EML 4905 Senior Design Project

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Pneumatic Pass-Thru Impact Wrench
100% Report

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11/25/2014

This B.S. Thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

ETHICS STATEMENT AND SIGNATURES

The work submitted in this B.S. thesis is solely prepared by a team consisting of Ryan Lucia, Felipe de la Cruz, and Milton Ceotto and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

Tools have been an essential component to human evolution. These physical objects and their respective properties enable us to complete certain tasks that would otherwise be impossible, at the very least, more difficult. Modern tools include hand tools, power tools, and even large, stationary machinery. Pneumatic (or air powered) tools have been omnipresent in the industrial and manufacturing setting, offering more power to weight, greater durability, and higher operating safety compared to electric powered equivalents.

One popular pneumatic tool is the air ratchet. This tool uses a small turbine to convert compressed air into rotational mechanical energy that develops a torque to drive mechanical fasteners via standard hex sockets. Some limiting factors for this tool are its low torque, low RPM's (rotational speed), and high air consumption (CFM or cubic feet per minute). A similar tool that offers remedy to this torque and speed issue is the air impact wrench. Like the air ratchet, it uses a small air turbine to drive mechanical fasteners via interchangeable sockets. Unlike the air ratchet, it features a mechanism that employs the conservation of energy. For the major portion of one revolution, the drive (turbine side) is separated with a rotating mass from the final output shaft. At the very end of that revolution, the rotating mass is engaged to the final output shaft, transferring its rotational inertia as an impact to the fastener. A higher final torque is achieved with the use of the impact mechanism, but at the cost of a larger tool that has a cumbersome gun configuration, unusable in many tight positions that mechanics and service engineers encounter.

Introduction

Problem Statement

The pneumatic ratchet currently does not have a mechanism to prevent the handle of the tool from disengaging from the final drive at maximum torque. In instances where the fastener is fully tightened and the user does not release the trigger in time, the tool will continue to rotate about the bolt or stud as opposed to rotating the fastener. Injuries caused by pneumatic ratchet are common in the workplace and include smashed knuckles, cuts and bruises. Pneumatic impact wrenches are superior in torque and rotational speed, but lack a light weight and nimble package. Pass-thru sockets are relatively new and few power tools exist that are capable of using them.

Air consumption for the pneumatic tools is another important factor. They consume on average about 4-6 cubic feet per minute of air at 90 psi. Reducing this would help reduce the cost of running a mechanics shop or manufacturing facility, directly impacting the facilities production, and reducing wasted energy needed to generate the supply air pressure.

Motivation

Air ratchets play a customary role in a variety of industries, encompassing both small and large manufacturing process. Also known as pneumatic ratchets, these air tools are primarily used to unscrew bolts, also giving the handler the ability to do so with minimal effort. Through a systematic arrangement of turbines and gearboxes, compressed gas is converted into mechanical energy which supplies the attached socket with a torque (25-75 ft-lbf) used to loosen the bolt.

The motivation for a new air ratchet design stems from the current model's inability to produce a significant torque and it's lacking of efficiency. The new design will focus on combining three existing technologies: pneumatic ratchet, pneumatic impact wrench, and pass-thru sockets. The pneumatic pass-thru impact wrench is expected to surpass the industry standard performance of most current standard pneumatic ratchets.

Literature Survey

This survey serves as a platform for the reader to be informed and gain knowledge on the many specifications of current pneumatic ratchets and wrenches, as well as the concept of the team's new design.

Background

Before discussing too heavily the current characteristics and designs of pneumatic ratchets, it is important to familiarize oneself with the origin of these air tools to better grasp the impact this project will have on their development.

Although relatively unknown to the general public, pneumatic tools have been around for centuries and are commonly used with all kinds of machinery and manufacturing processes (1). The earliest pneumatic tools may not have used electricity, but were a breakthrough for their times, employing the use of air in handheld tools such as bellows used by blacksmiths and smelters (1).

Pneumatic ratchets and wrenches are tools that use compressed gas as their main source of energy to perform their respective task, whether it be loosening or tightening a bolt or nut. In the case of a pneumatic ratchet, the compressed gas used to drive its shaft is air. Several limitations exist with the current design of these tools, mainly the inability of a pneumatic ratchet or wrench to navigate around long rods to reach a bolt, and the safety hazard that arises if the tool's torque capacity is exceeded. Pass-thru ratchets and impact wrenches, which diminish the threat of physical injury do exist, however, the proposed Pneumatic Pass-Thru Impact Wrench will aim to pioneer this industry by incorporating both the pass-thru and impact mechanism technologies into one design.

From bellows and pumps to ratchets and wrenches, pneumatic tools have seen a surge in development, increasing in all aspects of productivity, from their ergonomic viability to their increased torque and power efficiency.

Impact Wrench and Mechanism

An impact wrench is used to perform the same task as a handheld or non-impact wrench but is equipped with a much higher torque to get the job done. Reasons for using an impact wrench may vary, but it is most beneficial when trying to loosen or unscrew a nut or bolt that is wound tightly in place (2). Another instance where an impact wrench is advantageous is if a particular bolt is stripped to the point that a non-impact wrench cannot latch on properly to give it movement.

An impact wrench that uses compressed gas to function may supply a stubborn bolt with a enough torque to rotate due to the impact mechanism created by its inner components. This impact mechanism uses an anvil and hammer to apply a sudden, intense twisting motion to the nut or bolt, constantly agitating it until it finally loosens (2).

Most of these wrenches use one of two energy sources to operate: pressurized air and electricity. The benefit that a pneumatic impact wrench has over one powered by electricity is that it provides a higher torque, and is considered the most professional-grade impact wrench (2). In general, air tools usually weigh less and are easier to use than their electrically powered counterparts.

The average pneumatic impact wrench is made up of many different components, a few which are responsible for the impact mechanism, supplying the wrench with optimum torque and leverage on stubborn stripped lug nuts. The main components the impact wrench uses to achieve a superior torque capacity are the hammer and anvil. A rotor inside the impact wrench is connected through a spline in its side to a component called a rocker lever, which is housed inside the hammer cage. When air pressure is applied, the rocker lever begins to move, forcing the hammer and hammer cage to rotate (3). As the hammer rotates, it drives itself into the anvil's slot and remains engaged as long as the wrench is being powered (3). When the torque required to turn a stubborn nut or bolt exceeds a certain capacity, causing there to be resistance inside the mechanism of the wrench, the hammer will slip back out of the anvil's slot. The hammer, cage, and rotor will do one full revolution, thumping into the anvil's slot (3). The process of the hammer thumping into the anvil as it goes around will continue to occur until the torque supplied by the impact wrench eventually causes the nut or bolt to give and move out of place.

International Usage

The ratchet and impact wrench mechanisms are used in a variety of applications.

- Manufacturing, assembly, and maintenance
- Roller coasters, submarines, car engines, airplanes, and much more

Many industries worldwide can benefit from this multifunctional, ergonomic tool.

Environment Impact

The interior restructuring of this product will lead to a decrease in air consumption. Currently, pneumatic ratchets consume about 4-6 CFM (cubic feet per minute) at 90 PSI. The implementation of the impact mechanism will allow for less time needed to remove a bolt, directly reducing total air consumption.

Combining both tools (pass-thru ratchet and impact wrench) should reduce the future production of both tools, which will result in a smaller carbon footprint.

Power Consumption

Compressed air is often mistaken to be inexpensive or even a free source of power. On average, it costs over $30,000 a year to run a standard 1000 scfm air compressor due to the amount of electricity consumed. Manufacturing companies are likely to be equipped with machinery that utilizes compressed air as its source of energy. A typical 1000 scfm installation will waste about 30% of the compressed air generated, which amounts to about $9,600 annually in lost profits. A decrease in energy consumption will result in a direct increase in overall profits as well as providing a valuable contribution to the environment.

Waste Reduction

The possibility of accomplishing tasks in a reduced amount of time will decrease energy and electricity consumption. Air tools will lower the demand of batteries, reducing chemical waste.

Safety

A reactionless mechanism (the toll will not produce a force on the user's hand if the socket budges) isolates the final output from the drive turbine. Solely the mass momentum of the mechanism drives the output shaft. The newly designed mechanism will decrease injuries caused by current pneumatic ratchets common in the workplace, including smashed knuckles, cuts, and bruises.

Cost Effect

Merging the capabilities of a ratchet and impact wrench will eliminate the need of the mechanic, engineer, or company to invest in multiple tools. In many industries, particularly engineering, inefficiency in timing leads to lost revenue. The multi-functionality of the tool, along with increased torque output and higher RPMs, drastically cuts the time needed for the tool to perform its respective tasks.

Concept of Pneumatic Pass-Thru Impact Wrench

The pneumatic pass-thru impact wrench will combine three existing technologies: pneumatic ratchet, pneumatic impact wrench, and pass-thru sockets. The restructured design is expected to surpass the industry standard performance of most current pneumatic ratchets.

Constraints and Other Consideration

Starting with the most challenging part to be considered, the manufacturability of the material is something of extremely high importance. When designing a tool small such this one, with many details between every corner, it is important to keep in mind that the project must be something feasible to manufacture, and make sure that design considerations are taken in order to avoid problems during the manufacturing process. Hand in hand with the manufacturability comes the budget. When designing the part, it is also of vital importance to keep in mind that even when the manufacturing process is possible, the possibility of changing the design to the simplest way to manufacture it will save time and consequently money.

The size of the parts is also another constrain to the design. This tools are made in order to be ergonomic and to be able to fit in tight spaces in order to serve its purpose. Also the size of the tool would cause the air turbine to be squeezed or too big, what would cause a drop of pressure and consequently torque of the tool. Finally the materials available are another important constrain, since the material has to be strong enough to support the loads exerted into it, but also easy to manufacture for the reasons aforementioned.

Project Formulation

Project Objective

The objective of this project is to design and manufacture a wrench with the capabilities of three existing technologies: pneumatic ratchet, impact wrench, and pass-thru sockets. The implementation of these characteristics will produce a safer and more practical tool with a greater torque and ultimately result in a smaller, more powerful, and ergonomic package. In order to achieve our objectives, it is imperative that that our finalized product, the pneumatic pass-thru impact wrench, competes with or exceeds industry standard performance of similar tools.

On average, most pneumatic ratchets today with 3/8 and 1/2 inch socket drives produce an output torque of about 50 foot-pounds and a rotational speed of 130-150 rpms. The impact mechanism itself is expected to increase the torque by about 50 percent, to 75 foot-pounds, and the angular velocity by roughly 265 percent, to 400 rpms. Manufacturing the tool to possess the pass-thru function will enable long bolts or studs to extend through the socket and ratchet head.

Safety and ergonomics are taken into consideration during the design process of this project. The main concern involving pneumatic ratchets is knuckle and hand protection. If the torque needed to loosen a bolt surpasses the maximum allowable torque of the tool, that tool will continue to rotate, risking crashing the user's hand into another object in the vicinity.

Design

Conceptual Design

Many of the design components will be similar to the ones found in current air ratchets. Figure 1 is an example of a specialty air ratchet that has an integrated impact mechanism.

Figure 1 - Impact Ratchet Example

Figure 2 (4), below, shows an overview of all of the components found in this tool. Categories are labeled differently, corresponding to their section of the tool. In silver (left-most), the handle assembly can be seen. This includes the air coupler (to air hose/power source), trigger, and valve assembly. The air turbine, labeled in red, consists of multiple components. This system of the air ratchet has many variables that can be changed to optimize the balance between power output and air consumption. We will be modifying some parameters in our design to better fit the project goals, including efficiency, durability, and ergonomics. Blue labeled parts belong to the impact mechanism, in this case a Pin and Clutch impact mechanism. Following this picture we see a detailed picture for each one of the components aforementioned. At the other end, the ratchet head components are labeled in green. This is the other significant system that will have extensive modifications made to incorporate the pass-thru socket design feature.

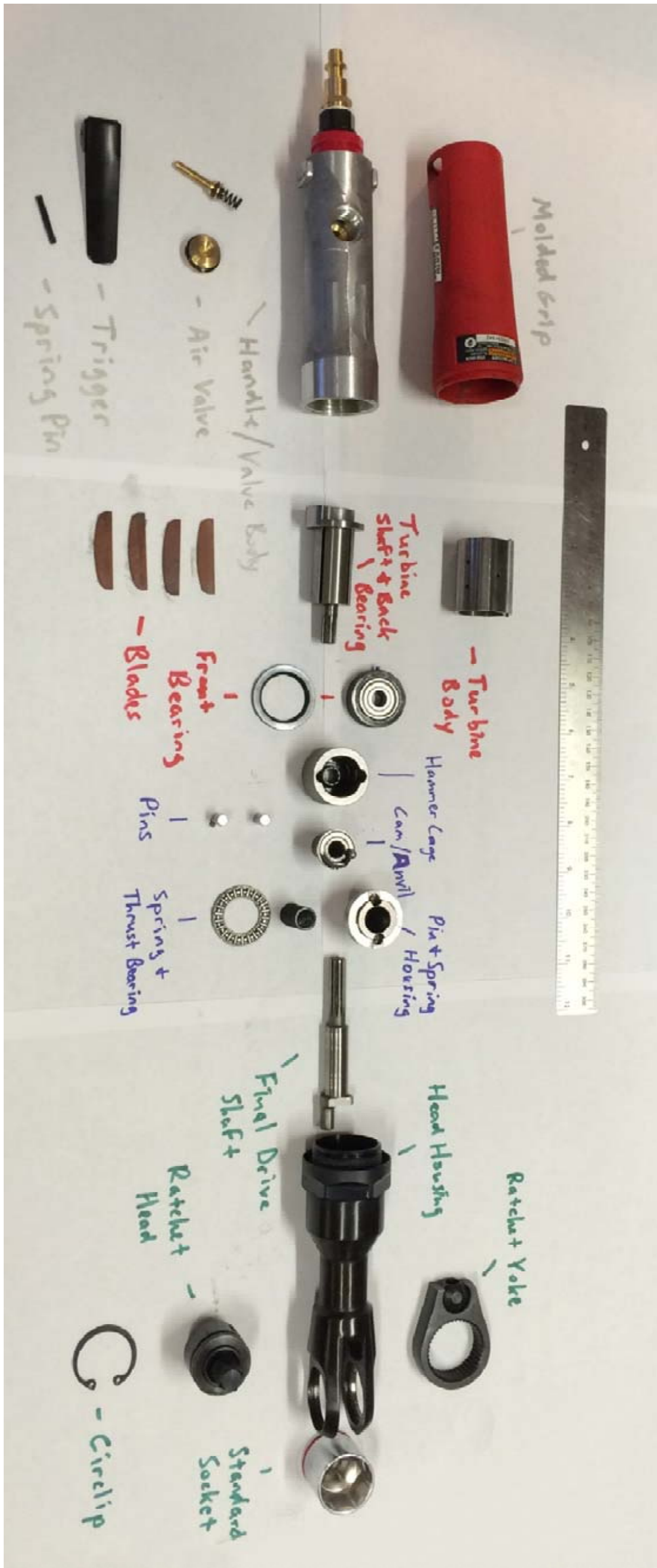


Figure 2 - Impact Ratchet Exploded View

Figure 3 - Air Turbine Components

Figure 4 - Pin and Clutch Impact Mechanism Components

Figure 5 - Ratchet Head Components

Figure 6 shows a conventional air ratchet, which features all of the same components with the exception of an impact mechanism. It is this unique impact mechanism that will enable the final design to achieve higher torque ratings compared to its "conventional" equivalent.

Figure 6 - Conventional Air Ratchet

The following figures show a comparison between standard sockets and our third design feature, pass-thru sockets. Figures 7 and 8 show a standard 3/8" ratchet equipped with a standard socket. Figure 8 emphasizes the limitation on applications that standard sockets can be used on, due to its designed limited depth, shown in Figure 12.

Figure 7 - Standard Ratchet and Socket

Figure 8 - Standard Socket Depth Limitation

Figures 9 and 10 show the relatively new tool technology, pass-thru socket and ratchet. We can see the unique design of the socket in Figure 10, which features a hole the entire way through the cylindrical cross section of the socket. One of the many benefits of this unique design can be seen in Figure 12, which depicts tightening of a nut on a long section of threaded rod. Also note the overall head height difference between standard sockets and pass-thru sockets (Figure 7 vs. Figure 9).

Figure 9 - Pass-Thru Ratchet and Pass-Thru Socket

Figure 10 - Pass-Thru Socket Infinite Depth

Figure 11 - Standard Ratchet Application

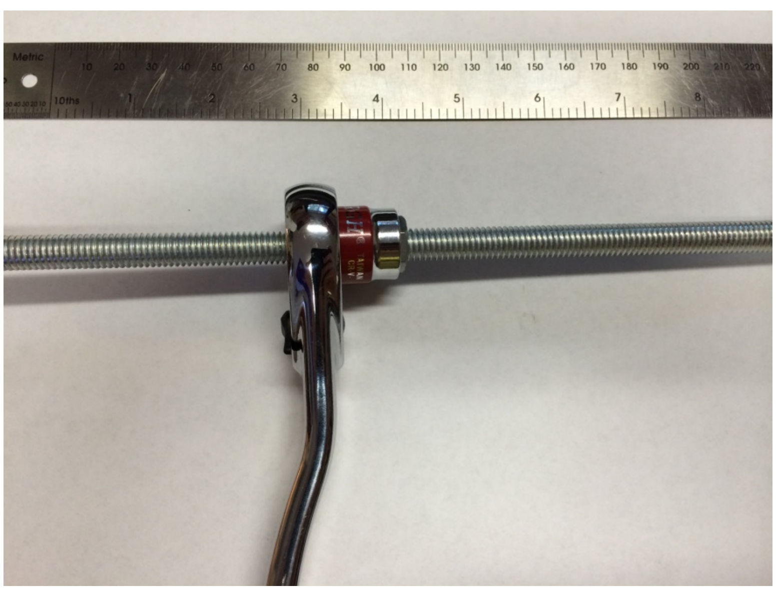


Figure 12 - Pass-Thru Socket Application

Proposed Design

Figures 13 and 14 show our proposed design. It is similar in shape and size to conventional air ratchets. The impact mechanism is proposed to be located in the middle section of the tool, shown as a hexagonal shaped housing in both figures above. The pass through head is also integrated to the design of this tool as shown.

Figure 13 - Proposed Design

Figure 14 - Proposed Design, Selected View of Ratchet Head

An important factor in the design of any tool is material selection. For pneumatic tools specifically, torque and mechanical wear are significant in the design selection of materials to manufacture the tool with. The most common materials for existing pneumatic tool technologies are hardened steel alloys for internal components and cast aluminum for a lightweight, yet strong housing. Both materials are relatively cheap and easily processed with common manufacturing techniques, such as casting, cutting, milling, turning, etc.

Analytical Analysis

In this segment, a brief overview on the analysis done in each section the Pneumatic Pass-Thru Impact Wrench will be presented. First of all, a few different components are found inside the ratchet head. The objective of these components is to transmit power from the shaft to the socket. The yoke is the central component, which is connected to the final drive shaft through the drive bushing, and the yoke also transmits its power to the ratchet head, which in our final design is replaced by a unique hub. The hub or ratchet head spins and since it is connected to a socket, it makes the socket spins as well.

Starting by the shaft, it transmits power to the yoke by spinning and making the drive bushing move the yoke sideways as shown in the picture below.

Figure 15 – Ratchet Head Moving from existing tool

By using the second law of motion, it is possible to calculate the value of the force produced by the shaft. The equations for the law of motion and force, respectively, are shown below.

$$\vec{F} = m\vec{a} \qquad\qquad T = F \times d.$$

Where F is Force, m is the mass, “a” is acceleration. T is the torque and d is the distance.

Moreover, we use of Von Mises maximum stress equation in order to make sure the shaft will support the load applied to it.

$$\sigma'_{max} = [(\sigma_m + \sigma_a)^2 + 3\,(\tau_m + \tau_a)^2]^{\frac{1}{2}}$$

Equation 1

Where σ'_{max} is the maximum Von Mises stresses, σ_m *and* σ_a are the midrange and alternating normal stresses and τ_m and τ_a are the midrange and alternating shear stresses.

Using the equation to find the torque required to raise or tightening the loads to a screw we can see how much torque is required at the socket head:

$$\boldsymbol{T_R = \frac{Fd_m}{2}\left(\frac{l + \pi f d_m \sec\alpha}{\pi d_m - f l \sec\alpha}\right)}$$

Equation 2

Where T_R is the torque required to raise of tightening the load, F is the force, d_m is the mean diameter, f is the friction coefficient, l is the length and α is half of the thread angle for the screw.

Finally the following equations calculates the force in our ratchet heat or hub's teeth:

$$T = \frac{d}{2} W_t \qquad\qquad W_t = 33000\,\frac{H}{V}$$

Equation 3 Equation 4

Where T is the torque, d is the diameter and W_t is the load being transmitted, H is power and V is the pitch line velocity. The calculations were made based off of the following parameters (5):

Screw Nominal Size	0.5 in
Threads per inch	20
Screw Material	SAE Grade 8 Fine Thread
Torque Factor	0.2
Torque Exerted	50 ft-lbf

Table 1 - Parameters

Nominal Size, Threads per Inch	Bolt and Screw Material
7/16-20 7/16-28 1/2-13 1/2-20	ASTM A354, Grade BC ASTM A354, Grade BD SAE Grade 7 SAE Grade 8

Parameter	Symbol	Value	Unit
Min. Proof Strength of Ext. Thread (Bolt)	S_p	120	10^3 psi
Min. Tensile Strength of Ext. Thread (Bolt)	$S_{ut.ext}$	150	
Min. Tensile Strength of Internal Thread[2]	$S_{ut.int}$	---	
Max Allowed Preload (% of Proof Strength)[3]	PPS	50	%
Torque Factor[4]	K	0.1	---
Design Factor against Stripping	n_s	1.2	---

Table 2 - Parameters

Note: [1] Information about this condition is needed for the calculations of thread stripping. If nut is being used as an internal thread, it's preferred to select a nut with a grade equal to or greater than the grade of the bolt being used.
Note: [2] This value is required if internal thread strength < external thread strength. Otherwise not needed.
Note: [3] Recommended values: 75 % for nonpermanent connections and reused fasteners. 90 % for permanent connections.
Note: [4] Use values given by your fastener supplier and manufacturer. If these values are not available from the suppplier, then see the "Supplements" section for the chart of torque factors K.
"Results" table and the table above were calculated using a calculator from: (6)

The required torque for tightening a screw is calculated in order to compare with the torque transmitted by the tool. Values estimated for the calculations of the torque required are based on assumptions of average use for the tool.

RESULTS			
Parameter	Symbol	Value	Unit
Nominal Size	--	1/2	---
Threads per inch	n	20	
Series Designation	--	UNF	
REQUIRED DIMENSIONS FOR CALCULATIONS			
Basic Major Diameter	d	0.5	in
Min. Major Diameter of External Thread	d_{min}	0.4906	
Min. Pitch Diameter of External Thread	d_{2min}	0.4619	
Max Minor Diameter of Internal Thread	D_{1max}	0.4574	
Max Pitch Diameter of Internal Thread	D_{2max}	0.4731	
Thread Tensile Stress Area	A_t	0.1600	in^2
Shear Area of External Thread (Bolt)	A_s	0.3839	
Shear Area of Internal Thread	A_n	0.5230	
TORQUE & PRELOAD RESULTS			
Calculated Preload	F_i	9597.19	lbf
Estimated Required Torque	T	39.99	lbf*ft
Min. Length of Engagement to Prevent Stripping (including design factor n_s)	L_e (or Q)	0.48	in

Table 3 - Torque Required Calculation

Upon the comparison of the required torque to lower the screw with the torque from the tool, another important calculation is needed, following the forces involved in the hub and pawl are analyzed.

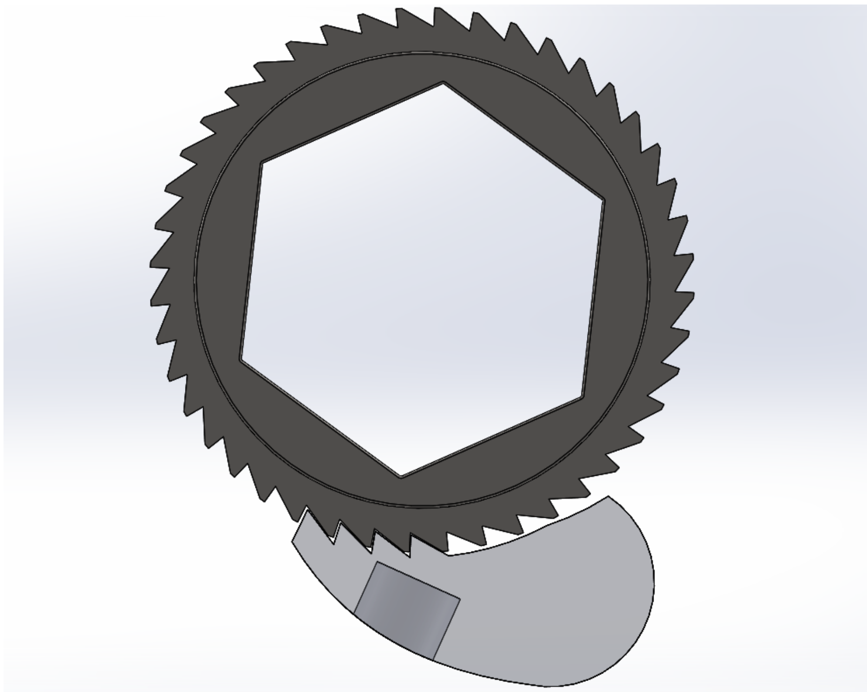


Figure 16 - Pawl & Hub mechanism

When the hub is spinning clockwise it does not experience significant resistance from the pawl. When the movement is counter-clockwise the pawl will engage the hub, as seen above, preventing the hub from rotating the opposite direction, in order to rotate the socket and target fastener. The forces acting on the teeth of each component are analyzed in order to prevent failure, since it would compromise the functionality of the tool. By the following calculations, the maximum stress found in the hub is contact stress, at a value of 195.5 ksi, which is less than the ultimate yield strength of hardened S7 tool steel at 220 ksi. By this, we can safely conclude that the tooth design has a safety factor of approximately 1.13.

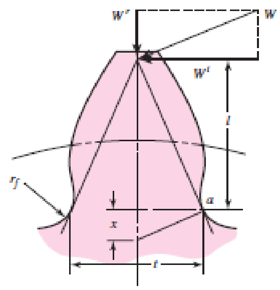


Figure 17 – Generic Tooth Profile

Analyzing the teeth from the hub will yield the following results:

Parameter	Value	Unit
Torque	600	lb in
Angular Velocity	385	RPM
V	2601	ft/min
Power	3.67	HP
W transmitted	46.56	HP

Table 4 - Force Transmitted

Further, calculating bending and wear analysis:

Hub Bending Analysis

Parameter	Value	Unit
Ko	1	Uniform Power Source
Kv	2.02	ft/min
Ks	1	
Pd	12.6	teeth/in
Km	1.1	
Kb	1	
F	0.5	inches
J	0.35	
Bending Stress	7449.3	psi

Table 5 - Bending

Hub wear Analysis

Ko	1	Uniform Power source
Kv	2.02	ft/min
Ks	1	
dp	0.29	
Km	1.1	
F	0.5	inches
I	0.1	
Cf	1.0	
Cp	2300	psi
Contact Stress	195.5	ksi

Table 6 - Wearing

Where:

Ko	Overload Factor
Kv	Dynamic Factor
Ks	Size factor
d	Pitch Diameter
Km	Load-distribution factor
F	inches
I	Geometry factor pitting
Cf	Surface condition factor
Cp	Elastic Coefficient
P	Diametral pitch
J	Geometry factor bending

Table 7 - Reference

Simulation

The purpose of utilizing a software simulation analysis for this project is to establish benchmark values for an existing pneumatic ratchet and using that data for direct comparison to the new design. This will provide verification for the new design, ensuring reliability of the device when it is placed under stress during normal operating conditions. An important highlight about these simulations is that numerical values of stress are not important, rather, the factor of safety will be the basis of comparison, reducing any possible errors arrising from the simulation methods used or inaccuracies produced by the program. For this to be effective, the simulations must be set up similarly in terms of geometry fixtures and external loads, as well as the generated mesh values. Simulations will also be run multiple times with varying mesh parameters to ensure convergence upon the calculated values.

Figure 16, below, displays the Factor of Safety (FOS) results of the original pawl. This component is found in the final stage of power transmission through the tool and sees a significant amount of stress and impacts. Using the original design as a "benchmark" value, we may directly compare the new design under the same operating conditions. To replicate the actual application of this pawl, fixed geometry was appiled to the faces indicated by the green arrows. Using a force of 10000 Newtons applied to each tooth face, the resultant FOS is 0.15, meaning, if this part were subject to the exact same constraints it would fail at an applied 1500 Newtons to each tooth face. Corresponding to the scale on the right, lower safety factor areas are designated by red, orange, and yellow, while high safety factor areas are in green or blue. Note that the scale is arbitrary in magnitude to best display the distribution of the more important Factor of Safety regions.

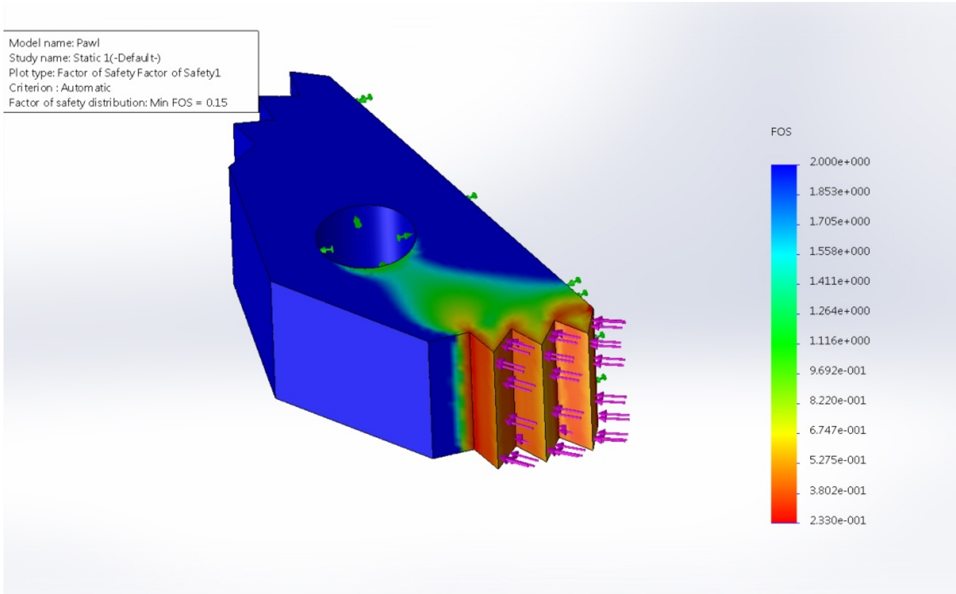


Figure 18 - Factor of Safety, Original Pawl

Figure 17, below, displays the FOS throughout the body of the Hub. To set up this simulation, fixed geometry, indicated by the green arrows, is created on the face of the hex feature along with a simple force normal to the surface, indicated by the pink arrows. As expected, the lowest FOS is located at the teeth where a force of 10000 Newtons are applied on each tooth face. The resulting convergent FOS is 0.33, more than twice the FOS of the original pawl. This indicates a more reliable component for the new design.

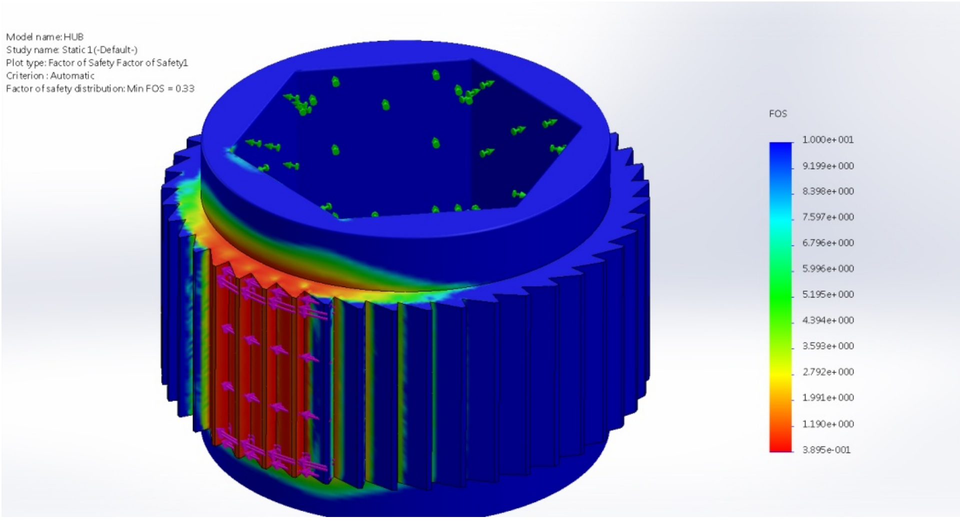


Figure 19 - Factor of Safety, Hub

The next simulation analyzes the corresponding component to the hub. This is the new/modified pawl. Using the same values for applied force and fixed geometry, a convergent FOS yields 0.19, seen in Figure 18. This value is slightly greater than the established benchmark of 0.15 in the original pawl. With these results, the new ratcheting mechanism design can proceed to further testing, including rapid prototyping and machining to do a final evaluation.

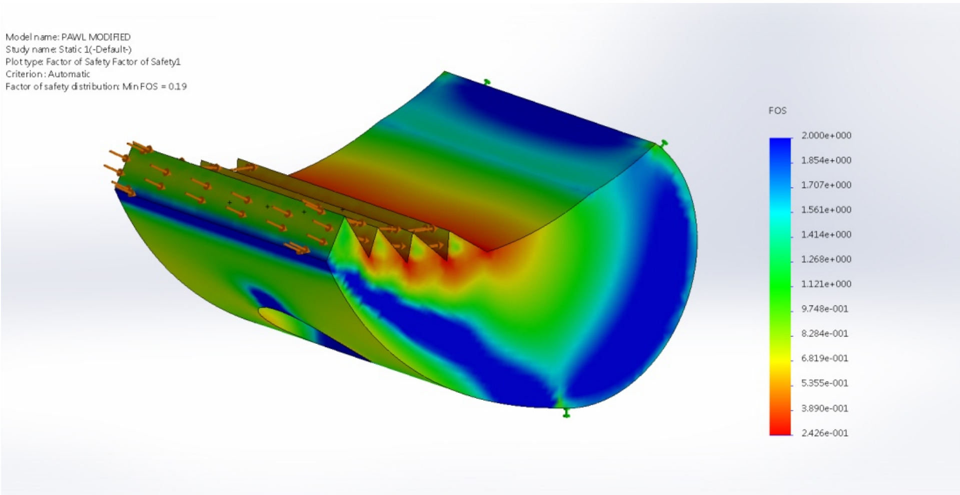


Figure 20 - Factor of Safety, Modified Pawl

Prototype

To better facilitate the design process we have incorporated methods of prototyping. The primary tool we utilized is 3D printing, specifically fused deposition modeling (FDM). We had a 3d printer readily available for use; a Solidoodle 3, capable of a print size 8x8x8 inches (200x200x200mm) with a layer resolution up to 0.004in (0.1mm). The material used was ABS plastic. We used the rapid prototyped (3D printed) parts for form and fit verification and visual aid during the design process. The ABS prototype will not withstand any significant stresses in the assembly, and therefore we relied on software simulation of the design elements and theoretical equations to verify functionality of the systems.

Figure 19, below, shows our initial rapid prototype components, including the yoke, pawl, and hub. To better inspect the design for fit and form with limited functionality we printed these components in a scale factor of 200%. The preliminary prototype assembly, Figure 20, proves itself excellent for fit, form and function with all tolerances in place for the final machining process. The ratcheting mechanism functions properly as well as the slip tolerance for the teeth in the race of the yoke.

Figure 21 - Rapid Prototype Parts

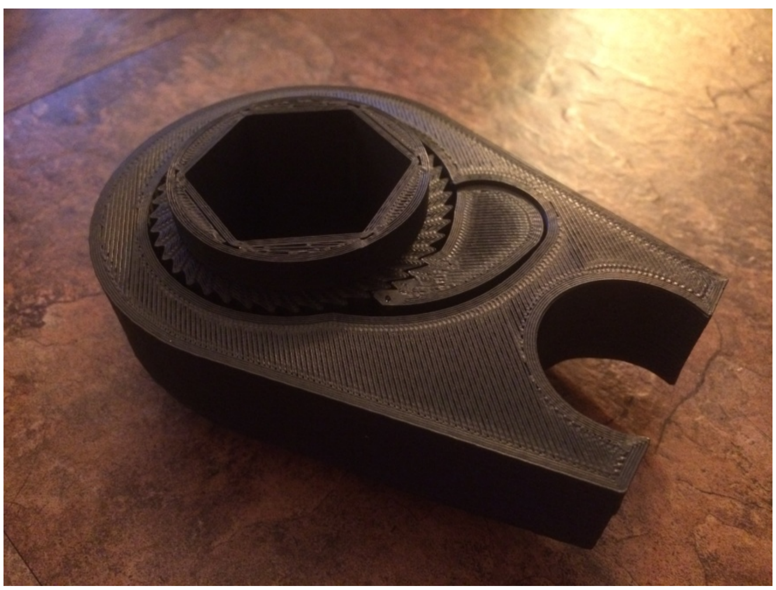


Figure 22 - Rapid Prototype Assembly

Figure 23 - 1:1 Rapid Prototype Model of Components

Figure 24 - 1:1 Rapid Prototype Assembly

Final Design

With proper verification through rapid prototyping and software simulation, we were able to proceed to the final design of the tool. This included all of the changes in minor details that we made throughout the preceding processes that helped facilitate the manufacturing steps to follow. Using a standard set of tolerances and following proper Geometric Dimensioning and Tolerancing, we developed completed drawings for each component of our design that fall outside of the pre-manufactured air ratchet's design. With each of the drawings completed, the parts may be manufactured by an external vendor, or in our case, manufactured in-house by our engineering team.

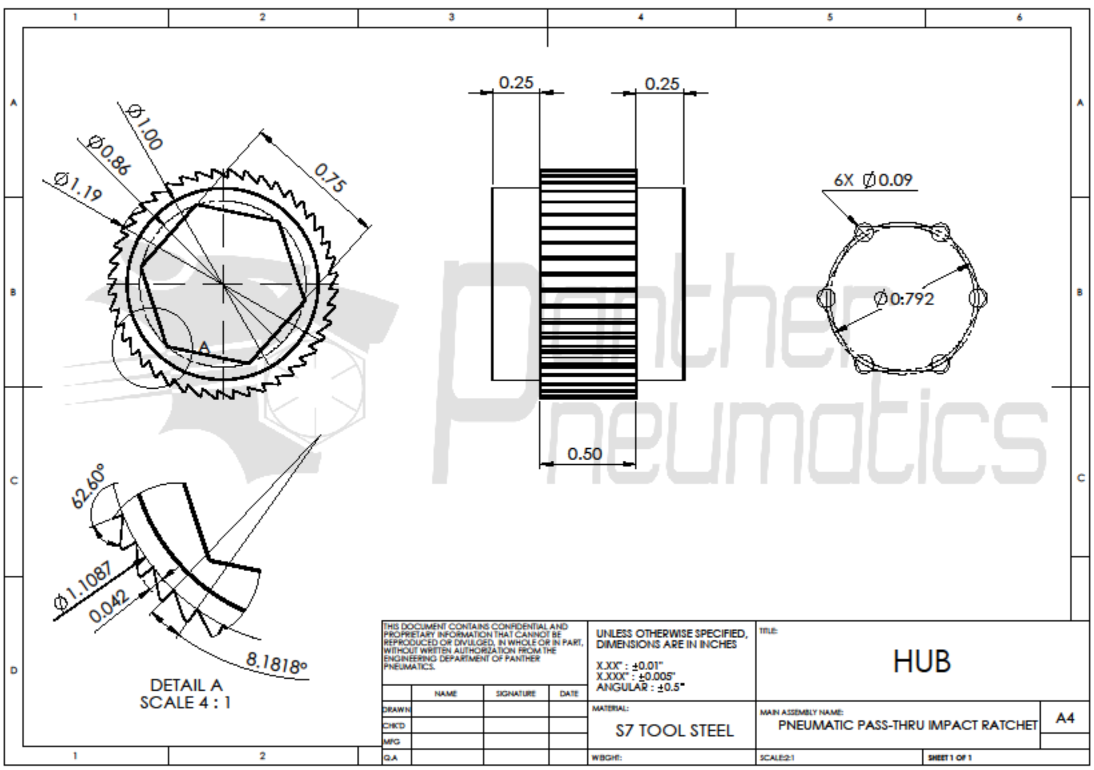


Figure 25 - Hub Engineering Drawing

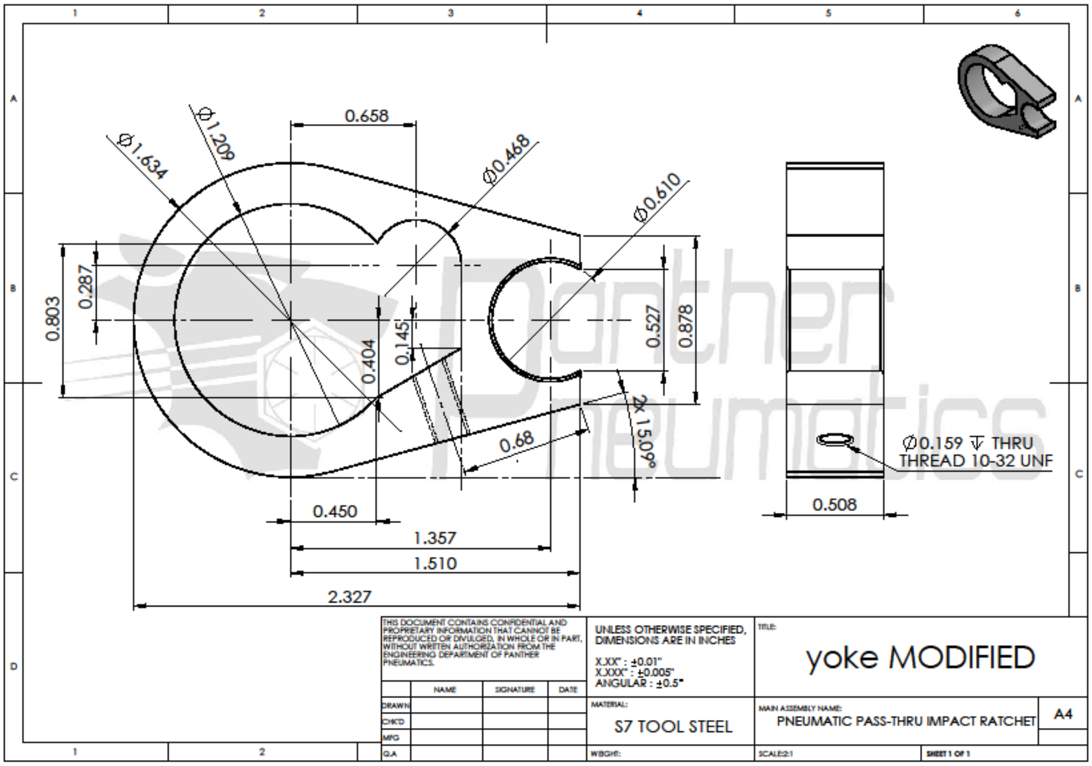


Figure 26 - Yoke Engineering Drawing

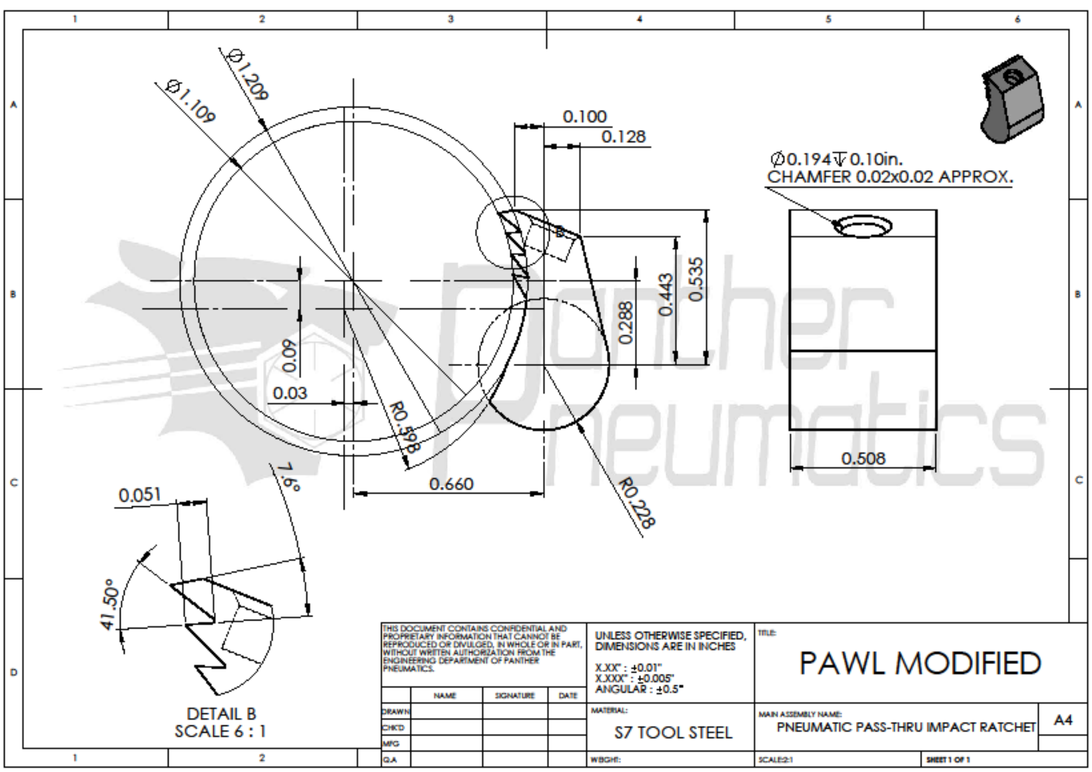
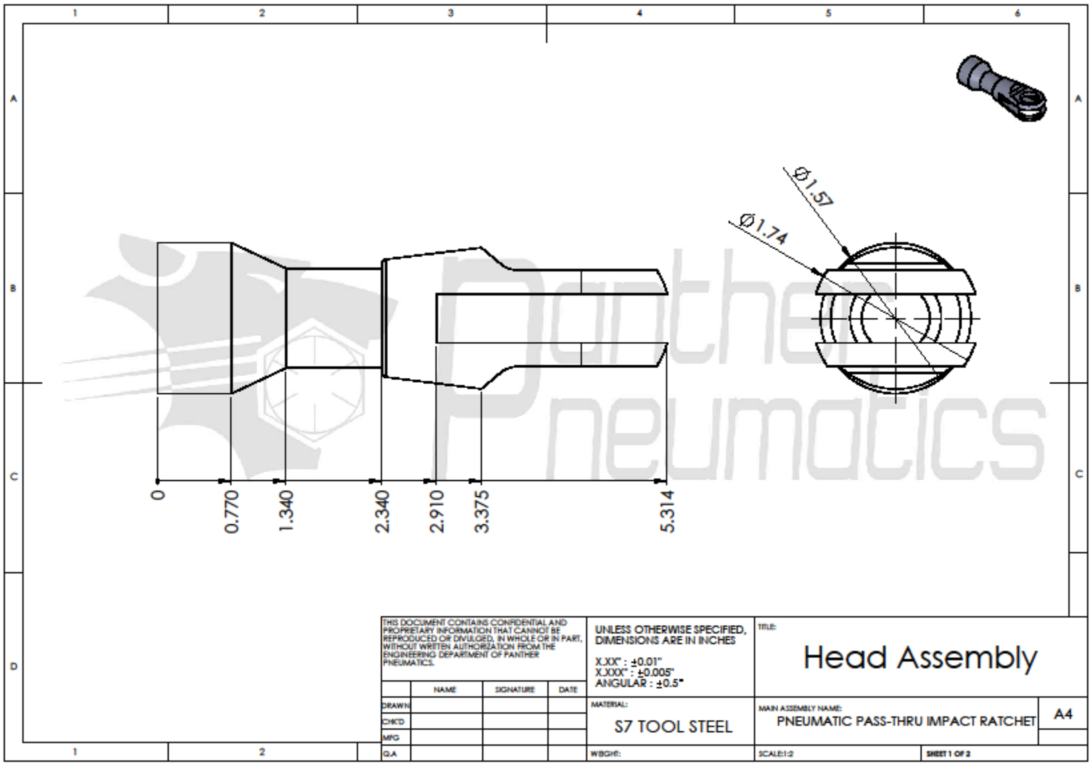


Figure 27 - Pawl Engineering Drawing



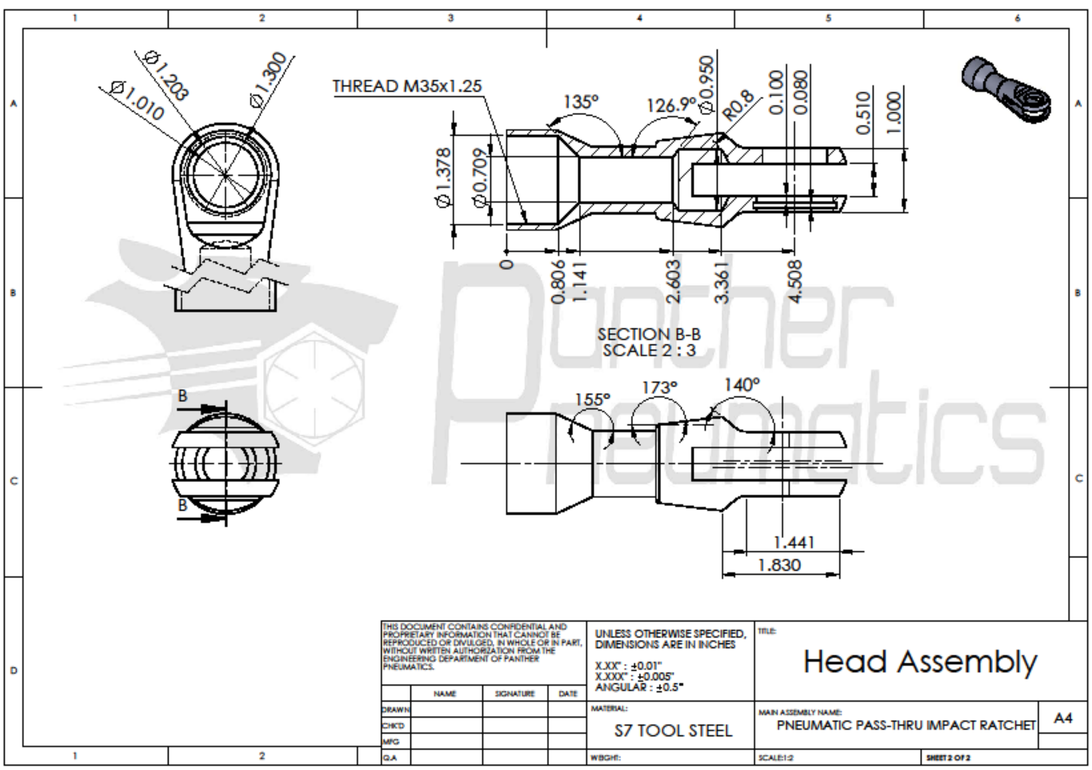


Figure 28 - Head Assembly Engineering Drawing

Material Selection

As seen in the engineering drawings for all of the components in our design, the material of choice is S7 tool steel. All of the characteristics of this particular alloy matched our requirements for this project. S7 is known for its shock resistance, displaying its remarkable characteristics in the form of chisels, punches, forming dies, shears, and many others. With the intense spike of force that some of these components are going to endure shock resistance is a must to ensure a long, dependable service life. The medium wear resistance property of S7 is countered in our design by incorporating large contact surface areas backed by a lubrication system.

Manufacturers supply S7 in the annealed state, or, a condition where the internal stresses have been relieved and the microcrystalline structure has been rearranged producing a softer material with excellent cold-working properties. This is critical in the manufacturing process, allowing the cutting tools to remove material with reduced tooling wear. Further processing of the material by methods of heat treating and tempering will restore the full strength and hardness of the metal components, which is crucial to the functionality and durability of the final product. Further details on the heat treatment process will be discussed in the following manufacturing process section.

Manufacturing Process

The Panther Pneumatic Engineering Team decided to manufacture each of the components used in the pneumatic pass-thru impact wrench with the equipment available to students at the Engineering Manufacturing Center at Florida International University, Miami, FL. Many factors went into the decision to manufacture the components in-house including cost, time, practical experience of the team members, and available machinery to produce these parts.

Machining of metals is a complex subject with an ever expanding technology base and a million-ways-to-do-one-thing face value to every design. One method of material removal is called milling. This process relies on the removal of material from a target surface using a rotational cutting bit. Milling is one of the most versatile machining processes, varying in size, speed, and precision. For all of the milling used in this project, a 2J Head Bridgeport Knee Mill was utilized. By incorporating a rotary table, we were able to machine round features, such as bores and radii's, necessary in each component manufactured. A vast arsenal of tooling was necessary including the following: 135° drill point spiral bit assortment, silver and deming bit set, 1" fly cutter, 1/4" 7/16" and 1/2" end mill, 1/2" ball end mill, and countersink bits.

Figure 29 - 2J Bridgeport Knee Mill, Vise, Rotary Table

Another extremely versatile machining process is turning. A machine known as a lathe rotates the work piece in its chuck as a fixed cutting tool removes material in two axes. This process is extremely accurate and quick for round feature machining. To do our turning, we utilized a Nardini MS1440 Engine Lathe. Tooling included left and right carbide cutters, HSS cutoff tool, tailstock drill chuck, and various drill bits. Miscellaneous additional tooling for the project are as follows: horizontal band saw, 4-1/2" angle grinder, 20 ton shop press, hand files, deburring tool, Dremel tool, etc...

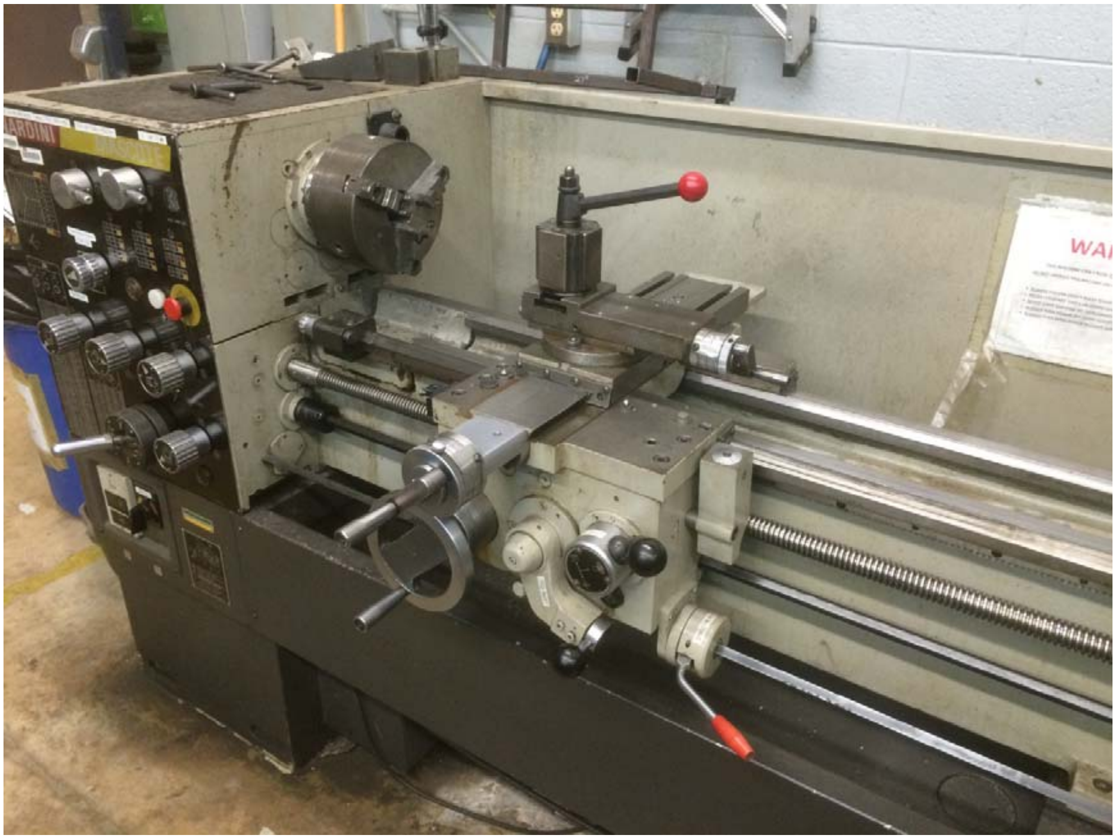


Figure 30 - Nardini Engine Lathe

The heat treating process is a critical step in the manufacturing of components made of a wide array of steel alloys. To complete this treatment process, we used a Knights KMT13 Heat Treating Box Furnace, shown below.

Figure 32 - Knights KMT13 Heat Treating Box Furnace

Figure 31 - Components Hardening at 1750°F

Heat Treatment of Tool Steels						
AISI	Preheat Temp. (1)	Austenitize Temp. (2)	Hold Time (Minutes)(3)	Ouench	Temper Temp.(6)	Typical Hardness HRC
S7	1350/1400	1725/1750	15-45	AIR (4)	350/600	54/58
O1	1250/1300	1450/1500	15-30	OIL	350/500	58/63
A2	1350/1400	1750/1800	20-45	AIR	400/1000	56/62
D2	1400/1450	1825/l875	15 45	AIR	400/1000	55/62
CRUWEAR	1400/1550	1850/2050	15-45	AIR	900/1050	58/64
3V	1450/1550	1875/2050	20-45	AIR	950/1050	56/62
M2	1500/1550	2050/2200	3-10	AIR (5)	1000/1100	58/65
M4	1500/1550	2050/2200	5-10	AIR (5)	1000/1100	58/65
9V	1500/1550	1950/2050	15-45	AIR (5)	1000/1150	44/56
10V	1500/1550	1950/2150	5-45	AIR (5)	1000/1100	56/63
15V	1500/1550	2050/2150	10-20	AIR (5)	1000/1100	56/63
https://www.crucible.com/eselector/general/generalpart2.html						

(1) Tools should be held in preheat range just long enough for temperature to equalize throughout material. A second preheat step at 1850/1900°F is recommended for vacuum or atmosphere furnaces when hardening temperature is over 2000°F.

(2) Higher austenitizing temperatures are used for slightly greater hardness; lower temperatures may provide slightly improve toughness.

(3) Hold times are typical soak times after material has reached the aim temperature. Longer times are for low austenitizing temperatures; high temperatures require shorter soaks. Variations in furnace type, load or part size, etc., may require varying allowances for parts to reach aim temperature.

(4) Interrupted oil quench may be required for very large sections.

(5) Although high speed steels may be air-hardened, a salt bath or other similar equipment is required to attain maximum hardness.

(6) Multiple tempers are mandatory for most grades. Consult individual data sheets for specific requirements. (7)

The chart above outlines all of the critical temperatures and times for the heat treatment of many common tool steels, where S7 is highlighted in yellow. By following this process the resulting hardness is between 54 and 58 HRC. Using this information, we created a heat treating temperature profile, shown below, to aide in the programming of the automated heat treating furnace. It is a good visual demonstration of the temperatures and times that allow the microcrystalline structure to rearrange from ferrite to austenite, greatly increasing the strength. This hardening process is called austenitizing.

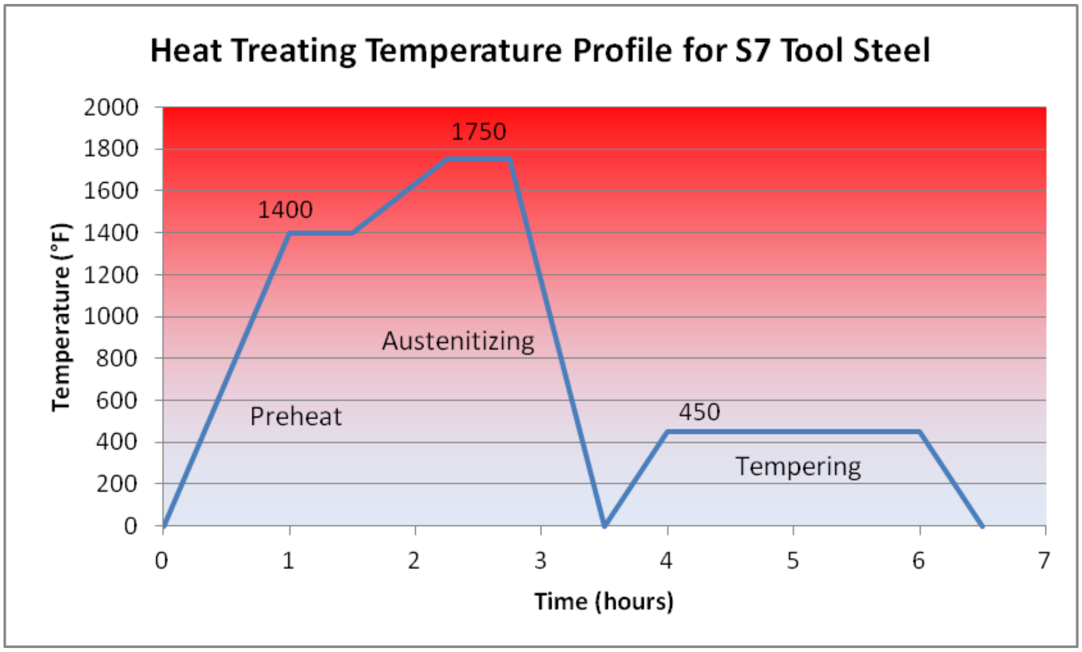


Figure 33 - Heat Treating Temperature Profile for S7 Tool Steel

Testing & Evaluation

With our completed pneumatic pass-thru impact ratchet, we have ran many extensive tests to verify all predicted results and ensure fulfillment of the project goals. These tests include evaluation of the torque and RPM rating, and long-term durability.

After manufacturing and heat treating was complete, it was imperative to test our tool and analyze the results to determine if we met our standards and expectations. Two main tests were performed that we felt were sufficient in determining our success: torque testing and rotational speed testing. The tool was very consistent and proved durable throughout the time that it was powered, never faltering. An explanation of each test is provided.

Torque Test

To test the torque capabilities of our new design, a bolt was welded onto a rectangular steel surface and a standard ¾ inch zinc coated nut was tightened and torqued with both pneumatic wrenches. For comparison, a standard pneumatic ratchet is used in all of the following tests. After this step, a standard ½ inch click type torque wrench was used to determine the torque applied to the nut. By starting at a minimum estimated torque value and increasing incrementally by 1 ft-lbf each trial, we indicated the moment the fastener yielded in rotation, signifying the torque wrench has just passed the torque that the respective pneumatic ratchet has provided to the fastener.

This procedure was followed for three trials for both tools in order to obtain a more accurate torque capacity rating for each tool. The resulting torque values for each tool were recorded and analyzed:

Torque Test			
Standard Pneumatic Ratchet			
Trial 1	Trial 2	Trial 3	Average
44	44	45	**44.3**
Panther Pneumatics Pass-thru Impact Wrench			
Trial 1	Trial 2	Trial 3	Average
58	57	59	**58**
note: all values in units of ft-lbf			

Table 2 - Torque Test Results

The results obtained for each tool were somewhat expected. The standard pneumatic ratchet that we tested was capable of supplying a torque very close to the manufacturer's proclaimed value, but did not exceed it. Our new design provided a torque of 58 ft-lbf, which met the initial expectations of our project.

RPM Test

The rotational speed of the new design, the pneumatic pass-thru impact wrench, was measured in order to determine the amount of time it would take (and save) to tighten a given fastener a certain length of threads. To perform this test, a small piece of reflective tape was attached to the side of a ¾ inch socket. A handheld digital tachometer was used to record the frequency of that piece of reflective tape while the tool was powered by its source of compressed air. The tape acted as an indicator for the sensor; every time it reflected the optical source from the tachometer it would record that as a pulse. This convenient piece of equipment allowed us to accurately determine the rotational speed of the tool in RPMs.

After several trials of testing for the tool's RPMs, an average value of 376 RPMs was calculated. The following table shows the resulting RPMs of each tool for each trial.

Rotational Speed Test			
Standard Pneumatic Ratchet			
Trial 1	Trial 2	Trial 3	Average
146	148	148	**147.3**
Panther Pneumatics Pass-thru Impact Wrench			
Trial 1	Trial 2	Trial 3	Average
376	378	375	**376.3**
			note: all values in units of RPM

Table 3 - RPM Test Results

Although in theory we expected our rotational speed values to be slightly greater, we were not surprised to see the numbers vary in practice. The figure below shows the tachometer used for this test.

Figure 34 – Handheld Digital Tachometer

Hardness Testing

To determine the effectiveness of our heat treatment process we employed the use of a Rockwell Hardness Tester before and after the heat treatment was performed. The idea behind a Rockwell Hardness Tester is to measure the amount of deformation of the surface of a target material caused by the instrument. A standard shape and size deformation tool, of material much harder than the target material, is loaded with a precise force in a methodical manner which displaces the surface material being tested. A final quantitative value of the difference of the vertical positions before and after the load is applied is measured via a dial gauge, thus displaying the Rockwell Hardness of that material.

Prior to heat treating our manufactured components, we ran multiple tests to determine the Rockwell Hardness of our S7 tool steel in the annealed condition. An average value of 10 HRC was produced. After heat treatment, we were pleased to find an average hardness value of 50 HRC throughout all components. As per the manufacturer’s material data sheet for ASTM S7 tool steel, following our exact heat treatment procedure will result in a hardness of 54-58 HRC. This discrepancy could be due to many factors, including the furnace used, the atmosphere during the treatment, slight time variations, and varying thicknesses of our machined components. The test setup for the Rockwell Hardness Testing can be seen below.

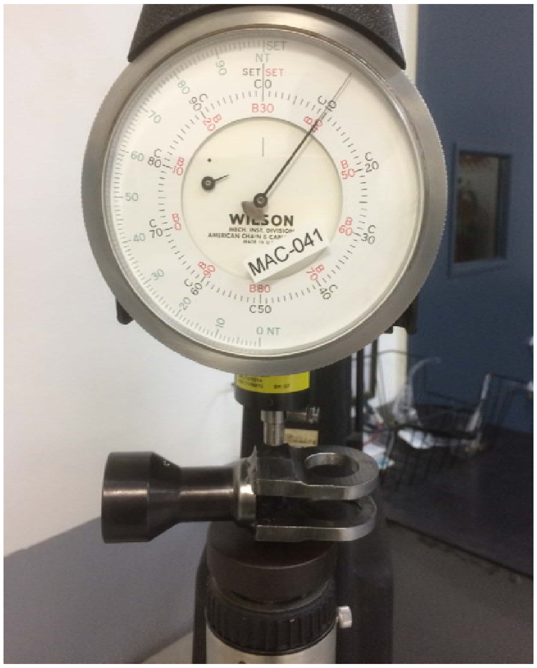


Figure 35 - Rockwell Hardness (HRC) Before Heat Treatment

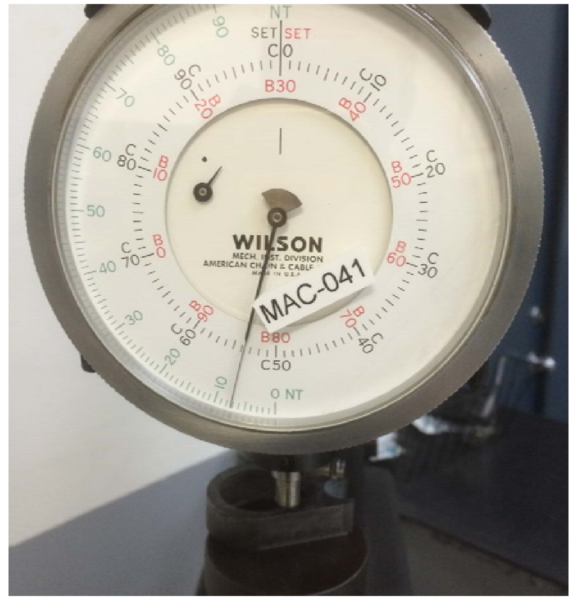


Figure 36 - Rockwell Hardness (HRC) After Heat Treatment

Final Product

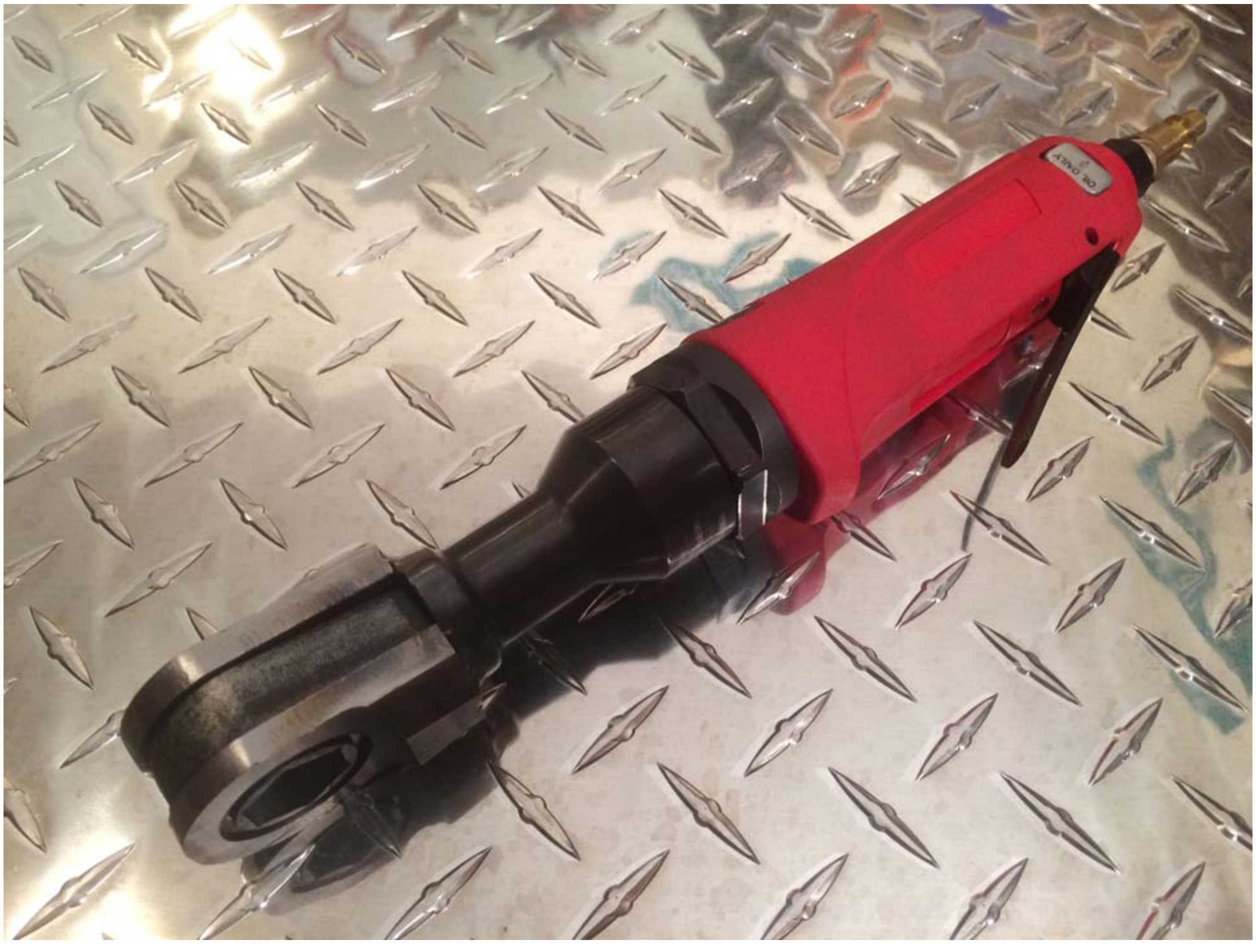


Figure 37 - Final Assembly

Figure 38 - Final Assembly, Ratchet Head Components

Figure 39 - Final Assembly, Top View

Conclusion

The successful completion of this project was a warm welcome to the team after many hours of strategic planning, conceptualization, and methodical manual labor was put into the production of this design. The initial goals of this project were to increase the output of the torque to a given fastener, increase the rotational speed of the tool, and increase user safety via a unique impact mechanism which momentarily disengages the turbine shaft to the final output shaft of the ratchet. Standard pneumatic ratchets average about 45-50 ft-lbf of torque, while the Panther Pneumatics Pass-Thru Impact Wrench is capable of producing 58 ft-lbf of torque. Standard ratchets also feature rotational speeds of about 150 RPM's while the Panther Ratchet is nearly triple that at almost 400 RPM! This is extremely significant in the overall efficiency of this tool in terms of energy consumption as well as time required to complete a given task. All procedures have been completed and verified through scientific methods and verified mathematically, both analytically and in software.

Further development of this tool could be made in a multitude of different areas. The first and foremost possible improvement for this tool would be to manufacture it using CNC machinery. This will prove to increase the tolerances set forth by the Panther Pneumatics Engineering Team, thus producing a far superior tool. Further optimization could be made in different components untouched by our team, such as the air turbine and impact mechanism. Both can be manipulated and optimized to produce an even better design.

Maintenance Program

The newly designed ratchet has proven to be reliable through various experiments. The tool was tested for torque and rotational speed and performed well under laborious treatment. Apart from the present functionality of the tool, it is recommended that the user takes good care of it, potentially increasing the life expectancy by years.

In order to maintain a reliable and sustainable ratchet, one should consider the following suggestions that are certain to increase the lifespan of the tool:

- Acquire a compressed air filter or regulator. This will ensure there are no contaminates in the compressed air used to power the tool.
- Maintain an operating pressure of 90 psi and below, its maximum allowable capacity. Attempting to exceed the permissible pressure may result in overheating. This will greatly compromise the integrity of the tool. (9)
- Keep tool lubricated daily, particularly after use. A light weight air tool oil is recommended. This oil (WD-40 is acceptable) will prevent any condensation from the air source onto the tool from coming in direct contact with the metal.

Risk Assessment

When in the workplace or at home, it is imperative that any risks that might cause harm to an individual be identified and eliminated. Handling power tools and large equipment requires a person(s) with experience or a supervisor carefully examining the equipment in use.

When designing this tool, steps were taken to warrant the user the highest level of safety. The impact mechanism inside the ratchet ensures the tool will refrain from continuing to spin if the torque delivered by the ratchet exceeds the fastener's torque. This mechanism will greatly decrease the risks the user takes from operating the tool. These risks include, but are not limited to, smashed knuckles, cute, and bruises. A 4 step risk assessment plan was created to inform the user of the recommended precautions taken to minimize risk before and after operating the tool:

1. Evaluate any surrounding hazards → Ensure that any obstacles that potentially disrupt the work area are removed.
2. Wear the proper PPE (Personal Protective Equipment) → There are many instances when working with pneumatic tools and require the user to wear protective equipment. Safety glasses should be worn when working in confined areas, such as under a car. Leaks, rust, and other foreign may contact the user's eyes if not properly protected.
3. Do not attempt to exceed the limits of the tool → If, for instance, the user attempts to use more air pressure than allowed by the ratchet, the components of the tool will be exposed to premature wear, potentially causing permanent damage to the tool. If the tool malfunctions, the user may also be put at risk.
4. Take proper physical care of the tool after each use → This includes, but is not limited to, lubricating the tool and storing it in a safe and dry environment, keeping it unexposed to the surrounding elements. Following this step will also help the user avoid being injured.

Cost Analysis

In addition to the cost of materials presented, the price per hour of work that each engineer puts in this project is included. During the year that the project took place approximately three hundred hours split between the three members were devoted. These hours are divided into research, design, prototyping, manufacturing, and miscellaneous. During research things like applications, materials and processes are taken into consideration. During design the hours are mostly the result of SolidWorks modeling and simulations combined with planning of other sources. During prototyping, printing, and testing of the design are included. Manufacturing is a component by itself and, finally, miscellaneous includes meeting times, presentations, design of posters, and preparation of reports.

Category	Description	Unit Cost	Quantity	Total Cost
Design	Impact Wrench	$100	1	$100
Design	Pass-Thru Socket	$40	1	$40
Design	Air Ratchet	$70	1	$70
Design				**$210**
Prototyping	ABS Plastic 1kg.	$30	2	$60
Prototyping	3D Printer Use	$0	2	$0
Prototyping				**$60**
Manufacturing	Shock Resistant S7 Tool Steel	$232	1	$232
Manufacturing	Machine Tooling	$141	1	$141
Manufacturing	Miscellaneous Hardware	$20	1	$20
Manufacturing	Manufacturing Facility Electricity	$0	450	$32
Manufacturing				**$425**
Hours	Research	$0	50	$0
Hours	Design	$0	70	$0
Hours	Prototyping	$0	50	$0
Hours	Manufacturing	$0	80	$0
Hours	Miscellaneous	$0	40	$0
Total Hours		$22	290	$6,380
Total Cost of Project				$7,075
Total Cost of Materials				**$695**

Table 8 - Cost Analysis

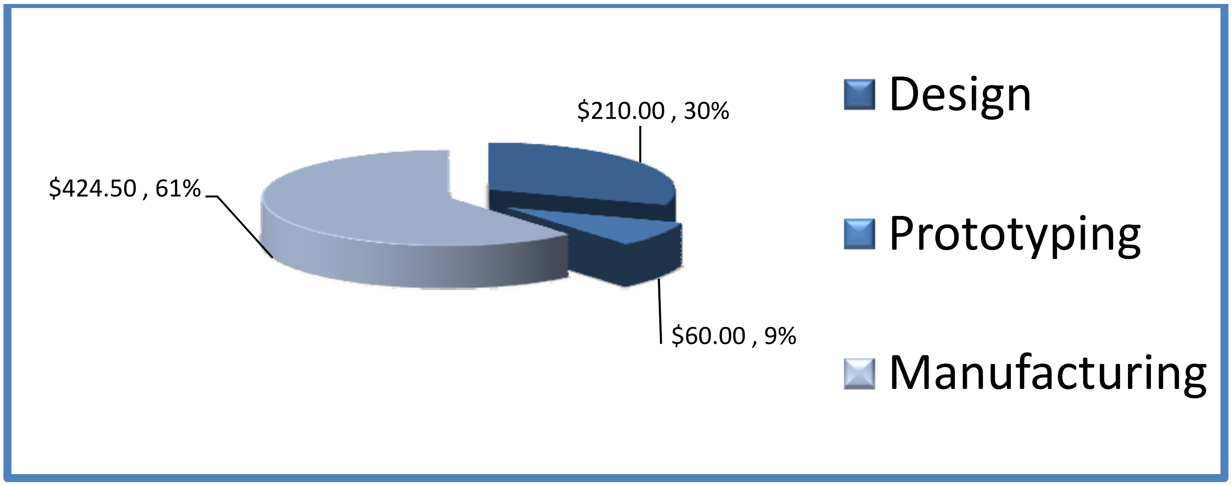


Figure 40 - Cost Analysis

Project Management

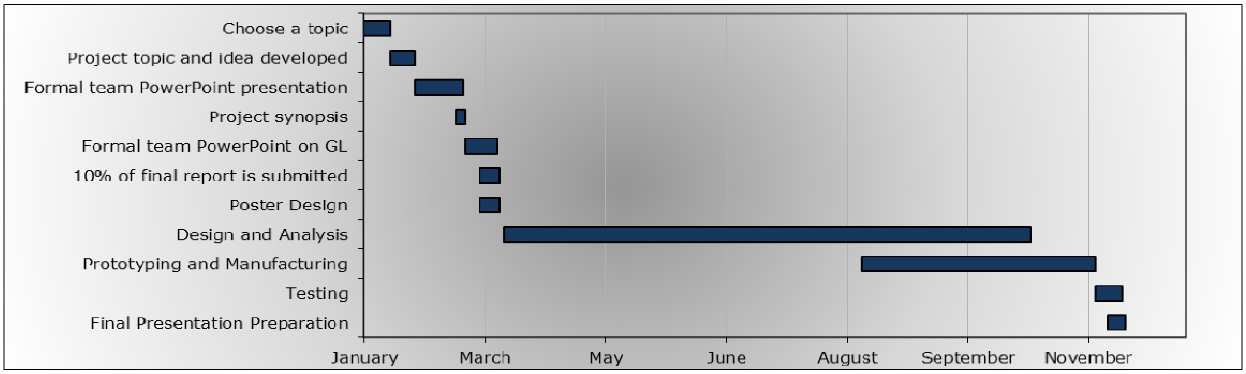


Figure 41 - Timeline

Event / Name	Start	End	Length
Choose a topic	1/21/2014	2/1/2014	11
Project topic and idea developed	2/1/2014	2/11/2014	10
Formal team PowerPoint presentation	2/11/2014	3/3/2014	20
Project synopsis	2/28/2014	3/4/2014	4
Formal team PowerPoint on GL	3/4/2014	3/17/2014	13
10% of final report is submitted	3/10/2014	3/18/2014	8
Poster Design	3/10/2014	3/18/2014	8
Design and Analysis	3/20/2014	10/24/2014	218
Prototyping and Manufacturing	8/15/2014	11/20/2014	97
Testing	11/20/2014	12/1/2014	11
Final Presentation Preparation	11/25/2014	12/2/2014	7

Table 9 - Timeline

In the above timeline, the time management for the project is presented. Initially, during the first four months of the project, most of the basis and fundamentals necessary to give rise to a new tool was achieved. The literature survey has provided research that extended throughout the entire year.

During the Literature survey stage, all three members involved had tasks to research as many different sources as possible and familiarize themselves with the proposed goals for this project. Following the completion of the literature survey, which took place in March, the design research and the initial design took place. During these stages, the entire group held the same responsibilities in order to keep all members on the team on the same pace with the newly acquired information and ideas for a design.

By summer, when the first semester was over, more tasks were required to be completed at once and therefore the need to divide tasks became more urgent. With an initial design completed, the next steps were prototyping, manufacturing and testing. Those tasks were divided as follows: Ryan Lucia was responsible for prototyping and testing while Milton Ceotto and Felipe de la Cruz were responsible for the manufacturing of the tool. This extended throughout the entire summer and most of the fall semester. During the end of the fall semester we established a final design including modifications made after testing and evaluation to conclude this project. By November, the final design had been manufactured, assembled and tested with success and met the initial goals of the project.

Things We Learned/Life Long Learning

There have been many new experiences for each team member throughout this project that will serve to benefit our careers as professional engineers in a forward-moving society. The first and most important experience was the team member interactions and how everyone functioned. The only way great feats of engineering are accomplished is through the seamless collaborations of every team member and their contributions to the task at hand.

Conformance to ethical standards is another priceless quality to any professional in the work place, and any person as far as that goes. Manufacturing a tool that increases user safety, and ensures the continued well-being of those using the equipment and those around is of utmost importance. Failing to omit minor details to attention could result in just the opposite effect, conscious of the engineer or not, this is and act of ethical malpractice.

During the design and manufacturing phase of this project we ran across many obstacles and were forced to re-design. This shows the importance of designing for production, aiding in the ease of manufacturing. An example of this is our revision of the yoke/pawl mating surface where we changed a complex arc to two straight lines, drastically reducing machining time and enabling us to produce these components using common manual machinery. Each team member also learned a great deal during the manufacturing process about tools, equipment, materials, and how they all interact with each other. We also learned the benefits of creating proper engineering drawings, which may be sent out to outside vendors for machining. This includes proper dimensioning and tolerancing, and what to designate with different values. These skills are essential for any engineer to complete his/her job effectively.

Through the design, manufacturing, and testing procedures carried out, the team received working experience with multiple common engineering related tools used in the industry. Starting with metrology equipment, calipers and micrometers are essentially a prosthetic for design engineers in the field. Test equipment such as the Rockwell Hardness Tester and Digital Tachometer are also commonly applicable in an engineer's workplace. Along with the instrumentation, we experienced a transformation in the metallurgical composition of the components that we manufactured. With all of these examples and even more that go unmentioned, this project has harvested knowledge and practical experience in each of the team members involved and will ensure an even further developed career experience in the future.

Standards Used in the Project

Component Level Standards

For design of pneumatic ratchets and wrenches, the goal is to optimize rotational speed and torque output. In order to achieve this, a list of standards should be followed including materials used, heat treatment preparation, and testing methods are needed to solve for factors such as stress and failure.

- Materials:
    - Hub, Head, Yoke, Pawl
        - ASTM S7 Tool Steel
            - Shock Resistant
            - High Compression Strength
            - Deformation Resistant
    - Bushing
        - SAE 841 Sintered Bronze
            - Self-lubricating
            - Oil-impregnated
    - Internal Retaining Ring
        - Carbon Spring Steel
    - Pawl Spring
        - Carbon Spring Steel
- Heat Treating
    - Preheat Temperature
        - 1350-1400 °F
    - Austentitize Temperature
        - 1725-1750 °F
    - Hold Time

        - 15-45 minutes
    - Quench in Air
    - Temper Temperature
        - 350-600 °F
    - Typical Hardness HRC
        - 54-58
- ASME Code of Ethics of Engineers
    - The Fundamental Canons
        - 1. Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.
        - 8. Engineers shall consider environmental impact and sustainable development in the performance of their professional duties. (9)

Special Thanks and Recognition

We would like to thank those who have helped our engineering team throughout the past two semesters of this project:

- Dr. Benjamin Boesl, PhD and Professor at Florida International University, Mechanical Engineering Department

  Dr. Boesl has guided us through the progress of our project since the first day of concept planning. His knowledge in material sciences and engineering principles has helped us in designing, manufacturing and testing our pneumatic ratchet. His teachings in lecture have also helped the progress of our design creation and allowed us to create a far superior product than without it!

- Mr. Rick Zicarelli, Director of the Engineering Manufacturing Center at Florida International University

  Mr. Z has been more than patient with our team through the countless times we visited his office to sign out tooling during the manufacturing process of our project. He has also given us many tricks of the trade and alternative methods of machining through his wealth of knowledge and experience.

- The engineering and manufacturing departments at Skeletal Dynamics, LLC

  Our friends Dennis, Dan, and Vo have given their time, efforts, and facilities/equipment to assist us with the heat treating process of our manufactured components.

- Mr. Osvaldo Fernandez, Graduating Mechanical Engineering Student, Florida International University

  Ozzie graciously provided our team assistance with his TIG welding skills, a vital step in the manufacturing process of this project.

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Appendix

Technical Datasheet

CARPENTER®

Unit Display :

Carpenter S7 Alloy Tool Steel

Print Now

Email Datasheet

Add to My Materials

Identification

AISI Number

- S7

Type Analysis

Single figures are nominal except where noted.

Carbon	0.50 %	**Manganese**	0.70 %
Silicon	0.30 %	**Chromium**	3.25 %
Molybdenum	1.40 %	**Iron**	Balance

General Information

Description

Carpenter S7 is a general purpose air hardening tool steel having high impact and shock resistance. It has good resistance to softening at moderately high temperatures. This combination of properties makes it suitable for many hot-work and cold-work applications.

It is available as a DeCarb-Free product. DCF bars have been cold finished in the mill eliminating the need for bar bark removal.

Both Carpenter S7 and Bearcat, a trademark of Bethlehem Steel, Corp., have the same AISI tool steel designation...S7.

Properties	
Physical Properties	
Specific Gravity	
--	7.83
Density	
--	0.2830 lb/in³
Mean CTE	
77 to 392°F	6.99 x 10^{-6} in/in/°F
77 to 572°F	7.22 x 10^{-6} in/in/°F
77 to 752°F	7.41 x 10^{-6} in/in/°F
77 to 932°F	7.60 x 10^{-6} in/in/°F
77 to 1112°F	7.78 x 10^{-6} in/in/°F
77 to 1292°F	7.93 x 10^{-6} in/in/°F

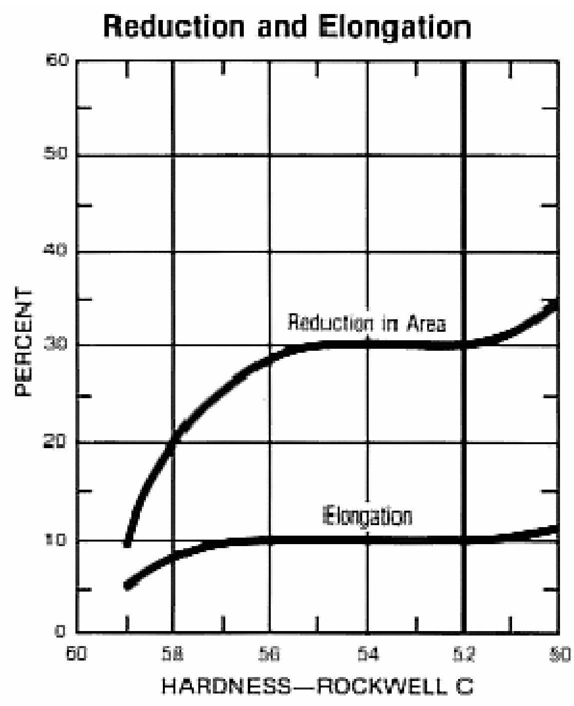
Mean Coefficient of Thermal Expansion

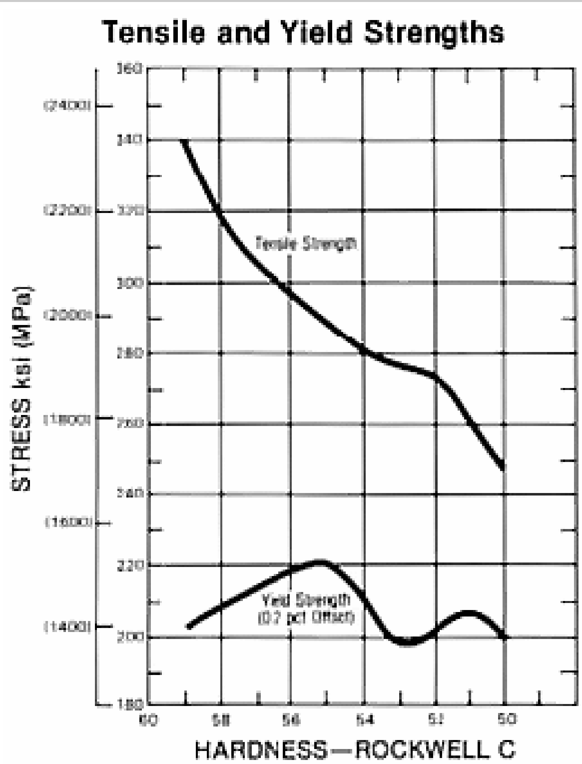
The following figures are the average coefficients between room temperature and the specified elevated temperature. They represent material in the annealed condition and the dimensions are in in/in/° temperature.

Temperature Range		Average Coefficient	
°F	°C	10^{-6}/°F	10^{-6}/°C
77/392	25/200	6.99	12.59
77/572	25/300	7.22	12.99
77/752	25/400	7.41	13.33
77/932	25/500	7.60	13.68
77/1112	25/600	7.78	14.01
77/1292	25/700	7.93	14.27

Critical Temperature (AC1)	
--	1445 °F

Typical Mechanical Properties





Heat Treatment

Decarburization

S7 alloy, like all high carbon tool steels is subject to decarburization during thermal processing and precautions must be taken to control this condition.

Modern furnaces are available which provide environments designed to minimize decarburization.

Annealing

For annealing, the steel should either be placed in a controlled-atmosphere furnace or packed in a suitable container, using a neutral packing compound. Heat uniformly to 1500/1550°F (816/843°C) and cool very slowly in the furnace at a rate of not more than 20°F per hour to a temperature below 1000°F (538°C), then allow to cool naturally. This will produce a maximum hardness of Brinell 223.

Hardening

Tools made of Carpenter S7 tool steel may be hardened by placing them in the furnace maintained at a temperature of 1700/1750°F (927/954°C). Let the tools heat naturally to the furnace temperature, soak for 20 minutes plus 5 minutes per inch (25.4 mm) of maximum thickness and quench.

Sections up to 2 ½" (64.5 mm) thick may be cooled in air. Heavier sections, i.e., with section thickness larger than 2 ½", should be oil quenched to 150°F (66°C). Temper as quickly as possible after the hardening operation.

Control of decarburization can be accomplished by using any one of the several modern heat-treating furnaces designed for this purpose. If endothermic atmospheres are used, a dew point between 40/50°F (+4/10°C) is suggested.

In older type manually operated exothermic atmosphere furnaces, an oxidizing atmosphere is required. Excess oxygen of about 4 to 6% is preferred.

If pack hardening allow 30 minutes per inch (25.4 mm) of packed thickness to ensure that the entire pack is uniformly at the hardening temperature.

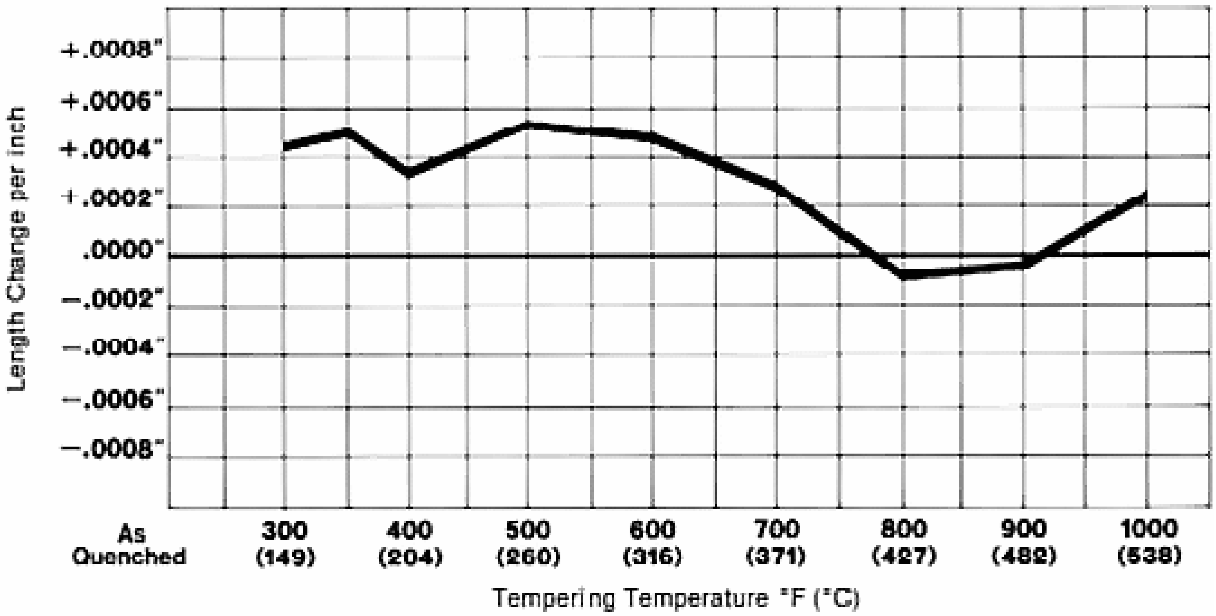
Deformation (Size Change) in Hardening

The hyperlink entitled "Size Change in Hardening" shows typical length changes of this steel when it has been properly hardened and tempered. Please note that the length change information is presented in inches per inch of original length. The chart shows that this alloy can be expected to expand slightly over most of it tempering range.

It should be remembered that tool steels hold size best when quenched from the proper hardening temperature. If overheated, they tend to show shrinkage after tempering. The temperatures used to develop this data are shown on the accompanying chart.

SIZE CHANGE

Air Cooled from 1725°F (940°C). Tempered 1 Hour at Heat 1" (25.4mm) Rd.



Stress Relieving

To relieve machining stresses for greater accuracy in hardening - first rough machine, then anneal below the critical at 1200/1250°F (649/677°C) a minimum of one hour at temperature and cool slowly, then finish machine.

Tempering

The best combination of hardness and toughness is obtained by tempering at about 400°F (204°C). This tempering temperature is therefore suggested for cold-work applications. Tempering at 900/1000°F (482/538°C) is usually desirable for hot-work applications.

Effect of Tempering Temperature on Hardness

Air Cooled from 1725°F (940°C), (Temper 1 Hour at Temperature)

Tempering Temperature		Rockwell C Hardness
°F	°C	
As hardened		59/61
300	149	57/59
400	204	55/57
500	260	53/55
600	316	52/54
700	371	51/53
800	427	51/53
900	482	51/53
1000	538	50/52
1100	593	43/48
1200	649	37/40

Workability

Forging

Heat uniformly and forge from a temperature in the range of 1950/2050°F (1066/1121°C). Do not continue forging below 1700°F (927°C) but reheat as often as necessary. Small, simple forgings can be cooled slowly in dry lime, ashes or other insulating material. The best practice for large forgings is to place them in a furnace heated to about 1400°F (760°C), soak uniformly at this heat, then shut off the heat and let the forgings cool in the furnace. This is not an anneal, and after the forging is cold, it must be properly annealed.

Machinability

The machinability of Carpenter S7 alloy may be rated at about 75/80% of a 1% carbon tool steel, or about 50/55% of B1112. Approximate turning speeds 85/90 surface feet per minute (0.48/0.56 m/s) are suggested when using high-speed cutting tools.

Other Information

Applicable Specifications

- ASTM A681
- QQ-T-570

Forms Manufactured

- Bar-Rounds

Technical Articles

- A Three-Point Program for Improving the Performance of Cold Work Tooling
- Coated Tools of High Strength, High Tough Steel Produce up to 100 Times More Powder Metal Parts
- The ABC's of Alloy Selection, Heat Treating and Maintaining Cold Work Tooling

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Edition Date: 07/01/1986