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Efficient and Easily-Integrated Energy Converter

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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 Dillon Watring, Felipe Gomez, and Ruth Quant 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, computer programs, 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

This report addresses the design, manufacturing, and testing process of an energy converter that converts a linear force into electrical power. The prototype created is to provide an alternate solution to the energy crisis. The energy converting unit is built as a table top design to allow it to be easily integrated into any applicable situation and easily modified if needed. The main application for the proposed design is to be deployed into several environments. The design of the energy converting unit was between a pneumatic energy converting system and a hydraulic energy converting system. The advantages and disadvantages of both are discussed and the final proposed design was decided off of these factors. Simulations were completed to ensure the safety of the components of the system. Experiments were performed for proof of concept and the prototype proved to effectively convert energy. Efficiency tests were performed to try and improve this model for commercial application.

INTRODUCTION

Problem Statement

Efficiency and accessibility have both been limiting factors in the implementation of hydraulic or pneumatic energy converters. Hydraulic energy converting systems are a system which uses a moving liquid under pressure in order to create electricity. Pneumatic energy converting systems are pretty much the same as a hydraulic energy converting system except that instead of a liquid, air is used. The problem is there is no one solution to provide an efficient and reliable form of energy conversion. Hydraulic energy converters are usually broken down into four separate parts. These parts are the hydraulic piston, the directional control valve, the hydraulic turbine, and the generator. These parts are typically individual components and are connected through a hydraulic line. Similarly, pneumatic energy converters can also be broken down into four parts; the piston, valves, a turbine or motor, and a generator. Creating a more reliable and efficient energy converter would allow access to a virtually untapped source of energy. Also, creating a way that the proposed energy converting unit could be a single unit that is be easily integrated will allow for use by a larger population and in new applications.

Motivation

There is a pending energy crisis that the entire world is facing due to the world's dependence on fossil fuels. With the production of oil not significantly increasing and the ever increasing demand for oil, there will be a shortage of supply. The discrepancy of the needed energy supply and the produced energy supply must be made up by other sources of energy. Solar and wind energy will undoubtedly make up a large percentage of this required energy, however there is still a virtually untapped source. Hydraulic energy converters will allow for this relatively unused source of energy to be utilized in previously unseen ways. The motivation behind creating an efficient and more importantly an easily implemented design for a hydraulic or pneumatic energy converter is to allow for the unused sources of energy to be accessed. This energy converter will, ideally, be able to be implemented into locations that traditional sources of energy could not be used. It will be inexpensive, efficient, and reliable which will allow it to be used virtually in any environment. Not only will it be cheap and efficient but it will have a very low, if any at all, environmental impact. The idea of allowing the unit to be a single component that would be installed and then would be able to receive electrical power from, will allow access to a larger amount of the global population and the ease of use will provide the keys to its success.

Literature Survey

While performing research on the topic of hydraulic energy converters, sufficient information was found to formulate a basis for comparison. With the found information, a standard for efficiency can be determined. Information on hydraulic energy converters were found and will be discussed in this section. The earliest found documentation on hydraulic energy converters is from 1979. This report is from the University of Massachusetts-Amherst and is about the use of hydraulic energy converters small wind turbine applications. In this article, the basis for hydraulic energy converters is discussed. The origination of the idea for the hydraulic energy converter came from William Froude's idea of the dynamometer. William Froude was an engineer from England that lived during the 19th century. He became known for his work in the field of fluid mechanics. His dynamometer was an instrument he created that could measure forces or torques. He came up with this design while working on ships and used this technology to actually create improved hulls in order to reduce drag and increase the performance [13]. Around 1877 is when Froude became aware of the potential for the mechanical displacement in his machine. He filled the cavities of his machine with a fluid and restrained the fluids by tubes. This would create a pressure which in turn would create a velocity. This velocity is what created the basis of the hydraulic energy converter. That fluid velocity can be run across a turbine and that turbine would in response create electrical power.

There were also a few more recent documents about hydraulic energy converters. However, interestingly enough the design has not changed much from the original ideas of Froude. The current literature is more about the actual efficiency of different hydraulic energy converters rather than their specific design. The components of a hydraulic energy converter do need to be discussed.

One key component of the entire hydraulic energy converter system is the hydraulic piston. Most hydraulic pistons are used in essentially the reverse of what this project wishes to accomplish. So essentially, the hydraulic piston is what is driven by a motor in order to apply a force in a certain location. This typical application is used in construction, manufacturing, and other applications. It was very difficult to find related information on a hydraulic piston for the application of a hydraulic energy converter; however, the detailed description of the hydraulic piston will be detailed. The first main part is the cylinder barrel. This is created from a single tube. The size of this barrel is determined using hoop stresses and optimized accordingly. There is also a cap that is placed on one end of the barrel and is usually welded into place. The next piece is called the head which is essentially the same as the cap but it has the piston assembly integrated. This head cap is usually threaded onto the barrel for ease of access to the piston assembly. The piston assembly consists of two main components; the piston and the piston rod.

The piston is the part that creates the different pressures inside the barrel on either side of the piston. This pressure difference is what typically causes the piston to apply the force but in the case for the hydraulic energy converter it is the force that drives the hydraulic motion across the turbine. The last part of the hydraulic piston and piston assembly is the piston rod. This is the piece that the piston itself is connected to and the plate, the area that the force would be applied, is connected.

Another important aspect of the hydraulic energy converter unit is the directional control valve. What this does is controls the direction of the flow so that the hydraulic flow is always going one way across the turbine. This is important because the efficiency would be drastically reduced if the hydraulic flow across the turbine was forced to go in two different directions. This would force the turbine to slow down before actually switching directions, reducing the efficiency. This is why it is essentially to add a directional control valve into the HEC unit. Upon research of the directional control valves, it was found that the majority of directional control valves are actually manually operated valves. These valves either restrict or allow the flow based on the pulling of a lever. Typically, the manual hydraulic valves run anywhere from $200 to $700. The valves that will be more useful for this project are the directional control valves with a solenoid. These include an electromechanical solenoid which allows the restriction or the flow of the hydraulic fluid across a hydraulic valve. These hydraulic valves were difficult to find an abundance of research documentation but the prices and overall schematics were able to be found. The average prices for a hydraulic solenoid valve were around $700 to $900. These valves are quite expensive but some alternatives were found that may be of use in the HEC unit. Upon further research, it was found that there are a few items that actually have solenoid valves inside of them. The main one is a washing machine that uses a solenoid flow valve to cut off and control the flow of water into the drum. These valves may be of use if some prior testing is done to ensure the valve withstands the pressures that will be created in the HEC unit. Another typical use for a directional control valve is in sprinkler systems. They typically use the control valve in order to allow the flow of water in order to water the lawn. This poses the same potential and problems as the washing machine valves. Overall, the directional control valve will be an important aspect of this design and will be necessary to ensure the highest efficiency possible.

The next main component that a literary survey was performed on was the hydraulic turbine. The hydraulic turbine is the most essential component of the entire system. This is because without a high performing turbine the efficiency will be extremely poor. A hydraulic turbine in its simplest explanation is a mechanical device that uses rotation in order to transfer the kinetic energy of a fluid flow into an electrical energy[6]. There are multiple different classifications of turbines that were researched in order to determine the optimal hydraulic turbine. The first type of turbine classification is an impulse turbine. The impulse turbine works in the way its name suggests. It uses the impulse of the moving fluid in order to extract the energy

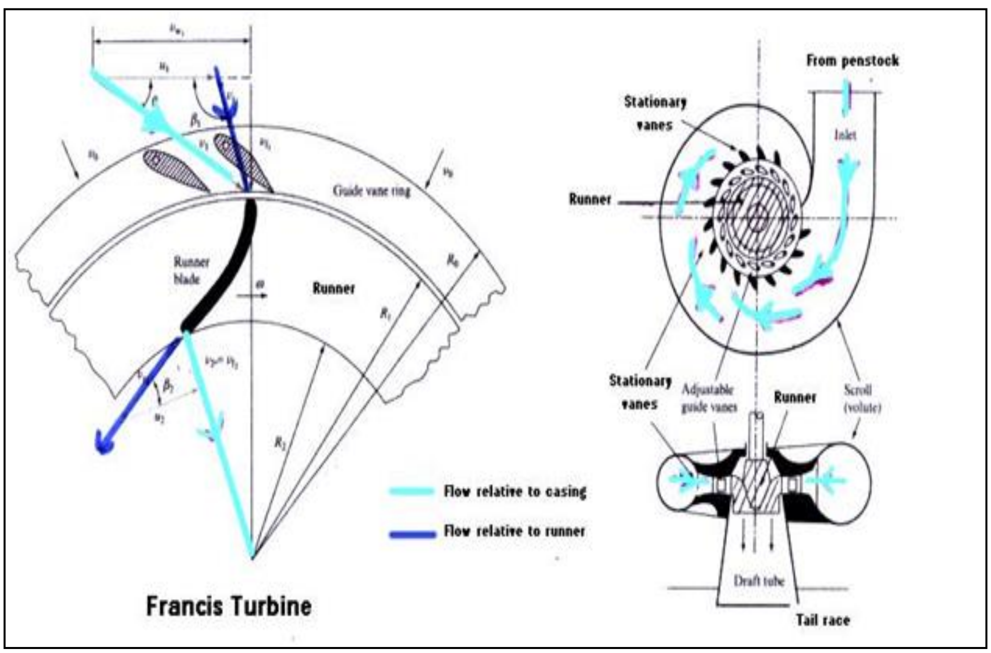


Figure 1. Francis Turbine [14]

by rotating the turbine caused by a tangential force created on the turbine[1]. The ideal design of this type of turbine is to have a very high inlet fluid velocity and a very low outlet velocity in order to extract as much possible energy from the moving fluid. For a hydraulic energy converter system, this turbine will be an ineffective solution. That leaves us with the other main type of turbine which is the reaction turbine. A reaction turbine uses the kinetic energy from the moving fluid and also the pressure stored within the system. The rotation in this turbine is due to the impulse reaction as well as the drop in pressure. The basics of the Francis turbine flow can be found in Figure 1. The fluid flows into the turbine horizontally and hits the blades and causes a pressure drop across the turbine. The blades are specially designed as a curved blade in order to allow the fluid to drop in pressure after the initial impulse of the fluid. This in turn creates even more rotational motion in the system. This type of turbine is typically operates completely submerged in water. The Francis turbine is considered a mixed flow turbine. What this means is that the fluid enters the turbine at an outer periphery and exits the turbine axially.

Another type of reaction turbine is the Kaplan turbine. Kaplan turbines are usually referred to as a propeller turbine because of the similarity to look of a ship propeller. The Kaplan turbine uses essentially the same method for creating electrical power as the Francis turbine does. It allows the fluid to pass across the turbine which creates an impulse and a pressure drop. A normal Kaplan turbine can be seen in Figure 2. This is very similar to the Francis turbine in appearance but actually works different. In the Kaplan turbine, the fluid actually crosses the blades themselves in an axial

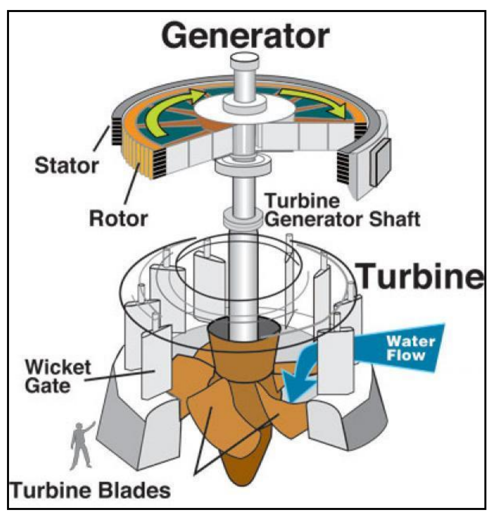


Figure 2. Kaplan Turbine [6]

flow. This means that the water may be coming in perpendicular to the turbine but will actually be axially by the time it hits the blades. This is different from the Francis turbine in that the Francis turbines the water hits the blades from a tangential flow. As you can see from Figure 2, Kaplan turbines are typically much larger and usually found in dams with a low velocity flow. However, a key point to the Kaplan turbines is they run most efficient at a low head [9].

The last component that will be a part of the HEC unit is the electric generator. An electric generator converts the rotational kinetic energy from the turbine into useable electrical energy. There are two main types of electrical generator that could be used in this project. There is a direct current generator and an alternating current generator. There is one direct current generator that will be discussed and that is the Homopolar generator. For alternating currents, the induction generator and the variable speed constant frequency generators.

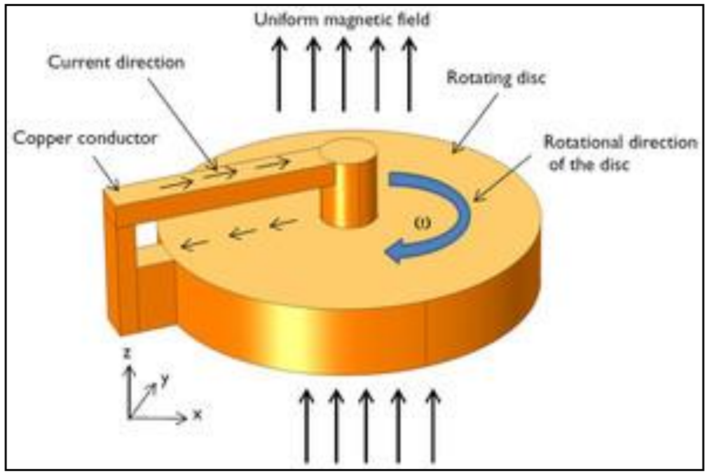


Figure 3. Homopolar Generator [8]

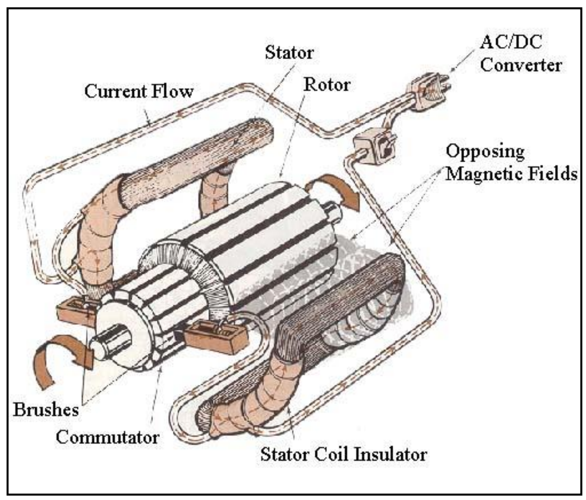


Figure 4. Induction Generator [7]

The direct current motor that was researched is called the Homopolar generator. An example of this type of motor, or more specifically the mechanism behind it, can be seen in Figure 3. This motor creates voltage based off of electrical polarity that occurs on the disc. This disc is placed perpendicular to a static magnetic field; this means the magnetic field does not change. The rotation on the field creates an electrical polarity on from the end of the disk to the center and creates a voltage [5]. The Homopolar generator is some times more commonly known as a Faraday Disc. These generators are unique because they produce relatively low voltage but have a potential for a high current.

The first type of alternating current generator is the induction generator. This generator creates electricity based off of induction. The mechanical rotation produces a current caused by an induction through a magnetic field. A typical induction generator can be seen in Figure 4. Induction generators work by rotating the brushes faster than the generators synchronous speed [11]. Above this rotational speed, the induction generator produces an electrical current. This current will directly be an alternating current. These types of induction generators are commonly used in wind turbines to produce electricity. Sometimes they are also used in hydro applications. Both of these applications, the induction generators are shown to have a decent efficiency.

There was also information that is related to the wave energy aspect of the hydraulic energy converter. These are known as hydraulic power take off systems, which are used specifically for wave energy conversions. Essentially how this is performed, a buoy is hooked up to a hydraulic power take off system. The oscillating motion of the waves allow for the buoy to rise and fall which creates a mechanical motion [2]. The mechanical motion is then converted into electrical power by the way of the hydraulic power take off system. A simple diagram of how this system works can be found in Figure 5. Although there are many patents for wave energy converters there are very few

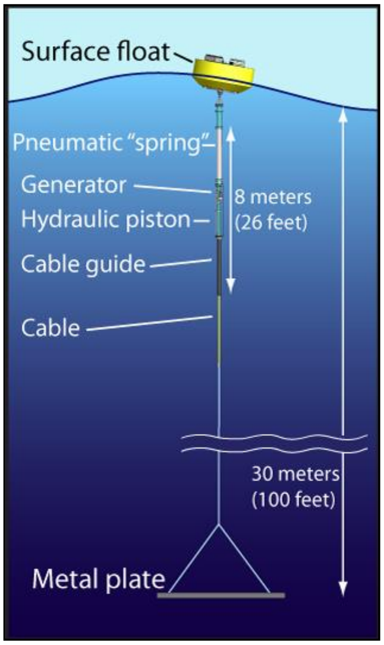


Figure 5. Wave Energy Converter [4]

that actually have been tested on a full scale. For the case which was found in the paper from Oregon State University, they use a hydraulic circuit connected to a generator, which actually converts the motion of the waves oscillating into electrical power [3].

An alternate option of hydraulics is to use air pressure. There are five basic elements of an air system also known as a pneumatic system, the air compressor, check valve, accumulator directional valve, and an actuator. These elements are similar to that of a fully hydraulic system and the only difference is what fluid is being channeled through the system to generate power at the end. In the case of a pneumatic system the fluid is air and can be compressed whereas a hydraulic system uses a fluid that cannot be compressed after a certain point. For a small energy converting unit, introducing an air compressor may be beneficial. The beauty of air compressors is that they are utilized in environments of all shapes and sizes from major power plants to small handheld items. An air compressor is a pump that compresses air to above ambient pressure to flow in a pneumatic system; it would be the equivalent of a hydraulic piston in a hydraulic system. The check valve is vital to the proper working of both a hydraulic and pneumatic system to control the fluid flow and pressurization. It should be noted that there are several types of valves in both hydraulic and pneumatic systems. There is a vital valve in hydraulic systems called the directional control valve as discussed above in this literature survey. The actuator is what actually converts the energy into another, in this case study it will be to electric power. In the case of both pneumatic and hydraulic this element of the system is the actuator.

As research continues about the similarities between pneumatic and hydraulic systems, as well as exploring other options, there is ways to enhance the operation and make the system more efficient. One way to assist with the efficiency of this is system is to introduce compressed air boosters. Compressed air boosters are low cost and amplify the pressure of the fluid. This addition will allow the system to run at a low pressure and maintain high efficiency. The booster will then be part of the converting unit.

Survey of Related Standards

There were several different industrial standards that were followed within this project. Standards from the American Society for Mechanical Engineers, ASME, were used for this project. The performance test codes, or PTC, were used as a guide for this project. The first one that was used is the PTC 28-2011. This PTC is for Hydraulic Turbines and Pump Turbines Energy Efficiency. It shows the standards for hydraulic and pumps turbines efficiencies that the system has to fall within. The next one that was used was PTC 18-2011 which is for Hydraulic Turbines and Pump Turbines Renewable Energy.

For this project, the standards from the International Organization for Standardization were also used. There were a few International Classification for Standards that were used. The ICS 93.160 for Hydraulic Construction was used. It is a standard for civil engineering that has construction guidelines for the hydraulic system. ICS 27.140 for Hydraulic Energy Engineering was also used when analyzing the turbine and how it will transmit power from the shaft to a power output to an application. Two other standards were used for this project from the International Organization for Standardization. The ISO 50001 is the one that is for Energy Management Standards. The last one that is used is the ICS 23 for Fluid Systems and Components for General Use – Valves. PTC 28-2011 is probably the most important one for this project. This standard outlines the best way to design and manufacture anything having to do with hydraulics. It outlines how to perform and calculate the tests on the hydraulic system which provided initial design constraints to follow. This PTC standard also provides which instruments and materials to use and how to measure and calculate efficiencies for each piece of the system.

These efficiency standards will base the efficiency improvement of the system. Ultimately, the goal of this energy converter is to create an entire system in one housing unit to be easily integrated into several application alternatives to get electrical power. The whole hydraulic system must be self-sufficient despite the application it will be integrated into to generate the electricity.

Discussion

This project will be completed and an energy converting unit will be developed and implemented. The motivation to come up with a way to solve the global energy crisis will drive the success of this project. The world's dependence on fossil fuels has multiple real and measurable negative impacts on the environment. Not only do fossil fuels negatively impact the environment but the demand for energy will quickly surpass the supply of energy. This will create the need for new, renewable, and clean energy sources. Although the solution to the world’s energy crisis cannot be solved by a single technology, this project will provide one part of the solution to the pending global energy crisis.

PROJECT FORMULATION

Overview

As discussed in the introduction, the proposed project will be to create an easily implemented and efficient hydraulic or pneumatic energy converter for the purpose of harnessing energy and using it to generate substantial power that can be stored. For the initial design of the project we will be creating a table top version of the energy converter that can ultimately be scaled up after the final proposed design is tested and proves to be efficient and adequate. The final energy converting unit will be built as a table top version with the intent that with some minor alterations to the design can be made that will allow it to be applied and implemented into a variety of different applications and situations. This unit will be made as an easy to use and an easy to maintain unit. The unit will be design to allow for a wider population to be able to use this system.

Project Objectives

For this project, there are three main areas of focus for what this project is striving to accomplish. The first goal is aimed to achieve is relatively simple. This hydraulic or pneumatic energy converter must be at least as efficient enough to power a small light source. This requirement is something that can be used as proof that the concept of a hydraulic or pneumatic energy converting system will work and can be used to harvest linear forces that would otherwise be wasted. The second important objective that the proposed system must accomplish is that it has to be easily implemented into different situations with little or no alterations to the initial design. This means that the hydraulic energy converter must be able to be adapted easily into a variety of different systems and applications. This design objective is important because in order for this project to be considered successful, it needs to with a very limited number of modifications be able to be adapted into any situation. The last goal for this energy converting unit is for the entire system to be able to be self-sufficient. This means that the entire hydraulic energy converter would not need to be connected to any electrical source. Although this seems like an unimportant goal relative to the previous two, it is just as important because what it means for this project is that it can be applied to areas that do not have access to traditional energy sources. This will allow it to supply energy to areas and regions of the world that do not have easy access to electricity. This will be a very difficult aspect of the energy converting unit to accomplish but can be done.

Design Specifications

This project has a few design specifications that must be followed. The first main specification has to do with the ability to easily implement the energy converter system. This project in its entirety is needed to fit within a cubic space of 3 feet by 3 feet by 3 feet. This allows for the entire system to be implemented into a variety of different applications.

The other main design specification that will be used for this project is that the entire energy system be integrated into a single unit. So instead of there being a separate piston, a valve, a turbine, and lines for the flow, the entire system will be one single component. This unit must remain under 80 pounds of weight. This is important in order to ensure that it will be easily integrated and able to be moved. Having a maximum weight of 80 pounds may limit the size to smaller than 3 feet by 3 feet by 3 feet but this will be acceptable as that dimension is a maximum desired size. This means that if the unit is able to be kept under 80 pounds and smaller than 3x3x3 then the project will meet the design specifications.

Addressing Global Design

One of the main reasons that this project must be easily integrated is in order to easily apply this unit into any environment or local. This unit would be able to be used in any country throughout the world in order to allow access to electrical power where otherwise there would be none. Part of the main goal of this project is to create access to electrical power in any part of the world. The reason that one of the main design goals was to create an integrated systems was so that other cultures and locals would be able to easily install the unit and receive electrical power from the unit. Another aspect of the global design of this energy converting unit is the fact that it will be very simple to operate and maintain. This means that the manual can be easily translated into many different languages in order for it to be used throughout the globe.

Discussion

Overall, this project was developed out of the need to address the growing energy crises that the world is currently facing. There will be many solutions to this energy crises and not just one catch all solution. The energy converting system, whether it be pneumatic or hydraulic, will hopefully be one aspect of the overall drive to create clean and renewable energy sources that can be implemented throughout the entire globe.

DESIGN ALTERNATIVES

Overview of Conceptual Designs Developed

Overall, the multiple different conceptual designs that were developed for this project will be very similar to the others with few variations of different aspects. The project narrowed down to one specific design that was determined to be the best solution for the overall design. One of the main differences between the three designs is the fact that some use hydraulics and some use pneumatics. This is a key to the selection of the final proposed designs. All three design alternatives have essentially the same main components, with a few additions for each specific one. They all will have a piston, some valves, a motor of some sort, and a generator. The valves will differ and the motors will differ.

Design Alternative 1

The first proposed design for this project was discussed briefly in the introduction and the project formulation. The proposed design for the hydraulic energy converter unit will be a single, fully integrated unit. This unit will consist of all the necessary parts of the hydraulic energy converter system. This HEC unit, or hydraulic energy converting unit, will consist of the hydraulic cylinder, the cylinder cap, the plunger, the piston rod, the directional control valve, the case, the case cover, the turbine, the generator, the battery pack, and some cold drawn, annealed seamless low-carbon steel pressure tubing. Steel tubing was chosen over hydraulic hose lines in order to minimize the chances of leaking and to maximize the service life of the parts. All of these parts will be placed within the case that will be a water tight compartment. The turbine, the generator, the hydraulic piston assembly, all the hydraulic tubing, the directional control switch, and the battery are all stored within this case in a specific alignment.

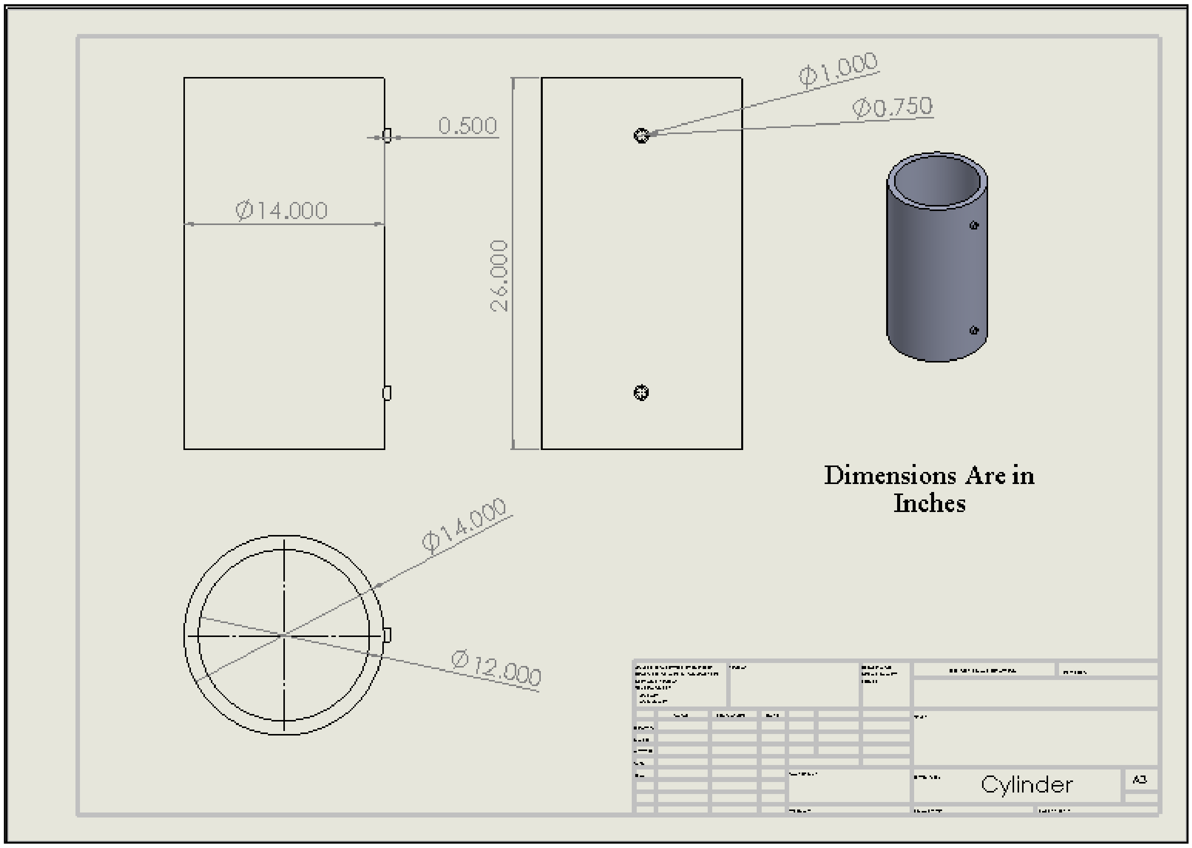


Figure 6. Cylinder SolidWorks Drawing

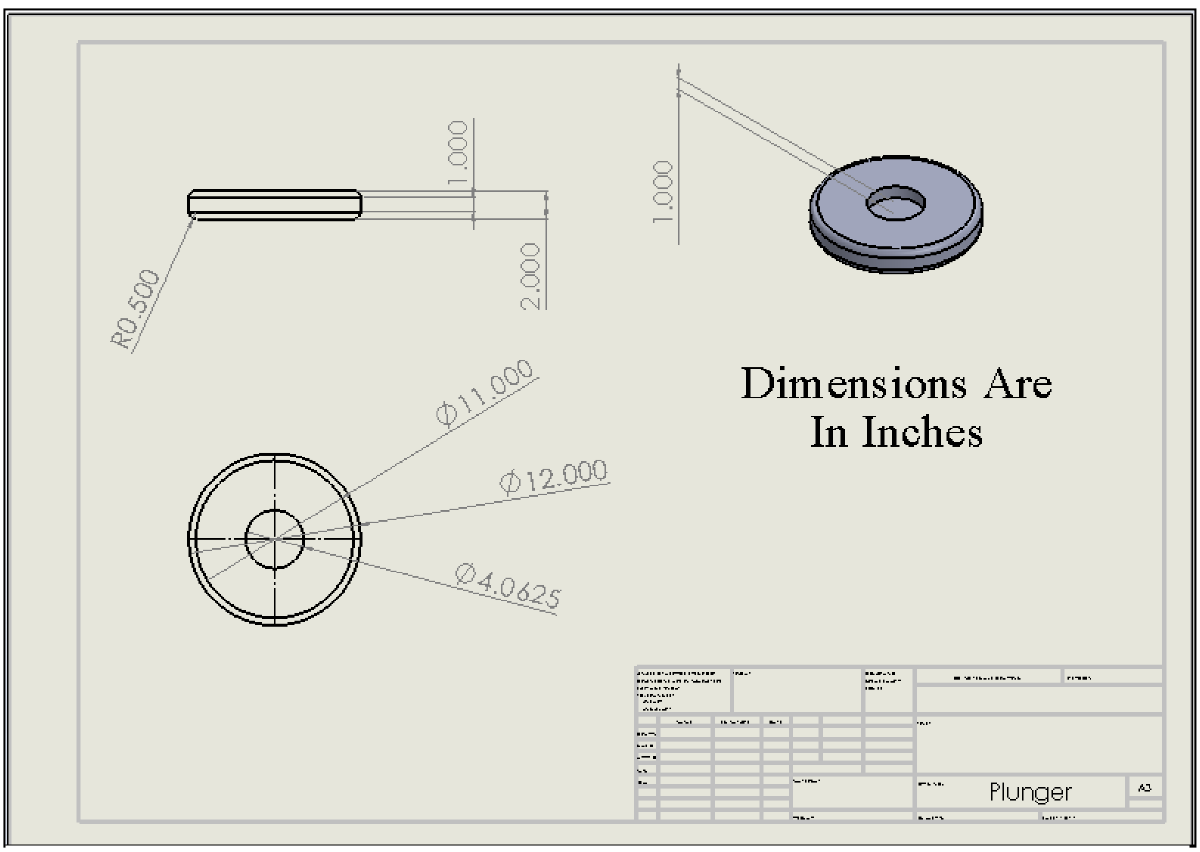


Figure 7. Plunger SolidWorks Drawing

First, the design of the hydraulic cylinder will be discussed. This hydraulic cylinder assembly will be comprised of multiple parts. The first one will be the cylinder. The SolidWorks drawing can be found in Figure 6. The cylinder will be 26 inches tall. The inner diameter will be 12 inches and the outer diameter will be 14 inches. This will allow for the wall's thickness to be one inch thick. The cylinder will include two holes that extend out of the cylinder wall by 0.5 inches and will have a thickness of 0.125 inches. This will be where the hydraulic tubing is attached and then ran into the directional control valve. The first hole will be located 6 inches from the top edge. The second hole will be 6 inches from the bottom ledge. The bottom portion of the cylinder will be an inch thick as well and will be assembled before any other part is attached.

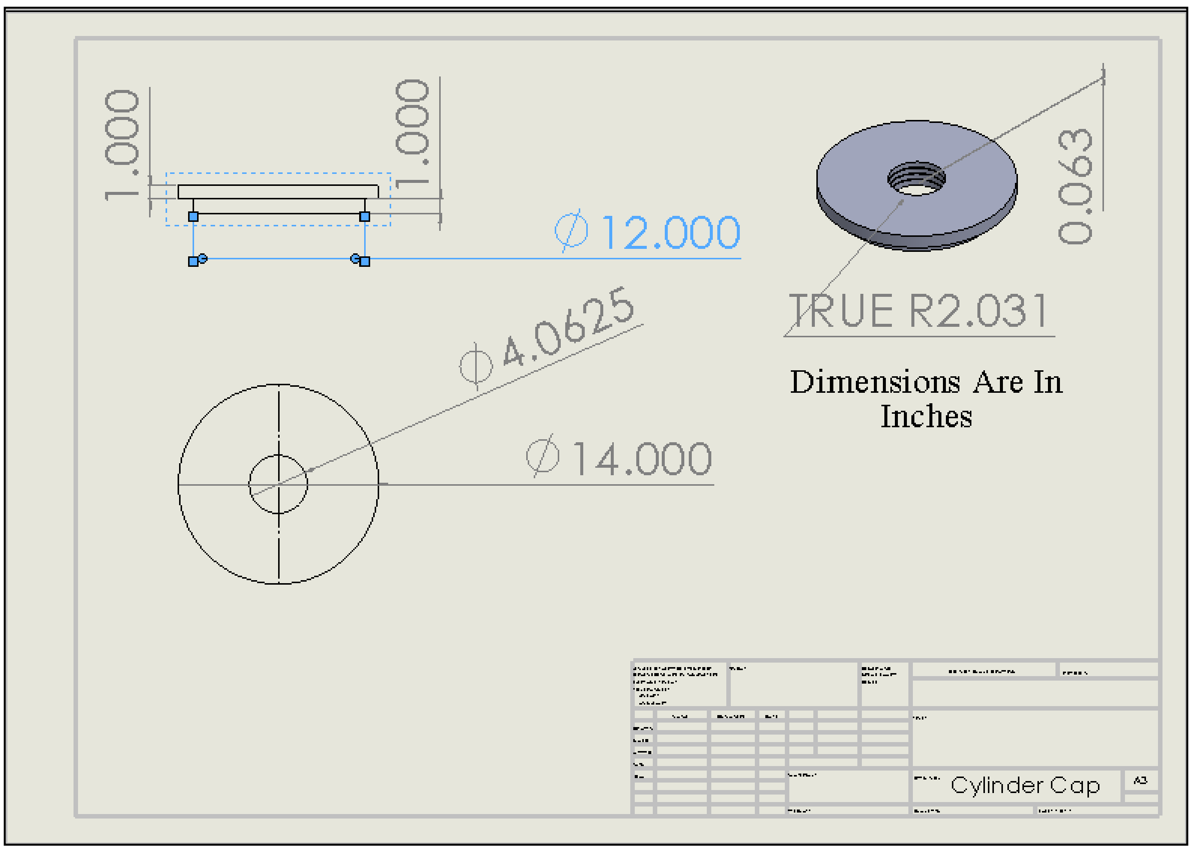


Figure 8. Cylinder Cap SolidWorks Drawing

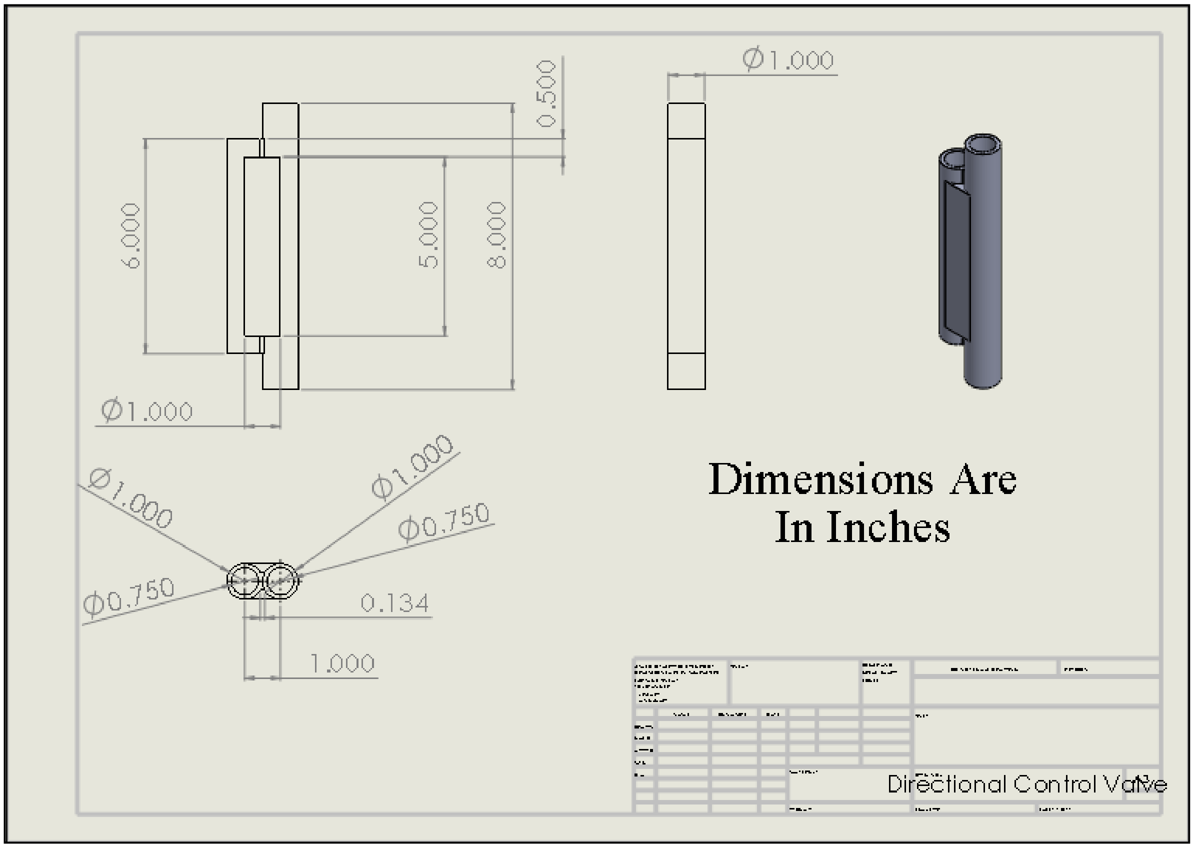


Figure 9. Directional Control Valve SolidWorks Drawing

The next part that will be discussed is the plunger. The plunger will fit inside the cylinder and will provide the pressure to move the hydraulic fluids. This plunger will be threaded on the cut hole in the center, top portion of the plunger. The dimensions of this plunger can be found in Figure 7. The plunger will have an outer diameter of 12 inches in order to fit within the cylinder to ensure a secure fit. The plunger will be inserted into the cylinder and then will be attached to the piston rod. The plunger will also be 2 inches thick and will have a filet on the edges with a radius of 0.50 inches.

The next part that will be placed is the cylinder cap. The cylinder cap will be placed on the top edge of the cylinder and will be welded onto the top of the cylinder. The cylinder cap will be slid over top of the attached piston rod. The cap will contain three o-rings in order to ensure a sealed hydraulic cylinder. The cap will have an outer diameter of 14 inches to match the cylinder. There will be a hole cut through the entire cap with a diameter of 4.0625 inches. This section will be 1 inch thick and another section will extend another inch at a diameter of 12 inches. This section of the cap will fit securely into the cylinder will it will be sealed with another gasket. Lastly, there will be three fittings for the gaskets that the o-rings will fit inside. The cap SolidWorks drawing will be in Figure 8.

The next item that will be discussed is the directional control flow valve. This will have a rough drawing as shown in Figure 9. The directional control valve that will be required for this project will have a desired outer diameter, for the hydraulic tubing, of 1.00 inch. It will also have an inner diameter of 0.75 inch. It will have four connections. Two of these connections will be going directly to the hydraulic cylinder. The other two connections will be going to the turbine. The directional control valve desired will be no longer than 8 inches long with a width of 2 inches. The directional control valve will work in a unique way. The inner valve will switch in order to allow for the flow to be controlled in the desired manner. A simple diagram of this mechanism can be found in Figure 10. This diagram will show how this component operates and actually switches the direction of the control.

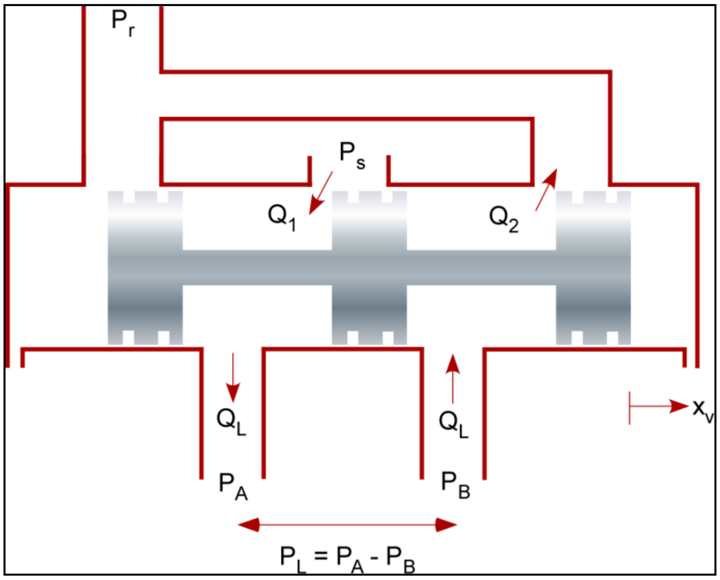


Figure 10. Directional Control Valve Diagram

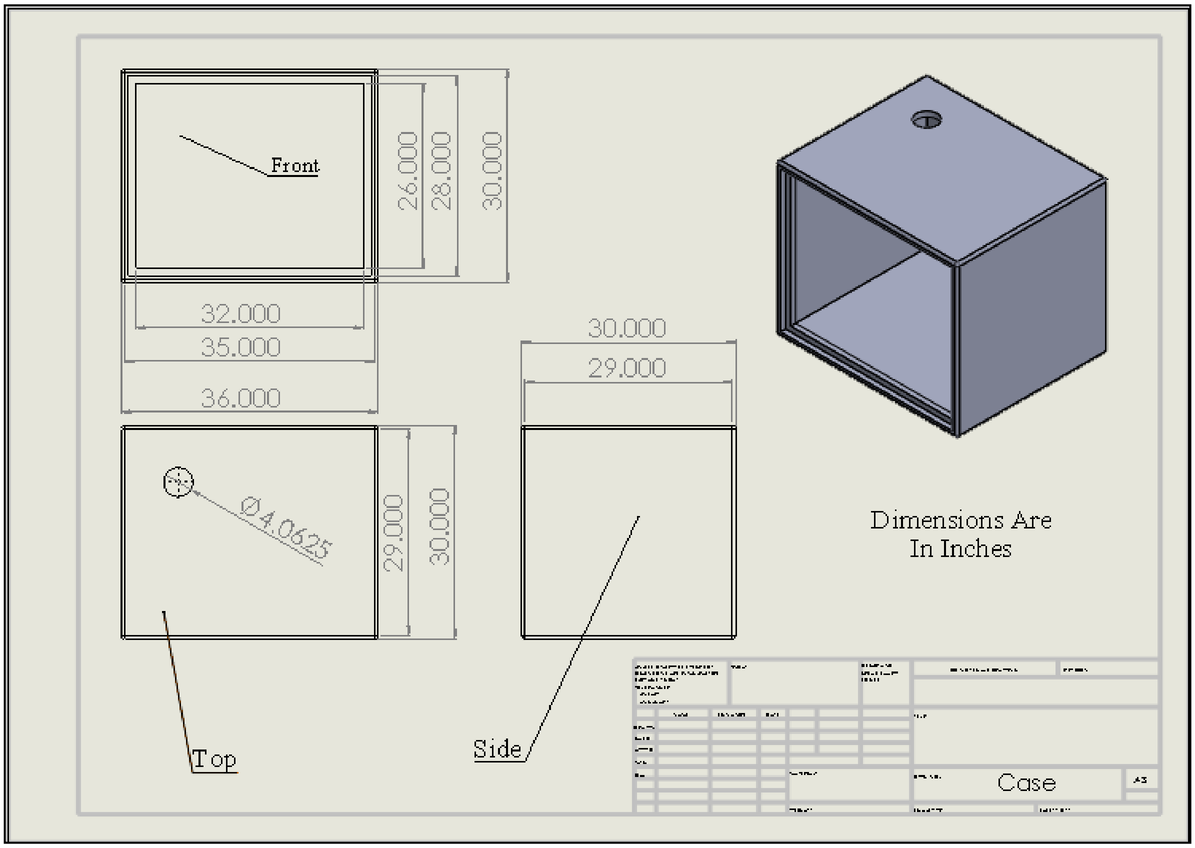


Figure 11. Case SolidWorks Drawing

The tubing that will be used for the hydraulic lines will be steel. Steel will be used rather than hosing for a few reasons. The first reason, which is also the main reason, will be because using steel tubing rather than hydraulic hose will greatly reduce the chance of the lines leaking fluids. Another reason that metal tubing will be used over the hose will be because of smaller bend radius. Surprisingly, the metal tubing will actually be able to bend at a much smaller radius which will be beneficial for this project because of the small workspace. The hydraulic metal tubing actually will actually allow for a much better heat dissipation as well and will be much lighter than the hoses. The hydraulic tubing typically will have a much longer useable life than the hydraulic hosing. That being said, there will also be many other factors that must be considered when using tubing. The metal tubing will also mean that there is a much higher transmission of vibrations throughout the system. This will have to be address in the analysis

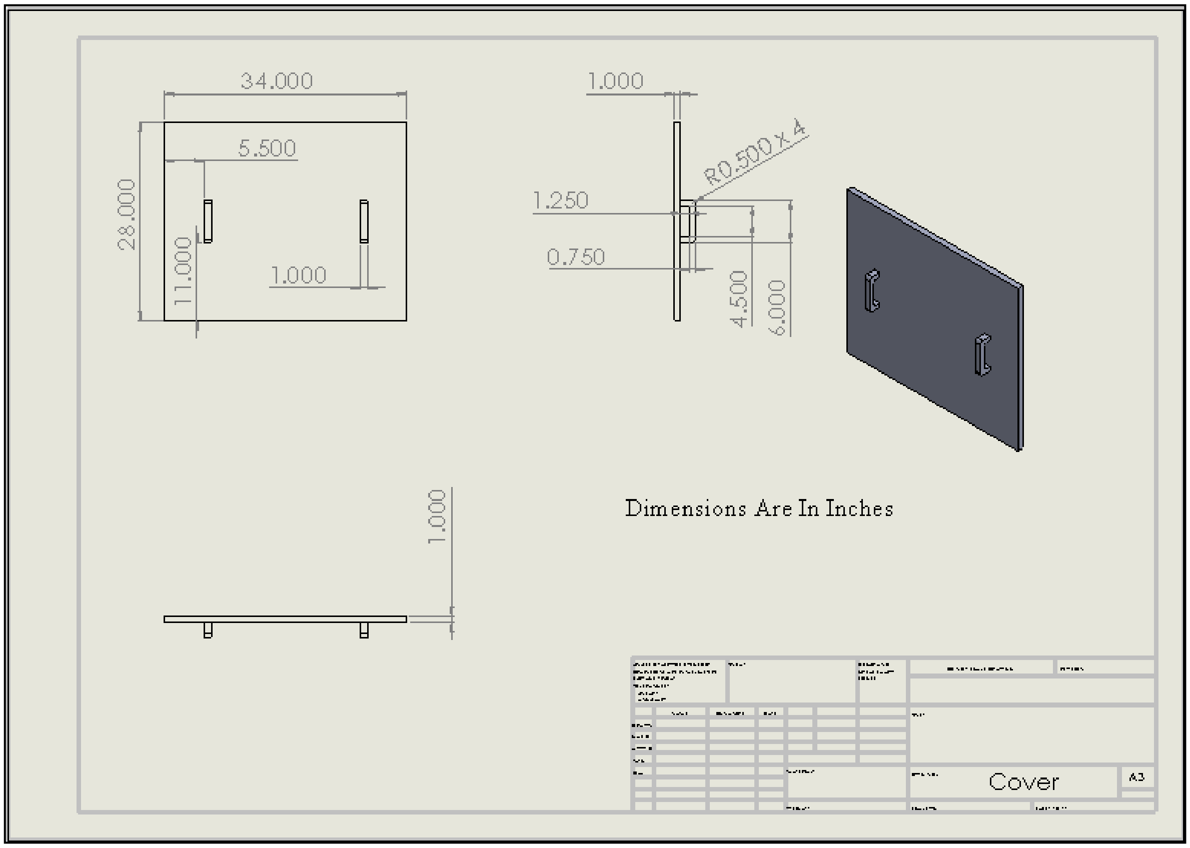


Figure 12. Case Cover SolidWorks Drawing

section of this report and will be vital in ensuring there is no failure due to vibrations in the hydraulic tubing.

The tubing that will be selected is a low carbon steel. This steel tubing will be cold drawn and annealed. The tube being cold drawn means that the metal is stretched by tensile forces in order to be pulled into the appropriate shape and size. This process will be done at or around room temperature which leads the name of cold drawn. This tubing will also be annealed which will heat the material to a certain temperature and allowed to cool slowly. This actually reduces the internal stresses of the tubing and actually toughens the material. The carbon steel tubing that will be used for this project has yield strength of approximately 310 MPa, which will be important in the analysis section of the report.

The hydraulic motor will be selected based off of the most efficient simulation that can be performed on SolidWorks Simulation and bought in order to implement. All of the hydraulic energy system's components will be placed in to a case that will be waterproof and as lightweight as possible. This case will allow for all of the components to be mounted into a single unit to allow for ease of access and easy implementation.

The components will be mounted within the case using different brackets. The entire case unit will have a rough dimension of 30 inches by 30 inches by 36 inches. This will remain within the design specifications so will be satisfactory for this project. All of the edges will have a filet of 1 inch. There will also be lip in which the case cover can be placed onto and bolted into place. There will be a hole with a diameter of 4.0625 inches in order for the piston rod to fit through. This hole will also have a series of o-rings in order to ensure pressure. All of the dimensions of this case can be found in Figure 11.

Finally, we have the case cover which can be found in Figure 12. Figure 12 shows the standard SolidWorks drawings. It shows all of the required dimensions in order to fit perfectly into the case. This cover will sit atop of a gasket to ensure that the case is watertight and will withstand a good amount of pressure. This cover will be attached either by way of clamps or by way of bolts. To determine this, the stress, strain, deformation analysis will be run on the entire system as well as a cost analysis of the materials.

Design Alternative 2

This design alternative will be similar to the first alternative but will use air as the hydraulic fluid rather than a liquid. This system will run as a continuous pneumatic energy converter where with each applied force, the air will be compressed to continue running the system. The power generated will we be consumed while the system runs. Maintaining the staircase example the compressed air from each step will travel through the hydraulic lines back to the HEC housing unit. This unit will run like the first design except that human power will be pushing down as the initial acting force. This design will need to include an air compressor but it will maintain the same valve mechanisms for the control and direction of the fluid.

The application will be the same as design and application alternative one, but using these different systems design the efficiency, as well as power output will differ in the quantitative results. Also this design must include and actively include the air compressor and the directional control valve to allow this design alternative to run properly as a pneumatic system with resemblance to the one hundred percent hydraulic system using a hydraulic fluid.

After the initial pump provided by the human power for the fluid to compress, the internal workings of the hydraulic system is the same. This design will be implemented around to make it work, for example, adding two or more separate valves, or adding compressed air boosters are options to keep the new fluid, air, moving without losing its power. This tool is used to compensate for the possible low force driving the system, depending on the human or initial force.

Design Alternative 3

The third design application will be similar to both of the previous design alternatives but will be closely related to the second design alternative. The third design alternative will be a pneumatic energy converter like the second design alternative. This unit will consist of a few core components that were also in the second design alternative. These are the pneumatic piston, the pneumatic motor, and the generator. Unlike the second design, the third design will have a key aspect that will make for an improved system. This is a compressed air tank. This will serve as essentially an energy storage device. The main difference that the third design concept will have with the second design concept is that this one will have the energy storage capability. Instead of just getting the instantaneous amount of air forced throughout the system, it will be able to have a prolonged, controlled flow of air due to the compressed air tank. This design will also consist of check valves in order to ensure that the flow of air only goes into the air tank and not escape. There will also be valves similar to the previous design alternatives.

An important difference in this system is that it will be an open system. What this means is that it will allow for air to enter into the system and escape the system. Both of the previous design alternatives will have a closed system. The pneumatic piston will only be attached at the bottom to an airline and the top one will be open. The line will than go through a check valve. This check valve will allow for the air to flow into the compressed air tank but not back the other way. This is the mechanism in which energy will be stored. The compressed air tank will be fitted with one side the check valve and the other side with a pressure gauge and a valve. The gauge will allow the user to check the pressure built up inside the tank and the valve will be to allow the air flow to run across the pneumatic motor to run the generator. The pneumatic motor will be similar to the hydraulic motor except that it will run off of air flow. The problem with this design alternative is that the open system design will limit the amount of environments that the energy converting system could be implemented into. This will be solved by creating a box that will allow for the system to be imitating a closed loop system.

Integration of Global Design Elements

In regards to the design process, assessing the design in a global context is crucial. First the idea of the design, the application, manufacturing, and logistics requires expansive knowledge aside from the strict science of engineering. A main driver of this design is efficiency. The goal is to make this design affordable and able to generate sufficient power for the cost of manufacturing and implementation. Ultimately, this idea is intended to be part of life like a common household item. In a home or part of a shopping mall where people walk through 26 day in and day out that the human power can provide the force for constant generation of electrical energy. The driving force behind the efficient and easily integrated hydraulic energy converter is to be integrated into all areas of the world from poor developing countries with limited electricity to the most lucrative parts of the world. Though this general design has been studied, it is not efficient to harvest electric power from hydraulic energy. Using this unit will give people all over the world access to power their household items or even simple things liking charging a cell phone.

Proposed Design

The design that was decided to be implemented is the third design alternative. Like discussed in the design alternative 3 section, this system will be a quasi-open looped system that will include a few different components. These components will be a pneumatic piston, check valves, a compressed air tank, a valve to control the flow of air, the pneumatic motor, and a generator. The design will also include air lines to carry the flow of air. There will also be a spring to allow for the pneumatic piston to return to its original position. The pneumatic piston will be purchased as this is the easiest way to integrate the piston. The valves will also all be purchased as well. The compressed air tank, the pneumatic motor, and the generator will also be purchased. The case that will encase all of the other components will be created and will be ensured that it is waterproof. The details of each of the components will now be discussed.

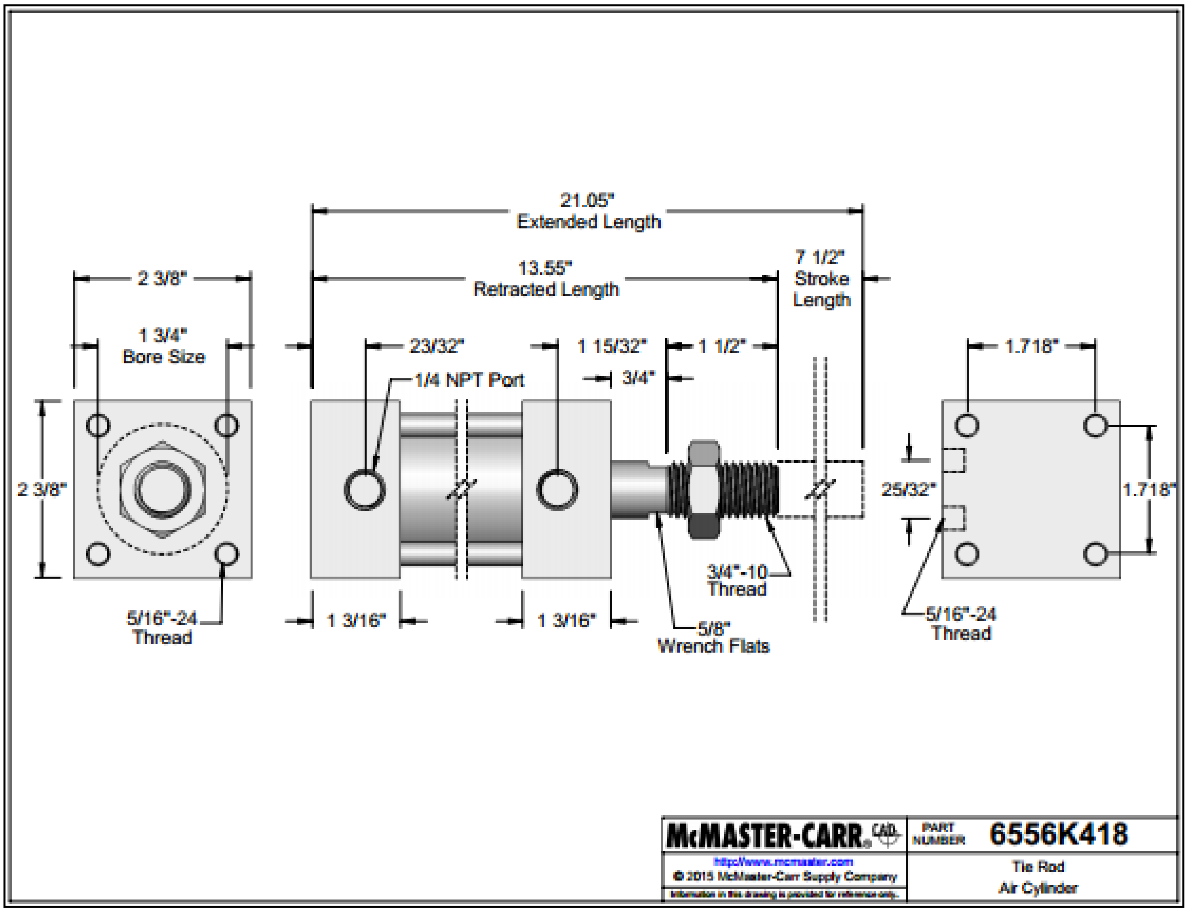


Figure 13. Piston

The first component of the pneumatic energy converting unit will be the piston. The piston that will be used will be a tie rod air cylinder that will have linearly acting motion. This component will be purchased from McMaster-Carr. Figure 13 shows the engineering drawing of this component. This piston will have a length of 13.55” when it is completely retracted. When the piston is fully extended, it will have a length of 21.05”. It has a width of 2 3/8” and has standard ¼” NPT female threading on both ends of the cylinder. This cylinder is rated for a maximum pressure of 250 psi but will create a pressure based of the weight of the force. A force of 120 pounds will create up to a 50 psi pressure, a force of 240 pounds will create a pressure up to 100 psi, 360 pounds will create a 150 psi pressure, and a force of 480 pounds will create a 200 psi pressure.

The next component will be a check valve. The check valve that will be used will also be purchased from McMaster-Carr, which can be found in Figure 14. A check valve is a valve in which the air flow is constricted to flow in only one direction. The check valve uses a spring to close the valve and prevent backward flow. This specific valve requires a minimum of 1 psi in order to open the valve. The maximum pressure that the check valve can operated at is 500 psi. It also has an operating temperature range from -20° to 180° F. It has a male inlet ¼" NPT connection and a male ¼" NPT connection. It has an overall length of 1 ½".

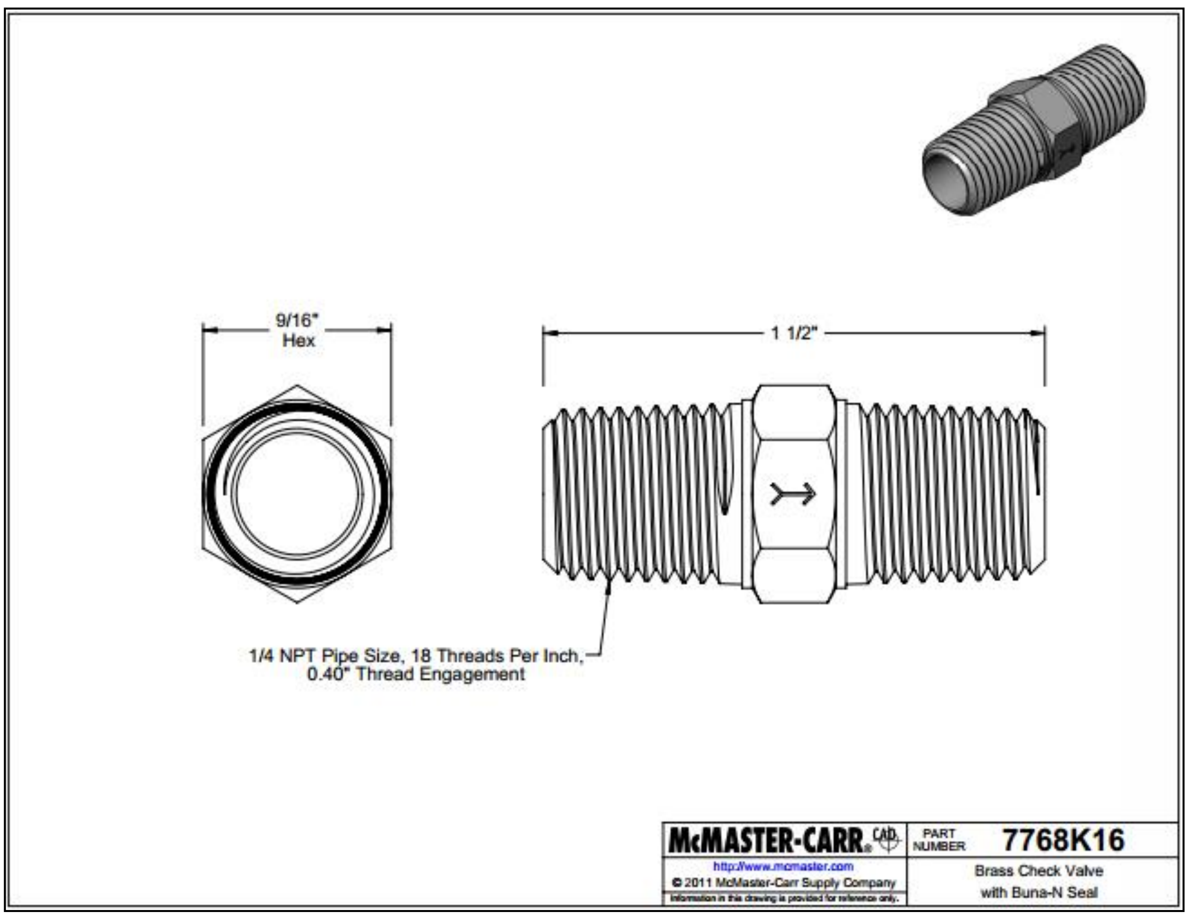


Figure 14. Check Valve

The next component that will be discussed is the air hose. There will be two air hoses purchased from McMaster-Carr. These air hoses will need to be at least 2 feet in length each. The air hose will be an EPDM, ethylene propylene diene terpolymer, rubber. This type of rubber has an extremely smooth interior finish to minimize the restriction of the flow. The air hose will consist of male ¼” NPT connections on both ends. This specific air hose has a minimum bend radius of 1 ½”, which means that is the smallest turn that this hose can make. It has a rating of 300 psi maximum pressure at room temperature. For this design, this hose will be sufficient in supplying the pressure desired.

In order to connect the air hose to the check valve, this design will require purchasing a

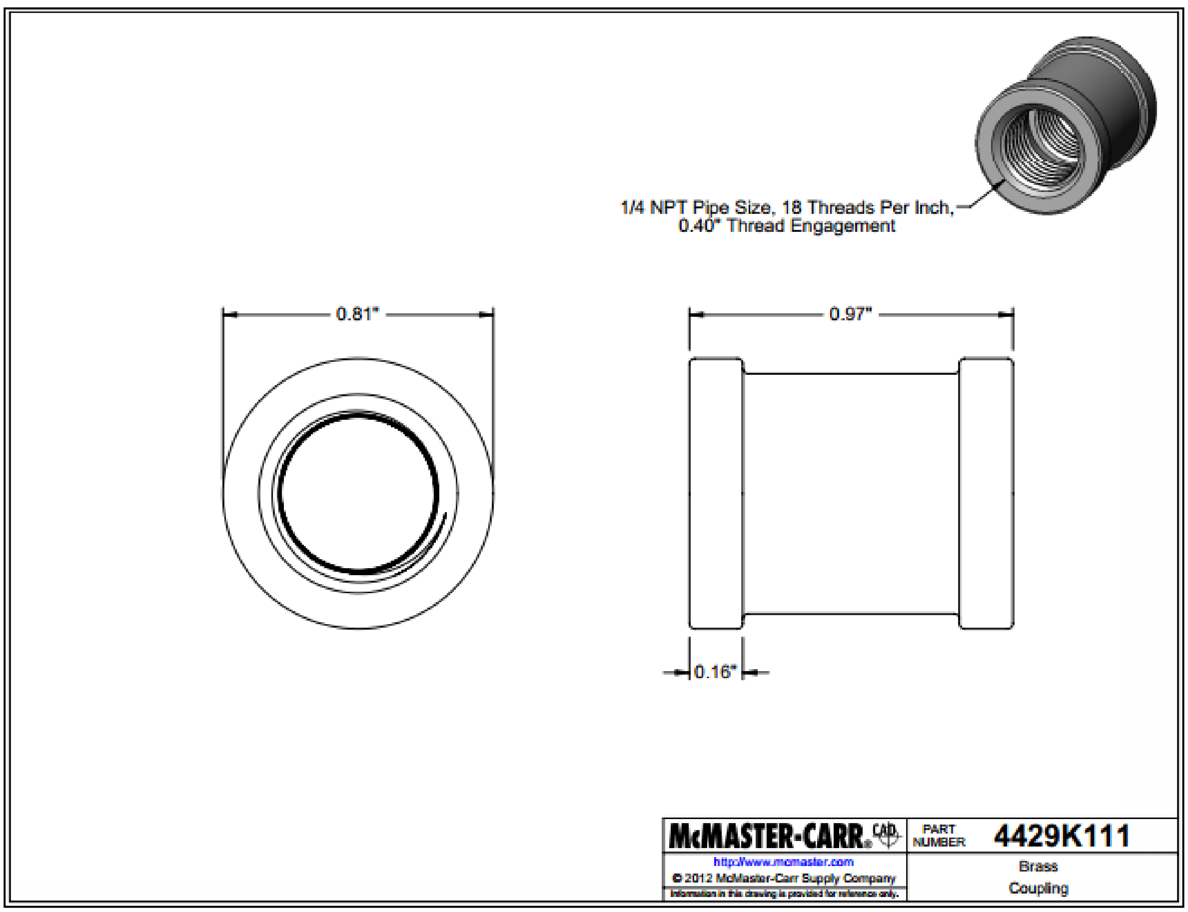


Figure 15. Coupler

coupler as well. This coupler, along with the rest of our purchases, will be purchased from McMaster-Carr. The drawing can be found in Figure 15 above. This coupler is a low-pressure brass coupler. It has an overall length of 0.97” and is a ¼” NPT female connection on both ends. It is rated at a maximum of 200 psi at room temperature.

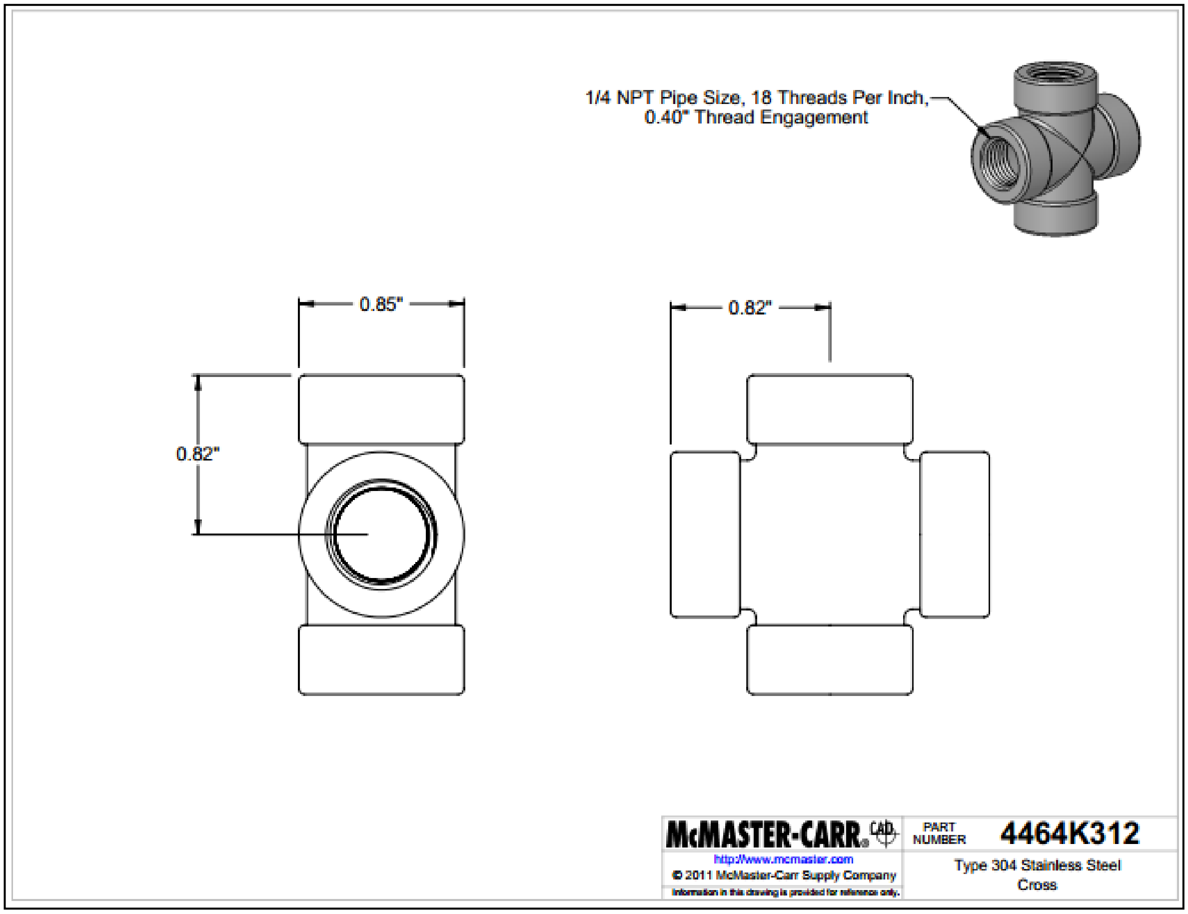


Figure 16. Cross

The next component that will be discussed is the cross joint. This cross joint will be a type 304 stainless steel pipe fitting. Figure 16 shows the dimensions of the joint. It is a four way connection for a ¼” NPT pipe fittings. All connections are female threaded. The joint has a maximum pressure rated at 150 psi at room temperature.

There will be a pressure gauge that will be connected to the cross joint. This pressure gauge will be a purchased part as well and will ensure an accurate pressure reading of the entire system. The pressure gauge that will be required will have a range of pressure readings from 0 to 160 psi. This gauge has an accuracy of +/- 2% and has a temperature range of -40° to 150° F. The gauge has a dial size of 3 ½”. This gauge will have a ¼” NPT male connection. Another part that will not have a drawing is the compressed air tank. This air tank will need to have a least a maximum pressure of 150 psi since the desired pressure will be 120 psi. Most of the tanks that are commercially available at this pressure rating have an approximate size of 13”x14”x24”. These tanks also typically have a ½” NPT female connection. This means that in order to connect to the rest of the system there will be an adapter required.

The adapter will also be a purchased part and the technical specifications can be found in

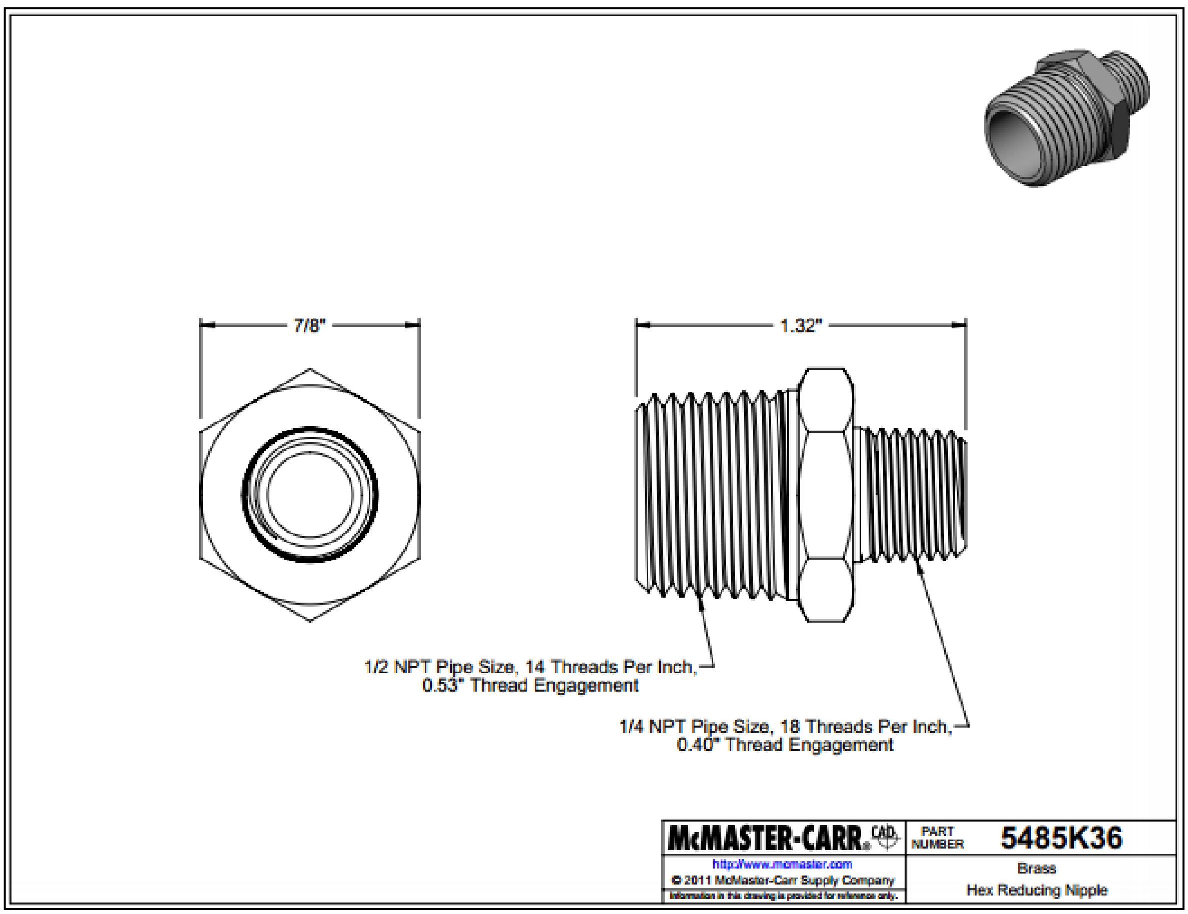


Figure 17. Reducer

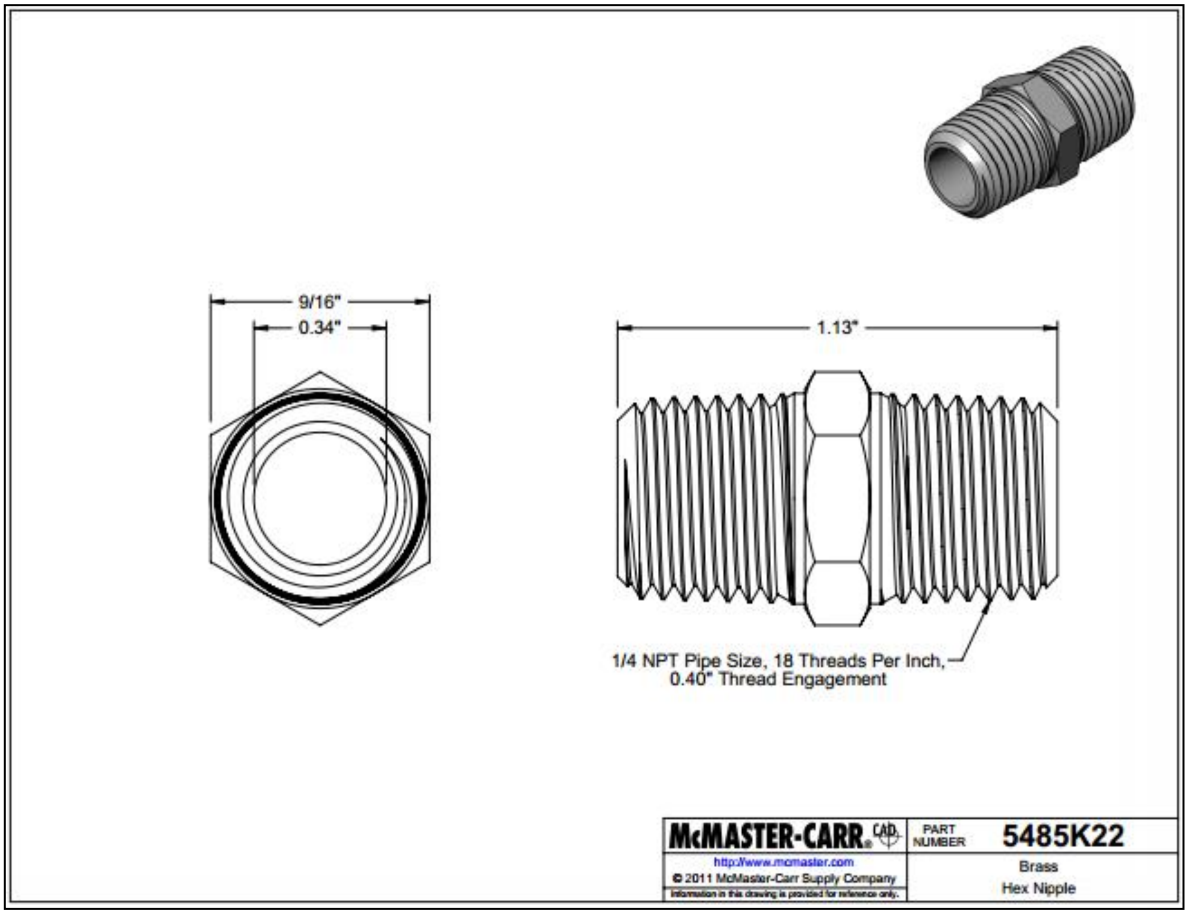


Figure 18. Adapter

Figure 17. The adapter is known as a hex reducing nipple. It reduces the pipe size from ½” NPT to a ¼” NPT connection. Both of the connections are male connections. This reducer has total length of 1.32” and has a maximum rated pressure of 1000psi.

The next component will be the regular ¼” NPT nipple. This will be a medium pressure brass hex nipple. Figure 18 shows the technical specifications of this part. It has an overall length of 1.13”. This connection has a ¼” male NPT connection on both ends. This nipple also has a maximum working pressure of 1000 psi at room temperature.

The tee will be a type 304 stainless steel connection. This connection will consist of three ¼” NPT female connections. The drawing can be seen in Figure 19. It has an overall length of

1.64” and has an overall height of 1.245”. This tee has a maximum working pressure of 150 psi at room temperature.

The next part will be the valve. This valve will control the flow of air when the user desires power, he/she will simply open the valve and the air flow will be released across the pneumatic motor. This purchased part can be seen in Figure 20. The overall length of the connection with the handle included is 4.58” and without the handle is 2”. This valve is rated at 200 psi for the maximum working pressure.

The last purchased component that will be discussed is the pop-off safety valve. This valve is a valve that will release air once the pressure is greater than a selected value. For this system, the desired pressure will be around 120 psi so a safety valve that engages at around 125

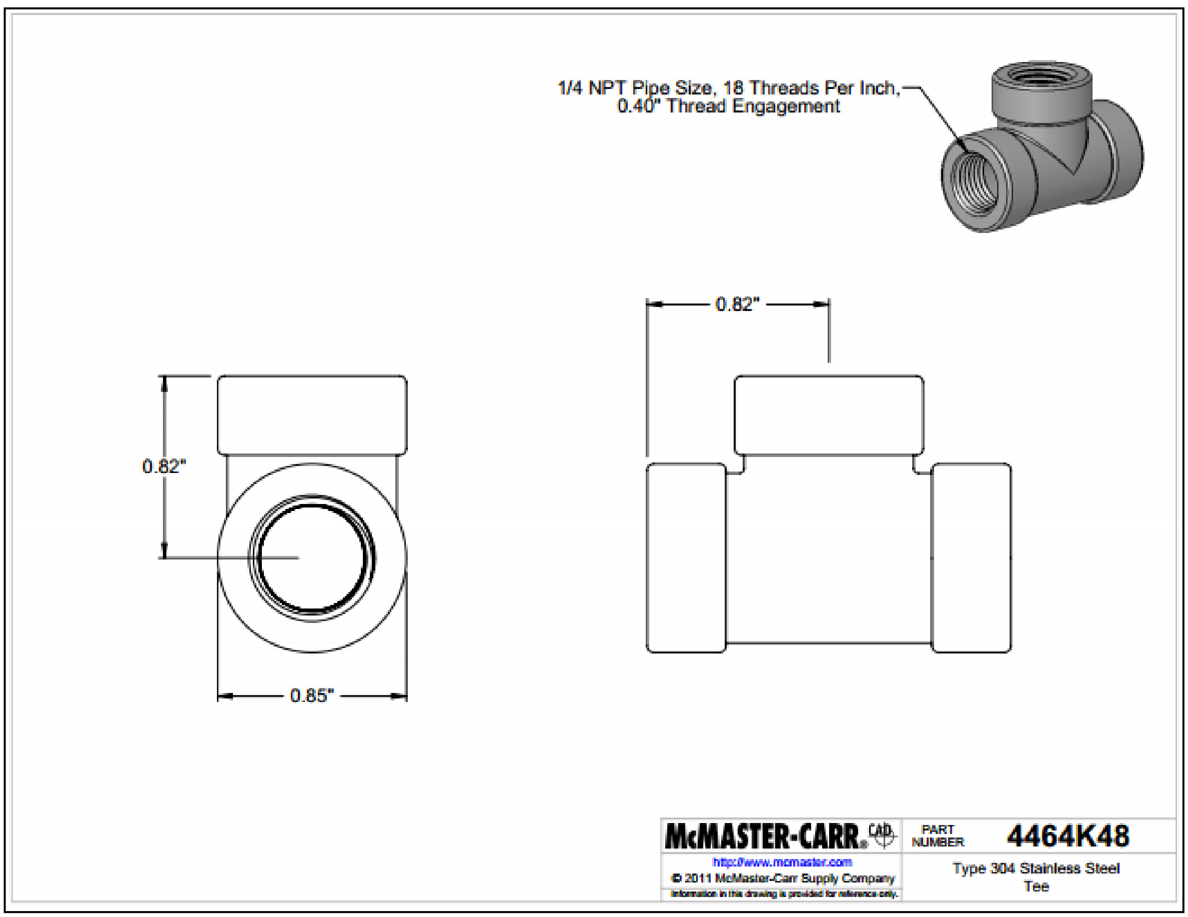


Figure 19. Steel Tee

psi will be ideal. The pop-off safety valve will have a ¼” NPT male connection and will attach to the top of the tee. The safety valve operates at a temperature from -40° to 400° F. It has an overall height of 3 1/8”. The vent location is on the side of the valve.

Some other components that will be vital to the system are the pneumatic motor and the generator. The pneumatic motor is an approximate 2.25” diameter centrifugal pump design. It has two ½” NPT female connections which will be attached to the air hose on one end. The pneumatic motor is attached to a drill chuck which will then be attached to the generator. One part of the design that is not finalized is whether or not a gear box will be designed. This will be determined after the initial analysis is completed.

The overall design of the system will be a series of the components connected in specific

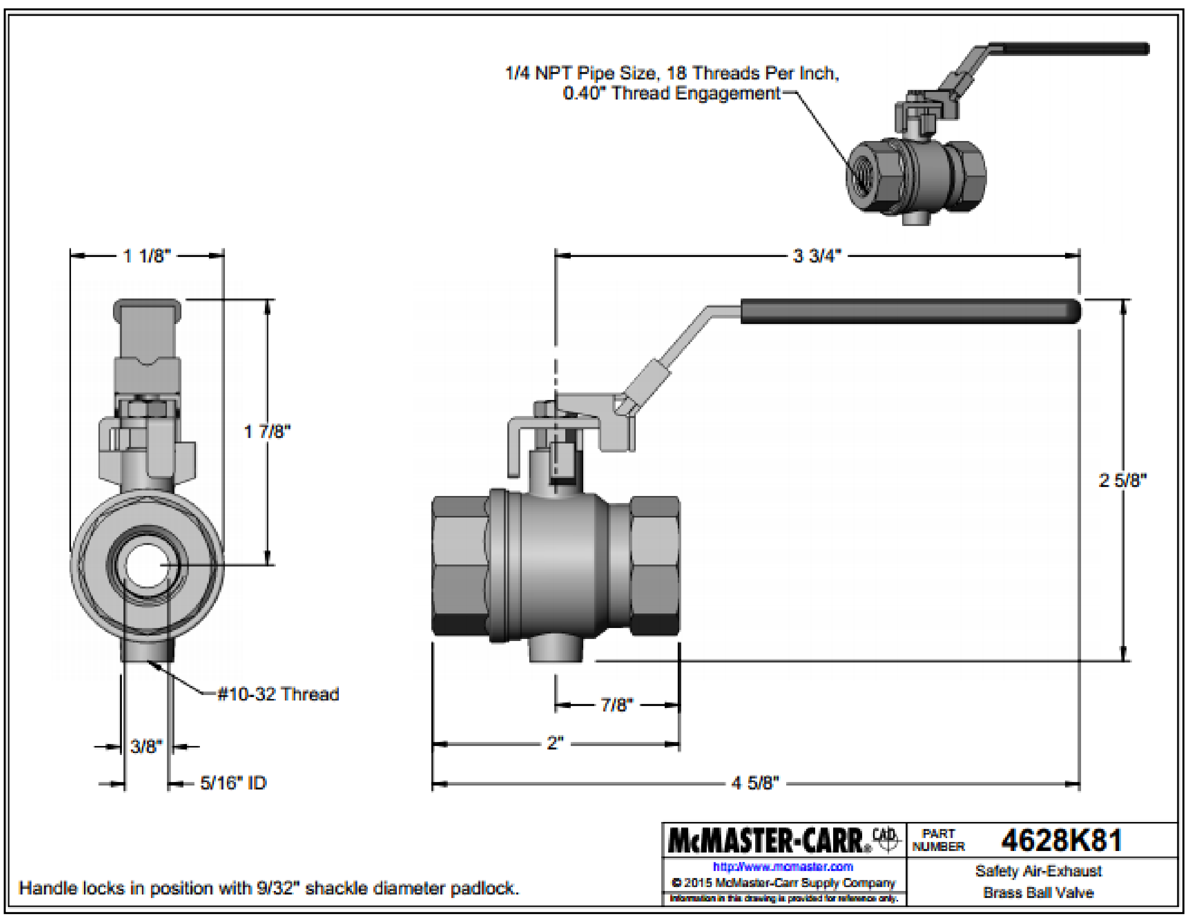


Figure 20. Valve.

order. The overall picture of the system can be seen in Figure 21 above. This rendered image includes all components except for the generator and the box enclosure. The system will start at the piston where a force will be applied to create a pressure and air flow from the bottom of the cylinder. This will be connected to the first air hose which will lead to the coupler. The coupler will be attached to the male connection on the air hose as well as the male connection of the check valve. The direction of the check valve is important and must be oriented in the correct way in order for the system to work. The check valve is then connected to the cross joint. The

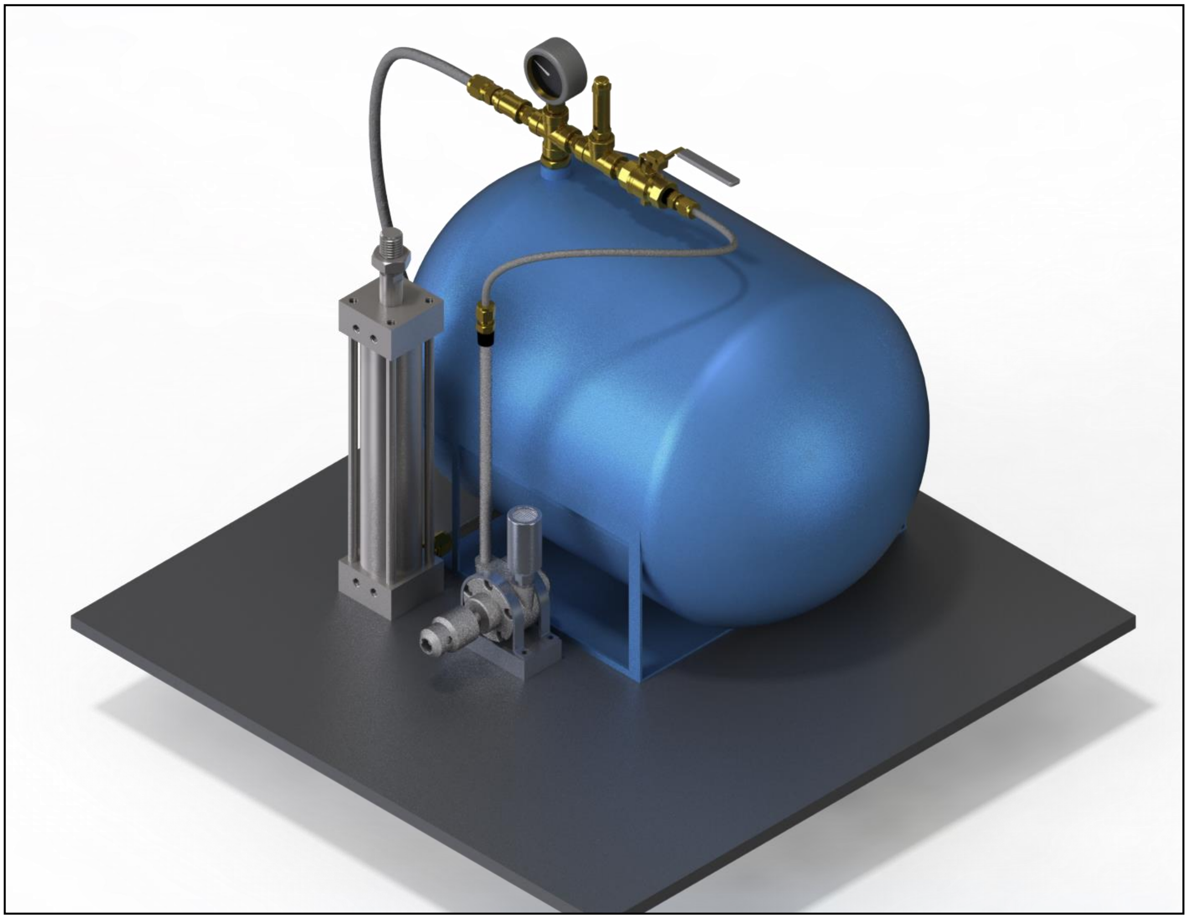


Figure 21. Rendered Design

cross joint will have the gauge connected to the top, the adapter connected on the bottom, and a nipple connected to the other side. The adapter will be connected to the air tank. From the nipple, the tee will be connected. On the top of the tee, the safety valve will be located. On the other connection of the tee another nipple will be located which will lead to the valve. This valve is what controls the flow of the air across the pneumatic motor. The valve will then be connected to the air hose which will be connected to the motor. On the exhaust ports of both the pneumatic motor and the piston, a muffler will be placed to reduce the amount of noise caused by the system. On the pneumatic motor, a drill chuck will be placed in order to attach to the generator. This whole system will be placed into an enclosure.

Discussion

When selecting a final design it was taken into account that design 3 was the best option because it had significant improvements over design 1 and 2. The improvement over design 1 and the enhancements to design 2 that were featured in design 3 proved to be beneficial to the overall idea of the project which was to find a cost effective way to harness some type of renewable energy. Design 3 was chosen over design 1 because the pneumatic energy converter design had some advantages to the hydraulic energy converter. For design 3 the key alteration that was made was that the hydraulic fluid will no longer be the driving medium of the energy converter it will be air. This decision was made because since the entire unit will be fitted into a waterproof enclosure all the components will be in close proximity to each other and if a leaking problem with the hydraulic lines were to present itself the hydraulic fluid could damage some of the components of the unit. To reduce this risk it was chosen to go with design 3 where air will flow through the lines instead. With this change the air hoses can easily be replaced if a leak were to occur and it removes the need to deal with hydraulic fluid. However aside from these improvements, what sets design 3 apart from design 2 is that it would have the ability to store the energy for later use. For design 3 the energy converter will have an air tank that will store the pressurized air. This tank will have a release valve that can be opened whenever the user requires the energy that is stored.

PROJECT MANAGEMENT

Overview

The team was made up of three members and all the team members tried to be equally involved in all the aspects of the project. However, the project was broken down into certain task that each member was mainly responsible for. While one member was the leader of a certain task the other members provided help and feedback to ensure that all members were up to date on the direction the project was taking. This also ensured that every member's ideas and inputs were taken into account in the whole process of creating and manufacturing.

Breakdown of Work into Specific Tasks

The team was broken down and split among the three team members. The first group member, Felipe Gomez first was in charge of the presentation and editing of the report. The PowerPoint and the team poster were both created by Felipe and an overview of the report was performed. Felipe was responsible for the constraints and other considerations section, the abstract, and a few of the discussions. Felipe also performed editing and revisions of the main report. Ruth Quant was the second group member. Ruth performed research on standards and wrote about those standards as it relates to this project. Dillon Watring performed the majority of the literature survey and documented each individual part. Each component was discussed in detail from Dillon Watring and Ruth Quant in the literature survey. Along with the literature survey, Dillon also wrote the overview and discussions of this section. Dillon Watring also created the SolidWorks parts for each of the component that will be used in the final design and created drawings that can be found in the figures. Dillon wrote the Proposed Design section of the report and discussed the specifics of the design in this section and discussed the specific size of the unit. He also detailed small miscellaneous parts that will be included within the project.

The SolidWorks modeling and simulations was completed by Dillon and Felipe. The kinematic analysis and animation was performed by Felipe using SolidWorks motion. The dynamic and vibration analysis of the system was completed by Dillon. As stated previously, the structural design was completed by Dillon and Felipe. The force analysis and stress analysis of the system was done by Dillon and consequently, he selected the best materials to be used for the energy converting unit. The deflection analysis, static design theories, and fatigue failure theories were all done by Dillon as well with help from Felipe. The final component design and selection was done based off of all of the information collected so far and performed by Dillon and Felipe. The development and building of the prototype was done by Felipe and Dillon. The cost analysis and acquiring all of the parts was performed by Dillon. Felipe typed up the descriptions of the cost analysis and helped with developing the testing. Ruth assessed and wrote the global impact of the design.

Gantt Chart

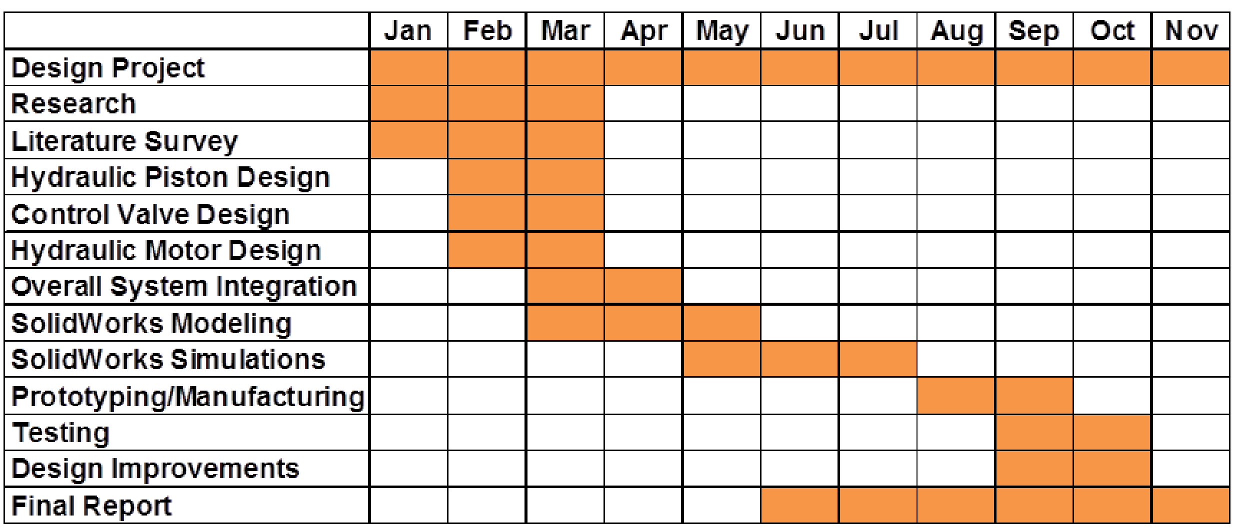


Figure 22. Gantt Chart

Breakdown of Responsibilities

Dillon Watring was responsible for the overall design of the energy converting unit. He was responsible for the research, design, and implementation of each individual component of the entire system. He was also responsible for the literature survey and the overall formatting of the report. Felipe Gomez was responsible for the editing and revising of the final report. Felipe was also responsible for the PowerPoint presentation and ensuring that the presentation was up to a high quality standard. Felipe was also responsible for supporting Dillon in creation and implementation of the components. The team poster was also Felipe's responsibility. Ruth Quant, the last team member, was responsible for the research and acquisition of related standards. She was responsible for implementing these standards and working with Dillon to set up the design of experiments using these standards. The team collectively was responsible for all of the analysis of the system, although it was broken down into specific tasks which was discussed previously. Felipe and Dillon worked mainly on the construction of the prototype and the design of the tests to be used. They both completely performed the testing on the system.

Patent/Copyright Application

The patent process in the United States of America is a multiple step process in which one must complete in order to obtain a patent or copyright. The first step is to determine the type of intellectual property that the project will be considered and from that information a patent, a copyright, a trademark, or some other intellectual property protection. The next step is to preliminarily search for your invention to ensure that it has not already been patented. The next is to determine the type of patent that is needed for your invention. The main two patents are the utility patent and the design patent. The main difference in these two patents is that the utility patent is patenting the process or implementation of machines, tools, or other inventions in a new and unique way. The design patent is to patent a completely new invention. Since the project is implementing existing components in a new fashion, the patent that would be required for this project is the utility patent. The next step one must take is to calculate the cost of the application. Applications depending on the type of patent have certain fees that apply to different situations. These fees include search fee, examination fee, and issue fee. Also applications that are filed via mail have an additional $200.00 fee. Furthermore one must decide if they will use a professional legal service that might require additional cost. After the first patent application is filed it will be reviewed and a letter will be sent out from the USPTO and if everything is in standing order. The letter will state a filing date. If the application is incomplete the letter will state that one must speak and work with an examiner from the USPTO to fix any discrepancies in the filed document. If the application is rejected twice one can appeal to the board PTAB and chose legal representation if necessary. After all required steps are taken and fulfilled and the examiner determines that the application is in satisfactory conditions on will receive a notice of allowance. The notice of allowance will list the issue fee and the publication fee that must be paid before the USPTO issues the patent. Lastly after all fees are paid the patent grant is mailed on the issue date and the process is complete.

Discussion

Overall, the entire project was a team effort that required efforts from all three group members in order to be completed. There were many individual components that were completed and the group worked fairly well to accomplish the tasks set forth.

ENGINEERING DESIGN AND ANALYSIS

Overview

In this section the different type of analysis that were performed on the final proposed design will be discussed. The dynamic and vibration analysis of the system will first be discussed. This will be a relatively short section as exact numbers will be difficult to obtain and more of an overview will be discussed. The structural design will be discussed as well as the force analysis of the system. The stress of each component will be discussed as well as the deflection that will be simulated in each component. The materials of each component will be discussed and the material selection of each manufactured component will be discussed. The designs cost analysis will also be performed in this section.

Dynamic/Vibration Analysis of System

Modeling of a pneumatic energy converting system will include one source, six elements in four different energy domains, and two gyrating transducers. The model that the system graph

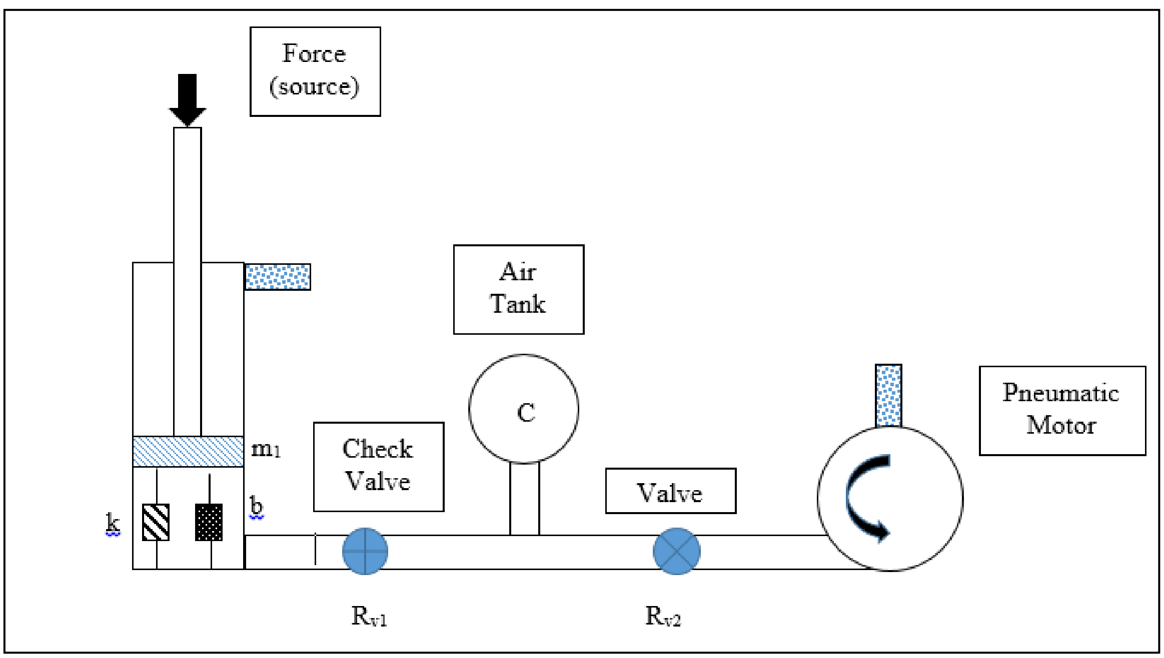


Figure 23. Model of Pneumatic Energy Converting System

will be derived from can be found in Figure 23. There will be at least one of each type of elements; A-Type, T-Type, and D-Type. A-Type elements are energy storage elements that are generalized capacitances. T-Type elements are also energy storage elements but are generalized inductances. Finally, D-Type elements are dissipative elements that are generalized resistances or dampers. The source of the system will be the linear force applied at the top of the piston. The velocity of this force will have a positive direction going down. The first element that will be discussed is the mass of the pneumatic piston. This mass will be labeled as m_1. This mass is considered to be an A-Type element. The next element that will be modeled is the spring that is attached to the pneumatic piston. This spring is a simple translational spring that is considered to be a T-Type element. The next element is that damper within the cylinder that is attached to the piston. This is considered to be a D-Type element. The next element that will be graphed is the resistance caused by the valve. This resistance will also be considered to be a D-Type element. There will be two different valves to model, the check valve and the regular valve.

The next part of the dynamic modeling of a pneumatic energy converting system is modeling the gyrating transducers. A transducer is a something that converts one type of energy domain to another energy domain. In this system, there are two gyrating transducers. A gyrating transducer has equations that relate one type of energy domain's across variables to another type of energy

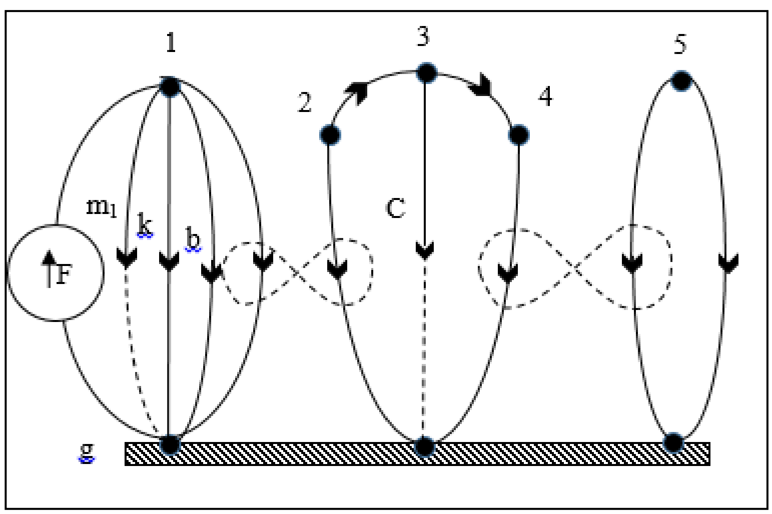


Figure 24. System Graph

domains through variables. The first gyrating transducer is converting the linear force to the air flow rate and is called a fluid piston cylinder. The second gyrating transducer is the pneumatic motor. This converts an air flow rate to a rotational velocity. This second transducer is modeled after the rotary positive displacement pump.

The next step in dynamic modeling is to draw the system graph. The system graph of the system is a graphical representation of a modeled system. It shows the relationship between the system's across variables and through variables. The system graph includes elements and sources as what are known as branches in the graph. The system graph for a hydraulic energy converting system can be found in Figure 24. The system graph shows each branch of the elements in the system. The first one on the very left is the source. Since the linear force goes in the direction of the positive velocity, which was earlier defined as positive going downwards, the sign of the force in the system graph is going up. The next branch in the system graph, from left to right, is the mass. The mass is shown as half of a full branch and the rest as dotted. This is because the mass is an A-Type element, which is always drawn as half dotted and half complete line. Next will be the translational spring, k, which will be a complete branch like the rest of the elements. The damper, b will also be a complete branch. The next branch is an arbitrary branch for connected the parts of the system graph. This is where the first gyrating transducer is located. In Figure 24, there is a dotted infinity symbol. This is what represents a gyrating transducer. The next gyrating transducer is also graphed as a dotted infinity symbol and the transformer is graphed as a dotted ellipse. The resistance due to the check valve, R_{V1}, is connected from node 2 and 3 because it is reducing the flow rate from point 2 and point 3. The capacitance is considered to be the air tank and is modeled similarly to the mass. The second valve, R_{v2}, is drawn from node 3 to node 4.

Elemental equations are an important aspect to system dynamic modeling. Elemental equations are equations in which two variables are related to each other by using a certain parameter. [1] Each type of element has a different form of elemental equations. A-Type elements are generally written as the through variable equals to the A-Type element multiplied by the derivative of the across variable with respect to time. For example, if the through variable is force, F, the across variable is velocity, v, and the A-Type element is the mass, m, then the elemental equation will be $F = m\frac{dv}{dt}$. The T-Type elements will have an elemental equation generally written as the derivative of the through variable with respect to time equals to the T-Type element multiplied by the across variable. For example, the F_k will be equal to the force due to the spring, the spring value k will be the T-Type element, and the across variable will be v, which is velocity. The general equation will look like this $\frac{dF_k}{dt} = k\,v$. Finally, the elemental equation for D-Type elements will take the general form of the through variable equals to the D-Type element multiplied by the across variable. Take F_b as the force due to the damper, the damper, b, as the D-Type element, and v as the velocity, which as previously mentioned is the across variable. The generalized D-Type elemental equation will look like this $F_b = bv$. The elemental equations for this system graph can be found in Table 1 below.

Table 1. Elemental Equations

A-Type Elements	$F_{m_1} = m_1 \frac{dv_{1g}}{dt}$
	$F_C = C \frac{dv_{1g}}{dt}$
D-Type Elements	$F_b = bv_{1g}$
	$Q_{R_{v1}} = \frac{1}{R_{v1}} P_{23}$
	$Q_{R_{v2}} = \frac{1}{R_{v2}} P_{34}$
T-Type Elements	$\frac{dF_k}{dt} = kv_{1g}$
Fluid Piston Cylinder – Gyrating Transducer	$v_{1g} = \frac{1}{A} Q_{P_{2g}}$
	$F_{v_{1g}} = AP_{2g}$
Rotary Positive Displacement Pump – Gyrating Transducer	$\Omega_{5g} = \frac{1}{D} Q_{P_{4g}}$
	$T_{\Omega_{5g}} = DP_{4g}$

The node equations are directly related to the generalized continuity of the system. The continuity of the system is based off of the relationship between the variables that must be true for a connected set of lumped elements because of the manner in which they are connected. This continuity is based off of the structure of the system. The node equations of the system are based off of the Vertex Law, which is also known as the Node Law. The Vertex Law states that for a system graph, the algebraic sum of the through variables entering the node is zero. In other terms, the sum of the through variables entering the node is equal to the sum of the through variables leaving the node. In the different energy domains, this law is known as something different. In the electrical domain, this is known as Kirchhoff's Law, or the conservation of charge. For linear mechanical and rotational mechanical, this law is known as the conservation of momentum, or more commonly known as Newton's 1st and 3rd Law. In fluid systems, the node law is known as the conservation of matter. Finally, the node law is similar to the conservation of energy for thermal systems. The number of node equations for this system is five. The node equations can be found below in Table 2.

Table 2. Node Equations.

Node	Node Equation
1	$F = F_{m_1} + F_b + F_k + F_{v_1g}$
2	$Q_{P_2g} = Q_{R_{v1}}$
3	$Q_{R_{v1}} = Q_{R_{v2}} + Q_C$
4	$Q_{R_{v2}} = Q_{P_4g}$
5	$T_{\Omega_5g} = T_{\Omega_5g}$

The path equations are related to the Compatibility Law, or the Path Law. The Compatibility Law states that the algebraic sum of across variables around any closed path is equal zero. The path law has certain variables that are scalar when dealing with different energy domains. For electrical energy, potential is scalar. For the linear mechanical energy domain, the distance is scalar. For rotational mechanical domain, the angular displacement is scalar. For fluid, the pressure is scalar. Lastly, for thermal, the temperature is scalar. The number of path equations that will be for a certain system can be found by taking the number of nodes minus the number of parts. That value will then be subtracted from the number of branches. This value will be how many path equations the system will have, and similarly, the amount of paths in the system graph that will be seen. For this system graph the number of path equations will be equal to seven. Table 3 shows the path equations for this particular system.

Table 3. Path Equations

Path	Path Equation
1	$-v_F + v_{1g} = 0$
2	$-v_{1g} + v_{1g} = 0$
3	$-v_{1g} + v_{1g} = 0$
4	$-v_{1g} + v_{1g} = 0$
5	$-P_{2g} + P_{23} + P_{3g} = 0$
6	$-P_{3g} + P_{34} + P_{4g} = 0$
7	$-\Omega_{5g} + \Omega_{5g} = 0$

This will be as far as the dynamic modeling will be taken because the path equations, the node equations, and the elemental equations can be used to solve for the unknowns once the constants and variables are given. Since these values are unknown and extremely difficult to find, it is in the best of interest of time to move on to the structural design of the system.

Structural Design

Now the structural design of the system will be discussed. Typically, structural design will focus on buildings, however, in this case the structural design will be the enclosure in which the entire energy converting unit will be located in. The structure will have a base of 24” by 24”. The structure will be ideally made out of a thin stainless steel. This will limit the amount the environmental exposure will have an effect on. The enclosure will eventually have three sides that are solid and then one side that will have an access panel. The sides of the enclosure have to be at least 16” high. The top of the enclosure will have holes in which the valve and the gauge will be put through. The piston will also have a hole in which it will go into. These will have to have a rubber grommet in order to ensure that the enclosure is sealed.

Force Analysis

The force analysis of the system will involve determining the pressure that will be created based off of the applied force. Like discussed previously in the components section, the piston has a linear relationship with the amount of force applied and the output pressure supplied. From the specifications on McMaster-Carr a linear graph can be created. Figure 25 shows this graph. From this, an equation is obtained that says F = 2.4 P. This means that the pressure that the piston can supply is 2.4 times the force applied to the piston. The average weight of a person is 195.5 pounds. This means that the system would be able to output approximately 82 psi if that is the force applied. To obtain the maximum pressure that will be desired in the system, which is 120 psi, the force applied will have to be 288 pounds.

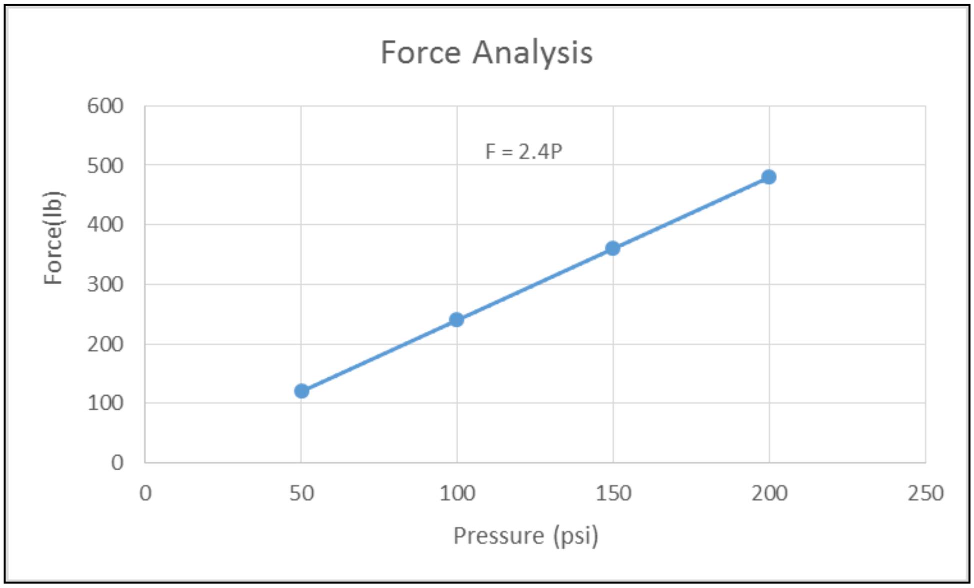


Figure 25. Force vs Pressure Graph

Stress Analysis

The stress analysis of the system will be completed by analyzing each individual component at a stress of 120 psi applied to each component. The stress in each component will be determined using a SolidWorks simulation on the part and analyzed using von Mises yield criterion to determine if the part fails. In SolidWorks, it is important to create a mesh on the material. The finer the mesh detail means the more accurate the simulation will be. Each component will be broken down into a number of nodes and elements which basically mean the amount of simple polygons the component is broken down into.

The check valve will be the first component that will be analyzed. The check valve will be broken down into 27,298 nodes and 15,297 elements. Figure 26 shows the stress analysis result from SolidWorks on the check valve. The red areas on the image are the locations of the highest stress. These are located at the ends of the component and at the thread locations. This indicates that check valve will fail at those locations first. But from the chart the maximum von Mises stress in this component at 120 psi is less than the yield strength of the material. The brass yield strength is approximately 230 to 240 MPa and the check valve has a maximum stress of about 12 MPa providing a safety factor of approximately 20. This means that at 120 psi the component will not fail.

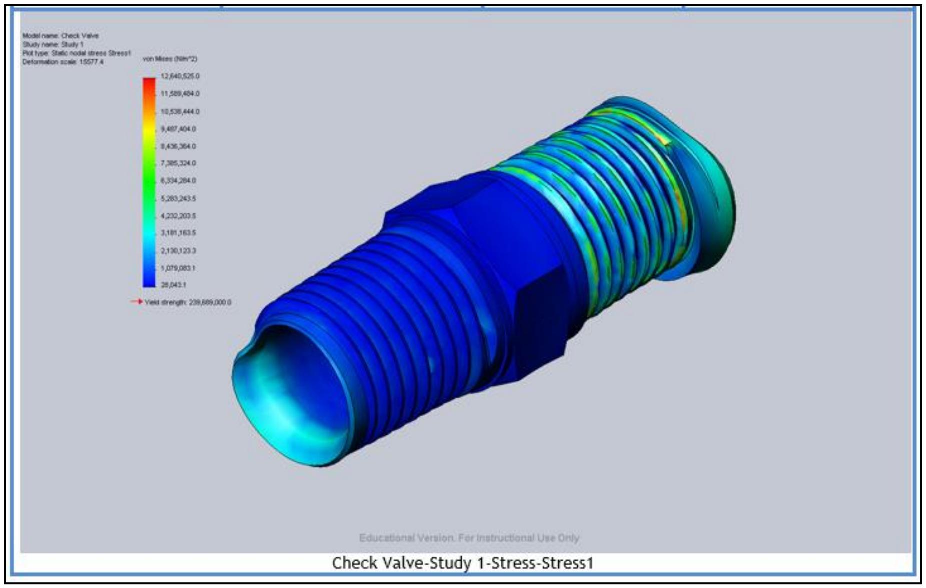


Figure 26. Check Valve – Stress

The next part that will be analyzed is the coupler. The stress analysis results from SolidWorks can be found on Figure 27. The coupler is broken down into 28,858 nodes and 17,531 elements. This component can be seen that almost no high stress concentration exists. This is simply because of the geometry of the component compared to the check valve that was previously analyzed. The yield strength for brass is around 230 to 240 MPa and you can see from the chart that the maximum stress that results in the coupler is about 5 MPa which would provide a safety factor of almost 48. This part will not fail.

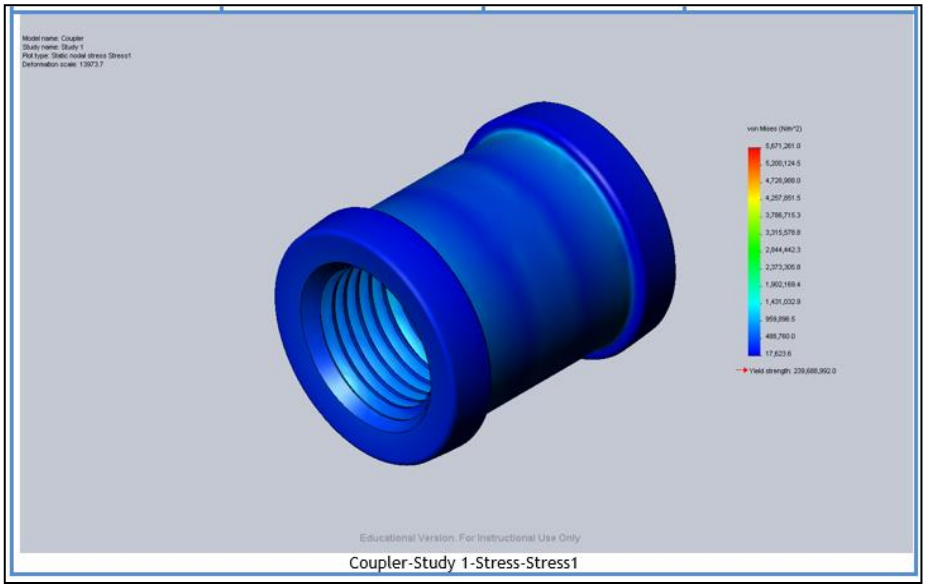


Figure 27. Coupler – Stress

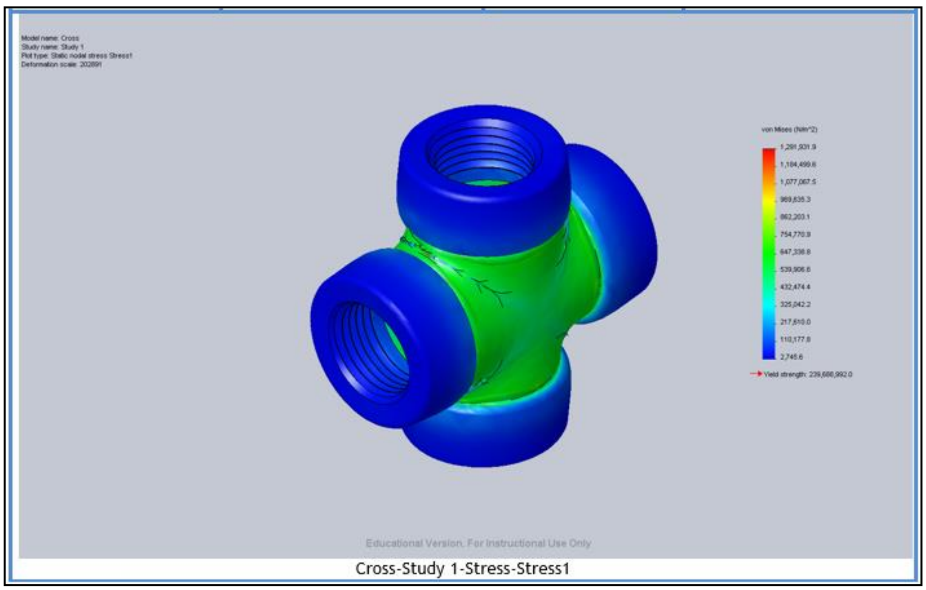


Figure 28. Cross – Stress

The cross joint is the next component which the results of the stress analysis can be found in Figure 28. The cross is broken down into 35,068 nodes and 20,741 elements. Although this component appears to be at a higher resolution because of the increased number of nodes and elements, it is not. The number of nodes and elements is based on the size of the component. So at the same resolution of mesh, a larger component will contain more nodes and elements. The maximum stress reached in the cross is approximately 1.25 MPa which means the part will not fail at a pressure of 120 psi.

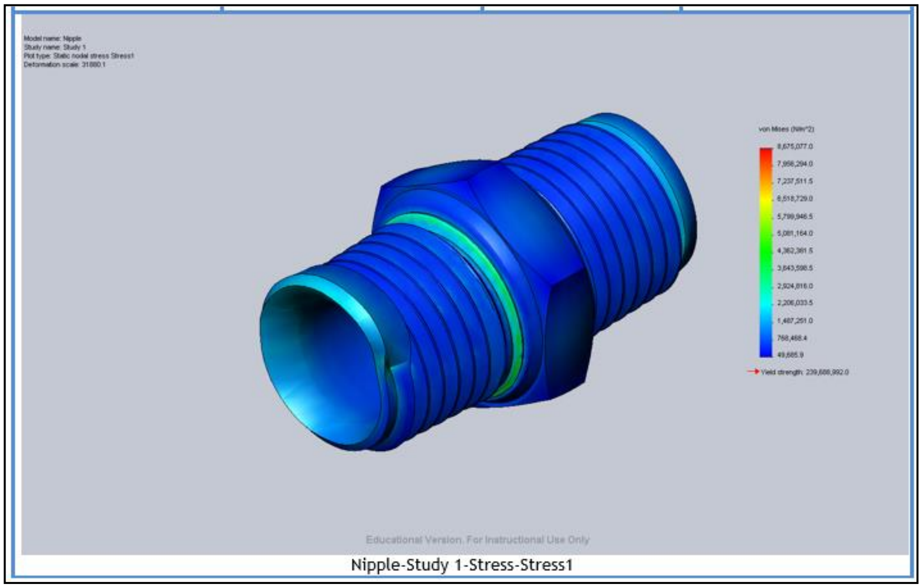


Figure 29. Nipple – Stress

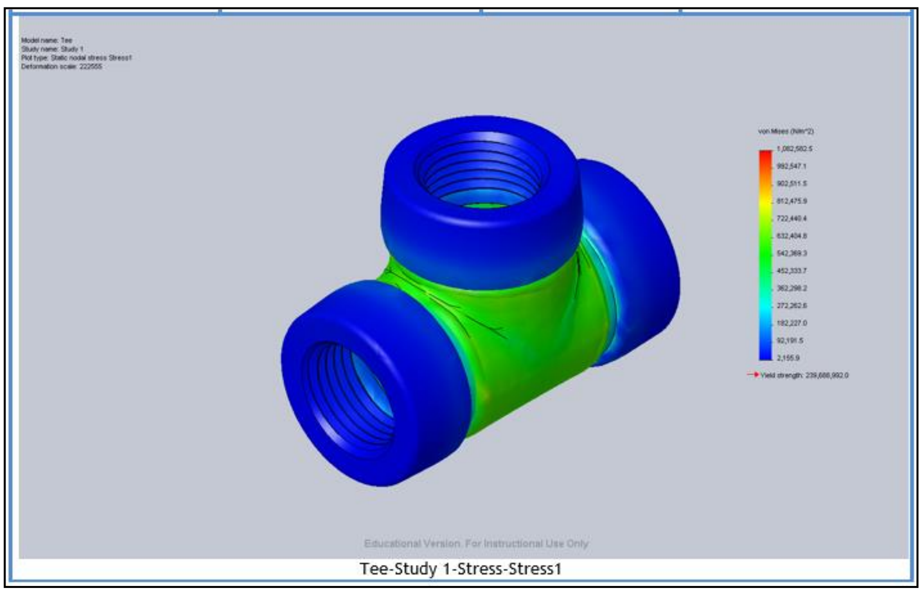


Figure 30. Tee – Stress.

The next component is the nipple which will be shown in Figure 29. The nipple is broken down into 27,141 nodes and 15,517 elements. The nipple has a similar effect due to stress that the check valve did. On the ends, the pressure caused the component to flare out. Although this will not be a problem for this design, it is a good thing to take note of. The maximum stress in the nipple will be about 9 MPa which means this component will be safe from failure.

The tee connector will be shown in Figure 30. The tee will consist of 31,536 nodes and 18,870 elements. The maximum stress that was simulated in this component was approximately 1.5 MPa. This means that this component will not fail under a pressure of 120 psi. Similarly, the valve was also analyzed using SolidWorks. This can be seen in Figure 31. This component was broken down into 34,780 nodes and 20,706 elements. The maximum stress seen in the valve is approximately 4.5 MPa which just like all of the other components means that the valve will not fail under a pressure of 120 psi.

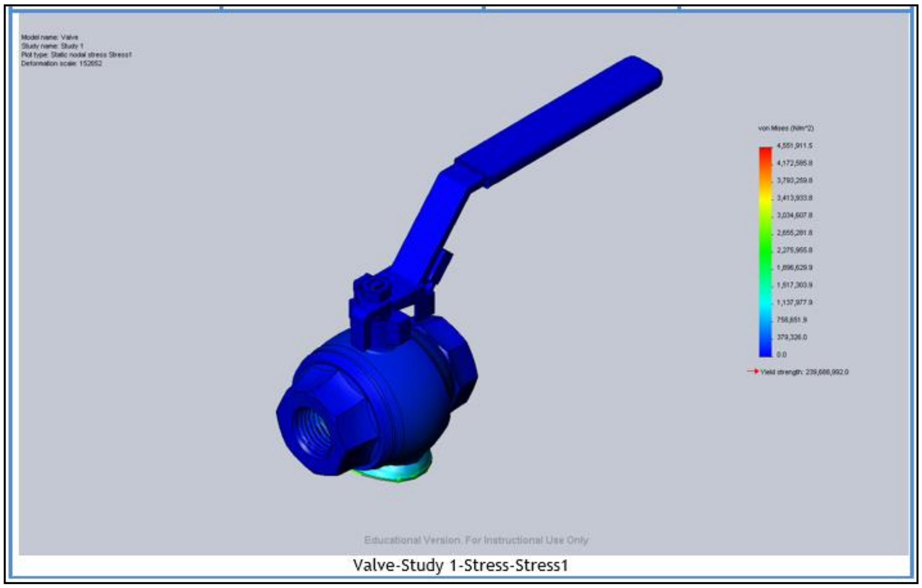


Figure 31. Valve – Stress

There were a couple components that a stress analysis using SolidWorks was not included within the report but performed. The first one is the piston. The reason that the stress analysis was performed for the piston is because the manufacturer guarantees that this component will not fail under the maximum rated pressure. The maximum stress that was found to be in the piston was approximately 12 MPa. Similarly, the air tank simulation was performed but images were not included because of the guarantees from the manufacturer. The tank's maximum stress that was found using the analysis in SolidWorks was approximately 8 MPa. Finally, the pop-off safety valve did not fail under a pressure of 120 psi. The safety valve was designed to release pressure at 125 psi. Since the SolidWorks model of this would be hard to simulate, just the stresses in the actual components were taken and found to be a maximum of 5.5 MPa.

Deflection Analysis

In this section, the deflection of each component will be analyzed using a similar method to the stress analysis. SolidWorks will be used to simulate the amount of deflection of each component when the component is exposed to a pressure of 120 psi. The same components that were analyzed for the stress section will be analyzed for a displacement results.

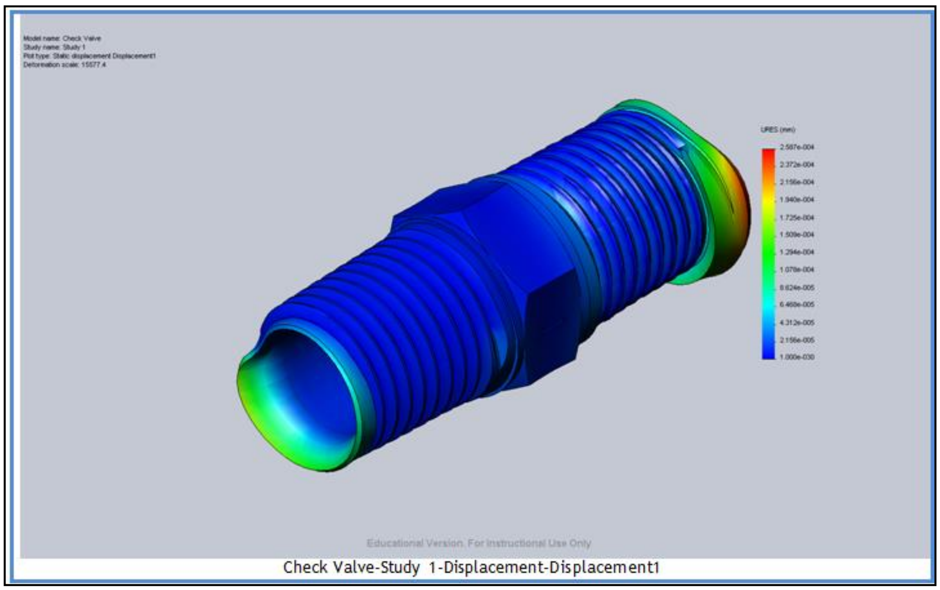


Figure 32. Check Valve - Displacement

The first component that will be analyzed is the check valve. Figure 32 will show the simulation of displacement on the check valve using SolidWorks simulation. This simulation shows that the check valve will flare up at the ends of the valve. Although it looks like the component has a large deflection, the actual maximum displacement is .00026 mm which is equal to 0.26 microns. In order to have an idea of how little this deflection actually is, common bacteria, which cannot be seen by the human eye, is typically 5 - 20 microns. Realistically, the check valve has no displacement.

The second component is the coupler. The displacement analysis of the coupler can be found in Figure 33. Similar to the check valve the amount of

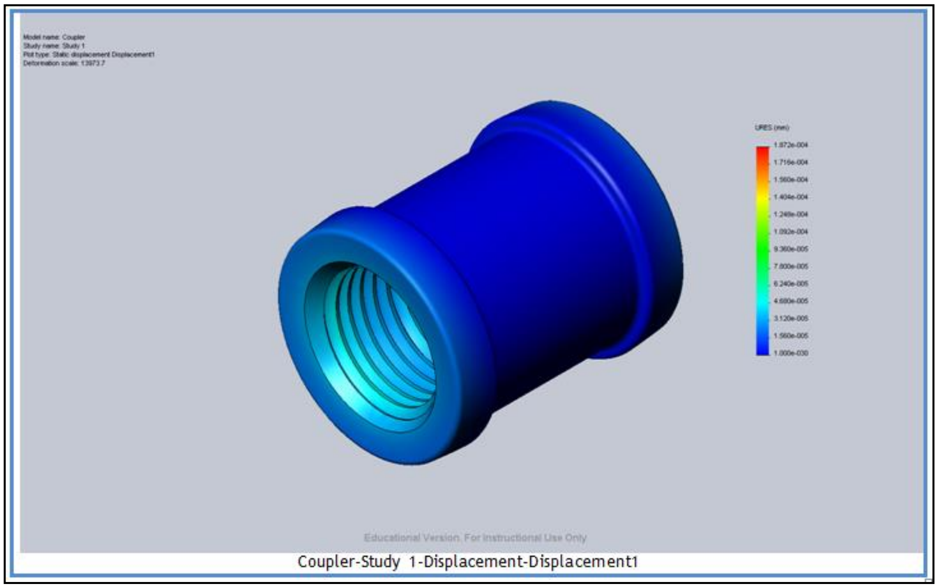


Figure 33. Coupler - Displacement

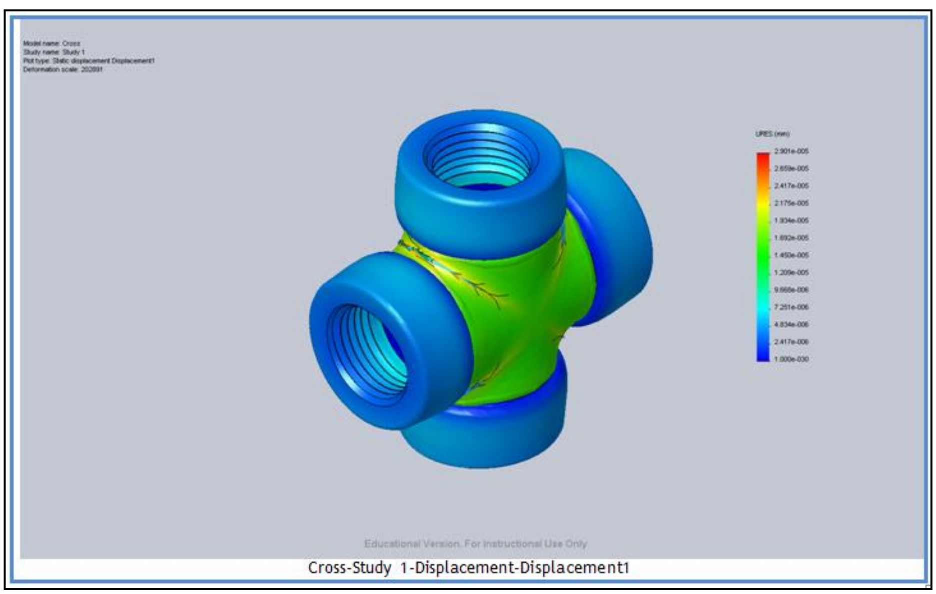


Figure 34. Cross - Displacement

displacement experienced by the coupler under a pressure of 120 psi. The maximum amount of displacement is 0.19 microns.

The results of the cross connection displacement analysis are shown in Figure 34. The maximum amount of displacement that the cross experiences is about 0.029 microns. Figure 35 shows the displacement in the nipple component. The maximum displacement that the nipple experiences is approximately 0.10 microns. So this component will not fail under a pressure of 120 psi.

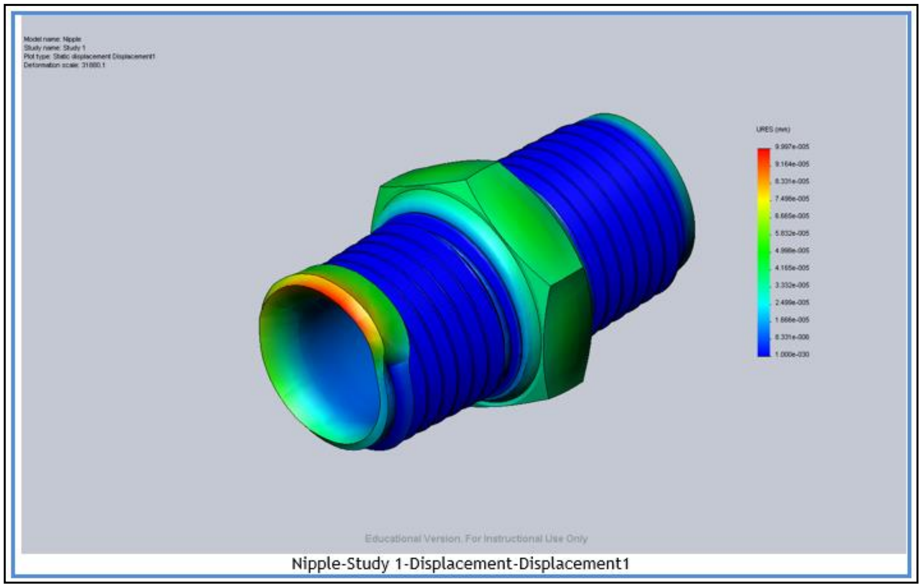


Figure 35. Nipple – Displacement

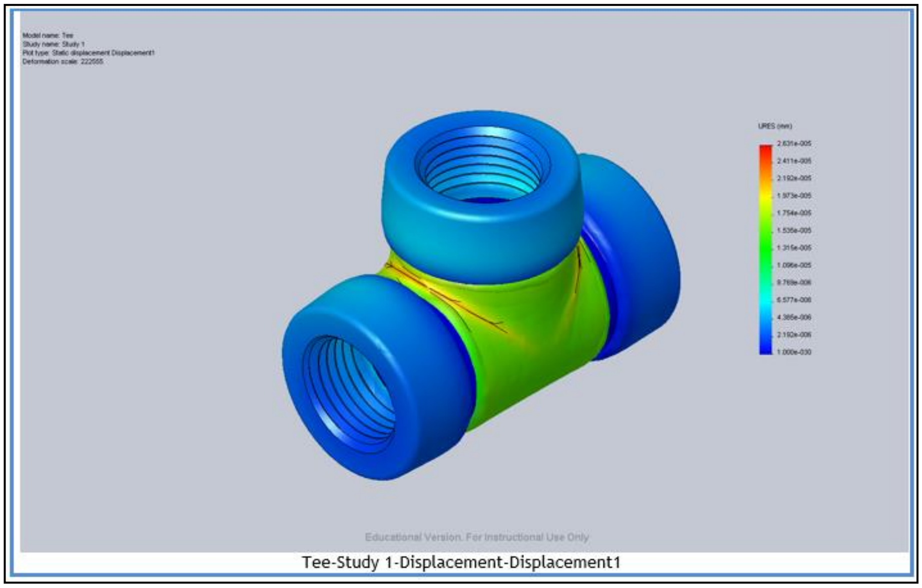


Figure 36. Tee – Displacement

The next component that a displacement analysis was performed on was the brass tee. This displacement simulation can be seen in Figure 36. The maximum displacement in the tee is found to be about 0.026 microns. Just like all of the other components, this displacement is so little that it can essentially be neglected. One thing to note about the tee is that if it fails, it will fail right at the joined sections.

The next and last component that the displacement simulation and analysis that will be shown is the valve. The valve is an important aspect as discussed previously in the report for multiple reasons. This valve is vital that it does not experience a large amount of displacement in order to ensure that the valve does not leak. Figure 37 shows this displacement analysis. The displacement that this valve experiences is 0.078 microns. This displacement is still on a part of the component in which it will not cause a leak. The valve parts that are vital to not leak experiences a displacement of about 0.0006 microns. In perspective, typical gas molecules have a size of about 0.0003 microns which means that even if this component displaces that maximum amount at a vital location only molecules at a time will leak which will be sufficient for this design.

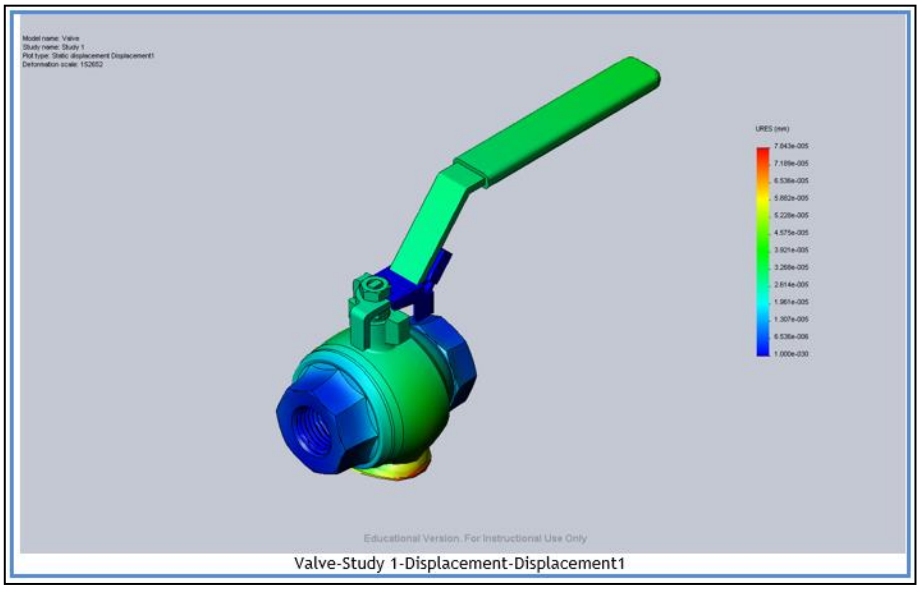


Figure 37. Valve – Displacement

The few parts that the displacement analysis will not be shown are the tank and the pop-off safety valve just like in the stress analysis. The tank actually experiences one of the larger amount of displacement in the components. The tank has a maximum displacement of about 0.09 mm or about 90 microns. This tank still will not fail under the 120 psi pressure and will return to the normal state after the pressure is released. The pop-off safety valve is another component that experiences displacement. The maximum displacement that the safety valve experiences is about 0.18 microns. Both the tank and the safety valve will be safe under the 120 psi pressure.

Material Selection

The material selection for each component was based primarily off of the specifications given on McMaster-Carr's website. For each component, the desired working pressure was selected to be about 100 to 120 psi. This essentially means that the component that was selected would be based off of having a higher maximum pressure than the 120 psi and cost effective at the same time. Not surprisingly, the most common material throughout the components that were selected was brass. There were also components that were steel and aluminum.

The first component that will be discussed is the tie rod air cylinder. This cylinder is made up of two essential parts; the body and the tie rods. The material used for the body of the cylinder is aluminum. This is because the aluminum still allows for the cylinder to be light weight. The tie rods in this specific part are made of steel. Although this will add to the overall weight of the cylinder, the steel will ensure a solid construction and will be more stable than aluminum tie rods. The purpose of the tie rods are to distribute the load so the cylinder itself does not take the brunt of the forces. The compressed air tank is another component that will be discussed. This component will be made out of an aluminum alloy. This will ensure the tank will be lightweight as well as still durable enough to endure the fatigue of constant increase and decrease in pressure. The gauge will be made of multiple different materials. The connections will be brass. The dial case will be made of ABS plastics and the lens will be made of polycarbonate.

The majority of the components are made of brass. These include the check valve, the nipple, the coupler, the reducing nipple, and the valve. All of these components meet the required pressure and the brass material makes the parts cheaper. A couple of the parts will be made of type 304 stainless steel. The two parts that are stainless steel are the cross joint and the tee joint. The reason that the brass items of these could not be purchased is because the maximum working pressure rated for these was 100 psi which would not be sufficient for this project. The air hoses will have two different materials. The air hoses are going to come with the connections already on the ends. These connections will be made of brass. The hose themselves will be made of EPDM rubber which, as discussed previously, will limit the amount of restriction on the air flow.

Cost Analysis

The cost of the entire pneumatic energy converting unit would actually be around $700 to $900 but was greatly reduced due to a couple of reasons. The first reason is that the big money item components were donated. The pneumatic motor, which was one of the components that were donated, would cost around $300. The cylinder cost $107.16. The check valve is going to cost $10.22. Two foot air hose cost $13.04 at a quantity of two it will cost $26.08. Pop-off safety valve (1/4 NPT) at least 100psi cost $19.45. Air muffler (1/4 NPT male) cost $2.23. Cross Joint (NPT F 1/4) cost $11.98. Coupler (F - F NPT 1/4) cost $5.70. Nipple (M - M NPT 1/4) cost $2.30 at a quantity of two it will cost $4.60. Multipurpose Gauge (1/4NPT) cost $15.57. The air valve will cost \$13.28. The T connection cost is \$6.91. The adapter will cost \$5.23, and the reducer will cost \$6.80. Finally the air tank will cost \$30.00. The final total cost will be \$265.21.

Discussion

It is expected that this proposed design should not change much when going into the prototyping phase. The only difference from what is discussed in this section to the prototype is the actual gearing of the pneumatic motor to the generator. This will be limited by the gears that will be able to be manufactured or purchased. Although the cost discussed in the cost analysis is believed to be fairly accurate, it will change a little bit due to this fact. Overall, this is a solid design and should function properly at 100 psi give or take 20 psi.

PROTOTYPE CONSTRUCTION

Overview

The overall prototype construction will be very similar to the proposed design. The proposed design includes most of the parts that are predicted to be used to complete this project. Only unexpected or unforeseeable components will be added and designs changed on the prototype from the proposed design.

Description of Prototype

The prototype that was built did not deviate much from the proposed design that was chosen. The prototype consists of a tie rod air cylinder that when pressed down upon would pump air through the air hose, through a series of valves, and into an air tank. The air is stored as compressed air inside the air tank. Then the compressed air that exits the air tank is regulated with a ball valve and is directed to the pneumatic motor. This pneumatic motor rotates and it is connected to the generator causing it to generate power. Some additional parts were included to the prototype that was not seen in the chosen design, as some unforeseen changes needed to be implemented. These changes and a more in depth description of the design itself are discussed in the prototype design.

Prototype Design

The prototype design of the pneumatic energy converting unit consisted of everything included in the final design that was discussed in the previous section. The tie rod piston cylinder is the main component of the pneumatic energy converting unit. This tie rod cylinder is attached to a red two foot length hose that is located at the bottom port of the cylinder. Attached to the top port of the cylinder will be the muffler in order to dampen the noise and to reduce the amount of particles that are intake into the system. The hose will then be attached to a tee. This is different from the initial design in the fact the hose in the design is connected to a coupler and then straight to the check valve. A problem arose that was not taken into consideration was the fact that when the piston would return to the initial up position, there was no way for it to intake air from the designed set up. This had to be solved by purchasing another check valve and placing the tee in a certain configuration. The tee would have the two check valves one that would allow air intake from the ambient and one that would allow the air flow to go into the tank. This is the main aspect that changed from the initial design.

The check valve will then be directly attached to the tank in the pre-existing connections that are on the tank. This is also one of the main difference from the initial design. In the initial design the tank had no pre-existing connections and an adapter had to be used in order to convert the ½" NPT connection to the ¼" NPT connections used throughout the rest of the system. In the prototype construction, the tank that was used was different from the initial design. This was because when researching the initial design the air tank was chosen based on the cost. When the parts were purchased this specific tank was unavailable so a more expensive tank had to be acquired. Although the tank was a bit more expensive the tank provided some advantages over the initially designed tank. All of the connections of this tank were ¼" NPT connections which was consistent with the rest of the system. This eliminated the need for a connector. The tank also included a pop off safety valve and a pressure indicator which eliminated the need for the other ones, however, the other ones were still used because of the resolution of the one built in on the tank. The last thing that changed is the ball valve of the system. When building the system, we noticed that the ball valve that was sent from McMaster Carr was slightly different than the one that was included in the initial design. This would not pose a problem because it was still rated at a pressure higher than the pressures that the system would experience.

The initial prototype design will also not include the case of the system. The reason behind this is the fact that things can be easily adjusted and changed in order to meet the requirements for certain test parameters that will be set forth in a later section. The case of the prototype will be constructed after initial testing is completed.

Parts List

The parts list is shown in Table 4. It shows the description of the item, the part number of the item, if there was one, and the amount of that item that was used in the prototype design.

Table 4. Parts List

Description	P/N:	QTY
Cylinder	6556K418	1
Check Valve (M - M)	7768K16	2
Air Hose (2 Foot)	1593N4	2
Pop-Off Safety Valve	9889K19	1
Air Mufflers	4450K2	1
Cross Joint	4464K312	1
Coupler	4429K111	1
Nipple	5485K22	2
Multipurpose Gauge	4089K81	1
Air Tank	n/a	1
Ball Valve	4628K81	1
Tee	4464K48	1
Teflon Tape	n/a	1

Construction

To construct the prototype most of the parts were acquired online at McMaster-Carr.com, the air hoses, the pressure gage, all the valves such as the check valves and the ball valve, and the tie rod air cylinder. The air tank that was used was purchased at a local Lowe’s hardware store. The generator was purchased online and the pneumatic motor was donated by Anthony Abrahao research scientist at Applied Research Center at FIU. After all the parts were attained the total construction time of the entire prototype from the initial proposed design took about 20 mins to build. However after construction was completed some unexpected problems arose. The main obstacle was that the proposed design didn’t take into account that as the air cylinder is pulled back up it would suck the air back out of the air tank to fill the cylinder once again. To counter this occurrence a check valve was placed between the hose coming from the air cylinder and the air tank. However a T joint also had to be added between the newly placed check valve and the air hose to avoid suction from taking place and so that the air needed can be draw in from the room and not the air tank. This became the simplest solution as no drastic changes needed to be made to the proposed design to solve this set back. Another minor setback was that as the air pressure built up inside the tank it began to leak out of some openings so the prototype was disassembled and thread seal tape was added to all the joint connections to keep the air from leaking out. After all the adjustments that had to be made the total build time was around 2 hours. The prototype is still missing the generator which will be added after some testing concludes which generator will be optimal choice. This is estimated to add about 20 mins to our total construction time.

Prototype Cost Analysis

Table 5 below will show the cost analysis of the entire prototype unit. This cost includes all but the generator cost which will be discussed in the final cost analysis of the entire system.

Table 5. Prototype Cost Analysis

Description	P/N:	QTY	Price	Total
Cylinder	6556K418	1	107.16	107.16
Check Valve (M - M)	7768K16	2	10.22	20.44
Air Hose (2 Foot)	1593N4	2	13.04	26.08
Pop-Off Safety Valve	9889K19	1	19.45	19.45
Air Mufflers	4450K2	1	2.23	2.23
Cross Joint	4464K312	1	11.98	11.98
Coupler	4429K111	1	5.7	5.7
Nipple	5485K22	2	2.3	4.6
Multipurpose Gauge	4089K81	1	15.57	15.57
Air Tank	n/a	1	67.9	67.9
Ball Valve	4628K81	1	13.28	13.28
Tee	4464K48	1	6.91	6.91
Teflon Tape	n/a	1	4.72	4.72
		Total	306.02	

Discussion

As it was previously stated in the engineering design discussion it was expected that the proposed design would not change much when going into the prototyping phase. The only big difference from the design that was included in the prototype was the addition of the actual gearing of the pneumatic motor to the generator as well as the extra T joint and check valve that needed to be implemented into the design. The cost of the prototype was also fairly close to the initial design. The additional cost came after the addition of some extra parts and the change of the size of the air tank that was purchased.

TESTING AND EVALUATION

Overview

Initial testing took place to ensure the functionality of the system. Future testing included exact energy input versus energy output as well as the efficiency of the whole system. Once initial test procedures were completed on the prototype, modifications were made to ensure that future tests give the results desired. Parameters for the initial testing include force calculations, tank pressure, circuit setup, voltage output, amongst others. Initial testing procedures were completed 5 times to ensure accuracy of results and insure proper system functions. The ultimate function expected from the system will be a force downward on a piston pushing air into a storage pressure tank that will then release the air pressure to spin a motor that is connected to the generator to generate energy and create electricity to run a simple circuit. This run through will be the prototype to further expand this system into generating greater amounts of energy for larger implementation and application.

Designing the experiment will go in a step by step basis to test each part of the system in conjunction to how the whole system will work together. Lastly testing will be done to improve overall output to guarantee enough energy and system efficiency.

Design of Experiments

The design of experiments were based off of engineering knowledge and a simple understanding of statistical analysis. There were three experiments that were designed in order to test the parameters of the pneumatic energy converting unit. The first test that was designed was the test for determining the amount of pressure based on the number of cycles of the piston displaced. The second test was in order to determine the accuracy and repeatability of amount of pressure that was acquired based on a set number of cycles of the cylinder displacement and to measure the amount of time that the system would run the pneumatic motor based on this pressure. The final test was designed in order to optimize the voltage and amperage output of the system by varying the dc motor that will be used for the generator.

The first test was designed to test the amount of pressure that would be obtained from a varying number of cycles. The test must be performed a minimum of three times in order to obtain a statistical average, but in order to increase the accuracy of the data collected, the test will be performed a total of five times. The test will not include the pneumatic motor or the generator. This is because the only focus of this test is to determine the pressure obtained by the number of cycles. The cylinder will be displaced a total of 50 times and the pressure will be recorded. Then it will be displaced 50 more times to obtain a total of 100 cycles and the pressure will then be recorded. This will be repeated up to 300 total cycles with the values of the pressure being recorded every 50 cycles. A prediction formula will be created in order to predict the amount of pressure within the tank at a given number of cycles.

The second test is to determine the repeatability and accuracy of the system. This will be completed by setting the number of cycles to a constant and then measuring the pressure in the tank. The next step is to release the pressure and record the time that it takes for the pneumatic motor to stop rotating. This will be the time approximate that the system will run based on the pressure of the system. This will be performed a number of times for varying cycles.

The final test is the most important test. Since the amount of voltage received will be determined based on the dc motor that will be used, the varying factor in this experiment will be the actual dc motor. The motors will be rated by voltage and the rotations per minute of the system. If a set amount of pressure is used for the test, then it can be assumed that the same amount of rotations per minute will be achieved for the pneumatic motor. This means that the amount of voltage that will be obtained will be determined based on the motors that is used. The amount of pressure will remain a constant of 40 psi. Then the voltage will be measured and the time it takes for the motor to stop rotation will be recorded. This will give a good prediction as the amount of voltage that can be obtained.

Test Results and Data

The test results will be the section in which the outcome of the previously described tests will be presented. The data for each test will be presented as a table form and a visual representation. The first data that was collected was from the first test. This data includes the amount of pressure within the air tank based on the number of cycles presented. This test was performed a total of five times measuring the pressure at every 50 cycles up to a total of 300 cycles. The raw data can be found in Table 6. This table shows the results for each trial as well as the average and standard deviation of the pressures obtained.

Table 6. Test 1 Results

Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Average		Std. Dev
Cycles	Pressure	Cycles	Pressure	Cycles	Pressure	Cycles	Pressure	Cycles	Pressure	Cycles	Pressure	
0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
50	4	50	7	50	5	50	8	50	7	50	6.20	1.64
100	10	100	12	100	11	100	12	100	13	100	11.60	1.14
150	15	150	16	150	14	150	14	150	15	150	14.80	0.84
200	21	200	22	200	18	200	21	200	22	200	20.80	1.64
250	26	250	28	250	24	250	28	250	25	250	26.20	1.79
300	32	300	34	300	30	300	32	300	30	300	31.60	1.67

Figure 38 shows this data in a visual representation format. Each trial is plotted as a different color point for each of the number of cycles. The average values are plotted as well and include a trend line. This trend line equation is given in order to be able to predict the pressure based on the number of cycles. Finally, the R^2 value is given as well to show how closely the predicted values will match with the actual values.

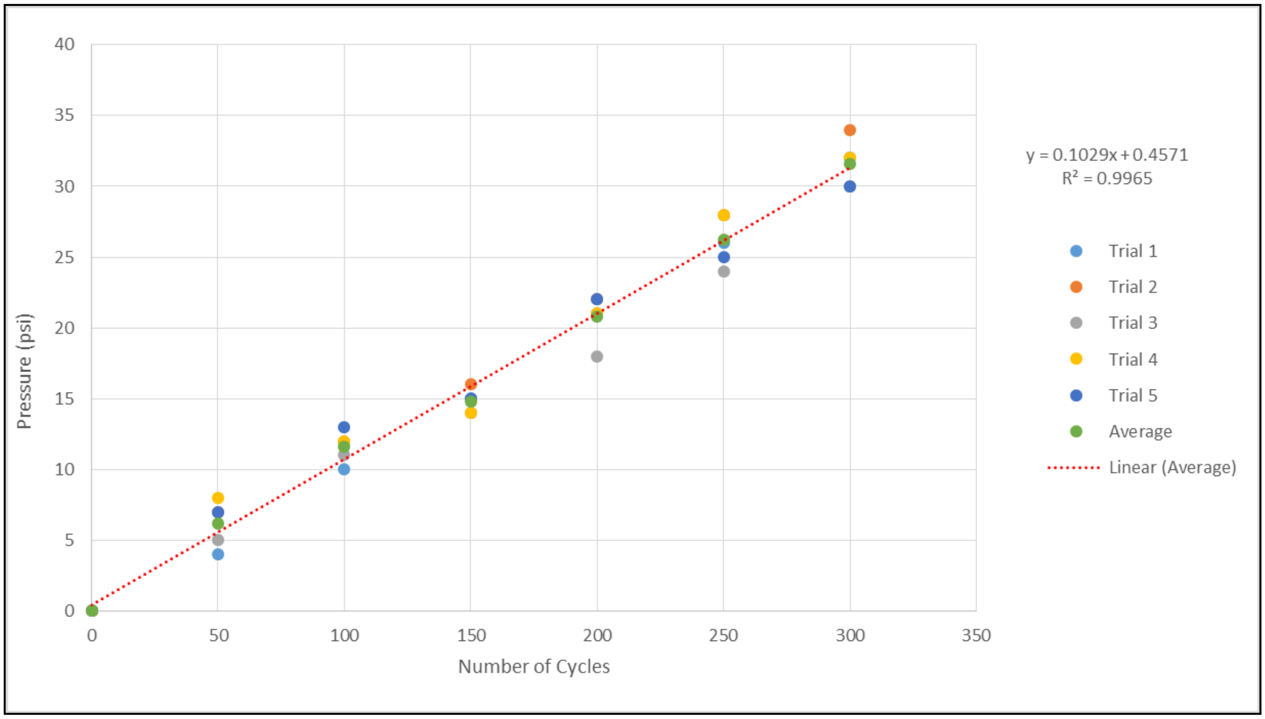


Figure 38. Graph of Cycles vs Pressure

The next test will be focusing on the amount of time that the system can operate at and the amount of pressure within the tank at a certain amount of cycles. Similar to the first test, there will be five trials of each 100 cycles, 200 cycles, and 300 cycles. Table 7 will show the raw data collected from this test and Figure 39 will show the graph of the number of cycles versus the amount of time the system will run for the average values calculated in Table 7. It is important to note that although the time was pretty consistent throughout the testing, it seemed like the rotations per minute of the system were inconsistent. This was noticed by the difference in the sound of the motor. When the motor sounded lower, the motor was rotating at a lower rpm then when it was a higher pitched. It seemed to vary throughout the time of operation.

Table 7. Test 2 Results

Cycles	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Average	
	Pressure (psi)	Time (s)	Pressure (psi)	Time (s)	Pressure (psi)	Time (s)	Pressure (psi)	Time (s)	Pressure (psi)	Time (s)	Pressure (psi)	Time (s)
100	11	24	12	25	10	24	10	22	11	26	10.8	24.2
200	19	50	21	49	18	47	22	50	18	49	19.6	49
300	31	79	33	79	28	76	29	78	31	79	30.4	78.2

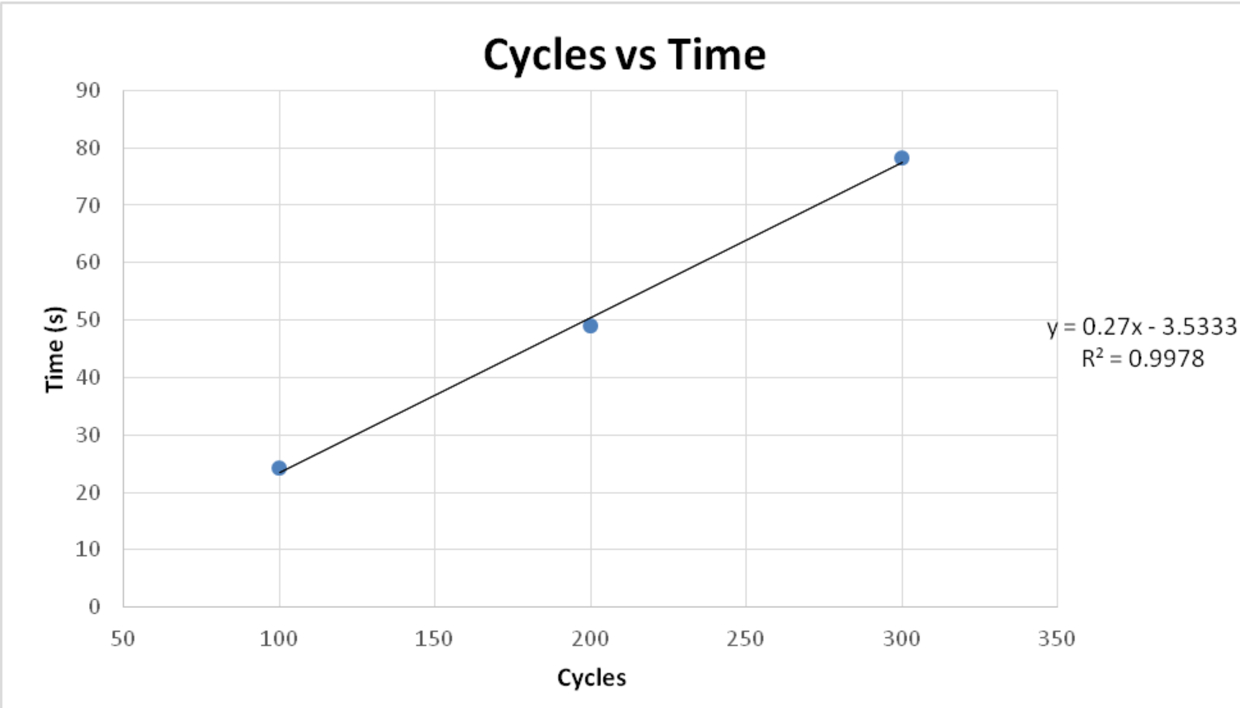


Figure 39. Graph of Cycles vs Time

The next test will be focusing on the amount of voltage that the energy converting unit can supply over a period of time. The unit will be cycled up to a point of 40psi. The valve will then be released and the voltage across the dc motor will be measured using a digital multi meter. When performed, the test showed that the voltage varied widely with time. This is probably due to the fact that the pressure in the tank will vary with each test. This is due to the human error that will come from reading the pressure gauge. Table 8 below shows the experimental data collected from this test. It shows all five trials and gives the average voltage for each time step.

Table 8. Test 3 Results

Time (s)	Test 1 Voltage (V)	Test 2 Voltage (V)	Test 3 Voltage (V)	Test 4 Voltage (V)	Test 5 Voltage (V)	Average Voltage (V)	Standard Deviation
1	34.3	38.1	31.9	35.9	36.7	35.38	2.38
2	37.3	41.7	41.3	42.3	41.5	40.82	2.00
3	37.6	40.8	40.9	41	41.2	40.3	1.52
4	37.2	39	39.4	40	40.2	39.16	1.19
5	36.8	37.3	38.2	38.6	39.1	38	0.94
6	36.3	36.5	37.5	37.5	38.7	37.3	0.96
7	35.8	36.3	36.6	36.6	37.3	36.52	0.54
8	35.3	35.8	35.9	35.3	36.4	35.74	0.46
9	34.6	35	35.6	34.9	35.3	35.08	0.38
10	33.9	34.3	35.1	34.5	34.9	34.54	0.48
11	33.7	34.1	34.4	34.4	34.6	34.24	0.35
12	33.4	33.8	34.2	34.1	34	33.9	0.32
13	33.2	33.6	33.9	33.7	33.6	33.6	0.25
14	32.8	33.2	33.4	33.5	33.3	33.24	0.27
15	32.1	33	33	33.1	33	32.84	0.42
16	31.7	32.8	32.7	32.7	32.8	32.54	0.47
17	31.4	32.4	32.4	32.4	32.5	32.22	0.46
18	30.9	32.1	32.2	32.2	32.2	31.92	0.57
19	30.6	31.9	31.7	32.1	31.9	31.64	0.60
20	30.1	31.5	31.3	31.6	31.7	31.24	0.65
21	29.7	31.3	31	31.4	31.2	30.92	0.70
22	29.1	30.6	30.6	31.2	30.9	30.48	0.81
23	28.7	30.3	30.3	30.8	30.5	30.12	0.82
24	28.2	29.9	30	30.5	30.2	29.76	0.90
25	27.3	29.1	29.5	30.2	29.9	29.2	1.14
26	26.6	28.8	29.1	29.9	29.6	28.8	1.30
27	26.4	28.5	28.4	29.3	29.1	28.34	1.15
28	25.8	27.8	27.9	29	28.8	27.86	1.27
29	24.9	27.2	27.5	28.5	28.6	27.34	1.49
30	24.7	26.8	27.1	28.4	28.4	27.08	1.52
31	24.2	26.2	26.6	27.6	28	26.52	1.49
32	23.1	25.5	26.1	26.9	27.5	25.82	1.70
33	22.2	24.7	25.3	26.5	27.2	25.18	1.93
34	20.6	23.9	24.2	25.6	26.8	24.22	2.33
35	19.9	23.2	23.5	25.7	26.3	23.72	2.52
36	18.6	22.5	22.8	25.1	25.9	22.98	2.85
37	17.5	22.1	21.9	24.4	25	22.18	2.95
38	16	20.9	21.2	24.1	24.6	21.36	3.43
39	15.3	19.6	20	23.4	24.2	20.5	3.54
40	14.3	18.5	19.4	22.9	23.8	19.78	3.80
41	13.1	17.5	18.8	22.6	23.1	19.02	4.09
42	12.8	16.1	17.5	21.7	22	18.02	3.89
43	11.7	15	16.9	21.1	21.2	17.18	4.07
44	10.2	13.7	15.5	20.2	20	15.92	4.27
45	9.7	11.9	14	19.5	18.1	14.64	4.12
46	9.2	11.7	13	18.2	15	13.42	3.40
47	8.7	10.4	11.9	17.4	14.2	12.52	3.40
48	8	10	11.1	15.9	13.1	11.62	3.02
49	7.3	8.9	10.6	14.3	12.2	10.66	2.74
50	6.6	8.7	9.3	13.1	11.5	9.84	2.52
51	6	8.4	8.5	12.4	10.8	9.22	2.46
52	5.6	7.9	7.8	11	9.8	8.42	2.07
53	4.8	7.2	7.1	9.9	8.7	7.54	1.92
54	4	6.5	6.5	9.2	7	6.64	1.85
55	3.3	5.9	5.8	8.2	6.6	5.96	1.77
56	3	5.4	5.1	7.4	5.7	5.32	1.57
57	2.6	5	4.4	6.7	5.2	4.78	1.48
58	1.5	4.1	3.2	6.3	4.9	4	1.80
59	0.7	3.8	2.6	5.4	4	3.3	1.76
60	0	2.6	1.4	4.1	3.1	2.24	1.59
61	0	2	0	3	2.2	1.44	1.37
62	0	0	0	2.5	0	0.5	1.12
63	0	0	0	0	0	0	0.00

This table shows exactly how much voltage can be acquired when the valve is fully opened and the digital multi meter is applied to the dc motor. One thing that should be noted is that this test will provide the maximum voltage that can be acquired at that pressure. The time that this test will last is the amount of time that the pneumatic motor can be run at the valve being fully opened. Table 9 below shows the amount of cycles that it took to acquire a pressure of 40 psi and the percentage error associated with the predicted amount. Figure 40 shows the voltage with respect to time for all five tests. The graph shows that it takes a small amount of time for the voltage to reach its maximum value and then it slowly decreases over time.

Table 9. Experimental Cycles vs Theoretical Cylces

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Experimental Cycles	398	400	395	402	400	399
Predicted Cycles	385	385	385	385	385	385
% Error	3.27%	3.75%	2.53%	4.23%	3.75%	3.51%

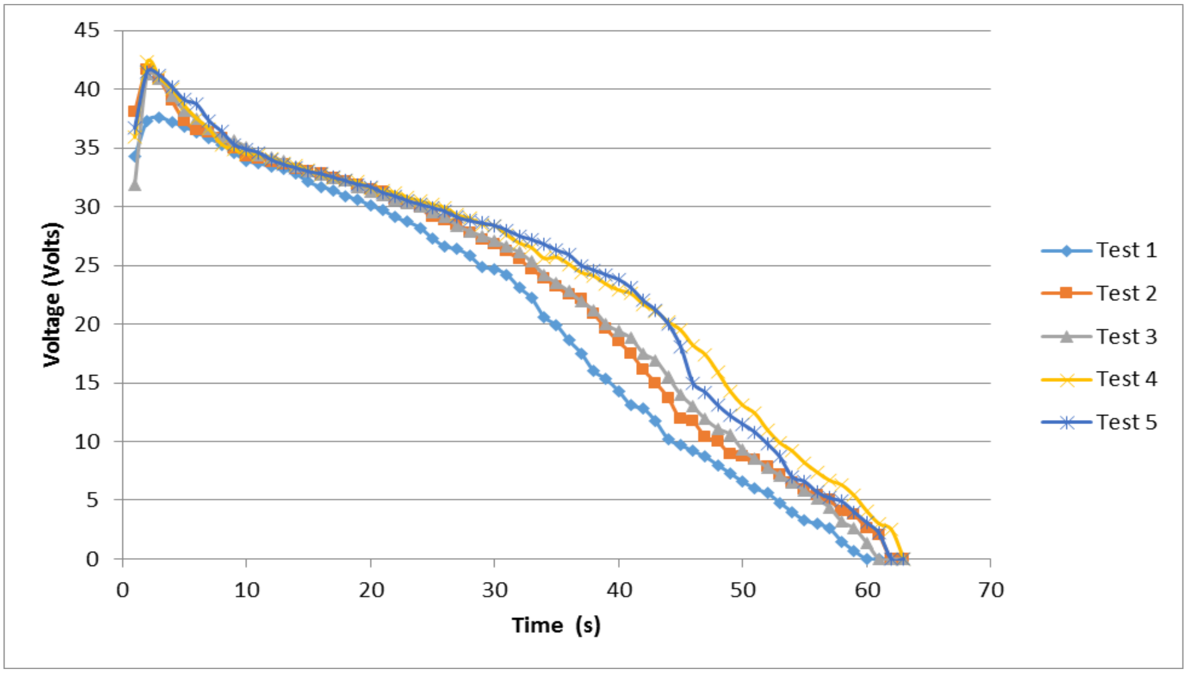


Figure 40. Voltage vs Time

The maximum voltage that the system reaches under a pressure of 40 psi is equal to 42.3 volts which happened during test 4. The average time that the system was able to operate between all five tests was 60.6 seconds. This is an approximation because the human error that is associated with taking the readings. Test number 1 had a maximum voltage of 37.6 volts and lasted approximately 59 seconds. Test number 2 had a maximum voltage of 41.7 voltage and lasted 61 seconds. Test 3 had a maximum voltage of 41.3 volts and lasted 60 seconds. Test 4 had a maximum of 42.3volts and lasted 62 seconds. Test 5 had a maximum of 41.5 volts and lasted 61 seconds.

Table 10. Equations for Efficiency

Input Power	$P = \frac{F \times D}{t}$
Mechanical Power	$P_{ME} = \Omega \times T$
Electrical Power	$P_{ELE} = V \times I$
Input – Mechanical Efficiency	$\eta = \frac{P_{ME}}{P} \times 100$
Mechanical – Electrical Efficiency	$\eta = \frac{P_{ELE}}{P_{ME}} \times 100$
Overall Efficiency	$\eta = \frac{P_{ELE}}{P} \times 100$

The efficiency of the entire system could be calculated from this data that was acquired. First, it will be important to look at the efficiency of the system with respect to thee input power and the mechanical power that will be outputted by the pneumatic motor. Then the efficiency for the mechanical power to the electrical power will be discussed. Finally, the overall efficiency will be found by comparing the input power to the electrical output power. The input power of the system was found by using this simple formula found in Table 10 above. The mechanical power formula will also be found in Table 10 as well as the formulas for all of the efficiencies. The input power came out to be 67.79 Watts, which was calculated from constants given from the tie rod cylinder and the force applied. The mechanical power was found by using the torque of the pneumatic motor multiplied by the angular speed of the pneumatic motor. The angular speed was averaged with respect to time in order to get a consistent value. The mechanical power was found to be 2.90 Watts. This allowed for an efficiency of 4.28%. The electrical power was calculated by taking the voltage of that was recorded and multiplying it by the rated amperage of the motor. This was found to be 2.26 Watts, which would allow for an efficiency of 77.85% when comparing the electrical and the mechanical powers. The overall efficiency was calculated to be 3.34%.

Evaluation of Experimental Results

The results that were obtained from the testing showed promising results. The first test showed that the pneumatic energy converting unit will be consistent. What this means is that the unit will be able to create a consistent amount of pressure for a certain amount of cycles that the tie rod cylinder is compressed. When the test was performed, the tie rod cylinder was compressed 300 times. When the pressure was read, the pressure of each result was within 4 psi of each other. This proves that the pneumatic energy converting unit has a high repeatability which is beneficial when expectations of the voltage that the unit is able to supply is given. This test also gives an equation to predict the amount of pressure able to be built up by the system based on the number of cycles which is roughly linear. For the third test, a pressure of 40 psi is desired and the predicted amount of cycles it will take will be 385 cycles.

The second test is an important test that will give vital information on the amount of time that the system can operate based on the amount of cycles. The test was performed by increasing the cycles in steps of 100 cycles all the way up to 300 cycles. From this test, it can be concluded that the amount of time the system will operate at is roughly linear with the amount of pressure. The predicted amount of time that the pneumatic motor can operate at can be calculated by using the given equation on figure 39. The predicted amount of time that the system can operate will be equal to 100.5 seconds if the predicted amount of cycles is used.

The third test is the test that ties the previous two tests together. This test shows the amount of voltage that can be obtained from the system based on a standard pressure of 40 psi. The number of cycles to obtain the 40 psi were also measured and the percentage error associated with the predicted value will be obtained. The first part of this test, which is the amount of time that the system will operate, will allow for a predicted amount of time to be compared with the actual time it ran. This comparison will be a good start to an efficiency calculation of the system. The predicted amount of time that the system would operate was 100.5 seconds. For the first trial of the third experiment, the amount of time the system operated for was 59 seconds. This gave an efficiency of approximately 58.7%. The second trial lasted for 61 seconds and gave an efficiency of 60.7%, which is an improvement from the first trial. The third trial operated for 60 seconds for an efficiency of 59.7%. The fourth trial operated for 62 seconds for an efficiency of 61.7%, which was the highest efficiency. The fifth trial operated for 61 seconds for an efficiency of 59.7%. The average amount of time that the system operated for was 60.6 seconds for an average efficiency of 60.3%.

There is a multitude of reasons for the efficiency of the system to be between 58% and 62%. The reason that the five tests are within a close amount of efficiency is because as stated before, the unit is very consistent. The pneumatic energy converting unit was extremely consistent throughout all three experiments. This would explain why the efficiency for each trial were close in values. The efficiency was much lower than initially desired due to a couple different reasons. The first main reason that affects the efficiency of the system is the mounting of the components. The connection between the pneumatic motor and the dc motor, or the generator, must be exactly aligned in order to avoid vibrations and wobbling of the motor. The pneumatic motor spun at such a high angular velocity that it begin to actually cause the dc motor to slip within the bracket. This will cause the efficiency to be less than expected if the motor was slipping. Another main reason for the low efficiency was the wobbling previously discussed. Wobbling between the connection of the pneumatic motor and the generator was noticed during all three experiments. This problem was addressed by mounting the pneumatic motor and the generator more accurately but was still present after the troubleshooting. Although wobbling was still noticed, the amount was greatly reduced. Another reason for the relatively low efficiency was something that was overlooked when the predicted time was calculated. The experiment for the amount of time that the system would operate for was performed under no loading of the pneumatic motor. The pneumatic motor was not attached to the generator for this test, so the torque required to rotate the generator was not taken into account. This torque would naturally decrease the amount of time that the system could operate. In conclusion, this reason was the main factor in the low efficiency of the system.

The second part of the third experiment was the voltage that could be supplied by the pneumatic energy converting unit. From research, the voltage that could be obtained from the dc motor was proportional to the angular velocity that given from the pneumatic motor compared to the rated rpm of the motor. For example, if a 12 volt dc motor that was rated at 1200 rpms was being operated at 1000 rpms, the expected voltage supplied could be approximated as 10 volts. The motor that was used for the third experiment was a 12 volt direct current motor that was rated at a 50mA amperage and a rotational speed of 500 rotations per minute. When this test was performed, something unexpected happened. The expectation was to receive, at best, 12 volts of direct current. From the results of this experiment, it can be seen that the maximum voltage that was obtained was equal to 42.3 volts. This means that the maximum rotation speed that the pneumatic motor was driving the generator at was around 1,762.5 rpm. From this result, a different motor can be used to change the results to a desired amount. If a voltage of 12 volts is desired then a dc motor rated around the 1,762.5 rpm can be used. The torque required to operate this dc motor would be approximately 1/3 of the torque of the motor used. The amount of time that this motor could operate for would be expected to be much longer if the torque is that much lower. Having a lower voltage for a prolonged amount of time could prove more beneficial than having a high amount of voltage for a relatively short time.

The relatively low efficiency can be explained by a couple reasons. First, the efficiency of the mechanical to electrical will be discussed because it will consist of the most efficient aspect of the pneumatic energy converting system. This efficiency was found to be 77.85%. The reason for the loss of efficiency in this aspect can be explained by two main reasons. The first one being the fact that there will be some power lost to heat loss in this system. The faster the pneumatic motor spins, the more friction it will cause which will increase the heat. The second part that attributes to the efficiency of the mechanical to the electrical will be the actual mounting of both the pneumatic motor and the dc generator. Unless the motors are mounted extremely accurately, there will be a loss of power due to this. This will be the cause of most of the energy loss in this section. The input power to the mechanical power will be discussed next. This will be where the majority of the power loss will come from. Most of this power loss will be due to the heat loss that will be caused by the compression of the air within the tank.

Improvement of the Design

This design was very consistent throughout testing which proves that it was designed relatively well. There were some components of the system that could be improved to increase the overall efficiency of the system. The first improvement that could be made was discussed in the previous section. A motor rated at the higher rotational speed and a lower torque rating could be used to increase the amount of time that the system could operate. This would mean that the voltage could be supplied for a much longer amount of time. In situations where this would be used to power a light source, this could provide light for a much longer period of time. Increasing the amount of time that the voltage could be supplied for will be one of the major improvements of the design.

An improvement from the prototype will be the case. The prototype was a bare bone unit that was used to prove the concept more than to be actually implemented into a situation. Although minor modifications could be made in order to actually use the pneumatic energy converting unit, major improvements must be made to obtain the level of quality desired for the final product. The improvement will be to create a metal housing that would be water resistant and particle resistant. What this would allow for will be for the unit to be implemented into situations that the unit will be desired in such as the speed bump application, the side walk application, or other applications of the pneumatic energy converting unit. This could be done from manufacturing a case with stainless steel construction with every opening containing a seal to prevent environmental exposure of the internal components.

Another improvement of the design that was discussed was the tie rod cylinder. The tie rod cylinder that was used was obtained mainly for financial reasons. It was the most cost efficient cylinder that was within the budget of the project that would provide the necessary forces for the system. This could be a component that could be improved by solely purchasing a better cylinder. The surface area of the internal cylinder could be increased in order to increase the volume of air that would be compressed into the tank with a given cycle. This would improve on the number of cycles to obtain a certain pressure. If the cylinder area was doubled then it could be expected that the amount of cycles to reach a certain pressure would be halved. There would be an issue when increasing the volume of air that would be compressed into the tank per cycle. This would increase the force required in order to compress the cylinder. One thing that was noticed during testing was the cylinder became more difficult to compress as the number of cycles increased. When the surface area of the cylinder increases, the force required to compress it would naturally increase. The decision for the size of the cylinder to be used would be based off of the application of the pneumatic energy converting unit. If the unit would be implemented into the speed bump application, then a much larger cylinder could be used in the system, which in turn would allow for a much larger air tank to be used. This scaling up of the unit would allow for the time of operation to be greatly increased. This leads to the next improvement of the pneumatic energy converting unit.

The air tank for the unit could also be changed to improve the pneumatic energy converting unit based on the application. This would be similar to the cylinder. The larger the scale of the implementation, then the larger air tank could be used which would lead to a longer operation of the system. This would mean that the voltage could be supplied for a much longer amount of time. Another aspect of the tank that could be improved would be the rated pressure of the tank. Similar to the tie rod cylinder, this air tank was selected due to budgetary constraints. With a larger budget, a higher pressure tank could be used which would allow for a higher volume of air to be stored. This would translate directly to a larger amount of energy that could be obtained from the unit.

Finally, the last improvement of the pneumatic energy converting unit would be the mounting of the components. As discussed previously, there was quite a bit of vibration and wobbling due to the high rotational speed of the pneumatic motor. A higher accuracy mounting could be done in order to improve the unit. For the prototype, the components were mounted using simple brackets that allowed for a compression on the components in order to keep them in place. Ideally, a custom manufactured apparatus would be made in order to accurately mount the pneumatic motor to the generator. In theory, this would increase the efficiency of the system by reducing the amount of vibration and wobbling.

Discussion

The data that was obtained from the prototype testing demonstrated promising results. Through multiple testing and calculation the pneumatic energy converting unit showed a steady consistence throughout the testing phase. The unit was able to provide a consistent amount of pressure after multiple trails this made it easier to calculate a fairly accurate voltage that the unit would produce. The results showed a direct relationship between the pressure and the amount of time the system will operate to be linear, from these results the unit was calculated to have an average efficiency of 60.3%. Since the pneumatic energy converting unit was extremely consistent throughout all the tests this average efficiency of 60.3% can be assumed to be fairly accurate.

DESIGN CONSIDERATIONS

Health and Safety

The idea behind this design is to create a system that is easily integrated into any environment while keeping a low profile. In other words, you want it to fit in without standing out. It was vital that the system did not impose any hazards while it is implemented. For ethical purposes, considering all health and safety implications was taken very serious. Beginning from the conceptual design process, we considered materials and fluids to be nonhazardous for the energy converter. For that reason, air was chosen as the fluid in the converter. Also, extensive structural analysis was done to ensure the safety of the system and prevent any accidents. Health and safety considerations are the reasons why standards are in place, especially standards from the International Organization for Standardization and the International Classifications for Standards. The final design maintains a sound structure to avoid any health or safety misfortunes.

Assembly and Disassembly

The assembly and disassembly of the energy converting unit was streamlined and made extremely simple. The assembly of the energy converting unit requires simple tools that are readily accessible. The assembly can be done by using simple Channellocks or an adjustable wrench. It will be preferred to have two of these types of tools available to use because it will make the process much easier, but the assembly can be done by using just one of these tools. The energy converter unit can be assembled by simply attaching the components in their respective locations. The procedure for assembling the energy converting unit will be shown below.

1) Begin with the tie rod cylinder. Screw the muffler into the top ¼” NPT female connection.

2) Screw one end of the red 2 foot hose into the bottom connection on the tie rod cylinder.

3) Screw the other end of the hose into one part of the pipe tee fitting.

4) Take one of the check valves and screw into one of the connections of the tee. Make sure that the air flow is going into the tee fitting.

5) Take the other check valve and screw into the last connection of the tee. Make sure that the air flow is going out of the tee fitting for this check valve.

6) At the other connection of the check valve that has the air flow going out of the tee, connect it to the air tank on one of the fittings.

7) In the other connection on the air tank, connect one of the pipe couplings.

8) At the other end of the pipe coupling, connect the cross joint.

9) Screw the pressure gauge into one of the connections of the cross joint.

10) Screw the pop off safety valve into one of the connections of the cross joint.

11) Screw the other coupling into the last connection of the cross joint.

12) Attach the ball valve onto the free end of the coupling.

13) Attach one end of the black hose to the other end of the ball valve.

14) Screw the other end of the black hose into the adapter.

15) Screw the adapter into the reducer.

16) Attach the reducer to the pneumatic motor.

17) Attach the chuck that is on the pneumatic motor to the electric generator.

18) Place all of the components into the case.

19) Finally, place the springs over the rod of the tie rod cylinder and tighten the nut.

The disassembly of the energy converting unit will be simpler than the assembly. All that is required is to disconnect all of the individual components of the unit. This is simple done by screwing all of the components counter-clockwise with respect to the top of the component. All of the components can be stored within the case when the energy converting unit is disassembled.

Manufacturability

The manufacturability of the energy converting unit was an important aspect of the design. The purpose of designing for manufacturability is to take into account all of the necessary procedures for manufacturing the product. A good example of this is taking into account machining limits, tool limits, and implementation limitations. All of these factors plus other ones affect how easily the product is manufactured. Designing for manufacturability also allows troubleshooting before reaching the prototype phase which can lead to saving money.

When designing for manufacturability of the energy converting unit, the main aspect that was taken into account involved the global design component. Since one of the goals of the energy converting unit was for it to be easily implemented into a variety of different environments and situations, the energy converting unit had to be extremely simple to manufacture. The only aspect that will have a difficult, and this is in comparison to the rest of the unit, manufacturing process will be the case. The case will be the main component that will require manufacturing. This case also will depend on the desired implementation of the unit. If the unit will be working in a caustic or harsh environment, then more work will go into manufacturing the case so that it will be more corrosion resistant. The case that was created for the prototype was a simple case to prove the concept more than anything and will not be part of the final design, or the future design. The case, like stated previously depending on the implementation, will have the potential of needing to be welded, riveted, bolted, sealed, and other procedures. Other than the case the only procedures of manufacturing is the electrical component. This also will depend on the application that it will be used for. Ultimately, the goal will be to essentially replicate a generator in that it will have a plug on the side of the case. This will be the situation for the base model, which is just the table top version. When alternating the implementation, like under water or in a speed bump this feature would be essentially useless. The manufacturing of this proof of concept version will be to create a small electrical component with a small capacitor and plug where a standard 115v plug can be plugged into.

Maintenance of the System

Regular Maintenance

There will be very little maintenance on the unit. This comes back to the fact that the unit was designed to be implemented into a range of environments and situations. Because of this fact, the energy converting unit needs to have very simple maintenance. The only regular maintenance that will be important in the energy converting unit is to make sure that rod in the toe rod cylinder is lubricated. This will be important because the rod will eventually lose its lubrication which will lead to negative side effects. Without lubrication, the rod will slowly erode material away from either itself or the cylinder casing. This will lead to a less efficient unit very quickly. The pneumatic motor will also need to be lubricated as it was noticed that as the pneumatic motor would spin, the lubrication would begin to spin out of the actual shaft. A more detailed guide to the minor maintenance of the system can be found in appendix b which will show the user manual for this unit.

Major Maintenance

The major maintenance will be considered repairs that happen infrequently or scheduled non-routinely. These type of maintenances will usually require for the unit to be put out of commission for a certain amount of time. Sometimes these types of maintenance will require additional funding that may or may not get expensive. For the energy converting system, the major maintenance that could occur is the replacement of a component. This would require additional funds as well as the system being shut down for a brief amount of time. The pneumatic energy converting unit has a very easy assembly and disassembly so when a component fails the first step will be to determine which component has failed. This can be performed by looking for a leak if the system is leaking air. This can be done by ear or using slightly soapy water. This will allow for the air escaping to create bubbles which will be visible to the human eye.

Another major maintenance that may be required will be to replace the dc motor. There will be a concern as to the dc motor eventually burning out. This would happen when the motor overheats the excess heat created could melt the varnish covering the coils within the motor. This would cause the motor to short circuit. The simplest solution to this happening will be to replace the motor. Since the motor will be relatively inexpensive, it will not cost a great deal to replace this component. It will be a possibility that the unit will be in a location that simply replacing a component will not be possible. If this is the case then the solution will be to try and bypass the component or in the case of the motor the windings will have to be rewound. This is an expensive and time consuming process that should be a last resort. A more detailed discussion of the major maintenance can be found in appendix b, the user's manual.

Environmental Impact and Sustainability

As stated earlier, the unit was designed to be implemented into a range of various environments. This was one of the reasons that the pneumatic energy converter design was chosen as oppose to the hydraulic energy converter. Taking into account that the unit needs to be environmentally safe the pneumatic unit provides a design that has several significant advantages over the hydraulic unit. The main advantage would be that if any of the unit's hoses were to rupture or begin to leak the pneumatic unit would only be leaking air into the environment and it can easily be fixed without damage to the unit or the environment. However, if the hydraulic unit was to leak, the hydraulic fluid would be released into the environment which can be harmful to the local wildlife. Therefore, to have a positive environmental impact the pneumatic unit was the best choice of all the proposed designs.

DESIGN EXPERIENCE

Overview

The design experience has been very revealing for all group members involved. It has been a learning experience from the conception of the design throughout its execution. There were several iterations of the initial design to the ultimate final design to produce a system that achieves the initial objective of the design idea to create an efficient and easily integrated energy converter.

Also, the simulations and analysis of all the parts of the system was a vital experience in the design process. It was important to analyze all forces and stresses on the system since it is intended to withstand various environments. Analysis of the system dynamics was performed to ensure that the way forward of the design and system prototype was accurate.

The building portion of the entire experience was one of the most exciting. It was rewarding to see the concept come to life. After the conceptual design, the building process brought about new problems, many “Form, Fit, Function” problems which caused alterations in the design layout. This, however, was very beneficial in this entire learning experience. For example, when connecting the piston cylinder to the system there was no spring back mechanism on the piston. This led to the addition of a compression spring on the piston rod. Additional considerations included the spring factor, length of the spring, material, and wire dimensions. It taught each team member basic problem solving skills as well as the engineering skills to modify the system.

System testing and experimenting was also a new experience for the team. Similar to the engineering curricula, this portion involved many calculations and graphical representations.

However, gathering actual data from a personal design was much different than a simple homework assignment. This data analysis involved assigning your own independent and dependent variables as well as initial conditions to obtain results within valid range, especially the efficiency calculations of the system.

Overall the design experience teaches fundamental skills in project management. Project management includes the design, the execution, the test, the final product, as well as all who is involved including the end user. This was especially true for this team. The team learned how to deal with different personalities and working methods though in the end, they came together as a team.

Standards Used in the Project

In continuation of the Survey of Related Standards, some standards were used more extensively than others. In the beginning, since the first design iteration was strictly a hydraulic energy converter, the Performance Test Code (PTC) 28-2011 for Hydraulic Turbines and Pump Turbines Energy Efficiency and PTC 18-2011 for Hydraulic Turbines and Pump Turbines Renewable Energy were used for the initial conceptual design as a system level standard. Utilizing these codes during the initial stage of the project was vital to deciding what the parts that will be implemented in the system. A hydraulic piston and motor were decided upon and the final design changed to a pneumatic system. The testing procedures from these PTC's were used in designing the experiments for the energy converter. Then all standards from the International Organization for Standardization were used for compliance throughout the building process. Especially, the Fluid Systems and Components for General Use – Valves was referenced as a component level standard while choosing the valves for the system. It was an important standard to understand the ball valve and check valve as well as their integration with the rest of the components of the energy converting system. Lastly, to gain a full understanding of the energy converting process, the ICS 27.140 standard from the International Classification for Standards was used for Hydraulic Energy Engineering. This standard was useful in the overall objective of this design to convert energy.

Impact of Design in a Global and Societal Content

This design arose with the purpose of having a global impact. This system's intended impact is to be utilized on an everyday basis in societies of all socioeconomic standings. The idea of generating alternative energy is mainly focused for underdeveloped countries and villages with little or no access to power. Conversely, the greater the use of this system in places of more advanced technologies with higher populations, the greater the amount of energy output. This is especially beneficial for higher socioeconomic societies to reduce the cost of maintaining a rising population.

Having a global mindset from the inception of this system allowed for the design process to flow smoothly. The last thing to address in order to introduce this system to the world is for it to become known. This is a system that urban and regional planners should know of to include in their developments. This is a design that has the ability to pave the future, literally. The reason being is that the system can be integrated into several applications as was discussed in earlier sections. People could go over the piston in several ways without exerting excess effort to push the piston, there could also be greater force exerted on the energy converting system from a car going over speed bumps or introducing it into larger mechanical systems. The future work required for the system is branding. With branding this design will make its mark on the world.

Life-Long Learning Experience

This experience has brought to light the need for life-long learning. The reason being is that in life and in the engineering profession there will always be a problem to solve and not all problems will have an obvious response. This design experience showed that there are unexpected obstacles that have to be overcome. Through the engineering curriculum, one is taught to think outside the box and find solutions as was done through this project. However, one is never done learning since the next problem that can arise can never be anticipated.

Some examples of realizing the need for life-long learning included the design process; how to build an entire machine from a simple idea that barely had an objective or purpose. Another example of this realization is learning of specific subject matter procedures and guidelines to abide by while keeping creativity. An additional example is that of interpersonal skills; people always continue learning how to work with different people to achieve an ultimate goal. Also as engineers one can ever stop learning how to communicate. Communication is a life-long lesson that is necessary not only in project management but in everyday life.

These team members can truly appreciate what was learned throughout this entire senior design process, their next steps prove it. Specifically, Dillon will be pursuing a doctoral degree following his Bachelor of Science in Mechanical Engineering. Ruth will be entering the aerospace industry where her employer will sponsor her Master's degree. Felipe will be entering the industry to continue hands-on learning in the workforce. This team will continue their learning in a variety of ways and these three ways are also not the only ways to continue learning because learning is never ending. This experience was influential in paving the way forward for the future, teaching the importance of life-long learning.

Discussion

The senior design project has proven to introduce students to the real works of the engineering industry. As seen in the design experience, students learned an immense amount of technical and problem solving skills. This particular design project is intended to address a global problem and this is an attempt to solve it. Earth is currently the only planet known to have sustainable life. It is the job of the citizens of this earth to maintain it and take into account all the types of people and societies that reside in it. Using this system will provide substantial energy to keep the world going without harming it. The pneumatic energy converting system will be easily integrated and efficient in any environment.

CONCLUSION

Conclusion and Discussion

The idea of a pneumatic energy converting unit came from originally a hydraulic energy converting unit. This hydraulic energy converting unit was an idea from a professor to convert small amounts of linear forces into a useable electric power. After an extensive literature survey and thorough research into all aspects that would go into a hydraulic energy converting unit, the work on this project began. An initial design of the hydraulic energy converting unit was created and components were researched. Throughout the research into the different components that would be required and designing the unit, multiple issues arose. One of these issues was if the system experienced a leakage. Multiple things would happen in this case. First the system would lose pressure and essentially stop working. Second, if there was a leak, the user would have to have a supply of hydraulic fluid in order to replenish the leaked fluid. Another issue that developed as this idea was explored more thoroughly was the fact that there was no reliable way of storing the energy except for expensive battery packs. Possibly one of the biggest issue that this project faced was budgeting. Hydraulic components would be extremely expensive in order to acquire. The design would likely cost $900 to $1200. Not only would this be an issue for the budgetary constraints of the group but it also would pose an issue for the affordability of the unit. Since one of the main goals of this project was to be able to implement it into areas which would otherwise have little or no access to a power supply, the more expensive the components cost would mean there would be less areas that it could possibly be implemented.

From these concerns, the idea of creating a similar system but using pneumatic, or air, instead of hydraulic became the focus of research and design. The unit would be very similar except for a few main differences. The unit would no longer need to be a closed loop system. For a hydraulic energy converting unit, the system would have to be a closed loop system which made the entire system more complicated. Using air as a fluid eliminated this need and the system could be an open loop system. This greatly reduced the complexity of the system by reducing the number of valves required as well as eliminating the need for a hydraulic fluid. Another huge benefit of using the pneumatic system over the hydraulic system was that the air could be stored in a compressed air tank and be released when the voltage supply would be desired. This was one of the major driving factor behind changing the system to a pneumatic system. The other main driving factor behind switching to the pneumatic system was the price. The pneumatic components were much cheaper than similar hydraulic components. The pneumatic system also allowed for less components to be used which would drive the cost down even more. The total expected cost for the pneumatic energy converting unit was estimated to be around $400 to $600, which would be approximately half of the cost of a hydraulic energy converting unit. This not only allowed for the unit to be funded by the students without additional external resources but it also allowed for the total cost of the unit to be extremely reasonable.

Once it was decided that the unit would be a pneumatic energy converting unit, the design was finalized. The pneumatic energy converting unit would include a couple major components; the tie rod cylinder, the air tank, the pneumatic motor, and the dc motor, or the generator. The rest of the components were common pipe connections that would be inexpensive and readily available. The tie rod cylinder was selected based off of the idea of this unit being a “table-top” version that would be more of a proof of concept rather than a product to actually be implemented into the field. This cylinder could be scaled up or down depending on the application like discussed previously. Similarly, the air tank was selected based off of this idea as well. The pneumatic motor that was chosen was actually a pneumatic motor that would typically be used in a pneumatic drill. This drill was donated to us by Anthony Abrahao. The design was completed and the construction of the prototype began.

During the prototype construction, there were very little issues that arose. One of the major issues that was present in the prototype construction was the fact that the tie rod cylinder could not return to an upright position due to the check valve. How the design was originally set up, the tie rod cylinder had a hose connected to a check valve going directly into the air tank. This did not allow for air to return into the tie rod creating a vacuum and causing the tie rod to essentially be stuck in the compressed position. This was solved by adding a tee joint and another check valve that would allow for the air flow to go back into the cylinder but would not allow for the air to exit out of that check valve. The other issue that arose during prototype construction was the connection to the pneumatic motor. This connection was not a standard connection which it was originally thought to be. This was fixed by simply researching and acquiring the appropriate fitting to connect the rest of the system to the pneumatic motor.

Three different experiments were created in order to test the pneumatic energy converting unit. The first test was to determine the pressure that could be built up within the air tank based on the number of cycles of compression of the tie rod cylinder. This test provided data that shows that the amount of pressure within the air tank will be linearly proportional to the number of cycles. From the experimental data, a formula for the prediction of the amount of pressure in the air tank from the amount of cycles was obtained. Using this equation, the number of cycles to compress the cylinder to obtain a certain pressure could be obtained within a 5% error, which is an extremely reasonable error percentage for any predicted value. The second test was designed in order to obtain the experimental data of the amount of time that the system could operate for based on the number of cycles. This data was plotted and an equation was developed in order to predict the time the system could operate under based on the number of cycles. This equation proved to have a much higher percentage error due to the fact that the torque required to operate the dc motor was not taken into account. This led to an error percentage of approximately 40%. The final test was the most important test. This test would determine the amount of voltage that the system could provide as well as the amount of time the system would actually operate. The first thing that was noticed from the five trials that was performed for this test was that the pneumatic energy converting unit was extremely consistent. The amount of time only varied by a couple of seconds. The voltage varied by a greater amount but this was attributed to the fact that the pressure gauge readings could have introduced a large human error.

The pneumatic energy converting unit prototype was able to consistently provide a voltage of 40 volts peak which would slowly drop over time. This voltage was much more than was expected for the system due to the fact that only a 12 volt dc motor was used. This means that the rotational speed was much greater than the rated speed on the motor. If the motor was replaced by a higher rpm rated motor that would have a much lower torque, then the pneumatic energy converting unit could supply a lower voltage, a target of 12 volts, for a much longer time period. As discussed previously, this would be a much more desirable situation for the pneumatic energy converting unit.

In conclusion, the overall goals of the pneumatic energy converting unit was accomplished. The concept was proven by the built “table top” prototype. The voltage that was acquired from the unit actually exceeded expectations by a great amount. If the air flow out of the tank will be released in a controlled manner at less than fully opened, then the time that the pneumatic energy converting unit can operate for met expectations. The only goal that the prototyped version did not meet was being waterproof. This was due to budgetary constraints of actually manufacturing and prototyping a waterproof case would be an expensive undertaking and it was deemed unnecessary in order to prove the concept through the prototype. The group learned many lessons about designing and researching a project that would help each individual as we continue our educational and professional experience.

Evaluation of Integrated Global Design Aspect

The pneumatic energy converter prototype was designed to be as portable as possible. This portability aspect was incorporated to allow it to be easily implemented in any situation or part of the world that would require electrical power to be generated. This prototype could be used in third world countries by being placed under speed bumps to generate electricity, the stored energy could then be used to power the street lamps that light the road. However, to achieve this in a third world country the prototype also needed to be affordable, this is why a main aspect of the prototype design was to make it as inexpensive as possible. Since the units are economical a few of them can be integrated at the same time into one speed bump and the return on the investment can be seen in a short time period.

Evaluation of Intangible Experiences

The development of this project from concept, to design, to simulation, and then to the eventual construction and testing of the prototype was a very rewarding experience for the entire team. Although, at times it was frustrating and demanding the team was able to work together and apply problem solving skills to ensure continued success and accomplish the goals that were set forth when this project began. This project has help all team members expand their hands on experience while applying their knowledge of engineering.

Future Work

There are multiple things that will be developed in the future in order to improve on the design of the energy converting unit. The main component of the future work required will be to tailor the pneumatic energy converting unit to a more specific application. For example, for implementation into the speed bump application discussed, the cylinder would not have a simple step plate but would be connected to a manufactured bump that would act as the speed bump. Every time a car would drive over this speed bump, the cylinder would be compressed. Since the car has a much higher weight than a human a much larger cylinder could be used.

Another important thing that needs to be done in order to optimize the pneumatic energy converting unit will be optimization of the voltage supply. This will need to be done by optimizing the dc motor that will be used as the generator. As discussed previously, the dc motor that will need to be used needs to be around 1,762.5 rpm. This will allow for the maximum voltage to be obtained around the voltage rating of the motor. It will also greatly reduce the torque required to drive the motor which will allow for the system to operate for a much longer time period.

Another thing that has already been discussed but will need to be done in the future will be the casing. Currently, the prototype is an exploded view with all of the components exposed. The very next step in this project will be to design and manufacture an enclosed case which will be water resistant and durable in order to last in harsh environmental conditions. Another step in this process will be to perform testing in order to determine the reliability of this case. This can be done by exposing the unit to an environmental chamber which will have an increased temperature and relative humidity. What this does is simulates a long term exposure to the environment. This will allow for the unit to be tested at a much shorter time frame for its reliability to be environmentally resistant.

REFERENCES

1) Dahlqvist, J. (2012, October 16). Impulse Turbine Efficiency Calculation Methods with Organic Rankine Cylce. Retrieved April 14, 2015, from http://www.diva-portal.org/smash/get/diva2:563284/FULLTEXT01.pdf

2) Dean, R., & Dalrymple, R. (1991). Water Wave Mechanics for Engineers and Scientists. *Advanced Series on Ocean Engineering, 2*.

3) Du Plessis, J. (2012, March 1). A Hydraulic Wave Energy Converter. Retrieved April 14, 2015, from http://www.crses.sun.ac.za/files/research/completed-research/ocean/j_duplessis.pdf

4) Fulton-Bennett, K. (2012, May 11). Harnessing the awesome power of the ocean waves. Retrieved from http://www.mbari.org/news/homepage/2012/powerbuoy/powerbuoy.html

5) Homopolar motor, homopolar generator. (n.d.). Retrieved April 14, 2015, from http://www.animations.physics.unsw.edu.au/jw/homopolar.htm

6) Hydropower turbines. (n.d.). Retrieved April 14, 2015, from http://www.renewablesfirst.co.uk/hydro-learning-centre/kaplan-turbines/

7) Index#1. (n.d.). Retrieved April 14, 2015, from http://bass.gmu.edu/~pceperle/WebProjectsSpr03/AlballamAlnajadah-ElectricMotors/main.html

8) Model Gallery. (n.d.). Retrieved April 14, 2015, from http://www.comsol.com/model/homopolar-generator-3d-14425

9) Newmills Engineering. (n.d.). Retrieved April 14, 2015, from http://newmillsengineering.com/products/item/4/kaplan-turbines

10) Rolland Jr, M., Cromack, D., & Heronemus, W. (1979). Performance Matching of Hydraulic Energy Converters and Wind Turbines for Heating Purposes. *Wind Energy Center Reports*.

11) Simoes, G., Chakraborty, S., & Wood, R. (2006, January 1). Induction Generators for Small Wind Energy Systems. Retrieved April 14, 2015, from http://inside.mines.edu/~msimoes/documents/pap10.pdf

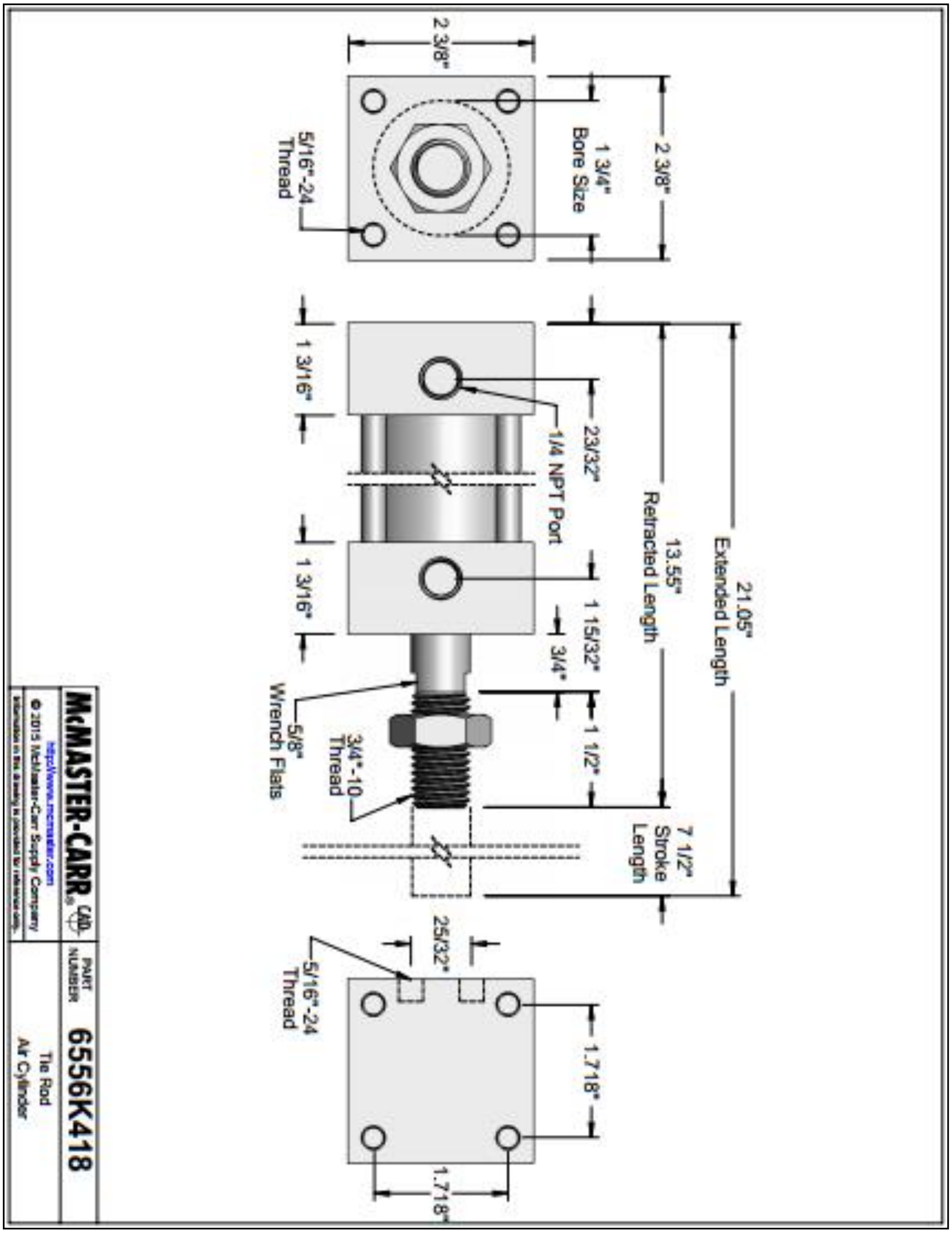
12) Wang, T., & Wang, Q. (2014). Efficiency Analysis and Evaluation of Energy-Saving Pressure-Compensated Circuit for Hybrid Hydraulic Excavator. *Automation in Construction,* (47), 62-68. Retrieved March 10, 2015, from servicewomen/locate/autcon

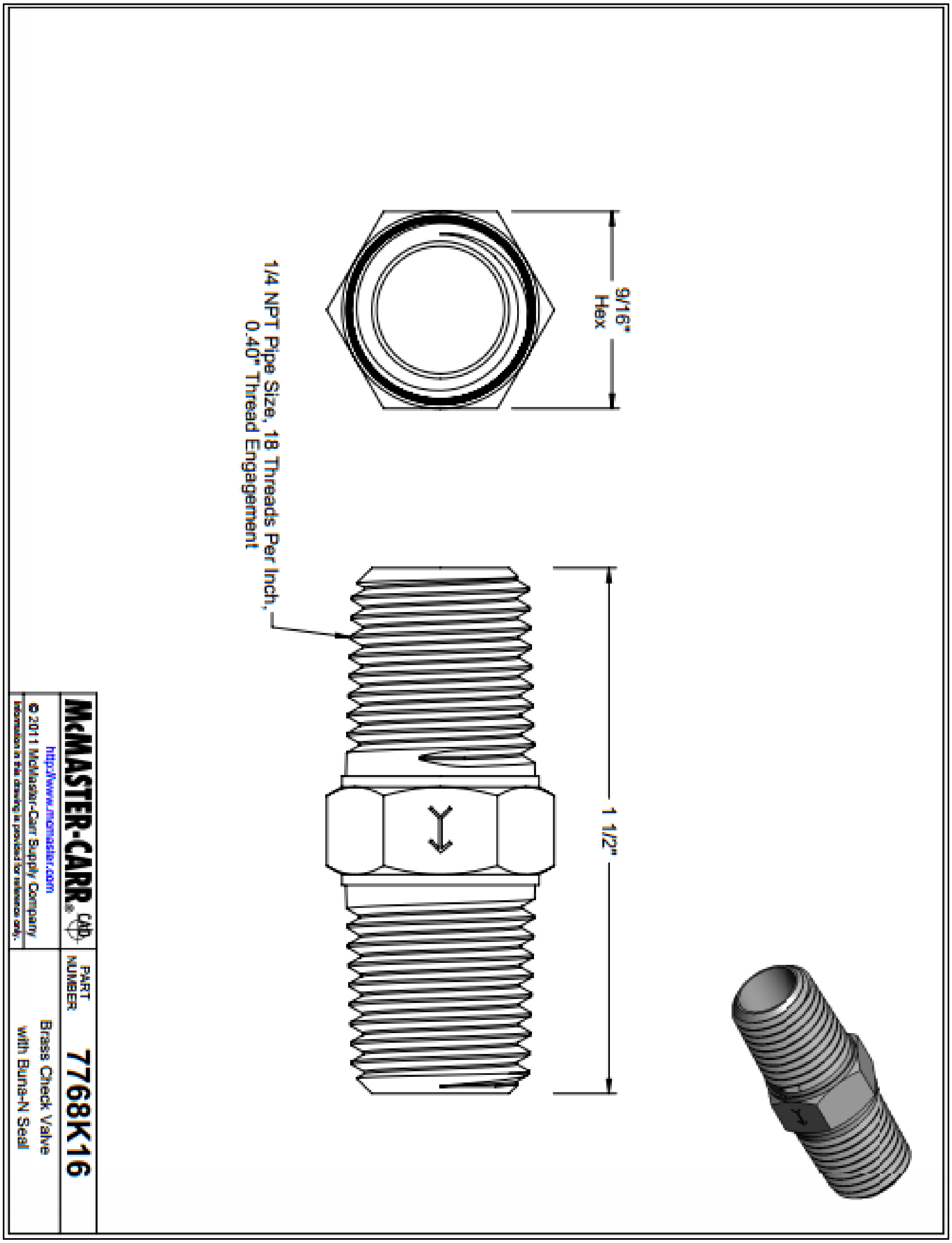
13) William Froude. (2015). In *Encyclopedia Britannica*. Retrieved from http://www.britannica.com/EBchecked/topic/220944/William-Froude

14) 2.3 Turbine selection. (n.d.). Retrieved April 14, 2015, from http://rivers.bee.oregonstate.edu/book/export/html/35

Appendix

Appendix A. Detailed Engineering Drawings




9/16"
Hex
1/4 NPT Pipe Size, 18 Threads Per Inch,
0.40" Thread Engagement
1 1/2"
McMASTER-CARR
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
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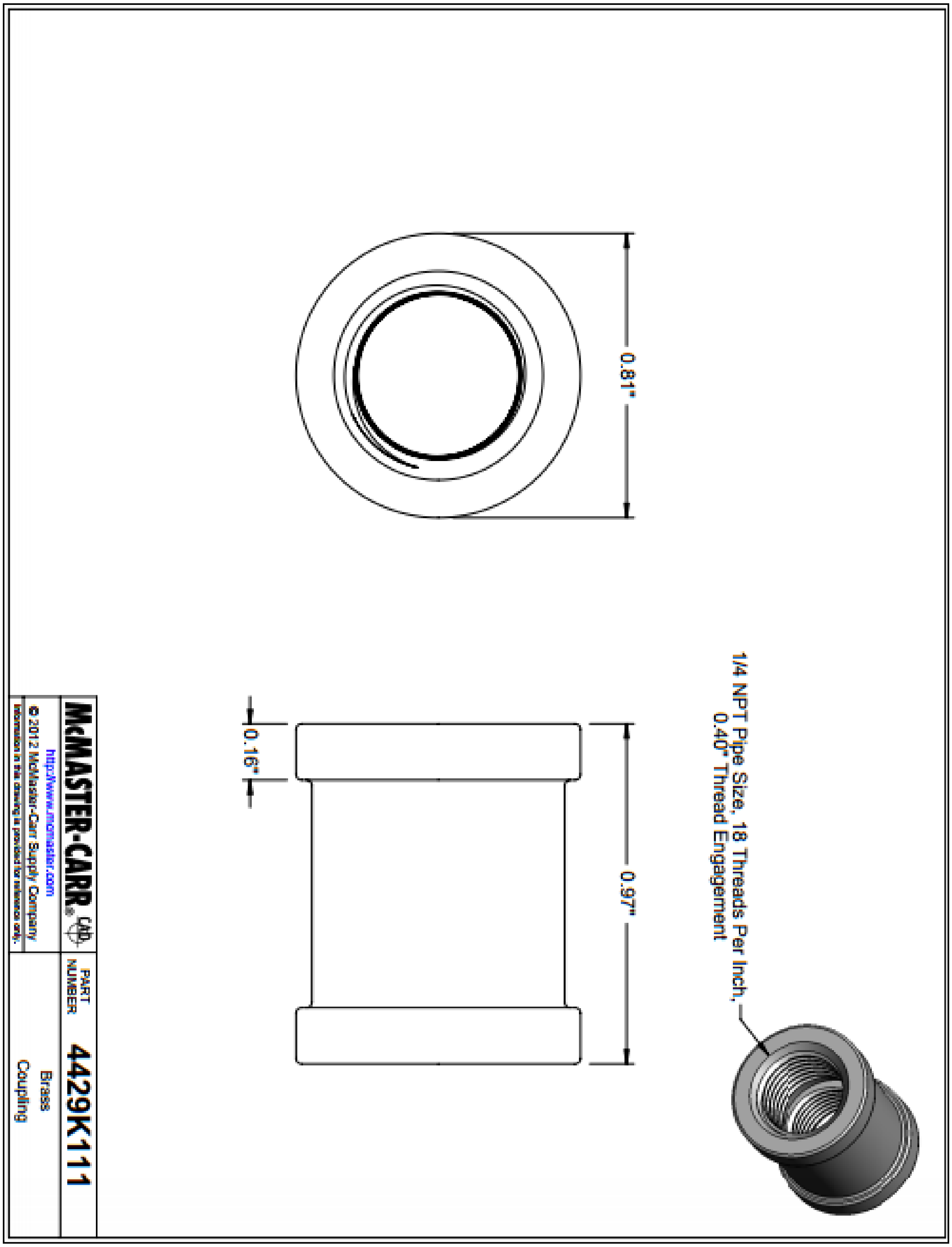
7768K16
Brass Check Valve
with Buna-N Seal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0.97"
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0.40" Thread Engagement
McMASTER-CARR
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
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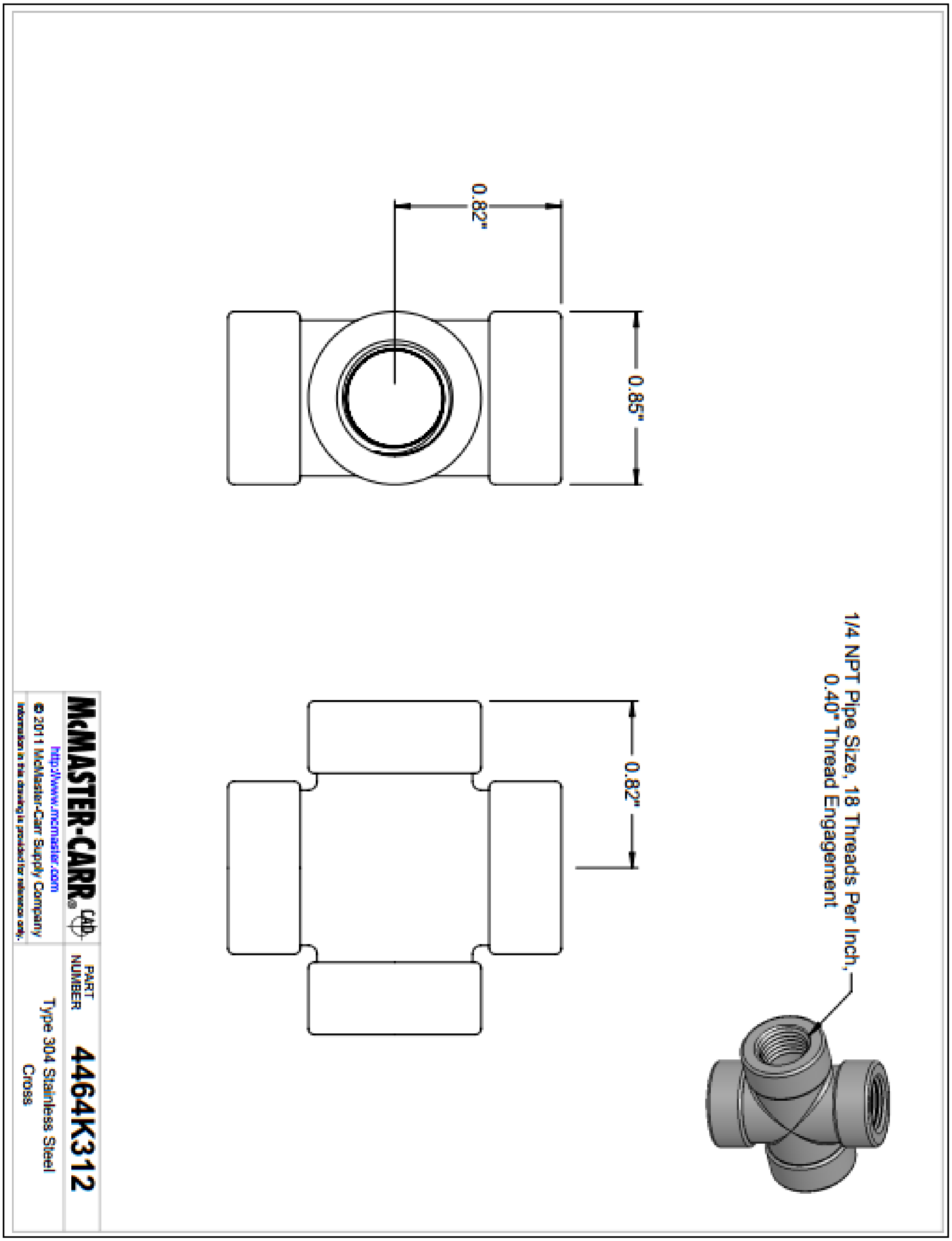
Coupling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0.40" Thread Engagement
McMASTER-CARR.
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
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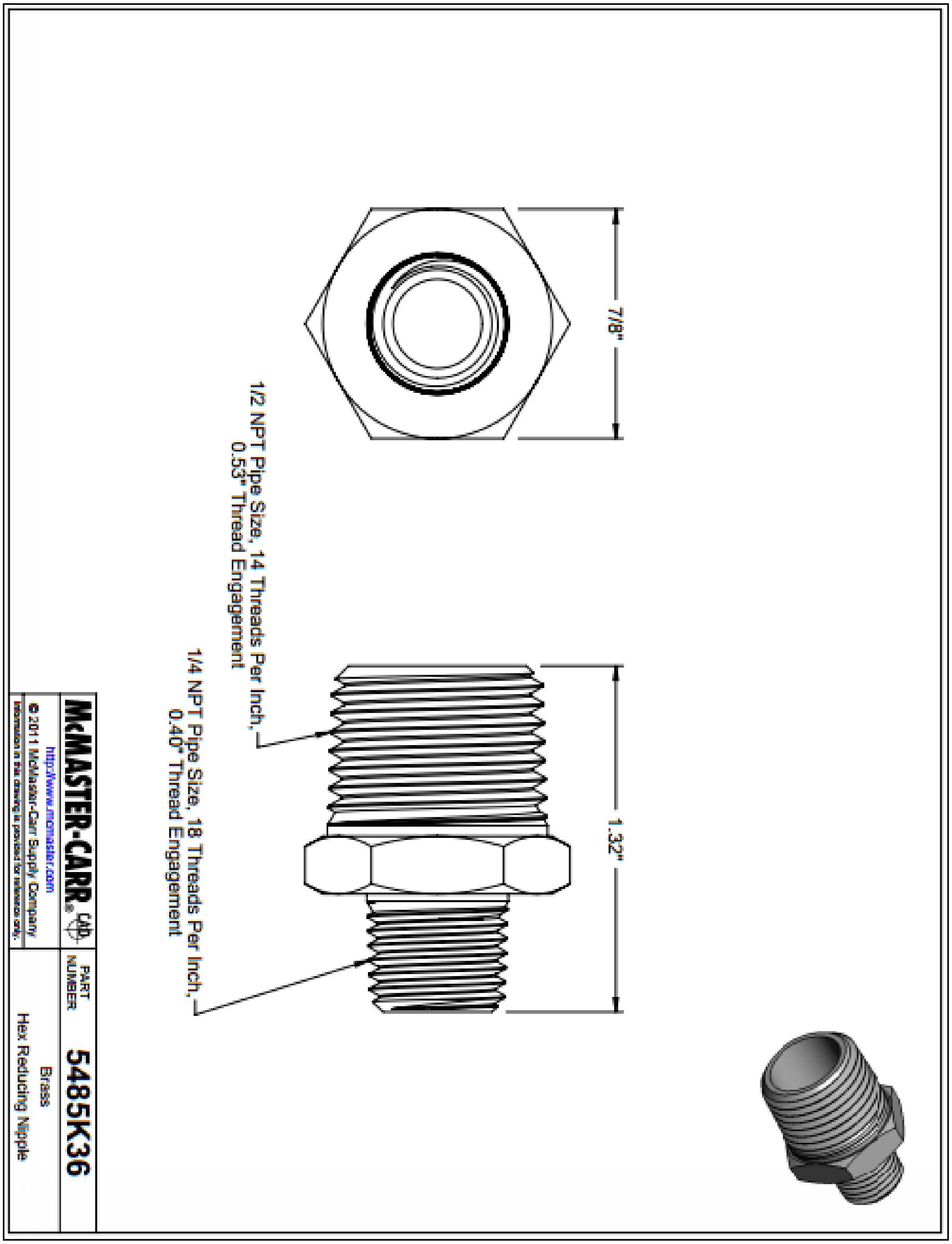

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0.53" Thread Engagement
1.32"
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McMASTER-CARR
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
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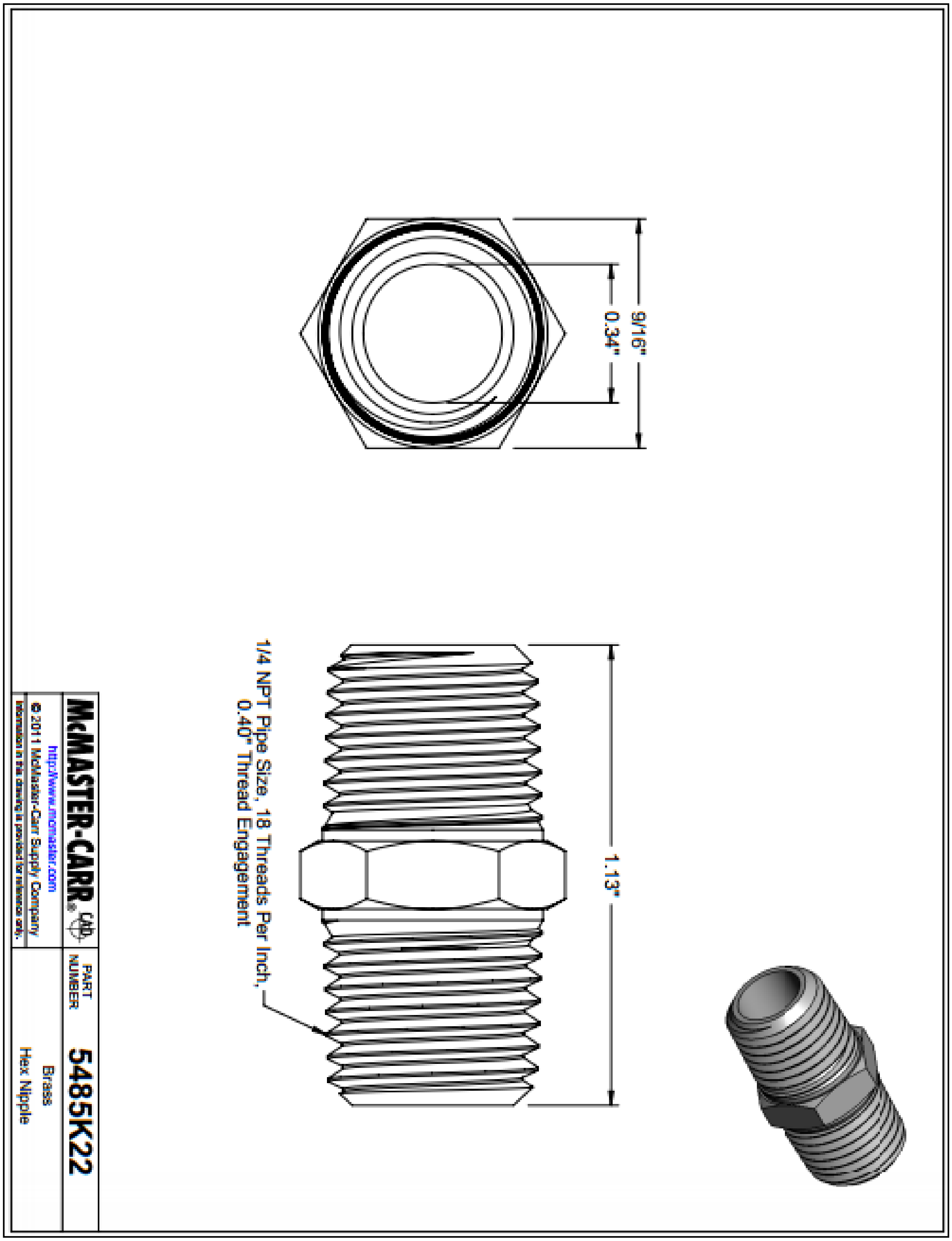
Hex Reducing Nipple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0.34"
1.13"
1/4 NPT Pipe Size, 18 Threads Per Inch,
0.40" Thread Engagement
McMASTER-CARR
http://www.mcmaster.com
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Information in this drawing is provided for reference only.
PART NUMBER
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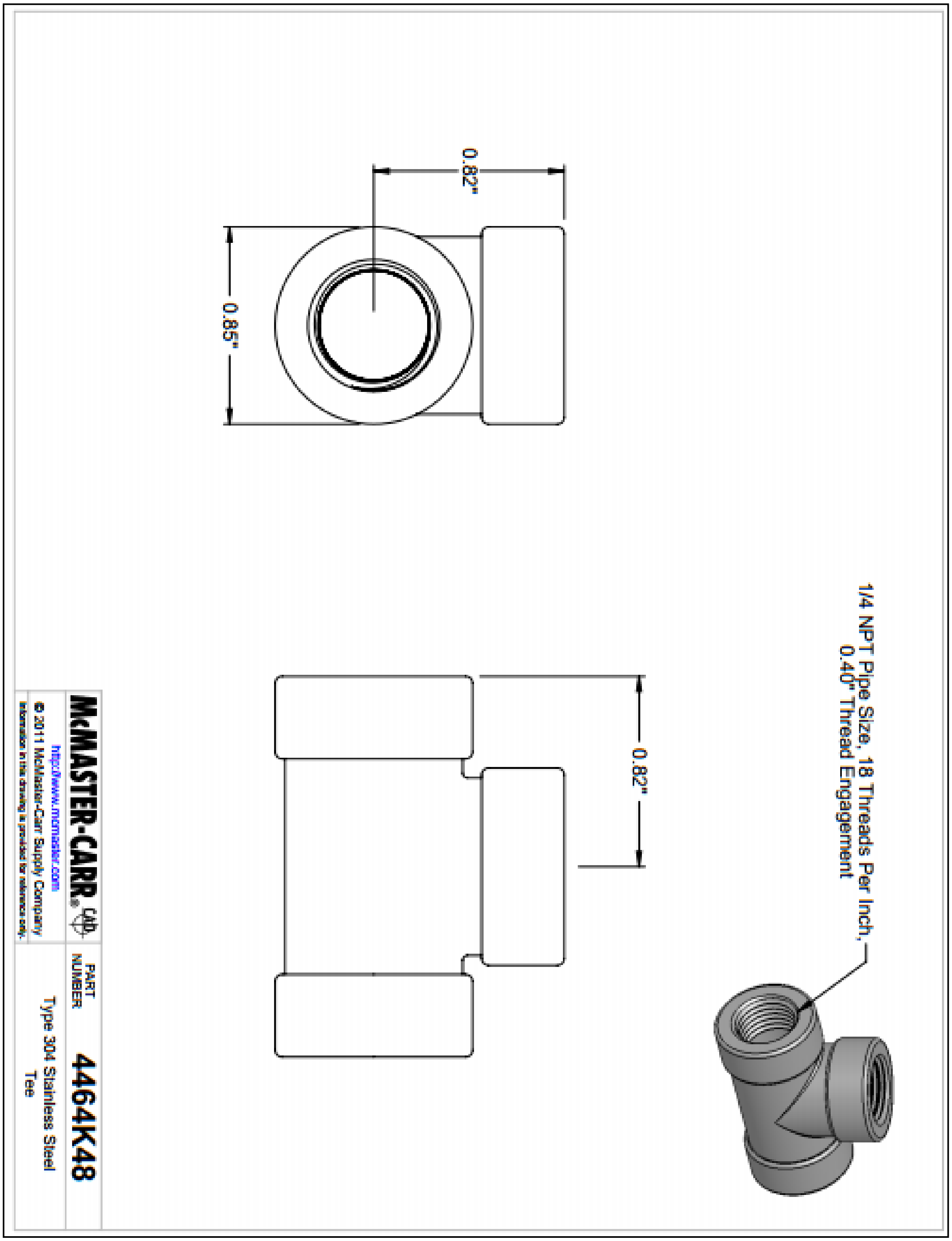
Brass
Hex Nipple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McMASTER-CARR®
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Type 304 Stainless Steel
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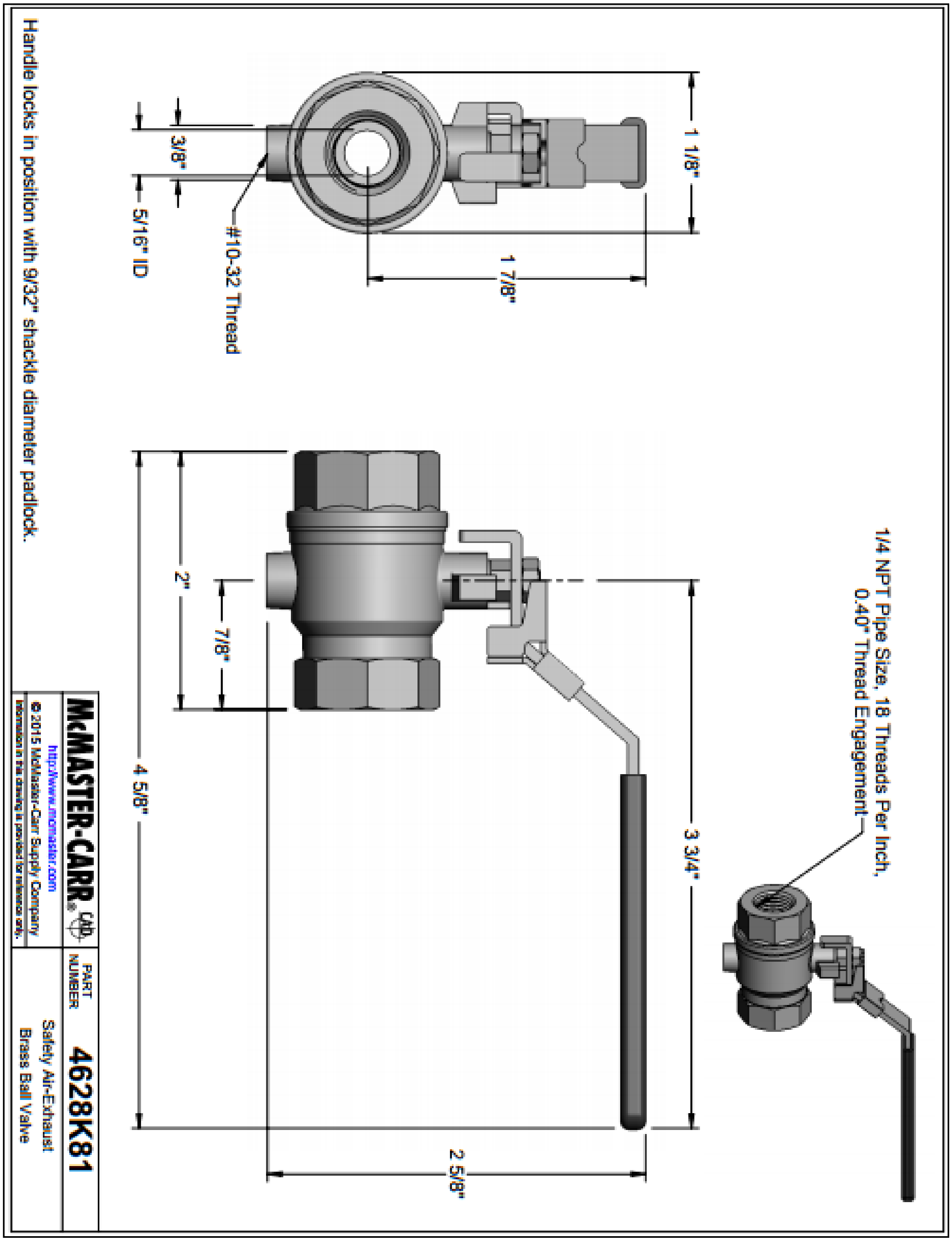
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3/8"
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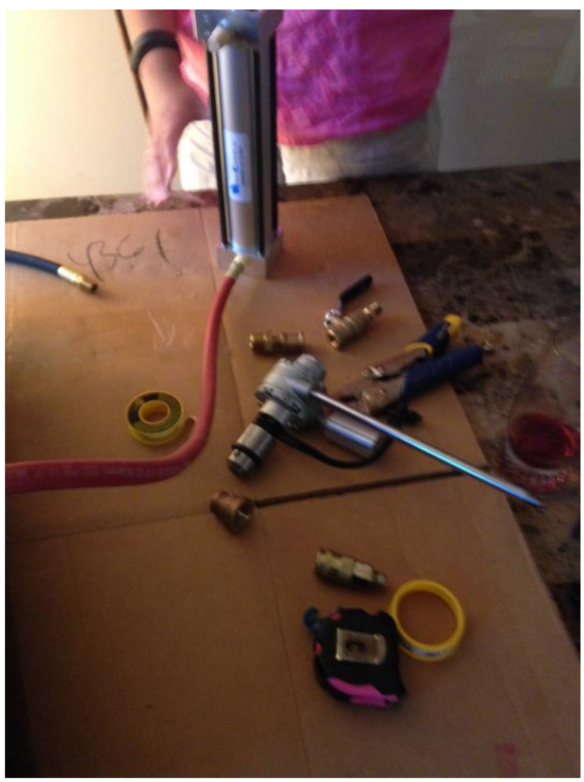
1/4 NPT Pipe Size, 18 Threads Per Inch,
0.40" Thread Engagement
2"
7/8"
3 3/4"
4 5/8"
2 5/8"
Handle locks in position with 9/32" shackle diameter padlock.
McMASTER-CARR
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
PART NUMBER
4628K81
Safety Air-Exhaust
Brass Ball Valve

Appendix B: Photo Album


60
80
100
40
120
20
140
0
psi
160
ASHCROFT




KOBALT
ASHCROFT
psi


KOBALT

Appendix C. Multilingual User Manual

The user manual will be on the following pages. First it will be in English and then it will be in Spanish.

USER'S MANUAL

Pneumatic Energy Converting Unit

Abstract

The installation, maintenance, and troubleshooting of the pneumatic energy converting unit.

Dillon Watring

Dwatr001@fiu.edu

Table of Contents

1.0 General Information

General Information section explains in general terms the system and the purpose for which it is intended.

1.1 System Overview

The pneumatic energy converting unit is a system which allows for the conversion of a linear force to an electrical power. The unit stores the energy from the linear force as compressed air within an air tank passively. When operational, the user controls the amount of air released from the tank to provide electrical power. The electrical power is generated by a pneumatic motor attached to a direct current motor which will act as a voltage supply.

1.2 Organization of the Manual

The user's manual consists of three main sections: General Information, Getting Started, and Using the System.

General Information section explains the general aspects of the system. It also discusses the overview of the system and its purpose.

Getting Started section provides the information on health and safety aspects of the system. It discusses the assembly and disassembly procedures for the system along with the tools required. It also discusses the installation guide of the system itself.

Using the System section provides a detailed description of the system functions as well as the maintenance of the system and frequently asked questions.

2.0 Getting Started

Getting Started section explains the health and safety considerations of the system. The section explains the assembly and disassembly procedures and tools as well as the installation of the system.

2.1 Health and Safety Precautions

The main health and safety precaution to take when getting started with the pneumatic energy converting unit is the fact that it deals with air as a fluid. Air is a compressible fluid so naturally there is a risk of bursting of components. A component bursting can occur when the pressure reaches the maximum rated pressure for that specific component.

2.2 Assembly and Disassembly

The assembly and disassembly of the pneumatic energy converting system is extremely simple and requires very few tools. Each component will simply be screwed into the next component. Some type of thread sealant is recommended to be used but is not required. The assembly procedure will be discussed but the disassembly procedure will not as it is simply the reverse of the assembly.

2.2.1 Tools Needed

The first required tool is two channel lock pliers in order to grip each component. Another required tool is the chuck to tighten the chuck attached to the pneumatic motor to the direct current motor, this will be provided. A screwdriver is also recommended to have access to in order to tighten the brackets when needed.

2.2.2 Procedure

1) Begin with the tie rod cylinder. Screw the muffler into the top ¼" NPT female connection.

2) Screw one end of the red 2 foot hose into the bottom connection on the tie rod cylinder.

3) Screw the other end of the hose into one part of the pipe tee fitting.

4) Take one of the check valves and screw into one of the connections of the tee. Make sure that the air flow is going into the tee fitting.

5) Take the other check valve and screw into the last connection of the tee. Make sure that the air flow is going out of the tee fitting for this check valve.

6) At the other connection of the check valve that has the air flow going out of the tee, connect it to the air tank on one of the fittings.

7) In the other connection on the air tank, connect one of the pipe couplings.

8) At the other end of the pipe coupling, connect the cross joint.

9) Screw the pressure gauge into one of the connections of the cross joint.

10) Screw the pop off safety valve into one of the connections of the cross joint.

11) Screw the other coupling into the last connection of the cross joint.

12) Attach the ball valve onto the free end of the coupling.

13) Attach one end of the black hose to the other end of the ball valve.

14) Screw the other end of the black hose into the adapter.

15) Screw the adapter into the reducer.

16) Attach the reducer to the pneumatic motor.

17) Attach the chuck that is on the pneumatic motor to the electric generator.

18) Place all of the components into the case.

19) Finally, place the springs over the rod of the tie rod cylinder and tighten the nut.

2.3 Installation

The installation of the pneumatic energy converting unit will depend on the application in which it is being used. For specific information on the installation procedures and guidelines call your local representative.

3.0 Using the System

Using the System section provides a detailed description of the function of the system along with maintenance of the system.

3.1 Overview

The pneumatic energy converting unit converts mechanical energy to electrical energy through use of a pneumatic motor attached to a generator. This will provide a voltage supply that can be used for the powering of small electronics, lights, sirens, or other low power consuming electronics. The system is designed in order to provide electric power to areas otherwise void of electrical power or to passively supplement the electrical power to existing infrastructure.

3.2 Maintenance

The maintenance of the system is broken up into regular maintenance and major maintenance. The regular maintenance is maintenance that will be performed on a regular basis in order to prevent failure of the system. Major maintenance is maintenance that is requires additional funding or down time of the system.

3.2.1 Regular Maintenance

The only regular maintenance is the lubrication of the pneumatic motor shaft. This requires any base oil group lubricant to be applied directly on to the shaft of the pneumatic motor. This is necessary to prevent wear on the shaft and reduces friction.

3.2.2 Major Maintenance

Occasionally, a major maintenance is required. This is typically replacing a component, which will be as simple as ordering a new component, removing the old component, and installing the new component.

MANUAL DE USUARIO

Energía Neumática Unidad de Conversión

Abstracto

La instalación, mantenimiento y resolución de problemas de la energía de la conversión de unidad neumática

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Tabla de Contenidos

1.0 Información General

Sección de Información General explica en términos generales el sistema y el propósito para el cual está destinado.

1.1 Resumen del Sistema

La energía neumática unidad de conversión es un sistema que permite la conversión de una fuerza lineal a una fuente eléctrica. La unidad almacena la energía de la fuerza lineal como aire comprimido dentro de un tanque de aire pasiva. Cuando operativa, el usuario controla la cantidad de aire liberado desde el tanque para proporcionar energía eléctrica. La energía eléctrica es generada por un motor neumático conectado a un motor de corriente continua que actuará como un suministro de voltaje.

1.2 Organización del Manual

El manual del usuario se compone de tres secciones principales: Información General, para empezar , y utilizando el sistema.

Sección Información general explica los aspectos generales del sistema . También se analiza la visión general del sistema y su propósito.

La sección Inicio proporciona la información sobre los aspectos de salud y seguridad del sistema. Se analizan los procedimientos de montaje y desmontaje para el sistema, junto con las herramientas necesarias. También se discute la guía de instalación del sistema en sí .

El uso de la sección del sistema proporciona una descripción detallada de las funciones del sistema, así como el mantenimiento del sistema y las preguntas más frecuentes .

2.0 Empezando

La sección Inicio explica las consideraciones de salud y seguridad del sistema. La sección se explican los procedimientos y herramientas de montaje y desmontaje, así como la instalación del sistema.

2.1 Salud y Seguridad Precauciones

La principal medida de salud y seguridad a tomar cuando empezar con la energía neumática unidad de conversión es el hecho de que se trata de aire como fluido. El aire es un fluido compresible así que naturalmente existe un riesgo de estallido de los componentes. Un componente de ruptura puede ocurrir cuando la presión alcanza la presión nominal máxima para ese componente específico.

2.2 Montaje y Desmontaje

El montaje y desmontaje del sistema de conversión de energía neumática es extremadamente sencilla y requiere muy pocas herramientas. Cada componente simplemente se atornilla en el siguiente componente. Algún tipo de sellador de roscas se recomienda para su uso, pero no es necesario. El procedimiento de montaje se discutirá, pero el procedimiento de desmontaje no ya que es simplemente el reverso de la asamblea.

2.2.1 Herramientas Necesarias

La primera herramienta requerida es de dos pinzas de bloqueo de canal con el fin de agarre de cada componente. Otra herramienta necesaria es la pinza de sujeción para apretar el mandril unido al motor neumático para el motor de corriente continua, esto será proporcionado . También se recomienda un destornillador para tener acceso a el fin de reforzar los soportes cuando sea necesario.

2.2.2 Procedimiento

1) Comience con el cilindro de la barra de acoplamiento. Atornille el silenciador en la "conexión hembra NPT superior ¼.

2) Atornillar un extremo de la manguera de 2 pies de color rojo en la conexión inferior en el cilindro de la barra de acoplamiento.

3) Atornillar el otro extremo de la manguera en una parte de la tubería tee apropiado.

4) Tome una de las válvulas de retención y el tornillo en una de las conexiones de la te. Asegúrese de que el flujo de aire se va en la conexión de salida.

5) Tomar la otra válvula de retención y el tornillo en la última conexión de la camiseta. Asegúrese de que el flujo de aire está saliendo del accesorio para esta válvula de retención de salida.

6) En la otra conexión de la válvula de retención que tiene el flujo de aire que sale del tee, conéctelo al tanque de aire en uno de los accesorios.

7) En la otra conexión en el tanque de aire, conecte uno de los acoplamientos de tubos.

8) En el otro extremo del tubo de acoplamiento, conecte la articulación transversal.

9) Atornillar el indicador de presión en una de las conexiones de la articulación de la cruz.

10) Enrosque la válvula de seguridad del pop fuera en una de las conexiones de la articulación de la cruz.

11) Enrosque el otro acoplamiento en la última conexión de la articulación transversal.

12) Coloque la válvula de bola en el extremo libre del acoplamiento.

13) Una un extremo de la manguera de negro hasta el otro extremo de la válvula de bola.

14) Atornillar el otro extremo de la manguera de negro en el adaptador.

15) Enrosque el adaptador en el reductor.

16) Fije el reductor al motor neumático.

17) Coloque el mandril que está en el motor neumático para el generador eléctrico.

18) Colocar todos los componentes en la caja.

19) Por último, coloque los resortes sobre la varilla del cilindro de la barra de

2.3 Instalación

La instalación de la energía de la conversión de unidad neumática dependerá de la aplicación en la que se está utilizando. Para obtener información específica sobre los procedimientos y pautas de instalación llame a su representante local.

3.0 Utilizando el Sistema de

Utilización de la sección del sistema proporciona una descripción detallada de la función del sistema junto con el mantenimiento del sistema .

3.1 Información General

La energía conversión de unidad neumática convierte la energía mecánica en energía eléctrica mediante el uso de un motor neumático conectado a un generador. Esto proporcionará un suministro de voltaje que se puede utilizar para la alimentación de aparatos electrónicos pequeños, luces, sirenas, u otros aparatos electrónicos de consumo de baja potencia . El sistema está diseñado con el fin de proporcionar energía eléctrica a las zonas de lo contrario vacía de energía eléctrica o para complementar de forma pasiva la energía eléctrica a la infraestructura existente.

3.2 Mantenimiento

El mantenimiento del sistema se divide en mantenimiento regular y el mantenimiento mayor. El mantenimiento regular es el mantenimiento que se realiza en forma regular con el fin de evitar el fracaso del sistema. Mantenimiento mayor es el mantenimiento que se requiere una financiación adicional o tiempo de inactividad del sistema.

3.2.1 Mantenimiento Regular

El único mantenimiento regular es la lubricación del eje del motor neumático. Esto requiere ningún lubricante grupo de aceite de base que se aplica directamente sobre el eje del motor neumático. Esto es necesario para evitar el desgaste en el eje y reduce la fricción.

3.2.2 Mantenimiento Mayor

De vez en cuando, se requiere un mantenimiento mayor. Esto normalmente se sustituye un componente, que será tan simple como ordenar un nuevo componente, la eliminación de la componente de edad, e instalar el nuevo componente.

HANDBUCH

Pneumatische Energieumwandlungseinheit

Zusammenfassung

Die Installation, Wartung und Fehlersuche der pneumatischen Energieumwandlungseinheit.

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Inhaltsverzeichnis

1.0 Allgemeine Informationen

Allgemeine Informationen Abschnitt wird erläutert in allgemeiner Form das System und den Zweck, für den es bestimmt ist.

1.1 Systemübersicht

Die pneumatische Energiewandlereinheitist ein System zur Umwandlung einer Linearkraftin ein elektrisches Strom ermöglicht. Das Gerät speichert die Energie von der Linienkraft als komprimierte Luft in einem Lufttank passiv. Wenn in Betrieb, steuert der Benutzer die Luftmenge aus dem Behälter freigesetzt wird, um elektrische Energie bereitzustellen. Die elektrische Energie wird durch einen pneumatischen Motor, um einen Gleichstrommotor, der als eine Spannungsversorgung fungiert angehängt sind.

1.2 Organisation des Handbuchs

Die Bedienungsanleitung besteht aus drei Hauptabschnitten: Allgemeine Informationen, Erste Schritte, und Verwenden des System.

Allgemeine Informationen Abschnitt werden die allgemeinen Aspekte des Systems. Es behandelt auch den Überblick über das System und sein Zweck.

Erste Schritte Abschnitt enthält die Informationen zu Gesundheits- und Sicherheitsaspekte des Systems. Es werden die Montage und Demontage Verfahren für das System zusammen mit dem Werkzeug erforderlich. Es behandelt auch die Installationsanleitung des Systems selbst.

Verwenden des System- Abschnitt enthält eine detaillierte Beschreibung der Systemfunktionen sowie die Wartung der Anlage und häufig gestellte Fragen.

2.0 Anfangen

Erste Schritte Abschnitt werden die Gesundheits- und Sicherheitsüberlegungen des Systems. Der Abschnitt erläutert die Montage und Demontage Verfahren und Instrumente sowie die Installation des Systems.

2.1 Sicherheitsvorschriften und Vorsichtsmaßnahmen

Die wichtigsten Gesundheits- und Sicherheitsvorsichtsmaßnahme, um zu nehmen , wenn sie mit dem pneumatischen Energieumwandlungseinheiterst begonnen , ist die Tatsache , dass es sich mit Luft als Fluid . Luft ist ein kompressibles Fluid, so gibt es natürlich eine Gefahr des Platzens von Komponenten. Eine Komponente Platzen kann auftreten, wenn der Druck den maximalen Nenndruckfür die jeweilige Komponente erreicht.

2.2 Montage und Demontage

Die Montage und Demontage des pneumatischen Energieumwandlungssystemsist sehr einfach und erfordert nur sehr wenige Werkzeuge. Jede Komponente wird einfach in die nächste Komponente geschraubt werden. Eine Art von Dichtungsmittel wird empfohlen, verwendet werden, aber ist nicht erforderlich. Der Montagevorgang wird diskutiert, aber die Demontageverfahren nicht, da es einfach die Umkehrung der Montage.

2.2.1 Benötigtes Werkzeug

Die erste erforderliche Werkzeug ist zwei Kanal sperren Kombizange, um Grip jede Komponente. Anderen erforderlich Werkzeug ist das Spannfutter, um das Spannfutter mit dem pneumatischen Motor, um den Gleichstrommotor angebracht ziehen, wird dieser zur Verfügung gestellt werden. Ein Schraubendreher wird auch empfohlen, den Zugang zu haben, um die Klammern bei Bedarf festziehen.

2.2.2 Verfahren

1) Beginnen Sie mit der Spurstange Zylinder. Schrauben Sie den Schalldämpfer in die Top ¼ "NPT Innengewinde.

2) Schrauben Sie ein Ende des roten 2 Fuß Schlauch in den Anschluss unten auf dem Zuganker Zylinder.

3) Schrauben Sie das andere Ende des Schlauchs in einen Teil des Rohres T-Stück.

4) Nehmen Sie eines der Rückschlagventile und Schraube in einen der Anschlüsse der T-Stück. Stellen Sie sicher, dass der Luftstrom wird in das T-Stück gehen.

5) Nehmen Sie das andere Rückschlagventil und Schraube in die letzte Verbindung des T-Stücks. Stellen Sie sicher, dass der Luftstrom aus dem T-Stück für dieses Rückschlagventil geht.

6) Am anderen Anschluss des Rückschlagventil, das den Luftstrom geht aus dem T-Stück hat, verbinden Sie es mit dem Lufttank auf einem der Armaturen.

7) In der anderen Verbindung auf dem Luftbehälter, schließen Sie eine der Rohrkupplungen.

8) Am anderen Ende der Rohrkupplung, schließen Sie das Kreuzgelenk.

9) Schrauben Sie das Druckmessgerät in einen der Anschlüsse der Kreuzgelenk.

10) Schrauben Sie den Pop-off-Sicherheitsventil in einen der Anschlüsse der Kreuzgelenk.

11) Schrauben Sie die andere Kupplung in der letzten Verbindung des Kreuzgelenk.

12) Bringen Sie den Kugelhahn auf das freie Ende der Kupplung.

13) Befestigen Sie das eine Ende des schwarzen Schlauch an das andere Ende des Kugelhahns.

14) Schrauben Sie das andere Ende des schwarzen Schlauch in den Adapter.

15) Schrauben Sie den Adapter in den Druckminderer.

16) Befestigen Sie den Druckminderer an die Druckluftmotor.

17) Setzen des Futters, das an der Druckluftmotor mit dem elektrischen Generator ist.

18) Setzen Sie alle Komponenten in das Gehäuse.

19) Schließlich stellen die Federn über den Stab der Zugstange Zylinder und ziehen Sie die Mutter.

2.3 Installation

Die Installation der pneumatischen Energieumwandlungseinheitwird von der Anwendung, in der es genutzt wird, abhängen. Für spezifische Informationen zu den Installationsverfahren und Leitlinien rufen Sie Ihre lokale Vertretung.

3.0 Verwenden des System

Verwenden des System- Abschnitt enthält eine detaillierte Beschreibung der Funktion des Systems sowie die Wartung des Systems.

3.1 Überblick

Die pneumatische Energieumwandlungseinheitwandelt mechanische Energie in elektrische Energie durch die Verwendung eines Druckluftmotors mit einem Generator verbunden. Dadurch wird eine Spannungsversorgung, die für den Antrieb von kleinen Elektronik, Lichter, Sirenen oder anderen stromsparenden Elektronik verwendet werden kann. Das System ist, um elektrischen Strom zum Ort der ansonsten frei von elektrischer Leistung bereitzustellen oder passiv ergänzen die elektrische Leistung an die vorhandene Infrastruktur entwickelt.

3.2 Instandhaltung

Die Wartung des Systems wird in regelmäßigen Wartung und größere Instandhaltungs gebrochen. Die regelmäßige Wartung Wartung, die regelmässig um ein Versagen des Systems zu verhindern geführt wird. Haupt Wartung Wartung, die es erfordert zusätzliche Mittel oder Ausfallzeit des Systems.

3.2.1 Regelmäßige Wartung

Die einzige regelmäßige Wartung ist die Schmierung des Druckluftmotorwelle. Dies erfordert eine beliebige Base Ölgruppe Schmiermittel direkt auf die Welle des pneumatischen Motors angewendet werden. Dies ist notwendig, um den Verschleiß an der Welle zu verhindern und die Reibung reduziert.

3.2.2 Wichtige Wartungs

Gelegentlich wird eine große Wartung erforderlich. Dieser ist in der Regel Austausch einer Komponente, die so einfach wie die Bestellung einer neuen Komponente, dem Entfernen der alten Komponente und der Installation der neuen Komponente sein wird.