

# Portable Wood Lathe

by

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## Abstract

Many amateur woodworkers do not have the luxury of a large shop with unlimited bench top space and storage area. Changing the design of a traditional lathe by eliminating the base realized a lighter, more compact lathe that can be set-up, aligned, and stored quickly while occupying less room. A survey was conducted to determine the space needs of woodworkers who use lathes. This survey was used to develop a House of Quality to clarify the needs that are most important to lathe users.

This final report presents the information acquired with a customer survey as well as through research of existing lathes and illustrates the best alternative with a Pugh diagram. In addition, the report details the design, fabrication, and testing of the Portable Wood Lathe to help amateur woodworkers maximize available bench top space.

A manufacturing and cost analysis details the price of each component as well as the labor to produce 18,000 Portable Wood Lathes a year. Total consumer cost is \$350.00 for one lathe. Also, the weight of the lathe is 64 pounds and has a storage footprint of about 1.4 square feet. Recommendations include reducing price and weight by using a lighter gage tube for the frame and conducting additional research to determine whether a smaller motor may be used. Additionally, machining threads on the work end of the headstock spindle would greatly increase the range of items that could be turned on the lathe.

The resulting prototype can turn wood of many different sizes and will adapt to a variety of benches. A result of testing indicate the Portable Wood Lathe functions as a traditional lathe, integrates the unique characteristics of the lathe without deterring the function, can be operated safely, and is comparable in price to similar lathes on the market today.

## Acknowledgements

Recognizing everyone who contributed to this project is not going to be an easy task but I will try. I apologize if I leave anyone out. It does not mean that I have forgotten your contribution, only that I could not remember all the names shortly before this project was due when my mind was a mess (a state I am quite comfortable in by now).

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## Table of Contents

Abstract .....	ii
Acknowledgements .....	iii
List of Figures .....	vii
Introduction .....	1
Proof of Design .....	1
Project Management and Resources .....	1
Research .....	1
Budget .....	2
Schedule .....	2
Scope of Report .....	2
Design Report .....	4
Alternative Designs .....	4
Alternative 1 .....	4
Alternative 2 .....	4
Alternative 3 .....	5
Design Selection .....	6
House of Quality .....	6
Proof of Design .....	7
Material .....	7
Swing-over-bed .....	7
Alignment and Alignment Time .....	7
Weight and Storage .....	8
Cost .....	8
Safety .....	9
Rotating parts guard .....	9
Bench .....	9
Operation .....	9
Speed .....	9
Deflection .....	10
Design .....	10
Frame .....	10
Clamp Assemblies .....	10
Tailstock .....	12
Headstock .....	12
Spindle Support .....	12
Spindle .....	13
Bearings .....	14
Sheaves .....	14
Motor .....	14
Slide .....	15
Manufacturing and Assembly .....	16
Clamps .....	16
Slides .....	16
Frame .....	16

Spindle Support.....	16
Tailstock.....	17
Belt guard.....	17
Manufacturing and Cost Analysis.....	18
Proof of Design.....	19
Speeds.....	19
Swing-over-bed.....	19
Deflection.....	19
Belt guard.....	19
Weight and footprint.....	19
Purchase cost.....	19
Alignment and alignment time.....	19
Conclusion.....	21
Recommendations.....	22
Frame.....	22
Motor.....	22
Headstock Spindle Support.....	22
Sheaves.....	22
Clamps.....	22
Headstock Spindle.....	23
References.....	24
Bibliography.....	25
Appendix A.....	27
Proof of Design.....	27
Appendix B.....	29
Concepts and techniques of machine safeguarding.....	29
Chapter 1 Basics of Machine Safeguarding.....	29
Chapter 2 - Methods of Machine Safeguarding.....	30
Appendix C.....	31
Pugh diagram.....	31
Appendix D.....	32
Customer survey.....	32
Appendix E.....	34
Customer survey results.....	34
Appendix F.....	36
House of Quality.....	36
Appendix G.....	37
Headstock drawing.....	37
Appendix H.....	38
Tailstock drawing.....	38
Appendix I.....	39
Clamp assembly drawing.....	39
Appendix J.....	40
Screw calculations.....	40
Appendix K.....	41
Clamp calculations.....	41

Appendix L .....	42
Spindle support Calculations and FBD .....	42
Appendix M .....	44
Spindle drawing .....	44
Appendix N .....	45
Ball bearing spec sheet .....	45
Appendix O .....	46
Motor spec sheet .....	46
Appendix P .....	47
Frame drawing .....	47
Appendix Q .....	48
Belt guard drawing .....	48
Appendix R .....	49
Portable Wood Lathe .....	49

## List of Figures

<b>Figure 1.</b>	Alternative 1	10
<b>Figure 2.</b>	Alternative 2	11
<b>Figure 3.</b>	Alternative 3	12

## Introduction

Millions of dollars and countless hours are spent each year attempting to decrease the size of items in order to make them more efficient or easier to store. Woodworking, which has hundreds of tools ranging in size from small hand tools to machine tools that take up the space of a small car, is no exception. For example, the lathe is one of the oldest woodworking tools and, despite modern technology, the basic design is still the same: the work piece is spun between two centers that are connected by a heavy, bulky base. For the professional woodworker this is usually not a concern however, to the amateur woodworker, who may have only a small shop or garage, bench top space may be hard to come by. A lathe design that can overcome the size and weight limitations of a traditional lathe would be a great benefit to the amateur woodworker whose bench top space is an endangered species.

The portable wood lathe prototype addresses these issues. By removing the base, the lathe has been broken down into a headstock assembly and a tailstock assembly that clamp individually to a bench. Once the assemblies are aligned, the function is that of a traditional lathe. After the turning operation is completed, the lathe can be quickly packed away into an area smaller than that of a traditional lathe.

### ***PROOF OF DESIGN***

The proof of design was the basis on which this project was judged [see Appendix A, Proof of Design]. The four design objective categories were function, cost, safety, and practicality.

The first category specifications ensure the lathe functions as a lathe. If these objectives cannot be met, the lathe is of no value. Second, the cost must be comparable to a medium duty lathe. Third, the lathe must be able to be operated safely. Rotating machinery is inherently dangerous and all precautions must be taken to ensure that the risk of injury is as little as possible. Last, the unique characteristics of the lathe (or features resulting from these characteristics) must not render the lathe impractical especially with regards to set-up time, weight, and space.

The design of the Portable Wood Lathe must incorporate all four of these objectives to be successful. All criteria included in the proof of design fall into one of these categories. Specific proof of design goals may not be attained yet the four design objective categories must still be met for a successful project.

### ***PROJECT MANAGEMENT AND RESOURCES***

Project management and resources consists of patent and safety research, funding, establishing a schedule, and the scope of report.

### **Research**

Conducting research for this project was necessary to ensure duplication of a product was avoided and that safety features were up to date with current standards.

Patent research for this project was carried out at the United States Patent and Trademark Office [1] web site. The majority of lathe patents relate to industrial metalworking lathes and their accessories. Few patents for wood lathes exist (in

comparison to metal working lathes) and no patents for two-piece wood lathes were found.

Research for lathe safety issues was conducted at the Occupational Safety and Health Administration [2] web site. Few regulations specific to wood lathes exist due to the simple design of a basic lathe (motor, headstock, and tailstock) and the need of the operator to have access to the entire part being turned from headstock to tailstock. Regulations for safety that pertain to this lathe were a fixed guard [see Appendix B, Concepts and Techniques of Machine Safeguarding] to protect the operator from incidental contact of the belt and sheaves and to protect the belt and sheaves from falling objects.

Research indicates that this project does not duplicate any previous work and that it can be done in accordance with current safety standards.

## **Budget**

The author funded the majority of the Portable Wood Lathe project. Materials that were in stock in the College of Applied Science, North Lab Facility as well as machining and welding equipment were used for the fabrication of the project.

The headstock spindle and the tailstock were contracted out to Nichols Enterprises in Stanfield, Oregon and built to design specifications due to the difficulty in machining a #2 Morse taper. All other components were purchased from local vendors.

Total cost of the prototype was approximately \$850 excluding the author's labor and materials provided in the North Lab Facility.

## **Schedule**

The project was carried out over a period of three University of Cincinnati academic quarters (autumn, winter, spring). The project proposal was written autumn quarter, the project design report was written in the winter quarter, and the project was built and tested in the spring quarter. Important dates are shown below:

- Final proposal November 11, 2001
- Design freeze February 15, 2002
- Design report March 13, 2002
- Proof of design May 2, 2002
- Tech Expo May 17, 2002
- Final report June 3, 2002

The above schedule provided a feasible plan of action and all major deadlines were met.

## **Scope of Report**

The remaining sections of this report will detail the entire design and build process. Proof of design objectives and the rationale for these goals will be discussed as well as materials used, assumptions, and forces on selected components. Manufacturing discussions will include methods and differences between the prototype and the

production design. Next, the procedures and methods of validating the functionality of the prototype will be described and the report will close with recommendations for correcting weaknesses and providing enhancements.

## Design Report

The design report details the planning of the Portable Wood Lathe beginning with the creation of alternative designs. After using a Pugh diagram to select the preferred design, a House of Quality determined the importance of the lathe specifications. This information was used in the design and selection of components for the lathe.

### **ALTERNATIVE DESIGNS**

Alternative designs supply the designers with a variety of options so that the best possible alternative is not passed up due to a lack of ideas.

Details have been omitted from the sketches (such as the motor, sheaves and pulley) to focus on the mounting devices for the base alternatives. Details that have been left out are consistent for all alternatives.

#### **Alternative 1**

The design for alternative one [see figure 1] uses two bars where the base on a traditional lathe would be located.

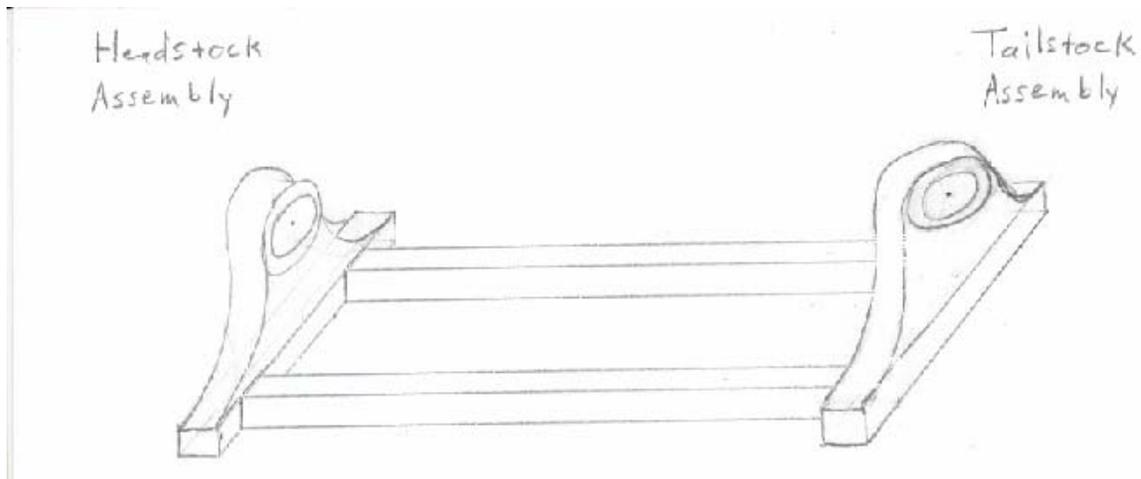


Figure 1 Alternative 1

These detachable bars ensure that the headstock and tailstock are aligned and square to each other.

#### **Alternative 2**

Alternative two [see figure 2] is broken down into three pieces: the headstock assembly, the tailstock assembly, and the base.

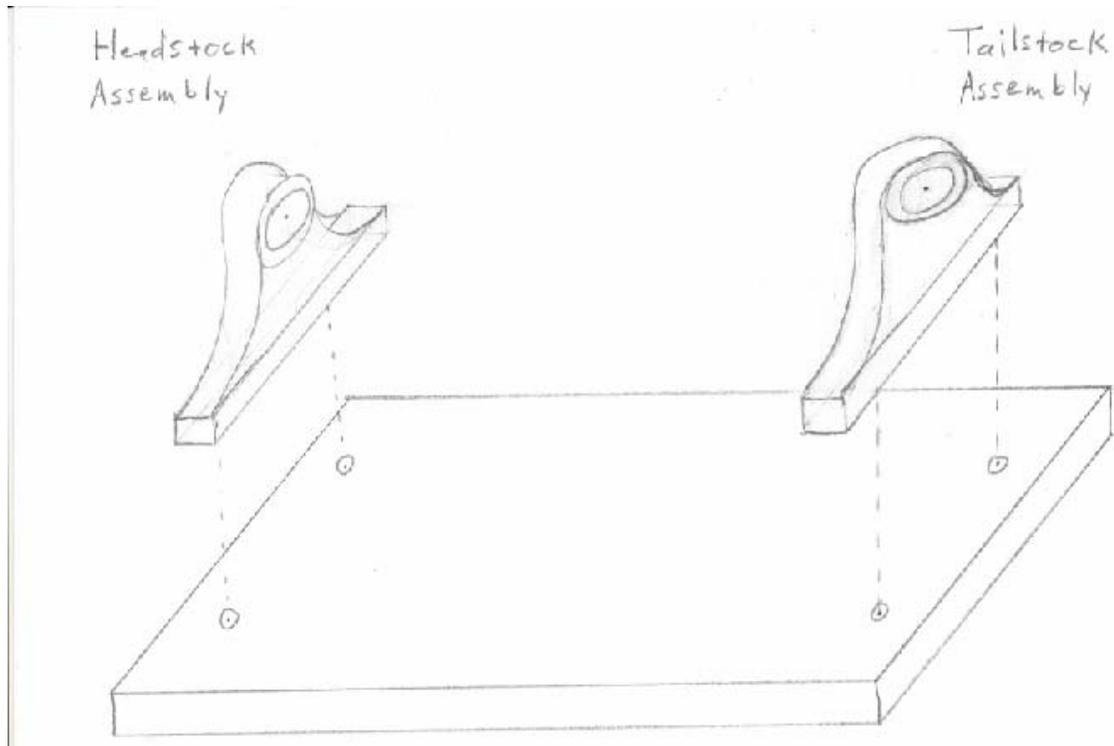


Figure 2 Alternative 2

The base connects the headstock to the tailstock similar to a traditional lathe, but the headstock and tailstock detach from the base and all three components can be moved individually.

### Alternative 3

The base has been eliminated for alternative three [see figure 3] and the lathe has been broken down into a headstock assembly and a tailstock assembly.

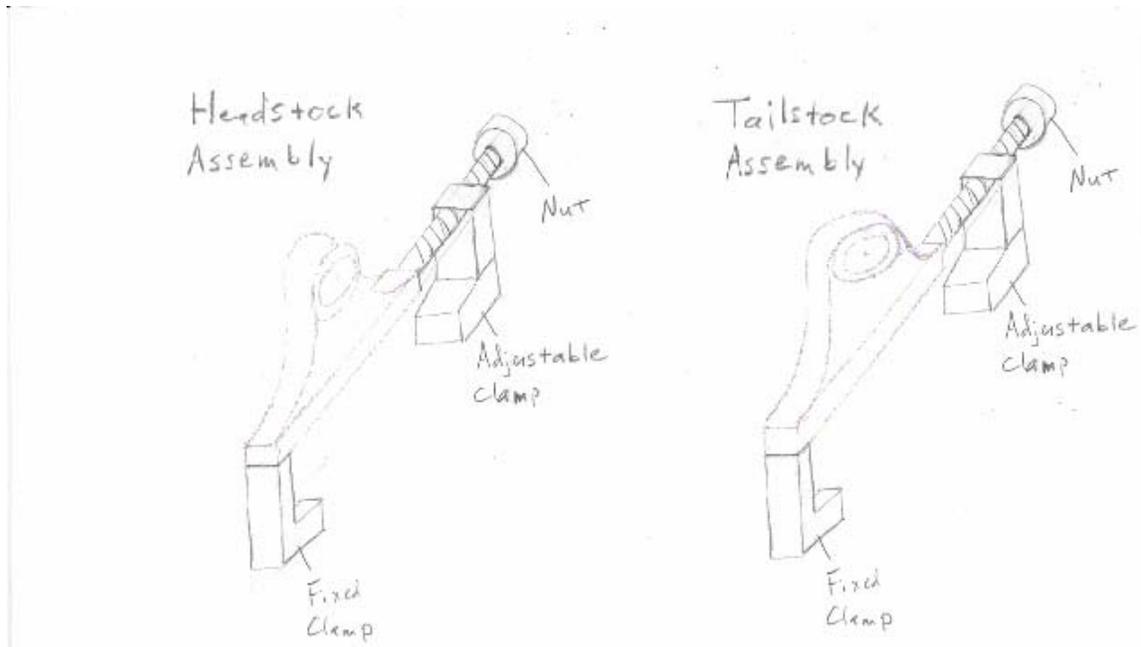


Figure 3 Alternative 3

The sides of the assemblies closest to the worker (work side) have clamps fixed to the frames. The far side of each assembly has a tightening mechanism that secures the assemblies to the bench.

### **DESIGN SELECTION**

The three alternatives were compared in a Pugh diagram [see Appendix C, Pugh diagram]. One alternative was selected as a datum and characteristics of all three lathes are rated with a plus (+), minus (-), or same (s). The alternative with the most pluses is chosen or if no pluses are rated, the datum alternative is chosen.

Using alternative three as the datum, alternative two scored low for portability, weight, and space because the detachable base would have to be heavy and long in order to function well as a base. Alternative three scored low in portability and weight for the same reason. There were no plusses rated indicating that neither of the alternatives scored higher than the datum alternative.

The results of the Pugh diagram revealed the best choice for the Portable Wood Lathe was alternative three.

### **HOUSE OF QUALITY**

The House of Quality is a tool used to determine the importance the customer places on each product characteristic. A survey allows the customer to choose the satisfaction level of different characteristics. The House of Quality, in conjunction with a customer survey, determines how important certain design requirements are to the end user.

A customer survey [see Appendix D, Customer survey] was distributed in the autumn quarter to 25 woodworkers. Ten responses were received [see Appendix E,

Customer survey results] and the results were consolidated and incorporated into a House of Quality [see Appendix F, House of Quality].

The results of the survey showed that the weight of the lathe, the material used in the lathe, and the swing-over-bed influenced customer satisfaction the most.

### ***PROOF OF DESIGN***

The proof of design lists the specifications that are most important to the successful completion of the project.

These specifications were established using the results from the customer survey, safety considerations, and characteristics of lathes currently on the market. The categories of the specifications include functionality, cost, safety, and practicality. All four categories must be satisfied for a successful project although individual specifications may not be met.

The proof of design was reviewed by the author and the advisor, Prof. Caldwell, and was the basis by which the final project was judged.

### **Material**

Material selection was based on weight, rigidity, and cost. One attribute was not necessarily more important than the other two rather, all three attributes were considered.

Most lathes are constructed of cast iron due to its rigidity and vibration damping properties. Since the bench absorbs the majority of vibration, the lathe will be constructed of steel.

### **Swing-over-bed**

Swing-over-bed is the largest diameter of the part that can be turned. The distance of a mounted center in either the headstock or tailstock is the maximum radius that can be turned. By increasing the swing-over-bed, the distance from the bench surface to the center of the headstock and tailstock is increased and thus increases the size of the headstock and tailstock.

Swing-over-bed is one of the three characteristics identified by the House of Quality that would influence customer satisfaction the most. A large swing would increase the weight yet a small swing would restrict the variety of parts a user could turn.

The limits chosen for swing-over-bed was six to ten inches. This range gives enough leeway for a variety of compromises for part size and lathe weight.

### **Alignment and Alignment Time**

Every lathe must be aligned. It is most important for a metal lathe to be aligned because of automatic feeding. Wood lathes however, are operated by hand and to ensure a properly cut part, the lathe is turned off and the part is measured. Despite the fact that it is not nearly as important to have a wood lathe aligned in terms of the turned part, if the alignment is off, the bearings will wear quicker than normal.

An advantage of a medium to small lathe is that upon moving the lathe to a new location, it still remains intact and ready to be used. The project lathe, though more

transportable, must be set-up and, if needed, taken down. The clamp used for securing the lathe to a bench, being a simple mechanism, is quick and easy to operate however, before operation the headstock and tailstock must be aligned. To align traditional lathes, live centers (an accessory that tapers to a tip to show the point of rotation) are put in both the headstock and the tailstock. The tailstock is then moved as close to the headstock as possible and the live centers are used to align the headstock and tailstock by sight. No measurements are taken. Due to the unique nature of this lathe, the alignment process will be carried out with an alignment tool and a procedure to be determined. When the headstock and tailstock are fully aligned, the tip of a live center mounted in the tailstock will be no more than four degrees off of a line passing through the center of a live center mounted in the headstock. The bearings will allow up to four degrees of misalignment but the procedure cannot be so time consuming that the advantage of portability is rendered irrelevant by an overly long alignment time.

Assuming one hour is the least amount of work time in which to be productive and the set-up and take down time is five minutes each, a five minute alignment time would allow a 75% productivity rate for the hour. Therefore, the alignment time will be five minutes or less for the tailstock to be aligned within four degrees of the headstock.

## **Weight and Storage**

To be an effective compromise for an ordinary lathe, the bench-mounted lathe must be light enough to set-up, take down, and store easily which makes weight an important factor. The House of Quality has identified weight as the most important aspect that impacts customer needs.

In order to be portable, the lathe must be able to be lifted by one person safely. *The Handbook of Human Factors and Ergonomics* [3, Pg 1098-1105], estimates of safe lifting are given. The maximum recommended weight lift for a female (industrial worker) in an eight-hour time period for two-handed symmetrical lifting is 44 lbs (59.4 lbs for males). The lift is from floor level to 31.5 inches. The container size for this study was 13.4 inches by 19.7 inches. Since a container of this size would have to have at least 6 to 10 inches of height to hold this lathe (for the swing over bed), the handles will be at a height above ground level (two handles, each side, above ground), which will lower some of the risk and allow a greater lift weight. However, raising the maximum lift weight to 50 lbs, even with the handles at ground level, will still have a safety factor of about 14%.

The measurable objectives for weight and storage area that the lathe will be equal to or less than 50 lbs and the storage container will have a footprint of 13.5 inches by 20 inches (264 square inches) or less.

## **Cost**

House of Qualities usually do not take the price of the product into consideration so research into lathe prices was conducted.

The research indicated most lathes cost over \$300 [4, 5, 6] and price can be influenced more by accessories than by size (examples of accessories include electronic speed control, braking, and reversible rotation); even many mini and midi lathes cost in

excess of \$300. Comparable lathes with few to no accessories cost in the range of \$300 to \$350.

Therefore, the measurable objective for the purchase cost is \$350 or less.

## **Safety**

A lathe is an inherently dangerous piece of equipment. Proper safety precautions are necessary to decrease the risk to the operator.

### **Rotating parts guard**

The Portable Wood Lathe transmits power from the motor to the part being turned by a belt and sheaves. Because of the rotating parts, the lathe can be a very dangerous piece of equipment.

In order to make this lathe as safe as possible, a guard will be put over the rotating parts not used by the operator while the lathe is in operation. The guard will be in accordance with OSHA standard 1917.15 (Machine Guarding). The guard will decrease the possibility of injury to the operator by preventing contact with the belt and sheaves.

### **Bench**

Since the Portable Wood Lathe does not have a base, the bench becomes an integral part of the lathe including the safety function of maintaining stability of the lathe.

The base on a lathe is generally made of cast iron, a material that can absorb vibration well. Since the project lathe has no base to serve this purpose it is assumed that it will be mounted on a woodworker's bench, a cabinetmakers bench, or a similar bench of sturdy construction that has a flat top and perpendicular sides.

## **Operation**

The most important way an operator can remain safe is to know the correct operating procedures for the equipment being operated. Due to the special features of the Portable Wood Lathe, being familiar with the operating procedures is even more important because additional precautions (such as ensuring the bench clamps are tight) must be taken.

It is assumed that the operator of the lathe is familiar with the proper operating procedures, the proper cutting tools, and the proper safety equipment for using a lathe. Understanding not only the operation of a lathe but the special consideration that the Portable Wood Lathe requires greatly reduces the likelihood of an accident.

## **Speed**

The speed of a lathe is how many rotations per minute (rpm) the part being cut turns. Similar to working with metals, hard woods require slower speeds and different operations, such as sanding, require faster speeds. The Portable Wood Lathe controls the speed by moving a belt across different sizes of sheaves.

The customer survey indicated that lathe users are satisfied with speeds from 300-3000 rpm. Therefore, the lathe will have at least 4 speeds; the lowest speed will be 300 plus no more than 300 rpm. The maximum speed will be 3000 minus no more than 700 rpm.

An assortment of speeds will match the variety of woods and operations to satisfy the majority of lathe users.

## **Deflection**

Deflection is the amount of movement of the lathe relative to the bench. There will always be at least a slight amount of deflection but too much deflection can be unsafe.

Excess movement of the lathe can compromise the hold the headstock and tailstock have on the part as well as causing incorrect tension on the belt or misalignment between the sheaves.

The headstock and tailstock will not deflect any more than .25 inches while cutting a part.

## **DESIGN**

Design of the Portable Wood Lathe entails not only the design of a lathe but a lathe that meets the requirements set forth in the proof of design.

## **Frame**

The base on a traditional lathe combines the components into a single working unit and maintains the position of each component relative to each other. Since the Portable Wood Lathe eliminates this piece, another structure is needed to support components within the headstock assembly and tailstock assembly.

The frame for the headstock [see Appendix G, Headstock drawing] and the tailstock [see Appendix H, Tailstock drawing] assemblies were constructed of  $\frac{3}{4}$  inch, 1/8-inch wall thickness, square, tube steel. This type of material was chosen because its flat surfaces provide a stable foundation when on a flat bench as well as a stable surface for accessories mounted on top. The frame was butt-welded together using acetylene gas. Grooves were cut in the top of the headstock frame and nuts inserted into the hollow of the tube. Bolts that secure the motor are screwed into the nuts. Movement of the motor is allowed when these bolts are loosened permitting the adjustment of the belt across the sheaves that controls speed. Tightening these bolts secures the motor to the frame.

This frame structure replaces the large bulky base of a traditional lathe with hollow tubes that significantly reduces weight.

## **Clamp Assemblies**

Dramatically reducing the weight of a lathe affects its stability. In order to counteract this loss of stability, a method of securing the assemblies was needed. By attaching a clamp finger (or clamp) to one end of the frame, a tightening assembly to the opposite side and by using the frame as the body of the clamp, a method of securing the lathe assemblies was developed.

The clamp assemblies [see Appendix I, Clamp assembly drawing] consist of two parts: work side parts and back side parts. The work side parts will be L-shaped pieces that will be secured into the frame with pins (for easy storage) and hook over the work side of the bench to secure the headstock and tailstock assemblies. For the production model, the clamps will be cast of gray cast iron into a T-shaped cross section (horizontal portion on top) and the area in contact with the bench will be round or oval similar to a C-clamp.

The backside of the clamp consists of three pieces: two threaded rods and a piece of steel with two threaded holes parallel to each other (double-nut). A section of threaded rod, fixed with a handle on one end, was inserted into the double-nut and on the opposite end of the threaded rod a flat piece was attached to contact the bench when the clamp was tightened. This piece was used to tighten the clamp assembly and secure the lathe to the bench. The other threaded rod screwed through the double-nut piece and into another threaded hole in the base of the lathe. This assembly was oriented so that the handle was on bottom.

The screw calculations [see Appendix J, Screw calculations] are for the threaded rod portion of the clamp assembly. The calculations assume two screw threads make contact for each threaded rod, the type of steel is SAE grade 1, and the size of the thread is ½-inch acme (10 threads per inch). Tensile area (the area of contact between matching threads) information was not available for acme threads however, an approximation was made by assuming that the acme tensile area is proportional to the coarse thread tensile area. Therefore, the tensile area of the coarse threads with a major diameter of .5 inch was decreased in proportion to the ratio of acme threads per inch to coarse threads per inch (10 tpi acme/13 tpi coarse) to yield an approximate tensile area for 10 tpi acme threaded rod. According to the calculations, 270 in pounds of torque can be applied to the clamp.

In order to approximate the amount of torque that could be applied by an operator, an experiment was conducted to show how much torque could be supplied by an operator (a 34 year old male was used). A round wooden dowel rod was used into which a hole was drilled to act as a pivot point when a metal rod was inserted into the hole. Three and one half inches were left on one side of the pivot point to act as the handle and six inches was left on the opposite side. An increasing amount of weight was added at the end of the six inch side until the subject could no longer turn the device effectively. The load at which the test stopped was 20 pounds or 120 inch pounds. The resulting factor of safety for the thread portion of the clamp is approximately 2.3.

The clamps are designed in a T shape to deal with the bending stresses. These parts will be cast however; the prototype clamps will be L-shaped. The calculations for the clamps assume the force is acting in the center of the clamps (see Appendix K, Clamp calculations). Maximum force the clamps will hold before yield is 2789 pounds. The maximum clamping load the rods will hold is 2700 pounds so the rods should yield before the clamps.

## Tailstock

The purpose of the tailstock is to support one end of the wood part and allow it to turn. The tailstock spindle threads allow movement along the axis of the spindle in order to mount the wood.

The tailstock consists of a ½ inch flat base, supports rising off the base, and a tube for the spindle. There are two holes drilled into the flat base to secure the tailstock to the frame after alignment. The tailstock adjustment bolts will be selected so that the diameter will allow the pivoting of the tailstock about four degrees in either direction during alignment. Once the headstock and tailstock are aligned, the bolts can be tightened to secure the tailstock in place.

Fabrication of the tailstock was contracted out to the designer's specifications due to the difficulty of machining a #2 Morse taper.

## Headstock

The purpose of the headstock is to secure one end of the wood part while connecting it to the motor so that the part will turn. The headstock is made up of a spindle support, spindle, bearings, and step sheaves.

### Spindle Support

The spindle support mounts the bearings that will support the headstock spindle. Correct mounting is essential to ensure the alignment of the headstock with the tailstock as well as the small sheave with the large sheave.

The requirements of the spindle support are to mount the bearings parallel with each other, collinear, and at a distance that allows the bearings to be set against the shoulders of the headstock spindle. Since there is a force generated along the axis of the part during cutting, the end of the spindle away from the part has a ¼-inch lip to prevent movement of the bearing along this axis. Because the shoulder of the spindle rests against this bearing and the work side bearing rests against the remaining spindle shoulder, the spindle and the work side bearing will not move along this axis.

Dimensions for the holes to mount the bearings were monitored carefully. The bearings were pressed into the spindle support so the holes required boring to very specific tolerances.

There is a cross member on each side of the spindle support that connects the ends. These cross members are positioned low enough to allow the belt to be disengaged from the sheave so that the speeds may be changed.

Any metal not structurally necessary was removed from the spindle support to reduce weight. Holes were drilled and tapped into the bottom of the support for mounting to the frame.

Stress on the spindle support comes from two sources: the force from the cutting tool against the part and the force from the tailstock spindle keeping the part held firmly between the headstock and tailstock. The force from the cutting tool being used by the operator is minimal. The blade is not pushed into the part along its radius, it is lowered onto the work at a near tangent and the wood turning into the blade produces a slicing action that results in thin shavings.

The forces from the tailstock spindle are from screws. Due to the mechanical advantage, stress calculations were necessary. In order to quickly determine if the design was strong enough, the point with the most stress was located and the max stresses determined using Mohr's circle. Both the headstock and tailstock receive stress due to the clamping force securing the part and the force from the cutting tool on the part. The tailstock however, has a much larger cross section on its supports. Therefore, max stresses will be calculated for the headstock. Both the clamping force and the cutting tool force cause bending stress in the spindle support of the headstock. The corner on the work side and inboard toward the part will not only see both stress, the corner of the support nearest the user will be in tension from both forces. This corner at the line where the support meets the cross member is the location the stress was calculated [see Appendix L, Spindle support calculations and FBD].

The force holding the part between the headstock and tailstock will act along the center of each spindle. The tailstock spindle is tightened enough to ensure the part is snug between the headstock and tailstock and does not move from side-to-side. In order to calculate stress, an estimation of the force necessary to hold a part securely was needed. A test was conducted with two mounted points (similar to center points). One mount was solidly backed; the other mount was attached to hanging weights. Progressively more weight was added until the part withstood a vigorous shake by hand. The result was used as an estimate for the clamping force. At 20 pounds the part remained between the two points. The number was doubled to 40 pounds as a factor of safety.

The cutting force was found by putting a vertical chisel on edge (cutting edge) in contact with a piece of wood and adding weight until the chisel began to cut the wood. It was found that 5 lbs would cut the wood. To allow for harder woods, a factor of safety of four was used. As a result, 20 lbs is used in the calculations as the required cutting force.

The moments and the bending stresses were calculated for each of the forces. Since both stresses put the corner in positive tension, the stresses were added. Using Mohr's circle, the maximum normal stress was calculated to be 1901 lbs/in<sup>2</sup> and the maximum shear was calculated to be 1114 lbs/in<sup>2</sup>. This yields a factor of safety of about 13 in tension and 31 in shear for gray cast iron.

## Spindle

The headstock spindle transmits rotation from the motor to the wood. It must have a diameter in the center suitable for the sheave and smaller diameters on either side so that the press fit bearings have a shoulder to contact. The spindle should be as small as possible to reduce weight.

The spindle [see Appendix M, Spindle drawing] is seven inches long. The larger diameter is three inches long (just long enough for the sheave to fit) and the smaller diameters are two inches long.

The large diameter portion of the spindle is one-inch. This will allow the user to be able to turn medium duty work. The smaller diameter portions are .787 inch (20 millimeters) since the bearings could only be found in metric sizes. The differences in diameter allowed enough shoulder for the bearings to mount against. The work end of the spindle has a #2 Morse taper and the entire spindle is hollow so that accessories

mounted in the Morse taper can be ejected with a rod if stuck. Number two Morse tapers are the most widely used tapers on wood lathes and will allow the user the most flexibility.

## **Bearings**

Bearings for a traditional lathe that provide hours of trouble free operation in a dusty environment are easily located. However, special consideration must be given for the bearings in the Portable Wood Lathe.

Misalignment between the headstock and the tailstock is not a factor for the wood being turned on the lathe. However, misalignment will affect the wear of the bearings. Most bearings will wear unevenly with as little as  $\frac{1}{4}$  of a degree of misalignment. Since the Portable Wood Lathe must be aligned each time it is set up, it will never be aligned accurately as consistently as a traditional lathe so special bearings must be used to allow for misalignment. Double-row, self-aligning ball bearings handle up to four degrees of misalignment without adversely affecting wear. Four degrees is 2.5 inches of misalignment for every 36 inches of length.

By selecting double row, self-aligning ball bearings [see Appendix N, Ball bearing spec sheet], the Portable Wood Lathe is able to compensate for adverse conditions with no loss of functionality.

## **Sheaves**

Sheaves are used in conjunction with a belt to transmit torque from one shaft to another. Step sheaves are sheaves with more than one groove of varying diameters that change the rotational speed when a different diameter is used. There are a variety of sheaves and belts on the market today for a variety of applications.

Step sheaves were selected to control the speed rather than an expensive electronic speed-controlling device. Sheaves that would allow the user as many speeds as possible were preferred and the proof of design specification for speeds was four however, sheaves with at least four steps that could fit on a one-inch spindle could not be found. Three step sheaves were used instead.

The resulting speeds from the sheaves selected were 560, 1050, and 1900 RPM. More research to find four step sheaves is recommended.

## **Motor**

The motor supplies power to the lathe. Motor selection was based on the needs of the amateur woodworker and current production lathes.

Comparable lathes on the market today have motors in the range of  $\frac{1}{2}$  to  $\frac{3}{4}$  horsepower. The motor must be able to run on 115 volts so that it can be powered from a standard wall outlet. Bearings in the motor must be sealed for protection from the dusty environment. The preferred rpm is 1725 rather than 3450 so that the speed of the lathe is closer to the speed of the motor throughout the speed range.

The motor selected [see Appendix O, Motor spec sheet] is a Dayton  $\frac{3}{4}$  horsepower motor designed to be used as in a power tool. All requirements were met and

in addition, the motor has a capacitor start for high starting torques and will turn both clockwise and counter-clockwise.

### **Slide**

The slide provides a platform for the motor to sit on while it is being moved to adjust the belt. Not only will it provide more protection for the bolt grooves in the frame it also keeps the motor more stable while moving.

The slides must provide a flat surface on which to move and fit over at least one side to keep the slide in line with the groove. Bolts pass through the motor, slide, and frame grooves to secure the motor with a nut inside the square tubing. To change or tighten the belt, the bolts are loosened and the motor is slid along the frame. To secure the motor, the bolts are tightened.

The material chosen for the slides was one by one inch angle iron. Angle iron is easy to obtain, inexpensive, and fits all the slide criteria.

## Manufacturing and Assembly

The design phase of the Portable Wood Lathe was completed at the end of the winter quarter. Manufacturing began with the spring quarter. All work was carried out in the CAS North Lab Facility.

### **CLAMPS**

The clamps for the original design will be cast however, due to prototype limitations, the clamps were machined. Three-quarter inch flat stock was used for the general shape and the portion to be inserted into the steel tubing is milled to  $\frac{1}{2} \times \frac{1}{2}$  inch.

The double-nut for the prototype is also machined, rather than cast, from  $\frac{3}{4}$  inch stock. Acme threads were tapped into the double-nut and a threaded support rod along with a threaded clamping rod were screwed into the rod support.

The acme-threaded rod was cut to length and holes were drilled into the threaded rods so that smaller rods could be inserted as handles in order to turn the clamps. Holes were also drilled and tapped into the frame assemblies to attach the clamp assemblies.

### **SLIDES**

Slides for the original design will be sheet metal bent to the shape of three sides on the square tubing on which the motor slides. For the prototype however, angle iron was used due to the difficulty of bending small pieces of sheet metal.

A one-inch by one-inch piece of angle iron was cut to 5.5 inches long for each slide. About  $\frac{3}{16}$  of an inch was cut off the side that would be vertical to allow the slide to move without contacting the bench. Holes were centered on the top face and placed  $\frac{4}{8}$  inches apart to match the mounting holes in the motor.

### **FRAME**

The steel tubing for the frame [see Appendix P, Frame drawing] was oxyacetylene welded (OAW) using simple butt joints. Minor grinding operations were performed after welding due to heat expansion and contraction and the frames were tested for flatness on a flat granite plate.

### **SPINDLE SUPPORT**

Because of casting limitations, the spindle support for the prototype was machined rather than cast.

The spindle support was machined from a 4 x 6 x 8 inch block of mild steel. First, the block was rough-cut to size with a band saw. Next, each side was faced on a milling machine to smooth the side and square it with the rest of the faced sides. Upon reaching a side whose opposite had been faced, the block was milled to the final dimension.

Once the block was properly sized, the bottom was milled up to the horizontal supports. Next, the top was milled down to the horizontal supports and the material between the supports was removed.

Finally, the support was mounted in a lathe and a drill was used to cut the shoulder diameter then the bearing diameter. A boring bar was then used to finish the bearing diameter in order to allow the bearings to be press fit.

All machining was done in the North Lab of the College of Applied Science. Cutting tools used in milling operations were four inch and one-inch diameter, high-speed steel cutters. Drill bits used were 1 ¼ and 1 7/16 inch, high-speed steel bits. A carbide blade was used in the boring bar to finish the bearing holes.

### ***TAILSTOCK***

Like the headstock spindle, the tailstock was not constructed by the designer due to the difficulties of machining a Morse taper inside a threaded rod. However, to mount the tailstock to the tailstock frame, two 3/8-inch holes were drilled in diagonal corners of the base for mounting and alignment. Corresponding holes were drilled in the frame and bolts inside the frame secure the tailstock. Due to the small size of off-the-shelf bolts in relation to the hollow of the tube, custom bolts were made to prevent turning while the mounting and aligning nuts were tightened. These bolts were made from ¼ inch flat steel stock and cut to just under ½ inch (the inside dimension of the tube is ½ inch). Holes were then drilled and tapped to fit the mounting and aligning nuts.

### ***BELT GUARD***

The belt guard [see Appendix Q, Belt guard drawing] was made with a single piece of 1/16-inch sheet metal. Dimensions were laid out on the sheet and the metal was cut to size using a hydraulic sheer. A band saw was used to cut out the openings for the spindle support and the motor. Tabs for welding the belt guard were bent toward the inside of the guard using a hydraulic press. The press was also used to bend the sides of the sheet metal into the final shape. The sides of the belt guard were welded together along each of the welding tabs using a spot welder.

In order to secure the belt guard to the frame, two pieces of sheet metal were brazed to the headstock frame (one in front and one in back) and holes were drilled through this tab large enough for a ¼ inch wing nut to pass through. A corresponding hole was drilled into the belt guard and was tapped to fit the ¼ inch wing nut.

## Manufacturing and Cost Analysis

The manufacturing cost analysis was based on information provided by vendors and individuals familiar with current manufacturing processes (welding, machining, and casting). As a manufacturing facility, it was assumed that there would be distributors servicing regions across a specific geographic range to sell the product. These regions were modeled after sales in the Greater Cincinnati area.

Pro Tool Service, Inc. estimates the number of lathes (comparable to the Portable Wood Lathe) sold in the area to be about 150 per year and has three main competitors (600 lathes per year). Assuming this manufacturing facility services Ohio and the five surrounding states (Michigan, Indiana, Kentucky, West Virginia, and Pennsylvania) and each of these states has 20 regions, at 600 lathes a region the total lathe sales would be 72,000 lathes a year. Discounting mail order sales and assuming there will also be an average of three competitors in each region, the manufacturing facility should be able to produce enough lathes to supply one quarter of this market or 18,000 lathes annually.

In order to simplify the manufacturing analysis, the parts cost estimate was obtained from one source (McMaster-Carr) rather than each individual vendor, except for the motor. The motor cost estimate was obtained from the actual vendor (Grainger). Low cost items (nuts and bolts) were given a 5% discount when bought in bulk and higher priced items were given an 8% discount. The total estimated cost of off-the-shelf parts was \$262.08 per lathe.

To reduce the machining and welding time of the custom parts for this lathe, the spindle support, tailstock and clamps will be cast with gray cast iron. The clamps will need no further machining or welding operations. The spindle support and tailstock will both require machining on the bottom surfaces to ensure flatness and holes to be drilled, bored, and threaded. With the volume of 18,000 spindle supports and tailstocks, and 72,000 clamps, the casting estimate is \$0.63 per pound. Subsequent machining operations were estimated at \$40.00 and hour and welding at \$50.00 and hour. The headstock spindle was machined at a cost of \$37.00 an hour. The total cost of custom parts and labor was estimated at \$49.09 per lathe.

The total projected cost of one Portable Wood Lathe while producing 18,000 per year is \$311.18. With a 12% mark-up the cost to the consumer would be \$350.00, which is the maximum price allowed according to the proof of design. Although there are several possibilities that may make the lathe lighter and less expensive, the only difference between the prototype and the production model used in the estimate is that the tailstock, headstock spindle support, and the clamps are made from gray cast iron.

## **Proof of Design**

Proof of design was conducted at the College of Applied Science and in the author's garage.

### ***SPEEDS***

Due to the difficulty in finding four-step sheaves that can be mounted on a one-inch or greater diameter spindle, the lathe has three speeds. The speeds were measured with a hand-held RPM gage and are 560, 1050, and 1900 RPM.

### ***SWING-OVER-BED***

Swing-over-bed was measured with a steel rule while the lathe was mounted to a bench. The maximum diameter that can be turned is 9.25 inches.

### ***DEFLECTION***

Deflection of the lathe was measured while the lathe was in operation and the part was being cut midway between the headstock center and the tailstock center. A dial indicator measured the deflection at the bearing on the live center mounted in the tailstock as .005 of an inch, which is 98% below the proof of design limit of .25 inch.

### ***BELT GUARD***

In accordance with OSHA standard 1917.15 (fixed guard), the belt and pulley guard prevents the operator from making contact with dangerous moving parts, is secured to the machine, prevents falling objects from making contact with moving parts, and creates no new hazards or interferences.

### ***WEIGHT AND FOOTPRINT***

The total weight of the lathe is 64 pounds, which is 28% above the proof of design weight limit of 50 pounds. The footprint of the lathe when stored is 13.5 x 16 inches or 216 in<sup>2</sup>, which is 18% smaller than the proof of design footprint of 264 in<sup>2</sup>.

### ***PURCHASE COST***

The purchase cost for the consumer is \$350.00 with a 12% mark up.

### ***ALIGNMENT AND ALIGNMENT TIME***

Alignment was carried out with a 3/8-inch diameter alignment rod. The headstock spindle (as well as the tailstock spindle) has a 3/8-inch diameter hole for removing centers and chucks from the taper. The alignment rod is inserted through one spindle and into the other spindle (the tailstock adjusting bolts should be loosened before the rod is inserted). The rod should be inside the entire length of each spindle at the same time for maximum alignment. Sight the rod and tailstock from above and rotate the tailstock so that the rod is centered in the spindle opening. With one hand on the tailstock and the other hand on the rod, spin the rod and adjust the tailstock to the point where the

rod will spin with the least amount of effort. Tighten the tailstock alignment bolts. Alignment of the lathe with the aligning rod was done in less than one minute, a decrease of more than 80% to the proof of design limit of 5 minutes.

The misalignment testing was conducted immediately after the alignment process with the headstock assembly and tailstock assembly 36 inches apart (the maximum recommended distance). A light bulb was set onto the 3/8-inch diameter hole in the back of the headstock spindle so that it was in contact with the entire diameter of the opening. A piece of paper was set on edge in front of the tailstock with a mounted live center and the point of the center was pushed slightly through the paper. The circle of illumination through the headstock spindle was measured and a circle was drawn of the same approximate diameter centered on the hole where the point of the tailstock center pierced the paper. The paper was returned to the tailstock with the point in the hole and the circle of illumination was compared to the circle drawn on the paper. The comparison showed no discernable deviation between the two circles however, the edge of the illuminated circle was a transition area rather than a clear line. This transition area was approximately .25 of an inch thick so the accuracy of the misalignment testing was approximately plus or minus .25 of an inch. Using the Pythagorean theorem with a distance of 36 inches and four degrees of misalignment, the tailstock has a maximum misalignment distance of 2.5 inches. Assuming the tailstock was at the maximum misalignment accuracy range of the test, the misalignment was 90% below the maximum allowable range of 2.5 inches.

## Conclusion

There were 14 specifications in the proof of design and 11 of these were attained (an achievement rate of about 79%). The number of speeds (four) and the maximum speed (2300 – 3000 rpm) were not reached due to the inability to find four step sheaves that fit a one-inch or greater spindle. Manufacturing 18,000 lathes per year may make casting a unique four step sheaves economical if a pair cannot be found.

The weight specification (50 pounds) was exceeded by 28%. There are several suggestions that may reduce the weight of the lathe, most notably the motor (which accounts for almost half the weight of the lathe). The motor chosen was the largest motor (according to research) for comparable lathes on the market. It is possible that reducing the size of the motor will not diminish the work that may be done on the lathe.

The remaining 11 specifications were all met and some were exceeded by a large margin. The most notable of these are:

- Storage footprint reduced by 18%
- Alignment time 80% under specification
- Alignment within 10% of specification
- Deflection 98% below specification

The design objectives section in the beginning of this report lists four categories the proof of design specifications fit into. They are:

- The Portable Wood Lathe must function as a traditional lathe
- The Portable Wood Lathe must be able to be operated safely
- The Portable Wood Lathe must be priced comparable to similar lathes on the market today
- The unique characteristics of the lathe must not interfere with the functionality of the lathe

Based on the proof of design results, the project has met all four of these characteristics.

Since, the three specifications that were not met are still attainable with more development, all four design objective categories were met, the proof of design success rate was about 79%, and these results were from the first prototype [see Appendix R, Portable Wood Lathe], then this project was a success.

## Recommendations

### ***FRAME***

Eleven gage, 3/4- inch square steel tubing was chosen for the headstock and tailstock frames for its strength and rigidity however, because the frame sees little stress, 16-gage square steel tubing may be more appropriate. By using a smaller gage of steel, the price and weight of the lathe will be reduced.

For production assembly, a more suitable method of welding would be MIG welding rather than acetylene welding. MIG welding leaves a good surface appearance without slag, is faster than acetylene welding, and is easily automated.

### ***MOTOR***

The motor is the heaviest part on the lathe. At 26 pounds, it makes up almost half the total weight. A 3/4 horsepower motor with capacitor start has enough power to run the lathe however, many users may prefer to trade some of the power for less weight. Since the lathe weighs 64 lbs, it can be awkward for one person to move. A lighter motor would not only be more portable, it would reduce the cost. More customer feedback is needed to determine whether a smaller motor can be used on the Portable Wood Lathe.

### ***HEADSTOCK SPINDLE SUPPORT***

Machining time for the headstock spindle support was approximately 20 hours. In a production run with a skilled machinist, this time would decrease however, machining is still a very expensive process and the end product would reflect this. A more economical approach would be to cast the spindle support from gray cast iron. After the casting process, the spindle support would be machined to flatten the bottom and bore the holes for the bearings thus drastically reducing the machining time and the waste resulting from cutting. The lathe would also benefit from the gray cast iron's vibration damping qualities.

### ***SHEAVES***

Three-step sheaves were used because four-step sheaves that fit on a one-inch or greater diameter shaft could not be found. With the variety of sheaves in use and on the market today, it is likely that sheaves meeting the criteria are being produced. However, in the event that sheaves cannot be found, a high enough production rate can make specialty sheaves economical. More market research should be conducted to find a cost effective solution to this problem.

### ***CLAMPS***

Just as the headstock spindle support could be gray cast iron, so could the clamps. Cost savings from cast steel to cast iron is approximately 10 to 20% and the clamps will also help reduce vibration.

***HEADSTOCK SPINDLE***

The work piece end of a headstock spindle generally comes equipped with threads on the outside for mounting attachments that allow the user to turn items with a short length and large radius (such as bowls) unsupported by the tailstock. Due to the limitations imposed by the sheaves, these threads were not able to be included on the prototype. Assuming the production run includes sheaves that allow the headstock spindle to be larger than one-inch in diameter, a few minutes of machining threads would greatly increase the range of items that could be turned on the lathe.

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## Appendix A

### ***PROOF OF DESIGN***

The lathe will have at least 4 speeds; the lowest speed will be 300 rpm plus no more than 300 rpm. The maximum speed will be 3000 rpm minus no more than 700 rpm.

The swing-over-bed will be a minimum of 6 inches and a maximum of 10 inches.

The headstock and tailstock will not deflect or move with respect to the bench any more than .25 inches while cutting a part.

The motor, belt, and pulleys will have a safety guard in accordance with OSHA standard 1917.15 (Machine Guarding) and will fall into the category of a fixed guard.

The lathe will be equal to or less than 50 lbs and the storage container will have a footprint of 13.5 inches by 20 inches (264 square inches) or less.

The purchase cost will be \$350 or less.

Alignment process will be carried out with an alignment tool and a procedure to be determined. When the headstock and tailstock are fully aligned, the tip of a live center mounted in the tailstock will be no more than four degrees off of a line passing through the center of a live center mounted in the headstock. The alignment process will take no longer than five minutes.

The lathe will be constructed of steel for stability and rigidity.

There are parts and set-ups involved with using this lathe that the designer has little to no control over as well as assumptions that will be made about the user:

As stated in the proposal, the bench that the lathe will be mounted on is assumed to be a woodworker's bench, a cabinetmaker's bench, or a similar bench that has a thick top (typically one to four inches) and is of sturdy construction. This will absorb unwanted vibration that a lathe base would normally absorb. Also, the top and sides of the bench must be flat and perpendicular.

The lathe will consist of manufactured parts as well as various commercial parts. These commercial parts (motor, bearings, centers, etc.) will be assumed to be of good quality and properly balanced so as not to add any vibration to the system. If a commercial part is found that is defective or does not meet these assumptions the designer will not be held responsible.

The operator is assumed to be familiar with the safe operating procedures of a lathe. Since the commercial parts are assumed to be balanced, the mounted part will be the primary source of vibration in the system. A properly mounted part may greatly reduce the vibration of the turning part. It is the operator's responsibility to mount the part correctly and choose a speed that will allow for safe cutting of the part.

## Appendix B

### **CONCEPTS AND TECHNIQUES OF MACHINE SAFEGUARDING**

#### **Chapter 1 Basics of Machine Safeguarding**

OSHA 3067 1992 (Revised)

##### **Requirements for Safeguards**

What must a safeguard do to protect workers against mechanical hazards? Safeguards must meet these minimum general requirements:

**Prevent contact:** The safeguard must prevent hands, arms, and any other part of a worker's body from making contact with dangerous moving parts. A good safeguarding system eliminates the possibility of the operator or another worker placing parts of their bodies near hazardous moving parts.

**Secure:** Workers should not be able to easily remove or tamper with the safeguard, because a safeguard that can easily be made ineffective is no safeguard at all. Guards and safety devices should be made of durable material that will withstand the conditions of normal use. They must be firmly secured to the machine.

**Protect from falling objects:** The safeguard should ensure that no objects can fall into moving parts. A small tool which is dropped into a cycling machine could easily become a projectile that could strike and injure someone.

**Create no new hazards:** A safeguard defeats its own purpose if it creates a hazard of its own such as a shear point, a jagged edge, or an unfinished surface which can cause a laceration. The edges of guards, for instance, should be rolled or bolted in such a way that they eliminate sharp edges.

**Create no interference:** Any safeguard which impedes a worker from performing the job quickly and comfortably might soon be overridden or disregarded. Proper safeguarding can actually enhance efficiency since it can relieve the worker's apprehensions about injury.

**Allow safe lubrication:** If possible, one should be able to lubricate the machine without removing the safeguards. Locating oil reservoirs outside the guard, with a line leading to the lubrication point, will reduce the need for the operator or maintenance worker to enter the hazardous area.

## Chapter 2 - Methods of Machine Safeguarding

### Guards

Guards are barriers which prevent access to danger areas. There are four general types of guards:

**Fixed:** As its name implies, a fixed guard is a permanent part of the machine. It is not dependent upon moving parts to perform its intended function. It may be constructed of sheet metal, screen, wire cloth, bars, plastic, or any other material that is substantial enough to withstand whatever impact it may receive and to endure prolonged use. This guard is usually preferable to all other types because of its relative simplicity and permanence.

**Interlocked:** When this type of guard is opened or removed, the tripping mechanism and/or power automatically shuts off or disengages, and the machine cannot cycle or be started until the guard is back in place.

**Adjustable:** Adjustable guards are useful because they allow flexibility in accommodating various sizes of stock.

**Self-Adjusting:** The openings of these barriers are determined by the movement of the stock. As the operator moves the stock into the danger area, the guard is pushed away, providing an opening which is only large enough to admit the stock. After the stock is removed, the guard returns to the rest position. This guard protects the operator by placing a barrier between the danger area and the operator. The guards may be constructed of plastic, metal, or other substantial material. Self-adjusting guards offer different degrees of protection.

## Appendix C

### *PUGH DIAGRAM*

<b>Pugh Chart: Alternatives</b>		Alternative 1	Alternative 2	Alternative 3
Adjustable Speed		s	s	s
Spindle Brake		s	s	s
Portability		s	-	-
Weight		s	-	-
Space		s	-	s
Total +'s		0	0	0
Total -'s		0	3	2

+ Better Alternative  
 - Worse Alternative  
 S Same

## Appendix D

### ***CUSTOMER SURVEY***

1. Do you own a lathe?  
Yes / No
  
2. How big is the area/shop you work in?  
100 – 299 square feet  
300 – 499 square feet  
500 – 699 square feet  
700+ square feet
  
3. Which best describes how often you use a lathe?  
Several times a year  
Several times a month  
Several times a week  
Every day
  
4. How often do you setup/take down your lathe?  
Never  
Several times a year  
Several times a month  
Several times a week  
Every use
  
5. What is the average length of the turning blanks you use?  
Less than 6 inches  
6+ – 12 inches  
12+ – 24 inches  
24+ – 36 inches  
36+ – 48 inches  
More than 48 inches
  
6. What is the average diameter of the turning blanks you use?  
Less than 1 inch  
1 – 2 inches  
2+ – 6 inches  
6+ – 10 inches  
More than 10 inches

7. What is the maximum speed your lathe will turn?  
Less than 1500 RPM  
1500 to 1999 RPM  
2000 and 2499 RPM  
Between 2500 and 2999 RPM  
3000 RPM or more

8. How satisfied are you with this maximum speed (5 being most satisfied)?  
Rating 1 2 3 4 5

9. What is the minimum speed your lathe will turn?  
0 to 300 RPM  
301 to 500 RPM  
501 to 1000 RPM  
1000 to 1500 RPM

10. How satisfied are you with this minimum speed?  
Rating 1 2 3 4 5

Rate the following question on a scale of 1 to 5 (with 5 being the most desirable) by circling your response.

11. How important is it to be able to change locations with your lathe?  
Rating 1 2 3 4 5

12. How important is it to be able to use the area your lathe is mounted on?  
Rating 1 2 3 4 5

13. How important is it to be able to carry the lathe yourself?  
Rating 1 2 3 4 5

14. How important is it for the work piece to rotate in both directions?  
Rating 1 2 3 4 5

15. How important is it that the lathe slows the work piece to a stop rather than letting it 'free wheel' to a stop?  
Rating 1 2 3 4 5

16. Comments:
-

## Appendix E

### **CUSTOMER SURVEY RESULTS**

1.	All respondents own a lathe.	
2.	How big is the area/shop you work in?	Number of responses
	100 – 299 square feet	1
	300 – 499 square feet	4
	500 – 699 square feet	2
	700+ square feet	2
3.	Which best describes how often you use a lathe?	
	Several times a year	1
	Several times a month	2
	Several times a week	6
	Every day	0
4.	How often do you setup/take down your lathe?	
	Never	6
	Several times a year	2
	Several times a month	0
	Several times a week	0
	Every use	0
5.	What is the average length of the turning blanks you use?	
	Less than 6 inches	4
	6+ – 12 inches	4
	12+ – 24 inches	1
	24+ – 36 inches	1
	36+ – 48 inches	0
	More than 48 inches	0
6.	What is the average diameter of the turning blanks you use?	
	Less than 1 inch	1
	1 – 2 inches	0
	2+ – 6 inches	5
	6+ – 10 inches	3
	More than 10 inches	1
7.	What is the maximum speed your lathe will turn?	
	Less than 1500 RPM	0
	1500 to 1999 RPM	0
	2000 and 2499 RPM	1
	Between 2500 and 2999 RPM	2
	3000 RPM or more	6

8. How satisfied are you with this maximum speed (5 being most satisfied)?  
 Rating 1 2 3 4 5  
 Average rating: 4.89
9. What is the minimum speed your lathe will turn?
- |                  |   |
|------------------|---|
| 0 to 300 RPM     | 7 |
| 301 to 500 RPM   | 3 |
| 501 to 1000 RPM  | 0 |
| 1000 to 1500 RPM | 0 |
10. How satisfied are you with this minimum speed?  
 Average rating: 4.4
11. How important is it to be able to change locations with your lathe?  
 Average rating: 2.3
12. How important is it to be able to use the area your lathe is mounted on?  
 Average rating: 2.7
13. How important is it to be able to carry the lathe yourself?  
 Average rating: 1.7
14. How important is it for the work piece to rotate in both directions?  
 Average rating: 3.6
15. How important is it that the lathe slows the work piece to a stop rather than letting it 'free wheel' to a stop?  
 Average rating: 3.6

## Appendix F

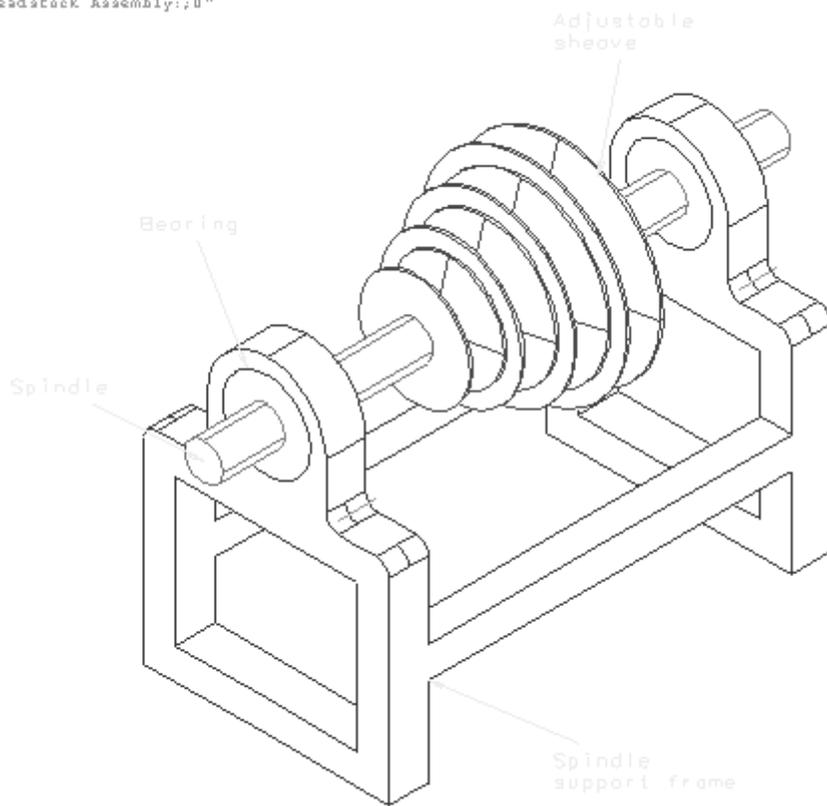
### HOUSE OF QUALITY

<b>QFD House of Quality</b>												
Design Requirements (How)						Customer Rating						
Customer Requirements (What)	Adjustable Speed	Spindle Brake	Portability	Weight	Space	Technical Importance	Importance (1-5)	Satisfaction (1 - 5)	Future Satisfaction	Modified Importance		
	Maximum Speed	1	1	1	1	1	4	4.7	4.7	4	4	
Minimum Speed	1	1	1	1	1	4	4.7	4.7	4	4		
Pounds	1	9	9	9	1	3.6	2.8	3	3.9	3.9		
Swing Over Bed	1	1	1	1	3	2.3	3.4	3.5	2.4	2.4		
Bench Size	1	1	1	1	1	1.7	3.9	4	1.7	1.7		
Material	1	1	1	1	1	2.7	3.1	3.5	3	3		
Technical Importance	4	4	43.8	13.1	7.1	22.5	4.23%	4.23%	46.30%	13.90%	7.51%	23.80%

# Appendix G

## HEADSTOCK DRAWING

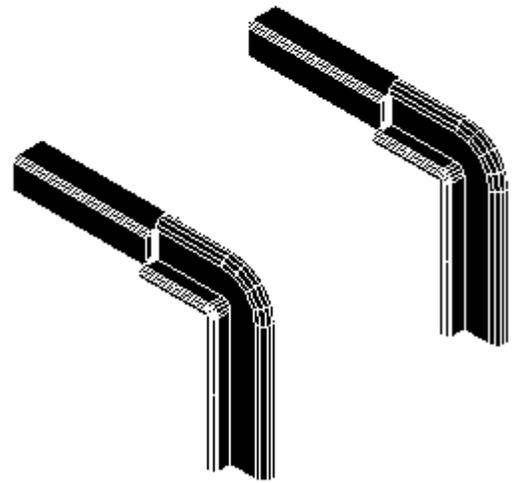
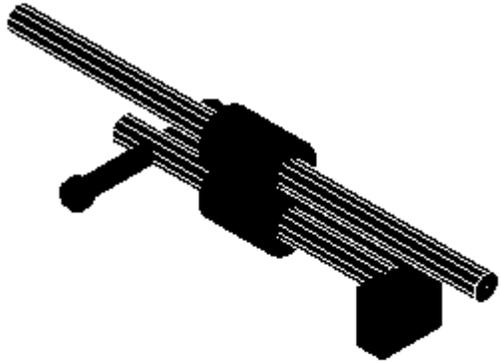
"Headstock Assembly:0"





# Appendix I

## *CLAMP ASSEMBLY DRAWING*



## Appendix J

### SCREW CALCULATIONS

Allowable torque for clamp screw threads

Allowable stress

$$\sigma_a = .75 P_s$$

where:

$P_s$  = proof strength

$$\sigma_a = .75 (33,000 \text{ lb/in}^2)$$

$$\sigma_a = 24,750 \text{ lbs/in}^2$$

Clamping load

$$C = A_t \sigma_a$$

where:

$A_t$  = tensile area

$$C = (.1092 \text{ in}^2)(24,750 \text{ lbs/in}^2)$$

$$C = 2701.56 \text{ lbs}$$

Allowable torque

$$T = D K C$$

where:

$D$  = nominal outside diameter of threads

$K$  = lubrication constant (.2)

$$T = (.5 \text{ in})(.2)(2701.56 \text{ lbs})$$

$$T = 270 \text{ in lbs}$$

## Appendix K

### CLAMP CALCULATIONS

Moment required to bend clamp

$$M = (\sigma_Y)I_x/c$$

where:

$$\sigma_Y = 36,000 \text{ lb/in}^2$$

$$c = .265 \text{ inch}$$

$I_x$  = moment of inertia with respect to the neutral axis

$$I_x = -Ad^2 - I$$

where:

$$A = .6136 \text{ inch}^2$$

$$d = .265 \text{ inch}$$

$I$  = moment of inertia

$$I = (1/8)\pi r^2$$

where:

$$r = .625 \text{ inch}$$

$$I = (1/8)\pi(.625 \text{ inch})^4$$

$$I = .0599 \text{ inch}^4$$

$$I_x = -(.6136 \text{ inch}^2)(.265 \text{ inch})^2 - .0599 \text{ inch}^4$$

$$I_x = .0168 \text{ inch}^4$$

$$M = (36,000 \text{ lb/in}^2)(.0168 \text{ inch}^4) / .265 \text{ inch}$$

$$M = 2282.26 \text{ lb inch}$$

Force required to bend one clamp

$$F = M/d$$

$$F = 2092.08 \text{ lb inch} / 1.5 \text{ inches}$$

$$F = 1394.72 \text{ lbs}$$

Force required to bend two clamps

$$F = 1394.72 \text{ lbs} \times 2$$

$$F = 2789 \text{ pounds}$$

## Appendix L

### **SPINDLE SUPPORT CALCULATIONS AND FBD**

Moment, M

$$M = (\text{length})(\text{force})$$

$$M = (2.35 \text{ in})(10 \text{ lbs})$$

$$M = 23.5 \text{ lb in}$$

Bending stress

$$\sigma = Mc/I$$

where:

$$c = \text{distance to neutral axis} = .313 \text{ in}$$

I = moment of inertia

$$I = (1/12)(b)(h)^3$$

where:

b = length

h = width

$$I = (1/12)(.5 \text{ in})(.626 \text{ in})^3$$

$$I = .010 \text{ in}^4$$

$$\sigma = (23.5 \text{ lb in})(.313 \text{ in}) / .010 \text{ in}^4$$

$$\sigma = 735.55 \text{ lbs/in}^2$$

Force from cutting tool

$$M = (2.35 \text{ in})(10 \text{ lbs})$$

$$M = 23.5 \text{ lbs}$$

$$I = (1/12)(.626 \text{ in})(.5)^3$$

$$I = .007 \text{ in}^4$$

$$c = .25 \text{ in}$$

Bending stress

$$\sigma = (23.5 \text{ lb in})(.25 \text{ in}) / .007 \text{ in}^4$$

$$\sigma = 839.29 \text{ lbs/in}^2$$

Mohr's circle

$$\sigma_Y = 1574.84 \text{ lbs/in}^2$$

$$\sigma_X = 0$$

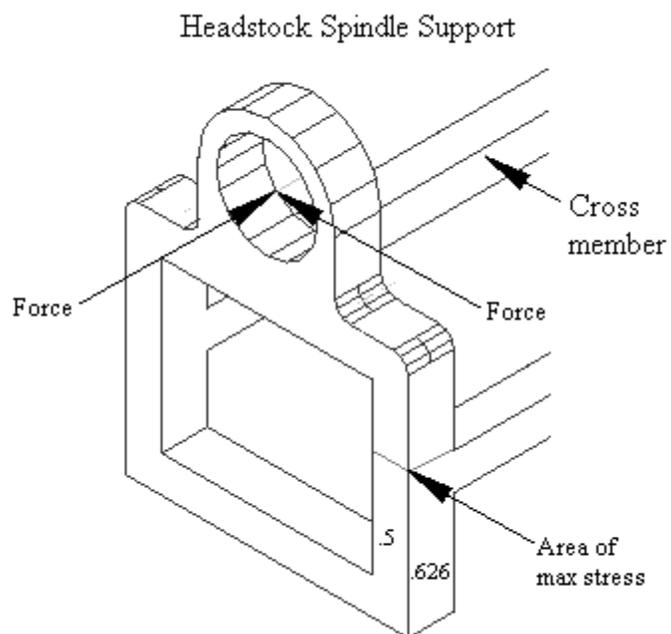
$$\tau_{XY} = 0$$

$$\sigma_{\max} = [(\sigma_X + \sigma_Y) / 2] + [((\sigma_X - \sigma_Y) / 2)^2 + \tau_{XY}^2]^{.5}$$

$$\sigma_{\max} = [1574.84 / 2] + [(-1574.84)^2 / 2]^{.5}$$

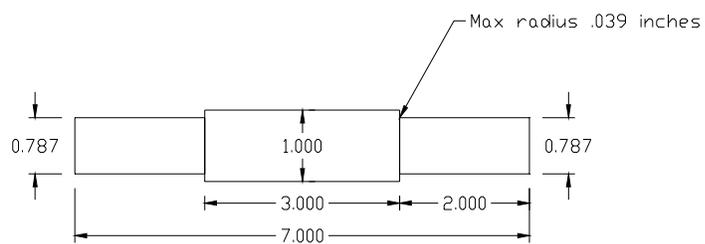
$$\sigma_{\max} = 1901 \text{ lbs/in}^2$$

$$\tau_{\max} = \left[ \left( \frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2 \right]^{.5}$$
$$\tau_{\max} = \left[ \left( \frac{-1574.840}{2} \right)^2 \right]^{.5}$$
$$\tau_{\max} = 1113.58 \text{ lbs/in}^2$$



## Appendix M

### SPINDLE DRAWING



Hollow spindle  
#2 Morse taper  
1 X 8 tpi RH threads on taper side

Lee Fritz

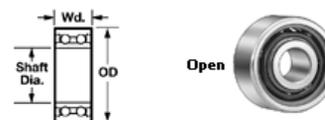
## Appendix N

### BALL BEARING SPEC SHEET

#### Double-Row Steel Ball Bearings — ABEC-1

Double-row ball bearings handle high radial loads. The balls are held in place at 25° angles between the inner and outer sleeves. They're ideal for pumps, gear motors, and large electric motors. Temperature range is -40° to +250° F. For tolerances, see page 981.

**Open bearings** have exposed ball bearings that are easy to clean. **Double-shielded bearings** have steel shields that help keep out dirt and preserve lubricants. **Double-sealed bearings** have removable rubber seals that touch the inner sleeve. They help preserve lubricants and block out dirt better than double-shielded bearings.



Bearing No.	For Shaft Dia., mm	OD, mm	Wd., mm	Dynamic Load Cap., lbs.	Max. rpm	Open		Double Shielded		Double Sealed	
						Each	Each	Each	Each		
3200	10	30	14.28	1,810	16,000	5885K11	\$18.73	5885K31	\$19.38	5885K51	\$20.84
3201	12	32	15.9	2,390	15,000	5885K12	20.64	5885K32	23.53	5885K52	25.58
3202	15	35	15.9	2,650	14,000	5885K13	20.64	5885K33	23.53	5885K53	25.58
3203	17	40	17.5	3,350	11,000	5885K14	20.04	5885K34	24.40	5885K54	26.04
3204	20	47	20.6	4,450	10,000	5885K15	22.18	5885K35	26.73	5885K55	28.76
3205	25	52	20.6	4,850	9,000	5885K16	26.62	5885K36	30.58	5885K56	32.80
3206	30	62	23.8	6,700	7,100	5885K17	31.98	5885K37	36.69	5885K57	39.40
3207	35	72	27	8,900	5,600	5885K18	39.40	5885K38	44.91	5885K58	48.49
3208	40	80	30.2	11,300	5,000	5885K19	48.16	5885K39	54.51	5885K59	64.91
3210	50	90	30.2	12,100	4,000	5885K22	60.31	5885K42	71.56	5885K62	75.20

# Appendix O

## MOTOR SPEC SHEET

**Grainger helps you get the job done.**

**Definite Purpose Motors**  
Power Tool

### Power Tool Motors

Used for high speed moderate starting torque woodworking and metal-working tools; wood lathes, sanders, grinders, table saws, planers and other applications where maximum HP load will not exceed nameplate rating. Suitable for all position mounting.

- Enclosure: Open dripproof
- Mounting: All position
- Service Factor: 1.0
- Ambient: 40°C
- Bearings: Double-shielded ball
- Insulation: Class A
- Rotation: CW/CCW



No. 5K600



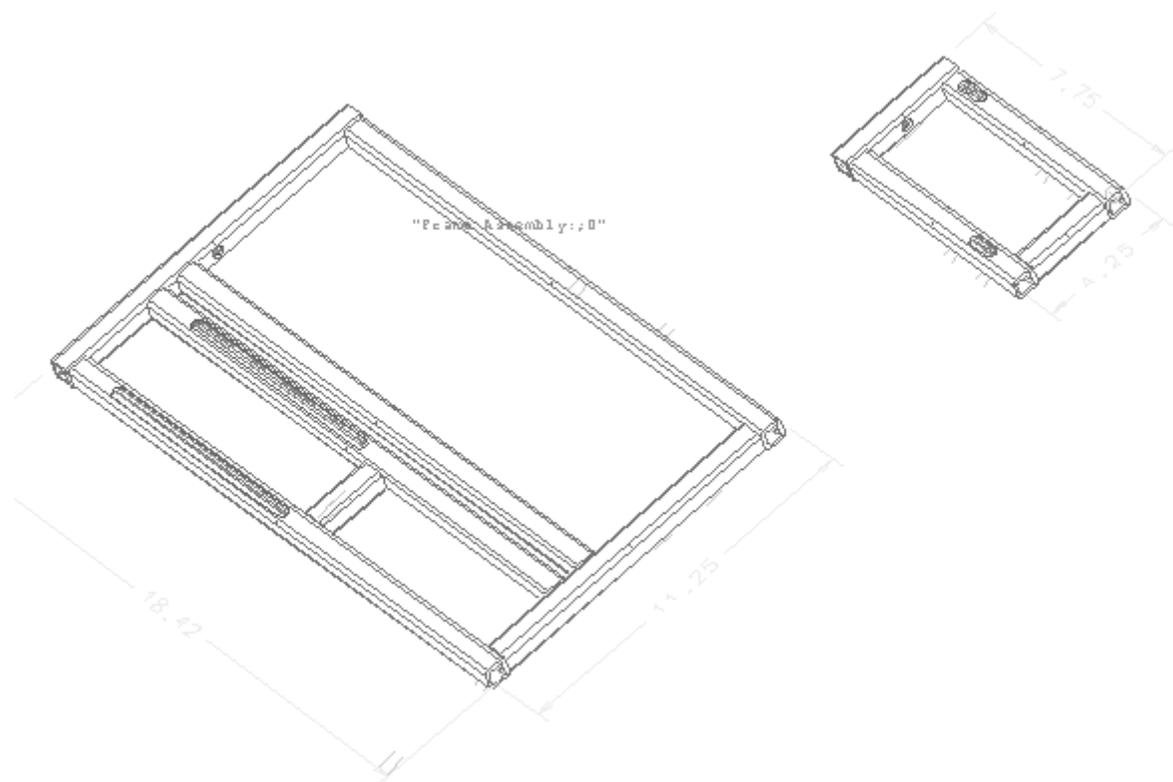
No. 4K141



HP	Nameplate RPM	NEMA Frame	Thermal Protection	Volts 60 Hz	Full-Load Amps	Bearings	Shaft Dimensions (In.) Dia. x Length	Stock No.	List	Each	Shpg. Wt.
<b>CAPACITOR-START, DOUBLE SHAFT, RIGID WELDED BASE</b>											
1/2	3450	56	Manual	115/230	8.0/4.0	Ball	5/8 x 1 1/2 ea.	<b>4K141</b>	\$208.00	<b>\$154.50</b>	19.0
1/2	3450	56	None	115/230	8.0/4.0	Ball	5/8 x 1 1/2 ea.	<b>5K285</b>	194.00	<b>143.60</b>	19.0
1/2	1725	56	Manual	115/230	9.0/4.5	Ball	5/8 x 1 1/2 ea.	<b>4K142</b>	234.00	<b>173.25</b>	19.0
1/2	1725	56	None	115/230	9.0/4.5	Ball	5/8 x 1 1/2 ea.	<b>4K781</b>	219.00	<b>162.25</b>	22.0
3/4	3450	56	Manual	115/230	9.8/4.9	Ball	5/8 x 1 1/2 ea.	<b>4K143</b>	240.00	<b>177.75</b>	25.0
3/4	3450	56	None	115/230	9.8/4.9	Ball	5/8 x 1 1/2 ea.	<b>5K286</b>	225.00	<b>167.00</b>	25.0
3/4	1725	56	Manual	115/230	11.4/5.7	Ball	5/8 x 1 1/2 ea.	<b>4K144</b>	270.00	<b>200.50</b>	27.0
3/4	1725	56	None	115/230	11.4/5.7	Ball	5/8 x 1 1/2 ea.	<b>4K783</b>	256.00	<b>189.75</b>	26.0
1	3450	56	Manual	115/230	14.4/7.2	Ball	5/8 x 1 1/2 ea.	<b>4K145</b>	256.00	<b>189.75</b>	24.0
1	1725	56	Manual	115/230	13.6/6.8	Ball	5/8 x 1 1/2 ea.	<b>4K146</b>	298.00	<b>221.00</b>	30.0

# Appendix P

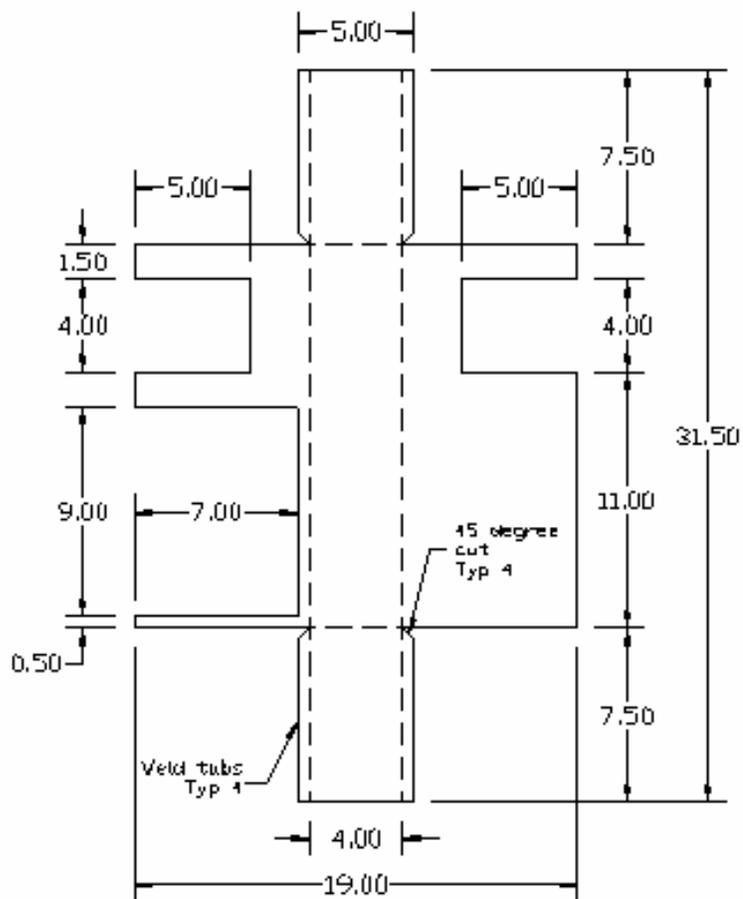
## FRAME DRAWING



## Appendix Q

### **BELT GUARD DRAWING**

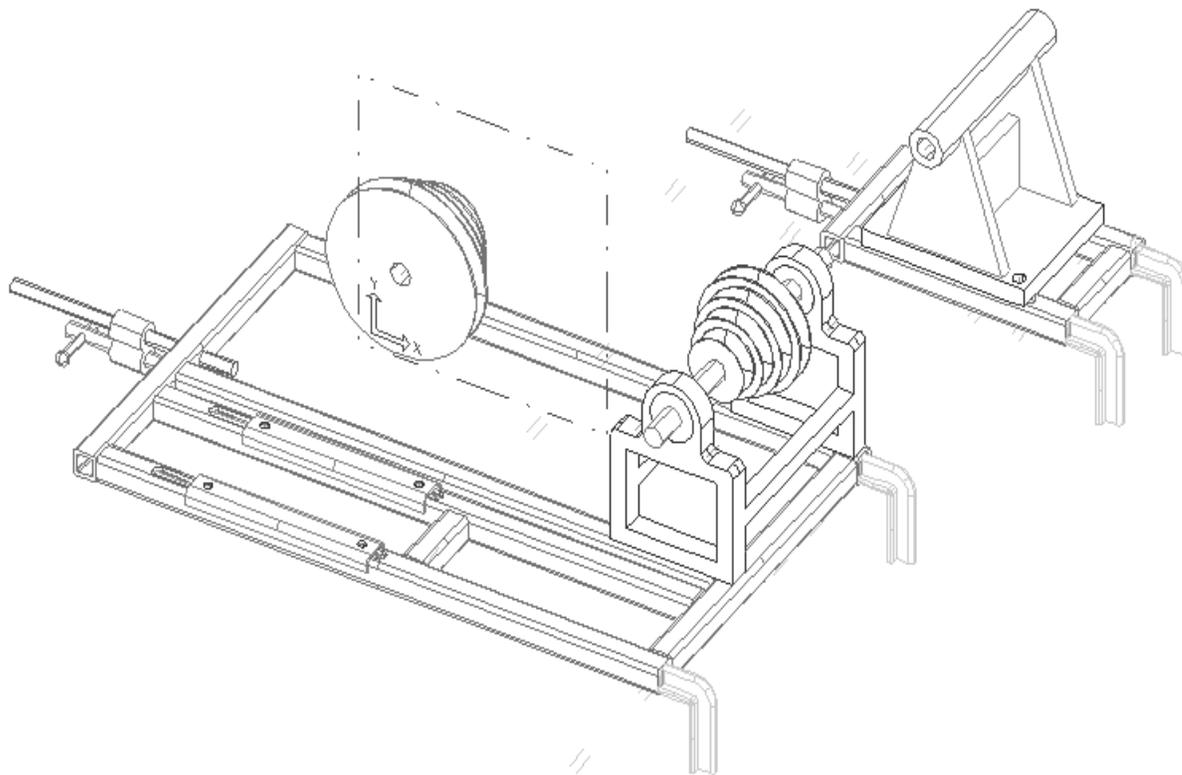
Belt Guard Layout Drawing  
1/16" sheet metal



View is toward the inside  
All units are in inches  
Dashed lines indicate 90 degree bends  
Make all bends to the inside  
Spot weld along all four weld tabs

## Appendix R

### *PORTABLE WOOD LATHE*



Motor is removed for clarity