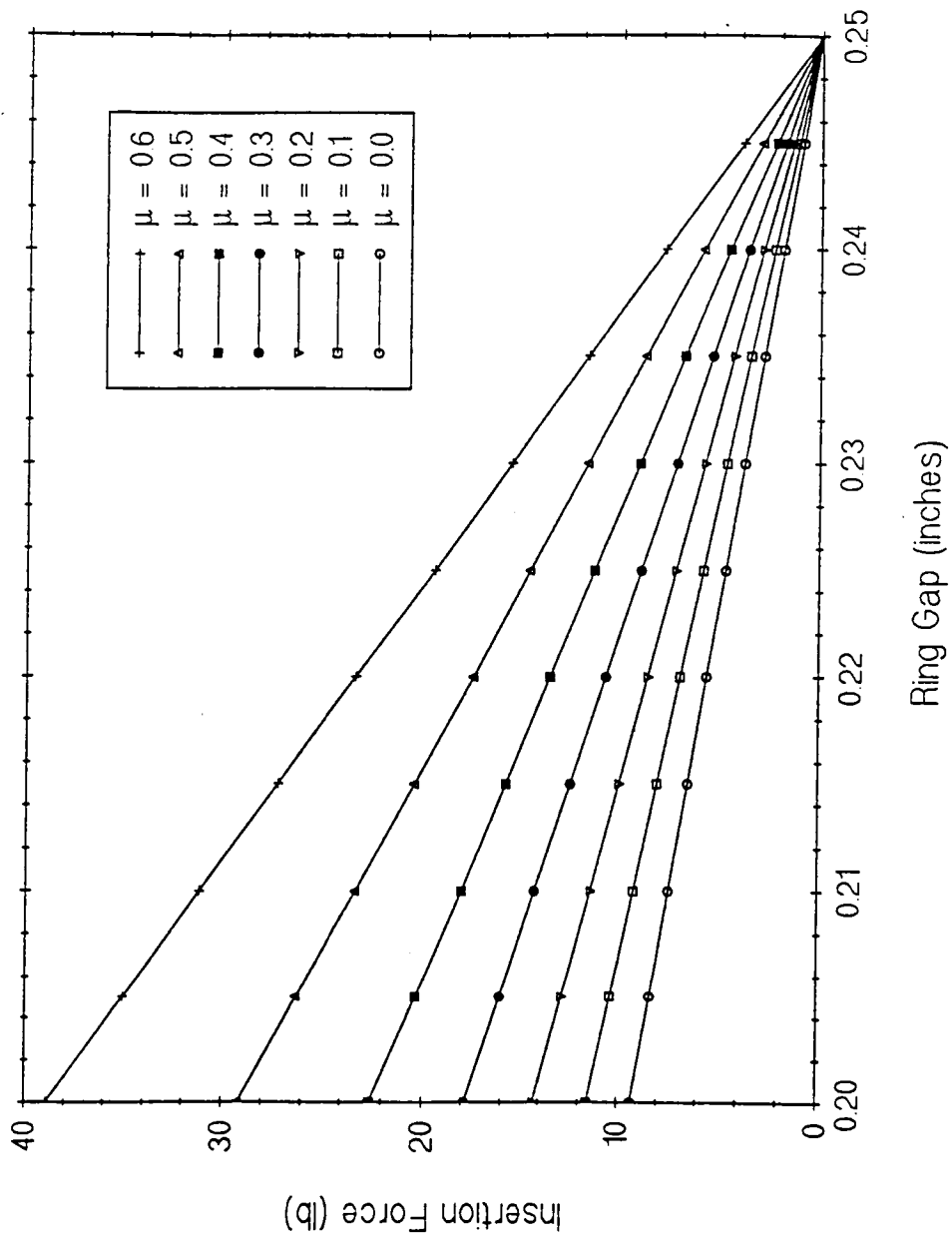
Insertion Force vs. Available Gap

$E = 450000 \text{ psi}$ $\beta = 0$



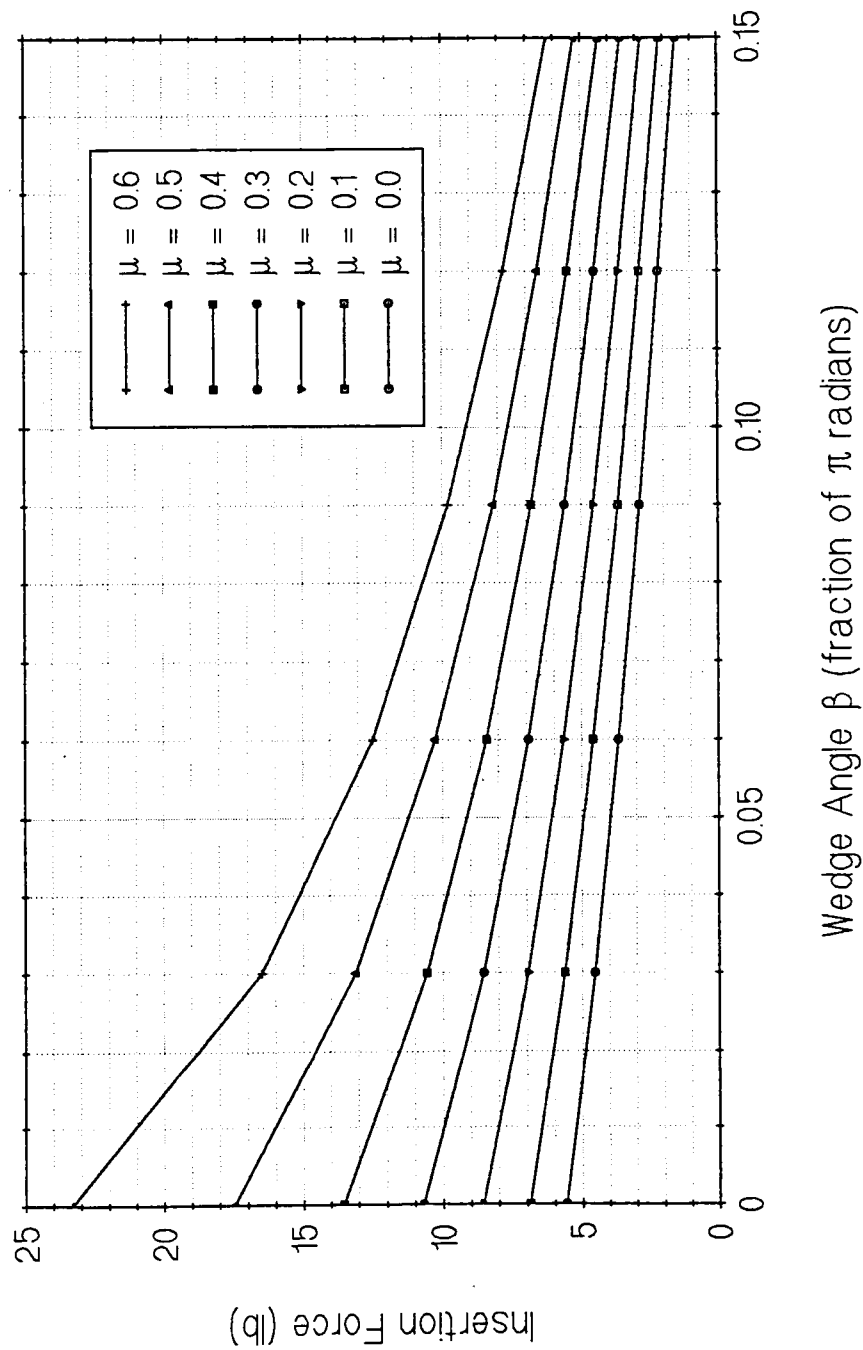
Insertion Force vs. Available Gap

$E = 500000 \text{ psi}; \beta = 0$



Insertion Force vs. Wedge Angle β

Available Gap = 0.22 inches



APPENDIX 6

Computer Numerically Controlled Milling Machine Paths:

Clamping Device Prototypes

Machine Path for Holes on Front View

.N5G70G75G90
'cncfrnt1 10-12-1993'
'1'
'TOOL NUMBER:1'
'SPINDLE RPM:2800'
N30G0X0.85Y-2.5T1M6
N35S2800
N40X0.7216Y0.9051
N45Z-0.325
N50G1Z-0.435F5.0
N55G3X0.8684Y0.7649I0.795J0.835F3.1
N60G3X0.7216Y0.9051I0.795J0.835
N65G0Z-0.275
N70Z-0.385
N75G1Z-0.495F5.0
N80G3X0.8684Y0.7649I0.795J0.835F3.1
N85G3X0.7216Y0.9051I0.795J0.835
N90G0Z-0.275
N95Z-0.445
N100G1Z-0.525F5.0
N105G3X0.8684Y0.7649I0.795J0.835F3.1
N110G3X0.7216Y0.9051I0.795J0.835
N115G0Z-0.275
'2'
.N125F3.1
N130X0.71Y0.4145
N135Z-0.325

N140G1Z-0.435F5.0

N145G3X0.8793Y0.3024I0.795J0.359F3.1

N150G3X0.71Y0.4145I0.795J0.359

N155G0Z-0.275

N160Z-0.385

N165G1Z-0.495F5.0

N170G3X0.8793Y0.3024I0.795J0.359F3.1

N175G3X0.71Y0.4145I0.795J0.359

N180G0Z-0.275

N185Z-0.445

N190G1Z-0.525F5.0

N195G3X0.8793Y0.3024I0.795J0.359F3.1

N200G3X0.71Y0.4145I0.795J0.359

N205X0.85Y-2.5M2

Machine Path for Outer Profile: Front View

.N5G70G75G90
'cncfnt2 10-12-1993'
'I'
'TOOL NUMBER:1'
'SPINDLE RPM:2800'
N30G0X0.85Y-2.5T1M6
N35S2800
N40X-0.0164Y0.18
N45Z0.05
N50G1Z-0.06F5.0
N55G3X0.3024Y-0.3744I0.312J0.
N60G3X0.3032Y-0.3744I0.304J-0.3119
N65G1X0.3112Y-0.3745
N70G3X0.3119Y-0.3745I0.312J-0.312
N75G1X1.2879Y-0.3765
N80G3X1.288Y-0.3765I1.288J-0.314
N85G3X1.6121Y0.1886I1.288J-0.001
N90G3X1.5579Y0.2195I1.5582J0.157
N95G1X0.0381Y0.2125
N100G3X-0.0164Y0.18I0.0384J0.15
N105G0Z0.1
N110Z-0.01
N115G1Z-0.12F5.0
N120G3X0.3024Y-0.3744I0.312J0.
N125G3X0.3032Y-0.3744I0.304J-0.3119
N130G1X0.3112Y-0.3745
N135G3X0.3119Y-0.3745I0.312J-0.312

N140G1X1.2879Y-0.3765
N145G3X1.288Y-0.3765I1.288J-0.314
N150G3X1.6121Y0.1886I1.288J-0.001
N155G3X1.5579Y0.2195I1.5582J0.157
N160G1X0.0381Y0.2125
N165G3X-0.0164Y0.18I0.0384J0.15
N170G0Z0.1
N175Z-0.07
N180G1Z-0.18F5.0
N185G3X0.3024Y-0.3744I0.312J0.
N190G3X0.3032Y-0.3744I0.304J-0.3119
N195G1X0.3112Y-0.3745
N200G3X0.3119Y-0.3745I0.312J-0.312
N205G1X1.2879Y-0.3765
N210G3X1.288Y-0.3765I1.288J-0.314
N215G3X1.6121Y0.1886I1.288J-0.001
N220G3X1.5579Y0.2195I1.5582J0.157
N225G1X0.0381Y0.2125
N230G3X-0.0164Y0.18I0.0384J0.15
N235G0Z0.1
N240Z-0.13
N245G1Z-0.24F5.0
N250G3X0.3024Y-0.3744I0.312J0.
N255G3X0.3032Y-0.3744I0.304J-0.3119
N260G1X0.3112Y-0.3745
N265G3X0.3119Y-0.3745I0.312J-0.312
N270G1X1.2879Y-0.3765
N275G3X1.288Y-0.3765I1.288J-0.314
N280G3X1.6121Y0.1886I1.288J-0.001

N285G3X1.5579Y0.2195I1.5582J0.157
N290G1X0.0381Y0.2125
N295G3X-0.0164Y0.18I0.0384J0.15
N300G0Z0.1
N305Z-0.19
N310G1Z-0.3F5.0
N315G3X0.3024Y-0.3744I0.312J0.
N320G3X0.3032Y-0.3744I0.304J-0.3119
N325G1X0.3112Y-0.3745
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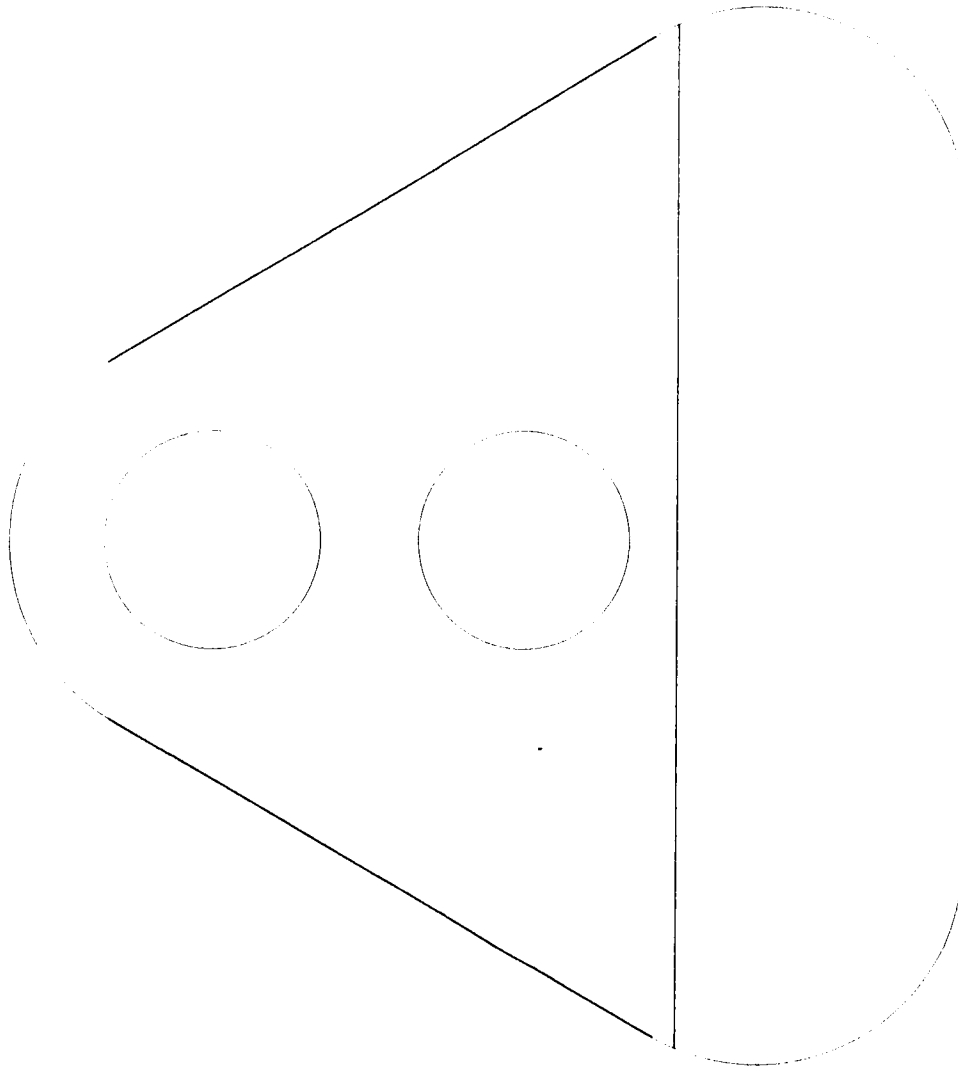


Figure A6.1 Sketch of CNC Milling Path for Clamping Device (Front View)

Machine Path for First Half of Extrusion Profile

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N60G3X-0.51Y1.2119I-0.25J1.212F52.0
N65G1X-0.5094Y0.0249F2.0
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N80G1X0.3765Y0.3429F2.0
N85G3X0.2613Y0.4238I0.175J0.1785F52.0
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N1040G1Z-0.54F5.0
N1045X-0.25
N1050G3X-0.3125Y1.212I-0.25J1.212F100.0
N1055G1Y0.F5.0
N1060G3X0.2255Y0.2163I0.J0.F6.2
N1065G3X0.2193Y0.2235I0.1755J0.1789F100.0
N1070G3X0.0747Y0.1876I0.158J0.161F17.5
N1075G3X0.0744Y0.1869I0.1342J0.1686F100.0
N1080G1Y0.1868F5.0
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N1095G2X-0.0625Y0.I0.J0.F2.5
N1100G1Y1.212F5.0
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N1135G1Y0.F5.0
N1140G3X0.2255Y0.2163I0.J0.F6.2
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N1150G3X0.0747Y0.1876I0.158J0.161F17.5

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N1175G2X-0.0625Y0.I0.J0.F2.5
N1180G1Y1.212F5.0
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N1200G1Z-0.66F5.0
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N1210G3X-0.3125Y1.212I-0.25J1.212F100.0
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N1220G3X0.2255Y0.2163I0.J0.F6.2
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N1230G3X0.0747Y0.1876I0.158J0.161F17.5
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N1240G1Y0.1868F5.0
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N1250G3X0.0513Y0.0356I0.1027J0.0713F100.0
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N1310G3X0.0747Y0.1876I0.158J0.161F17.5
N1315G3X0.0744Y0.1869I0.1342J0.1686F100.0
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N1330G3X0.0513Y0.0356I0.1027J0.0713F100.0
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N1390G3X0.0747Y0.1876I0.158J0.161F17.5
N1395G3X0.0744Y0.1869I0.1342J0.1686F100.0
N1400G1Y0.1868F5.0
N1405X0.0432Y0.0905
N1410G3X0.0513Y0.0356I0.1027J0.0713F100.0
N1415G2X-0.0625Y0.I0.J0.F2.5
N1420G1Y1.212F5.0
N1425G3X-0.125Y1.2745I-0.125J1.212F100.0
N1430G0Z0.1
N1435Z-0.73
N1440G1Z-0.84F5.0

N1445X-0.25
N1450G3X-0.3125Y1.212I-0.25J1.212F100.0
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N1480G1Y0.1868F5.0
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N1550G3X0.0747Y0.1876I0.158J0.161F17.5
N1555G3X0.0744Y0.1869I0.1342J0.1686F100.0
N1560G1Y0.1868F5.0
N1565X0.0432Y0.0905
N1570G3X0.0513Y0.0356I0.1027J0.0713F100.0
N1575G2X-0.0625Y0.I0.J0.F2.5
N1580G1Y1.212F5.0
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N1600G1Z-0.95F5.0
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N1615G1Y0.F5.0
N1620G3X0.2255Y0.2163I0.J0.F6.2
N1625G3X0.2193Y0.2235I0.1755J0.1789F100.0
N1630G3X0.0747Y0.1876I0.158J0.161F17.5
N1635G3X0.0744Y0.1869I0.1342J0.1686F100.0
N1640G1Y0.1868F5.0
N1645X0.0432Y0.0905
N1650G3X0.0513Y0.0356I0.1027J0.0713F100.0
N1655G2X-0.0625Y0.I0.J0.F2.5
N1660G1Y1.212F5.0
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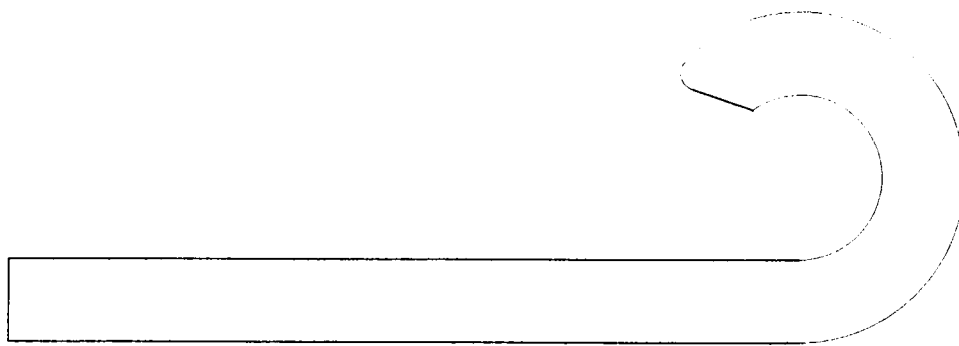


Figure A6.2 Sketch of CNC Milling Path for Clamping Device (First Side View)

Machine Path for Second Half of Extrusion Profile
(Mirror Image of First Half of Extrusion Profile)

.N5G70G75G90
'cncmir 10-12-1993'
'I'
'TOOL NUMBER:1'
'SPINDLE RPM:800'
N30G0X3.0Y0.T1M6
N35S800
N40X0.51Y1.212
N45Z0.05
N50G1Z-0.25F2.0
N55Y0.
N60G2X-0.3744Y0.3463I0.J0.
N65G2X-0.3575Y0.3645I-0.1755J0.1789
N70G2X-0.136Y0.4451I-0.158J0.161
N75G1X-0.135Y1.2123
N80G2X0.125Y1.472I0.125J1.212
N85G1X0.25
N90G2X0.51Y1.212I0.25J1.212
N95G0Z0.1
N100Z-0.2
N105G1Z-0.5F2.0
N110Y0.
N115G2X-0.3744Y0.3463I0.J0.
N120G2X-0.3575Y0.3645I-0.1755J0.1789
N125G2X-0.136Y0.4451I-0.158J0.161
N130G1X-0.135Y1.2123

N135G2X0.125Y1.472I0.125J1.212
 N140G1X0.25
 N145G2X0.51Y1.212I0.25J1.212
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 N155Z-0.45
 N160G1Z-0.75F2.0
 N165Y0.
 N170G2X-0.3744Y0.3463I0.J0.
 N175G2X-0.3575Y0.3645I-0.1755J0.1789
 N180G2X-0.136Y0.445I1-0.158J0.161
 N185G1X-0.135Y1.2123
 N190G2X0.125Y1.472I0.125J1.212
 N195G1X0.25
 N200G2X0.51Y1.212I0.25J1.212
 N205G0Z0.1
 N210Z-0.7
 N215G1Z-1.0F2.0
 N220Y0.
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 N230G2X-0.3575Y0.3645I-0.1755J0.1789
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 N240G1X-0.135Y1.2123
 N245G2X0.125Y1.472I0.125J1.212
 N250G1X0.25
 N255G2X0.51Y1.212I0.25J1.212
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 'TOOL NUMBER:2'
 ' SPINDLE RPM:2800'
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N315G2X-0.0747Y0.1876I-0.158J0.161F17.5
N320G2X-0.0744Y0.1869I-0.1342J0.1686F100.0
N325G1Y0.1868F5.0
N330X-0.0432Y0.0905
N335G2X-0.0513Y0.0356I-0.1027J0.0713F100.0
N340G3X0.0625Y0.I0.J0.F2.5
N345G1Y1.212F5.0
N350G2X0.125Y1.2745I0.125J1.212F100.0
N355G1X0.25F5.0
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N370Z-0.01
N375G1Z-0.12F5.0
N380Y0.
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N415G2X-0.0513Y0.0356I-0.1027J0.0713F100.0
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N425G1Y1.212F5.0
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N490X-0.0432Y0.0905
N495G2X-0.0513Y0.0356I-0.1027J0.0713F100.0
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N505G1Y1.212F5.0
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N615G1Z-0.3F5.0
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N625G2X-0.2255Y0.2163I0.J0.F6.2
N630G2X-0.2193Y0.2235I-0.1755J0.1789F100.0
N635G2X-0.0747Y0.1876I-0.158J0.161F17.5
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N1195G2X-0.0747Y0.1876I-0.158J0.161F17.5
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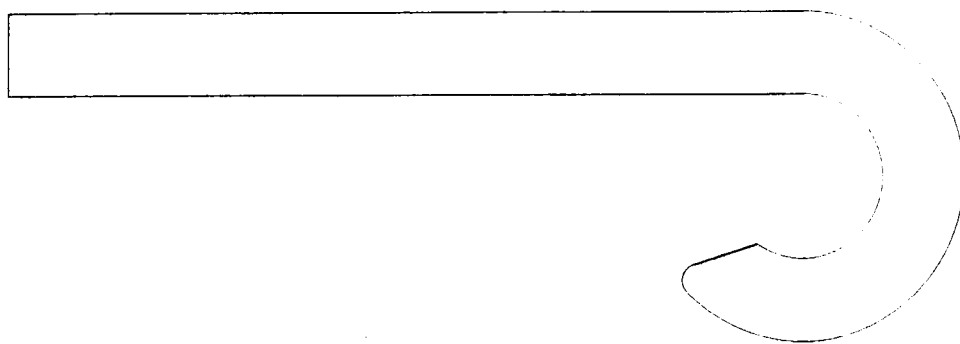


Figure A6.3 Sketch of CNC Milling Path (Second Side View; Mirror Image of First Side View)

APPENDIX 7

Record of Invention for the Force Reaction Device

RECORD OF INVENTION

Musical Instrument Input Cord Force Reaction Device

This invention pertains to the design of a device to react any sudden jerks on the input cord of a musical instrument such that the input cord remains inserted into the input jack. The device will also prevent contact between the surfaces of the instrument body and the cord itself, thus preventing excessive damage to the surface finish of the instrument. This device will be referred to as the force reaction device (FRD).

The device will attach firmly to the instrument body (IB) without requiring any permanent changes to the instrument itself. In order to allow the instrument to still fit within the carrying case, the FRD will be attached by means of a quick release pin (QRP) and receptacle (R). The R will be rigidly attached to the IB in place of the strap button (SB) using the existing or a similar strap button screw (SBS). The R will be sufficiently small as to not require more space than the original SB, thus allowing the instrument to still fit within the carrying case. The QRP will be of the push button locking variety; that is, the QRP will not release itself from the R unless the push button is depressed.

The FRD will hold the instrument cable by means of a snap fit piece in which the a portion of the length of the cord will be inserted. Once the FRD is in place and the instrument cord is inserted into the FRD, any sudden jerks on the cord will be reacted by the QRP, R, and SBS arrangement. The reaction of the jerk forces by the SB and SBS is currently used by numerous musicians; the problem with this method lies in the fact that the instrument cord comes in contact with the IB and slowly deteriorates the surface finish of the instrument. The FRD will continually keep the cord away from the device; the snap fit portion of the FRD (and therefore the instrument cord itself) is a constant distance away from the IB equivalent to the length of the R. This prevents any contact between the IB and the cord.

One advantage of this design lies in the fact that attachment of the FRD requires no permanent alterations to the instrument itself. A new aspect of this idea is the attempt to protect the instrument finish from wear caused by the cord. Ease of use is imperative; this aspect is second only to the importance of the proper functioning of the FRD.

Inventor: _____ Date: _____

Understood on this date by: _____ Date: _____

VITA

Chris Widner is originally from Fayetteville, Tennessee. He graduated from Lincoln County High School in May, 1988. The following August he began his attendance at the University of Tennessee, Knoxville. He received the degree of Bachelor of Science in Mechanical Engineering in May, 1992. He immediately began graduate work at UTK and received the degree of Master of Science in Mechanical Engineering in December of 1993. At the time of this writing, he plans to begin continued graduate work at UTK in pursuit of a Doctoral degree in Mechanical Engineering.

On a personal level, Chris is a dedicated and sometimes obsessive guitarist/musician. It is his goal to continually and effectively apply his educational background to the musical industry.