FINAL DESIGN REPORT

ENGR. 340 – SENIOR DESIGN PROJECT

TEAM 7: Aim to P.L.E.A.S.E.

(Pure Liquid Eliminating air shock equipment)

Peter Anjorin
Sarah Chandrasekar
Dan Kuiper
Eddie Lucas

May 13, 2005

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Our customer Naake Motorsports needs a machine that is able to remove air from a pre-assembled shock absorber and re-fill it with light weight shock oil. This is necessary to improve the performance and durability of these shock absorbers and also to improve on the cycle time for the current manual filling process, which gets little air out of the shock. Working collectively as a team, we came up with a machine that is fully automated and carries out this process with the push of a button and in half the time required for the current filling process, while at the same time improving the quality of the shock absorber by getting 90% of the air out.

1 INTRODUCTION

Naake Motorsports is a company located in California that specializes in suspension systems. They deal with springs and shocks used in these systems. The springs control the amount of deflection at a given force and the shocks control the rate at which that deflection is reached. These shocks are general performance shocks used in race cars. Examples of shocks they hold include QAI and Carrera shocks. In their business they are involved in rebuilding internal components of shock absorbers to get varied responses from the shock. The last step involved in building a shock involves filling it with 5 weight shock oil.

The ideal way to get predictable, constant motion out of a shock is to get as much air out as possible. This is because the less air there is in the shock the better the response to internal changes. This would also reduce hysteresis which is the uncertainty in the response of the shock due to spring back. The current method employed is a process of manually filling the shock and then stroking it and tapping the sides in order to get as much as air possible out of it. The problem with this method is that it is quite inefficient. With the current process, the typical worker spends 10-15 minutes filling a shock and is limited to the amount of air that can be removed from the shock.

As a team we have decided to team up with Naake Motorsports and come up with a more efficient and effective solution for their shock filling process at the most affordable cost to them.

2 CHALLENGES

There were a couple of challenges that our team had to overcome. We were a team of four seniors in engineering with various internship experiences in the workplace. Some of the other challenges included fulfilling the specific goals set out by our sponsor, Naake Motorsports. We also needed to consider the Design Norms in order to express our consideration for stewardship. These obstacles helped us outline our project objectives, which are given below:

2.1 PROJECT OBJECTIVES

2.1.1 Size

The size of the whole machine must be small enough to sit on a regular work bench and be light enough to easily handle. This constraint is because the machine should be easily movable as there is the possibility it would have to be shuttled between different race tracks on a race trailer as opposed to just remaining in the shock shop.

2.1.2 Cycle Time

The cycle time for filling a shock with oil and removing air out of it must be below ten minutes. Currently, the manual shock filling process at Naake Motorsports, assuming there are no hitches and everything goes as planned, takes between 10 to 15 minutes. We would like to keep the cycle time less than 10 minutes so that the machine can save time as well as deliver better quality shocks over the current process. This is a great challenge when we consider the fact that the hole diameter through which we will fill the shock is 3/32 in.

2.1.3 Reservoir Capacity

The capacity of the reservoir tank should be about one pint. This constraint is necessary to maintain our size and weight constraints without loosing functionality of the machine. The reservoir only needs to contain the volume of oil necessary to fill the largest shock size.

2.1.4 Vacuum Pump Capacity

The vacuum pump needs to be strong enough to extract most of the air out of five weight shock oil. This vacuum pump also needs to be powerful enough to reduce the air pressure in the shock to at least ten percent of atmospheric pressure.

2.1.5 Durability

The machine needs to be strong enough for regular daily use. Currently, Naake Motorsports re-builds about twelve shocks per day and the machine needs to be able to do this. Also it should be able to withstand the abuse of the work environment it will be placed in. It is probably going to get dropped and maltreated a little bit and be susceptible to multiple oil splashes.

2.1.6 Power Supply

The machine will be powered by an AC power source delivering 120 Volts at 60 Hertz, because this is the most standard power source that would be available where the machine is to be used.

2.1.7 Target Budget

Our target budget is in the range of $600 - $800. Out of this budget, $300 is going to be made available by Calvin College. The remainder is going to be provided by our sponsor, Naake Motorsports.

2.1.8 Level of Functionality

The machine should have the capabilities of mounting two shock sizes for filling. It is going to serve a shock with a seven inch stroke and a larger shock with a nine inch stroke. It should also be relatively easy to operate. Operators should be able to simply attach the shock to the machine and the push a button to begin the shock filling process. There will be a short owner’s manual delivered to the customer to aid in the operation of the machine.

2.1.9 Weight Goal

This machine should only weigh between 40 and 60 pounds. This constraint is for ease of movement between race tracks and storage in a race trailer

2.1.10 Seals

These all need to be air tight. This constraint is necessary to ensure that we are able to hold a vacuum pressure in lines. We need to test each line to make sure that our fittings and valves are tightly sealed

2.2 DESIGN NORMS

An important part of our design is how we integrated the design norms to guide us in the manufacturing process of this machine. It was important for us to understand how our customer was going to use the machine and how it would fit into their environment. Also we were concerned with a design that was efficient and made use of our scarce resources appropriately and cost effectively. Some important design norms we considered are listed and explained below.

2.2.1 Stewardship

We want to provide Naake Motorsports with this equipment because we believe it is going to help them economically by reducing the amount of time that is currently spent filling shocks. This project would help improve the quality of shocks by eliminating air and also reducing the amount of oil that is wasted during the shock filling process. By using less oil and time, this machine has honored this norm.

2.2.2 Transparency

This project also seeks to increase the ease of the shock filling process at Naake Motorsports. This would be done by delivering equipment that fills the shock by the push of a switch rather than the manual filling process that currently goes on. The sensor lights have been designed to be as easy to understand as possible.

2.2.3 Trust

We want to deliver a machine that our customer can rely on for quality, functionality, and durability. The machine should eliminate most of the air out of the shock. There can never attain complete elimination of all the air because a perfect vacuum is impossible on earth. The machine is also going to be easy to operate and sturdy for use on a daily basis to match the demand for use. Many of the components used are industrial grade and should perform repeatably for years to come.

2.2.4 Cultural Appropriateness

This is also a design norm worth considering because we would like the machine to fit into the environment it is intended for. In order to do this we first needed to understand the culture it was going to be used in and this was possible because one of our team members had work for Naake Motorsports over the summer. General people operating the machine would be your average handy man with average mechanical knowledge. However, it is still important to have operating guidelines laid out that could be easily understood.

2.3 CHRISTIAN PERSPECTIVE

We approached the design of this project from a Christian perspective. We want to be good stewards of the resources that have been made available to us by Calvin College and Naake Motorsports and deliver a quality product that solves the problem presented to us. We also want to come up with a design that is profitable and fulfills the all the needs of our customer.

3 SOLUTION

3.1 DESIGN PROCESS

Once we understood our requirements and the scope of this project, our next step was to come up with a workable design. We met as a team to discuss the objectives that we needed to fulfill and came up with an initial design. The preliminary prototype can be seen in Figure 1.

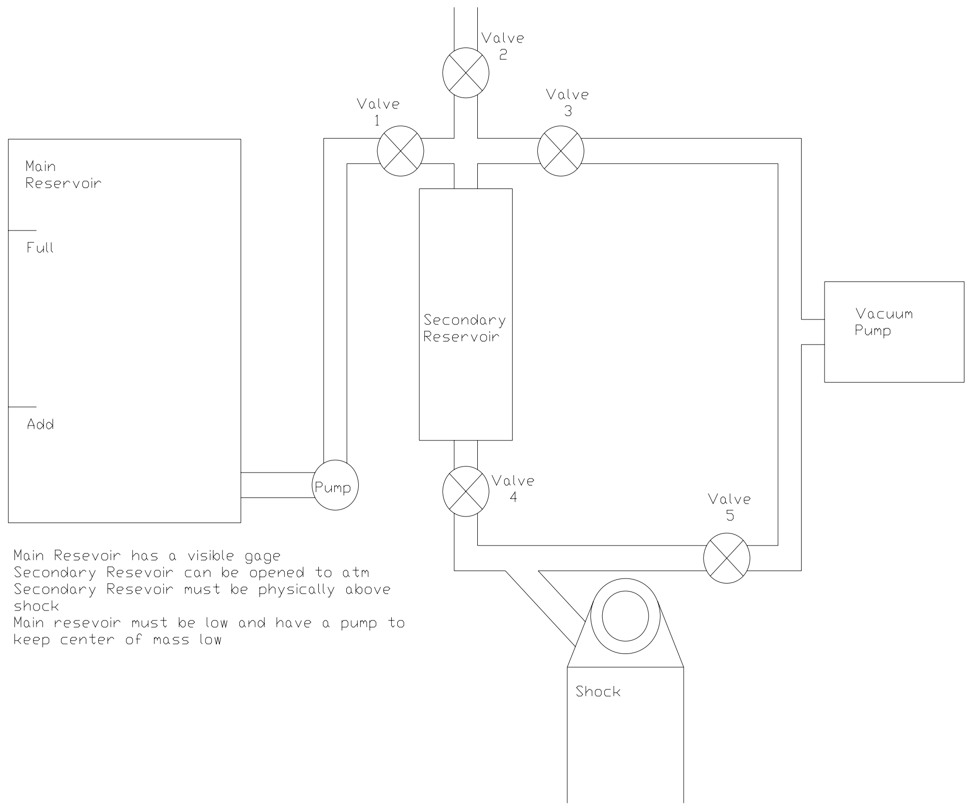


Figure 1: Initial Design

3.2 EXPERIMENTS

3.2.1 TEST 1 – Effect of vacuum on oil properties

In this test we wanted to determine if the properties of the shock oil change when it was under a vacuum. This was important because if, for example, the viscosity of the oil changed by 50% our shock oil would no longer perform as expected. Another thing we wanted to observe in this test was if air re-entered the oil after a vacuum was pulled on the shock oil and then re-introduced into the atmosphere. In order to perform the experiment we needed the following items:

- Shock oil – 2.5% weight
- Glass jar (to hold vacuum)
- Vacuum pump
- Tubes to connect the system

We connected the system and pulled at different intensities/speeds on the oil in the jar. Then we waited for air bubbles in the oil to rise and documented the results. At this point in time we removed the vacuum and observed if air reentered the oil in the jar. We compared the results of different vacuum intensities. From this data, we concluded on the most efficient vacuum, and made decisions based on the amount of air re-introduced into the oil.

3.2.1.1 RESULTS– Effect of vacuum on oil properties

We used a vacuum that pulled a pressure 27% of atmospheric pressure (0.27 atm). For a 300 mL volume of oil, the time required to pull a part vacuum (without seeing anymore air bubbles) was about 1 minute and 35 seconds. After pulling the vacuum, the shock oil was introduced back to the atmosphere (1atm) and allowed to sit for about 2 minutes. We then pulled another vacuum on the shock oil and re-introducing it to atmosphere. However, we could not see any more bubbles leaving the shock oil.

3.2.1.2 CONCLUSIONS - Effect of vacuum on oil properties

This test shows that air does not re-enter the shock oil when it is re-introduced to atmospheric pressure. The more times you pull a vacuum on the shock oil and then agitate it to get air bubbles in, the less time it takes to draw the vacuum on the shock oil

We will be able to pull a vacuum on this shock oil without changing physical properties such as density and viscosity. After air has been pulled out of the shock oil, it is possible to re-introduce this oil to the atmosphere without getting more air bubbles into this oil. This is also proves the theory that the shock oil is a lot more dense than air.

3.2.2 TEST 2 – Atmosphere vs. Vacuum for shock filling time test

This test was to find out how much time it would take practically to fill the shock with shock oil. This was done in two scenarios, the first scenario was keeping the shock enclosure at atmospheric pressure and the second scenario was drawing a vacuum to 27% of atmospheric pressure on the shock enclosure. The materials we required for this experiment were a shock provided by Naake Motorsports, a machine aluminum threaded connection point for filling the shock (shown in Appendix E), heavy duty hose, a vacuum source, shock fluid, and services from the machine shop.

For this experiment we drilled and tapped for a 6-32 screw for the other side of the shock. Then the aluminum fitting was made in the machine shop. The system was connected as shown in Figure 2. We performed a gravity test where we placed the reservoir one foot above shock, connected it with tube and then measured the time it took for the fluid to fill the shock to a specific volume. We also performed a Vacuum test over the second fitting. We compared the results of the gravity test vs. the vacuum test and derived conclusions in order to implement an efficient mechanism.

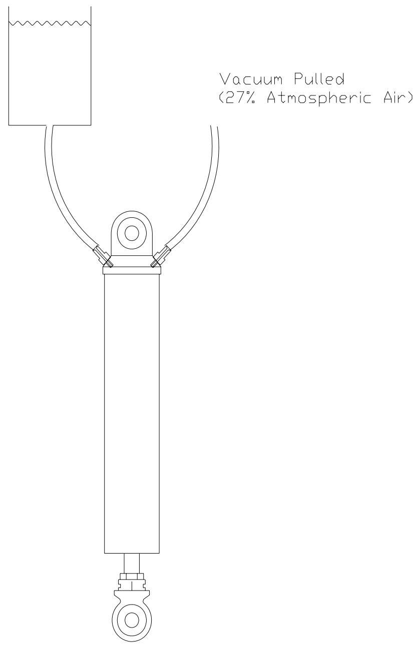


Figure 2: Experiment 2 Setup

3.2.2.1 RESULTS - Atmosphere vs. Vacuum for shock filling time test

We used a vacuum pump that reduced the air pressure to 27% of atmospheric pressure. We let the shock oil flow in by gravity on the first part. We observed that it took about 3 minutes 50 seconds to fill the shock with 100 mL of oil. For the second part, we pulled a vacuum on the shock before filling it with oil and observed that it took about 15 seconds to fill the shock with 100 mL of shock oil. This took less than ten percent of the time that gravity alone took and we incorporated this into our design.

3.2.2.2 CONCLUSIONS - Atmosphere vs. Vacuum for shock filling time test

This showed us we could save a lot of time by pulling a vacuum on the shock before filling it with oil. It would not be feasible to have a cycle time of about 4 minutes without pulling a vacuum on the shock

3.3 FLOW CALCULATIONS

We also did some calculations using the Bernoulli energy equation to find how fast, theoretically, the shock would fill given all our constraints and variables shown in Figure 3. The equations and solutions are found in Appendix D. From our calculations we found that it would take about thirty seconds to fill the shock, based on the assumption that a vacuum is drawn on the shock and that we are using a perfect suction fitting on the shock body.

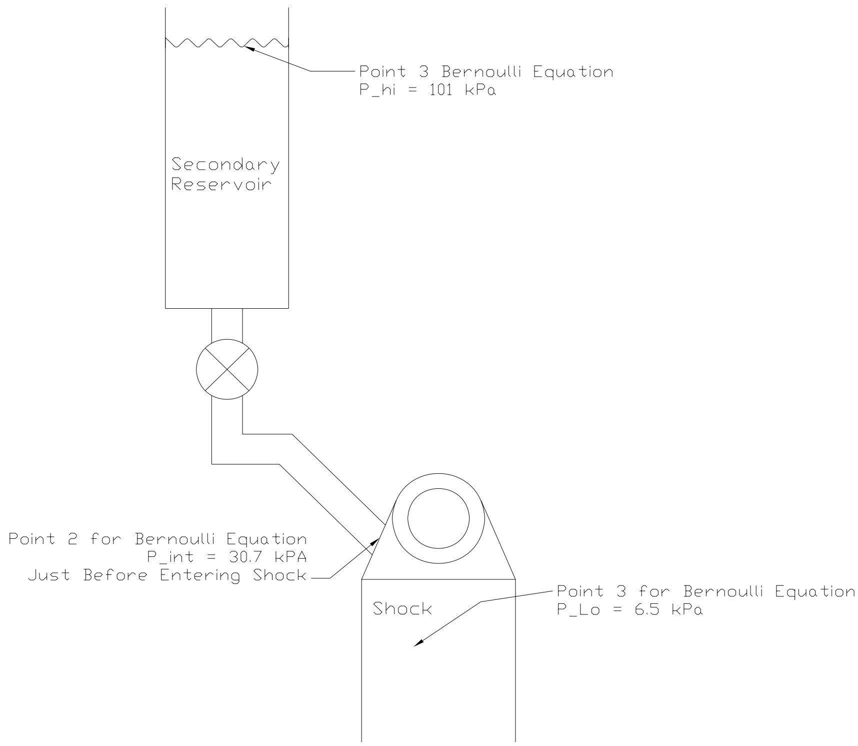


Figure 3: Bernoulli Setup

3.3.1 Flow calculation results

Note: The filling hole on the shock for the oil is 0.106 inches in diameter.

Parameter	**Value**
P1 (kPa)	101
P2 (kPa)	30.7
P3 (kPa)	6.5
Time for Filling (sec)	30
Oil Velocity, V2 (m/s)	6.54

3.4 DESIGN CHANGES

As we transitioned from the design phase to the implementation stage we realized that we might have to make couple more changes. After some conversations with the customer we realized that we did not need the primary reservoir. The customer felt that it would be more convenient to directly pump the shock oil to the reservoir from a larger container of oil. The new design can be seen in Figure 4. Some of the changes made in the new schematic are the removal of the main reservoir and the addition of a pressure gauge.

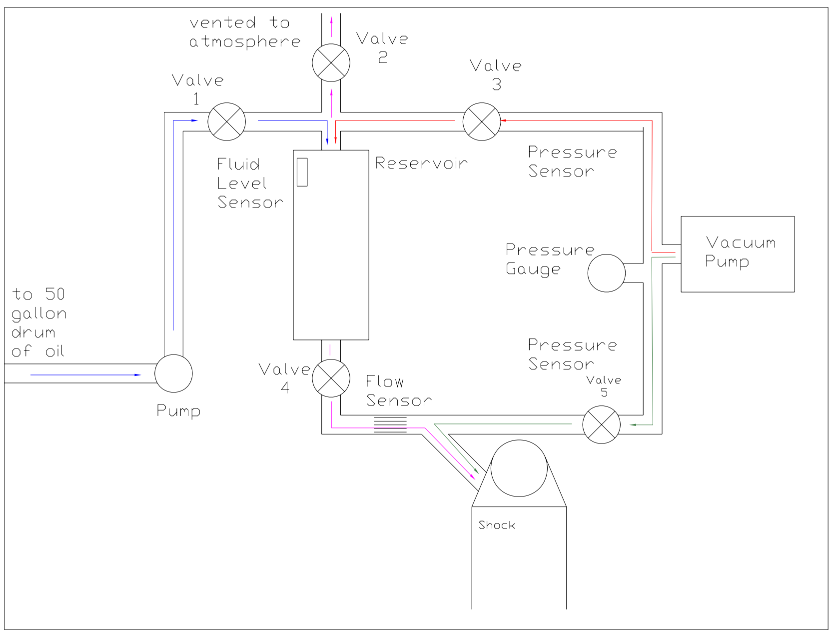


Figure 4: New Design

There were a number of changes that were incorporated into our prototype after construction to ensure the machine was working in the desired way. Some of the changes were extremely vital while others were simply to make improvements. The second pressure sensor and the flow sensor were removed in the final assembly. A toggle switch was also added for the 7"/9" shock bodies. We carried out a couple of experiments in order to validate our design ideas and draw some conclusions. From this testing, we decided to move several of the valves relative to the frame for better functionality. The description of the operations of the system is explained in the next section. Figure 5 outlines the design of our final product.

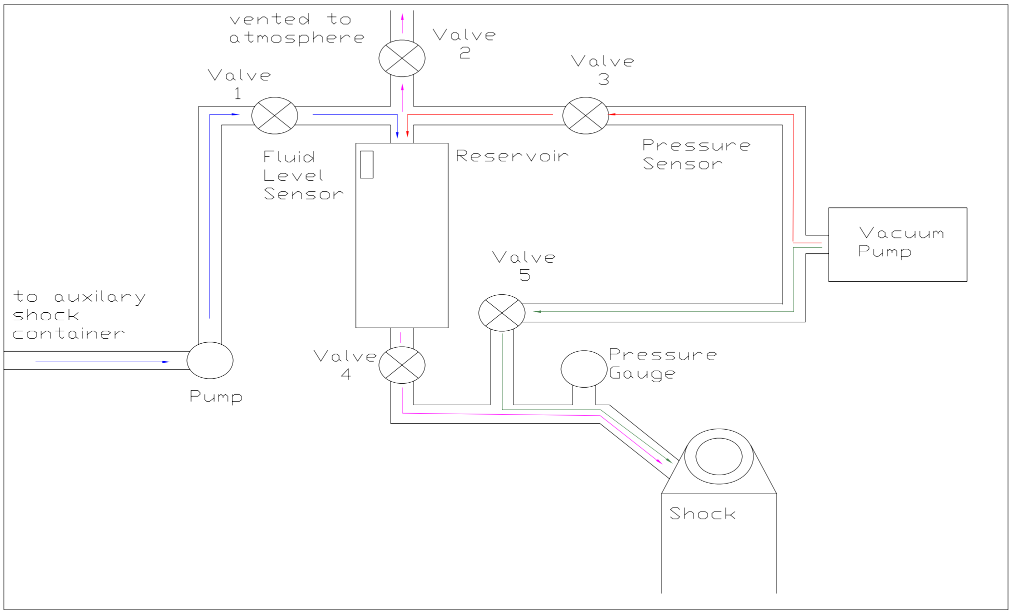


Figure 5: Final Design

3.5 ELECTRICAL DESIGN

3.5.1 Controls

We used a PLC to control the operations of the valves and the pumps. The PLC program was used to efficiently direct the sequence of the valves and the time that each one opens and closes. In order to implement the electronic controls we came up with an electrical schematic where we mapped out the I/O for our prototype. The electrical schematic that outlines the electrical connections is found in Appendix C-2. The Input-Output list is found in Appendix C-1. The entire PLC program was written in ladder logic. The PLC program had to be modified constantly during testing in order to get the outputs we desired at the proper times.

3.5.2 Process

The machine has a front panel that gives users all the operational options. One of the options includes the operator being able to choose to run the machine in either manual or automatic mode. Another option is choosing between a 7” and a 9” shock body. The shock filling process is divided into four main sequential steps that are explained in more detail in Appendix A-2. The function of each step is explained below:

Step 1: The pump starts to fill the reservoir with oil. Once the fluid sensor in the reservoir goes off, it transitions to step 2. Valve 1 is opened in order to allow the shock fluid to pass through and valve 2 is opened to atmospheric pressure.

Step 2: The vacuum pump is turned on and it pulls a vacuum on the shock oil in the reservoir. Valve 3 is opened and closed when a vacuum has been held for a set time. We have a pressure gauge which tells us if the lines and valves are holding a vacuum.

Step 3: A vacuum is pulled on the shock body. Valve 5 is opened in order to allow the vacuum to be formed on the shock. A pressure gauge and a timer mark when the step is complete.

Step 4: Valve 4 is opened and the oil passes to the shock for a short time. Valves 2, 3, and 5 then open to vent the line and force the oil into the shock.

Steps 2-4 need to be repeated a set amount of times depending on the shock size. Steps two through four need to be repeated approximately nine times to fill a seven inch shock and approximately thirteen times to fill a nine inch shock. For trouble shooting purposes, the PLC has been programmed to give the operator the option of reducing or increasing the number of time steps 2-4 are repeated. In order to subtract one cycle from the preset, the operator needs to hold down “Fault reset” and press “Step 3”. Similarly, if the operator wants to add a cycle to the preset, the operator needs to hold down “Fault reset” and press “Step 4”. The owner’s manual, with further instructions, can be found in Appendix A.

4 BUDGET

At the start of the project, we wanted our budget to be under $1400. As we got closer to purchasing the products we realized that we had underestimated the cost of some of the components. For example we had $200 set aside for the PLC, but the model we needed cost almost $600. Since it was a senior design project the labor was free. The total we spent was $780. We were only able to get this price because of many donations and the use of some used parts. The price that would be incurred by someone who builds this machine from scratch will be approximately $4631. The bill of materials can be found in Appendix B.

5 CONCLUSION

The outcome of this project was different from what we had originally planned for, but it was still successful. The prototype is completely functional and reduces man hours to fill a shock. It also delivers a better quality shock with considerably less air in it.

We also learned how to work effectively as a team. Effective communication and making use of strengths of team members was crucial in completing this project. It was also important to consider the design norms and the needs of our customer, Naake Motorsports, while building the prototype for this shock filling machine.

We would like to thank Mike Naake, Professor Ned Nielsen, and Dave Warsen for their great contributions to this project.

6 RECOMENDATIONS

There are several things that could have been done a little better on this project. The pump that we chose for filling the reservoir was far too slow because it only had 1.6 gallons per minute flow rate at three feet of head. If this machine were ever redone, there would need to be a pump with at least twice that flow rate and it would have to be self priming. The diaphragm vacuum pump with 1/16th horsepower that we used served its purposes well and should not be changed. The oil filter before the pump could have been slightly redesigned. A better valve could have been added to the bottom of it for better drainage, possibly even a valve that is sensitive to when it is full. The solenoid valves were only able to hold vacuum in one direction and this would be nice to change. The size of the reservoir was sufficient, but it might have worked better if it had been a little bit larger. There were a lot of leftover inputs left in the system that could have been used. These could have been more useful as troubleshooting guides.

7 APPENDIX

APPENDIX A: MACHINE OPERATIONS

A-1: OWNER'S MANUAL

Shock Filling Machine Instruction Sheet

Basic "Auto" Cycle Instructions:
Lift Clamp and slide shock into place on the studs
Turn On/Off switch to "On" position
Select 7" or 9" shock size on the selector switch
Select "Auto" on the Manual/Auto selector switch
Press "Auto Cycle Start" push button and allow cycle to progress
Warning: If anything appears to be going wrong press "Fault Reset" to stop the process

Troubleshooting guide:

(Step 1 fills the reservoir; Step 2 pulls a vacuum on the reservoir; Step 3 pulls a vacuum on the shock; Step 4 allows fluid to flow to the shock; Steps 2-4 are repeated)

To step the machine through a manual cycle:
Place shock in place and turn on the system
Select "Manual" on the selector switch
Press step 1 to 4 in order, waiting for the blinking light to go solid before progressing
Repeat steps 2 through 4 until shock is full
(This process can be done to determine the proper number of times 2-4 should be repeated in the auto cycle)

To see "Auto" presets for step 2-4 repeats:
Select 7" or 9" on the selector switch
Select "Manual" on the selector switch
Press "Step 4" and the light will blink the number that is in the preset
Toggle "Auto/Manual" selector switch when complete

To change "Auto" presets for step 2-4 repeats:
Select 7" or 9" on the selector switch
Select "Manual" on the selector switch
Hold down "Fault Reset"
Press "Step 4" to add 1 to the preset
Press "Step 3" to subtract 1 to the preset
Release "Fault Reset"
Toggle "Auto/Manual" selector switch when complete

To Empty Reservoir for Maintenance Purposes
Select "Manual" on the selector switch
Press "Step 2" and "Auto Cycle Start" at the same time to get fluid flowing
Press "Fault Reset" to stop fluid flow

A-2: CODE DESIGN

Note: Close valves after step complete

Step 1

- Check fluid level sensor (marks complete)
- Open valve 1
- Open valve 2
- Start pump
- Step 1 light goes on
- Stop pump

Step 2

- Check vacuum pressure sensor (marks complete)
- Start vacuum pump
- Open valve 3
- Step 2 light goes on

Step 3

- Check vacuum pressure sensor (marks complete)
- Open valve 5
- Step 3 light goes on

Step 4

- Check timer (marks complete)
- Open valve 4
- Open valve 2
- Check timer (marks complete)
- Open valves 2, 3 and 4 to vent system
- Step 4 light goes on

Repeat steps 2, 3 and 4 until shock is full

APPENDIX B: BILL OF MATERIALS

ELETRICAL COMPONENTS

Part	Description	Model Number	Quantity	Price	Supplier	Acquisition
1	Vacuum Pump	4Z026	1	$162.90	Grainger	Purchased
2	PLC	1761 - L32 AWA	1	$100.00	Ventura Mfg.	Purchased
3	Skinner Solenoid Valves		5	$400.00	Parker Fluid Control	Donated
4	Primary Pump	2P037	1	$57.20	Grainger	Purchased
5	Moisture Filter		1	$70.00	Eddie Lucas	Donated
5	Float Level Switch	50195K73	1	$19.55	Mcmaster	Purchased
6	Flow Switch	42015K4	1	$86.15	Mcmaster	Purchased
7	Pressure Switch	PSW-626	3	$195.00	Omega.com	Purchased
8	Wiring			$12.01	Lowe's	Purchased
9	Switches		3	$18.00		Donated
10	Indicator lights		5	$50.00	Steelcase	Donated
11	Wire Connectors		35	$7.00		Donated
12	Strain Relief Fittings		4	$8.00	Steelcase	Donated
13	Pressure Gauge	4253043	1	$8.60	Mcmaster	Purchased
		Spent	**Total**	**$641.41**		
		Actual	**Total**	**$1,194.41**		

FRAME COMPONENTS

Part	Description	Model Number	Quantity	Price	Supplier	Acquisition
1	3/4" Square Tubing		30ft	$27.18	Central	Purchased
2	Electrical Enclosure	B121206	1	$60.00	Automation Direct	Donated
3	Sheet Metal		1.5 ft^2	$12.00	Physical Plant	Donated
4	4" Square Tubin		1/2 ft	$10.00	Physical Plant	Donated
5	De-Sta-Co Clamp		1	$5.00	Rapid Line Inc.	Donated
6	Legs		4	$1.00	Physical Plant	Donated
7	Bolts, Nuts and Screws			$3.00	Physical Plant	Donated
		Spent	**Total**	**$27.18**		
		Actual	**Total**	**$118.18**		

FITTINGS AND HOSES

Part	Description	Model Number	Quantity	Price	Supplier	Acquisition
1	Brass Fittings	4A493	20	$50.00	Bond Fluidaire	Purchased
2	Hose Connectors		12	$30.00	Bond Fluidaire	Purchased
2	Vacuum Cup	5427A753	2	$12.88	Mcmaster	Purchased
3	1/4" Vacuum Hose		12ft	$15.00	Physical Plant	Donated
4	1/2" Oil Hose		6ft	$3.53	Lowe's	Purchased
5	Teflon Tape		I roll	$2.00	Physical Plant	Donated
14	Shutoff / Drain Valves		3	$15.00	Bond Fluidaire	Purchased
		Spent	**Total**	**$111.41**		
		Actual	**Total**	**$128.41**		

LABOR

#	Job	No. of Hours	Labor rate	Cost	Service Supplier	Acquisition
1	Cutting	10	$35.00	$350.00	Team Members	Donated
2	Welding	10	$35.00	$350.00	Team Members	Donated
3	Grinding and Finishing	10	$35.00	$350.00	Team Members	Donated
4	Painting	1	$45.00	$45.00	Rapid Line Inc.	Donated
5	Fitting Components	10	$35.00	$350.00	Team Members	Donated
6	Electrical Wiring	7	$35.00	$245.00	Team Members	Donated
7	Others (Design, Testing)	30	$50.00	$1,500.00	Team Members	Donated
		Spent	**Total**	$0.00		
		Actual	**Total**	$3,190.00		

		Overall Spent	**Total**	**$780.00**		
		Overall Actual	**Total**	**$4,631.00**		

APPENDIX C: ELECTRICAL CONTROLS

C-1: INPUT-OUTPUT LIST

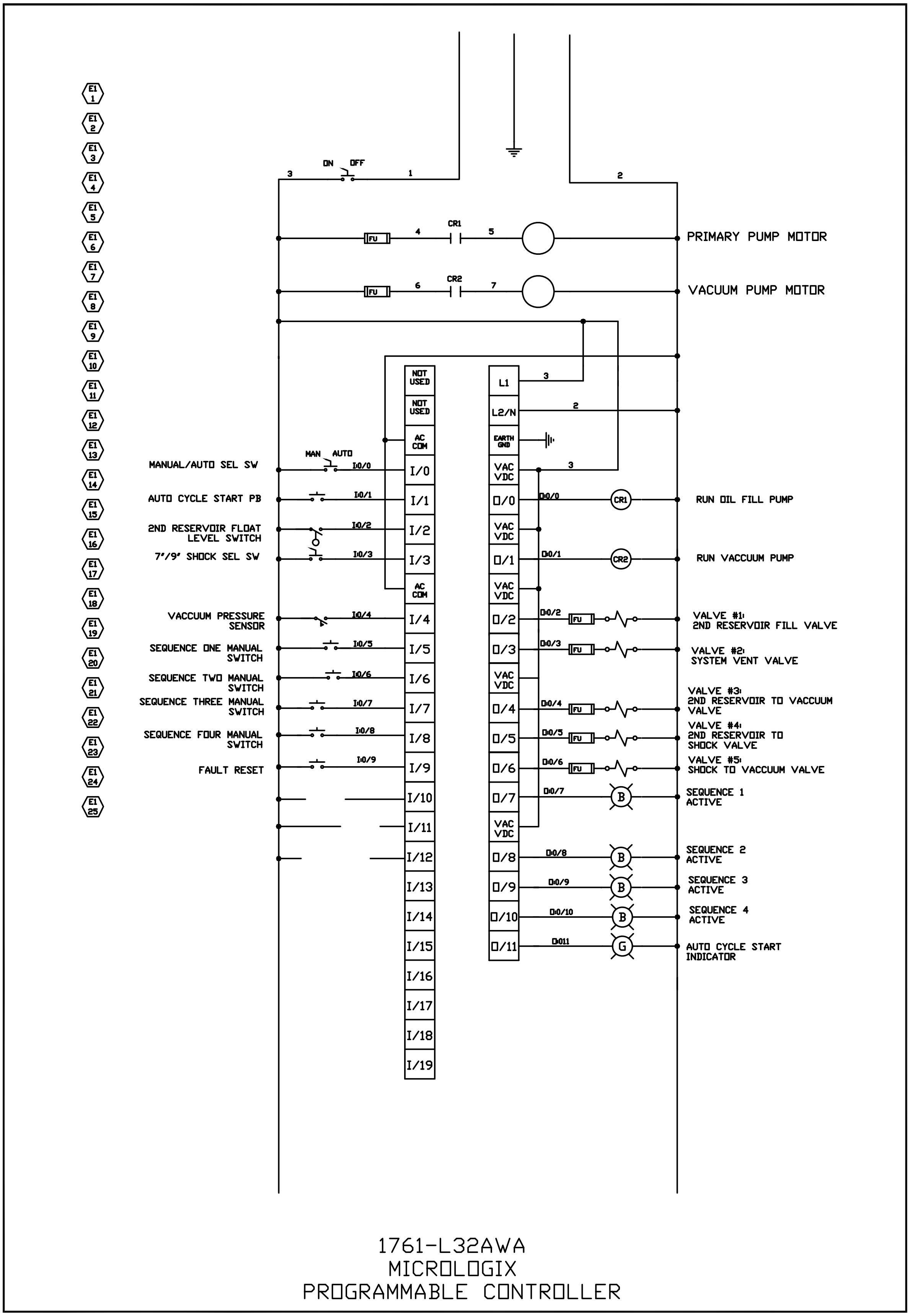
Input List

1. I:0/0 (Auto/Manual Switch)
2. I:0/1 (Auto Cycle Start PB)
3. I:0/2 (Secondary Reservoir Fluid Level Switch)
4. I:0/3 (7”/9” Shock Switch)
5. I:0/4 (Vacuum Pressure Switch)
6. I:0/5 (Sequence 1 Manual)
7. I:0/6 (Sequence 2 Manual)
8. I:0/7 (Sequence 3 Manual)
9. I:0/8 (Sequence 4 Manual)
10. I:0/9 (Fault Reset)

Output List

1. O:0/0 (Oil Pump)
2. O:0/1 (Vacuum Pump)
3. O:0/2 (Solenoid 1)
4. O:0/3 (Solenoid 2)
5. O:0/4 (Solenoid 3)
6. O:0/5 (Solenoid 4)
7. O:0/6 (Solenoid 5)
8. O:0/7 (Sequence 1 Active)
9. O:0/8 (Sequence 2 Active)
10. O:0/9 (Sequence 3 Active)
11. O:0/10(Sequence 4 Active)
12. O:0/11 (Auto Start Cycle)

C-2 ELECTRICAL SCHEMATIC



APPENDIX D: BERNOULLI CALCULATIONS

Team 7: Aim to PLEASE

Simultaneous Equations

$$\frac{P_2}{\rho_{oil}} + \frac{V_2^{\ 2}}{2} + 9.807 \ [m/s^2] \cdot h_L = \frac{P_1}{\rho_{oil}} + \frac{V_1^{\ 2}}{2} + Z_1 \cdot 9.807 \ [m/s^2] \quad [J/kg]$$

$$P_2 - P_3 = C_D \cdot 1 / 2 \cdot \rho_{oil} \cdot V_2^{\ 2} \quad [Pa]$$

Variables

$P_{atm} = 101325$ [Pa]

$P_1 = P_{atm}$ [Pa]

$P_3 = 0.064 \cdot P_{atm}$ [Pa]

$\rho_{oil} = 1030$ [kg/m³]

$V_1 = 0$ [m/s]

$Z_1 = 0$ [m]

$Z_2 = 0.3$ [m]

$C_D = 1.1$

Head Loss

$K_{L,Resv,out} = 0.03$ Sharped Edge inlet/Well Rounded (0.5/0.03)

$K_{L,bend} = 0.3$ 90 deg miter bend w/out vanes/90 deg smooth bend flanged or threaded (1.1/0.3 or 0.9)

$K_{L,elbow} = 0.4$ 45 deg threaded elbow (0.4)

$K_{L,total} = K_{L,Resv,out} + K_{L,bend} + K_{L,elbow}$

$$h_L = f \cdot \frac{L_{pipe}}{D_{pipe}} \cdot \frac{V_2^{\ 2}}{2 \cdot 9.807 \ [m/s^2]} + K_{L,total} \cdot \frac{V_2^{\ 2}}{2 \cdot 9.807 \ [m/s^2]} \quad [m]$$

$L_{pipe} = 0.45$ [m]

$D_{pipe} = 0.01$ [m]

$$A_{cs,pipe} = \pi \cdot \left[\frac{D_{pipe}}{2} \right]^2 \quad [m^2]$$

$\upsilon = 0.000007$ [m²/s]

$$Re = \frac{V_2 \cdot D_{pipe}}{\upsilon}$$

$\varepsilon = 0.00001$ [m] Smoothed Rubber

$$\frac{1}{\sqrt{f}} = -2 \cdot \mathbf{log} \left[\frac{\varepsilon}{D_{pipe} \cdot 3.7} + \frac{2.51}{Re \cdot \sqrt{f}} \right]$$

Shock

$L_{shock} = 0.254$ [m]

$D_{shock} = 0.073025$ [m]

$$A_{cs,shock} = \pi \cdot \left[\frac{D_{shock}}{2} \right]^2 \quad [m^2]$$

$V_{shock} = A_{cs,shock} \cdot L_{shock}$ [m³]

Hole

$$D_{hole} = 0.1065 \ [in] \cdot \left| 0.0254 \cdot \frac{m}{in} \right| \quad [m]$$

$$A_{cs,hole} = \pi \cdot \left[\frac{D_{hole}}{2} \right]^2 \quad [m^2]$$

Volume Flow Rate

$\dot{V}_{hole} = V_2 \cdot A_{cs,hole}$ [m³/s]

Time to fill Whole Shock

$$Time = \frac{V_{shock}}{\dot{V}_{hole}} \quad [s]$$

Solutions:

A_cs_hole=0.000005747 [m^2]

A_cs_pipe=0.00007854 [m^2]

A_cs_shock=0.004188 [m^2]

C_D=1.1

D_hole=0.002705 [m]

D_pipe=0.01 [m]

D_shock=0.07303 [m]

Epsilon=0.00001 [m]

f=0.0329

h_L=4.815 [m]

K_L_bend=0.3

K_L_elbow=0.4

K_L_Resv_out=0.03

K_L_total=0.73

L_pipe=0.45 [m]

L_shock=0.254 [m]

P_1=101325 [Pa]

P_2=30686 [Pa]

P_3=6485 [Pa]

P_atm=101325 [Pa]

Re=9337

rho_oil=1030 [kg/m^3]

Time=28.32 [s]

Upsilon=0.000007 [m^2/s]

V_1=0 [m/s]

V_2=6.536 [m/s]

V_dot_hole=0.00003756 [m^3/s]

V_shock=0.001064 [m^3]

Z_1=0 [m]

Z_2=0.3 [m]

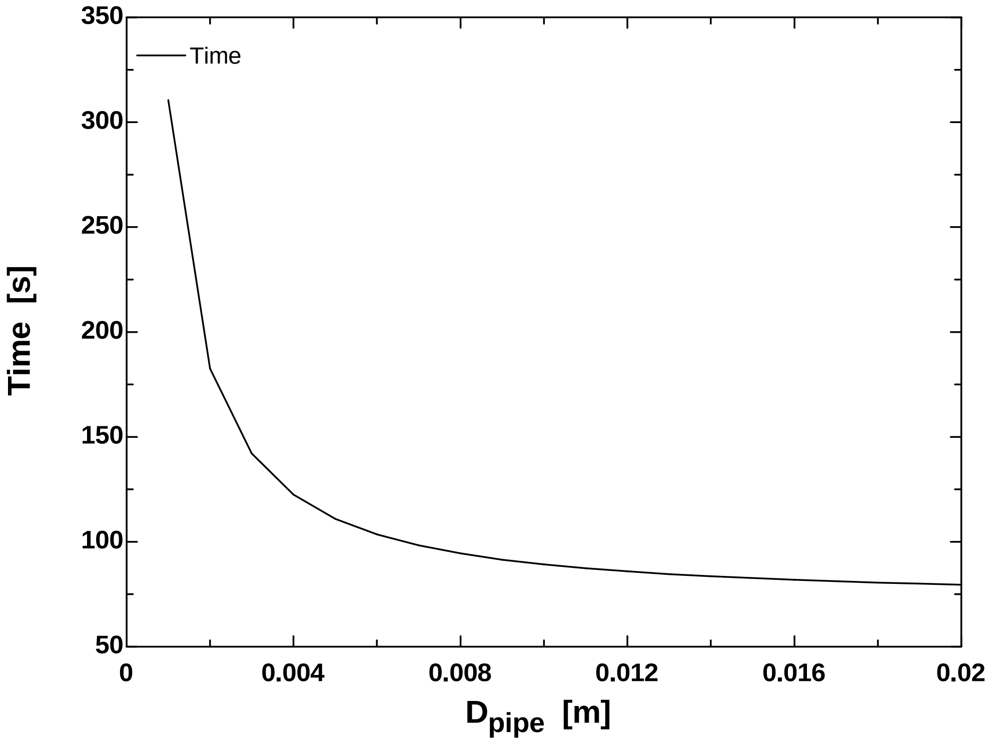


Figure D-1: Time to fill shock as function of Pipe Diameter.

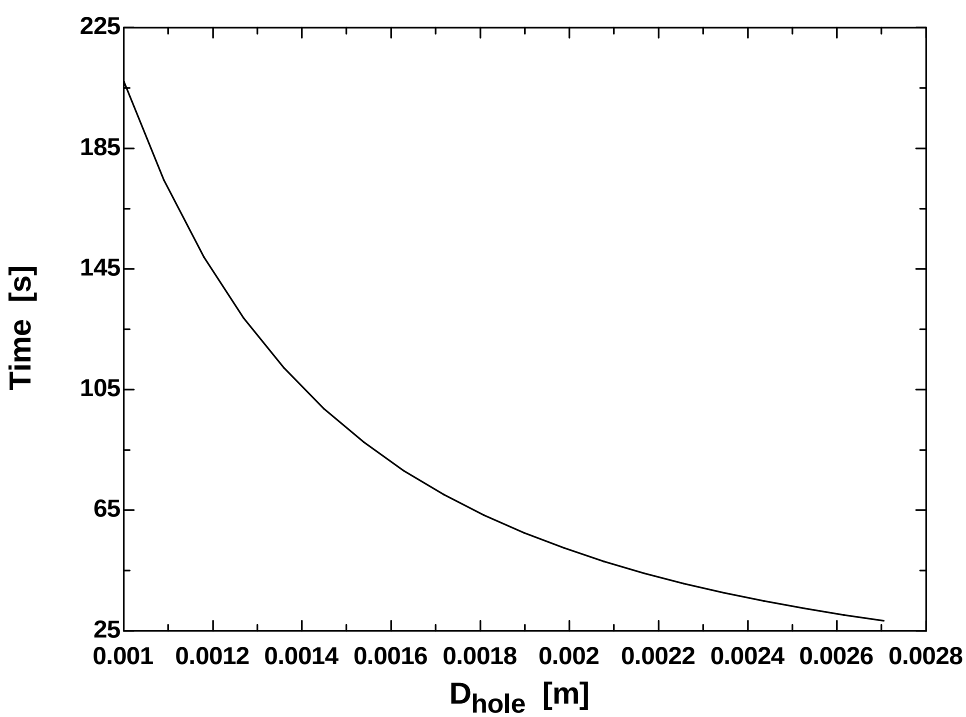


Figure D-2: Time to fill shock function of shock filling hole diameter

APPENDIX E: SHOCK FITTING DIAGRAM

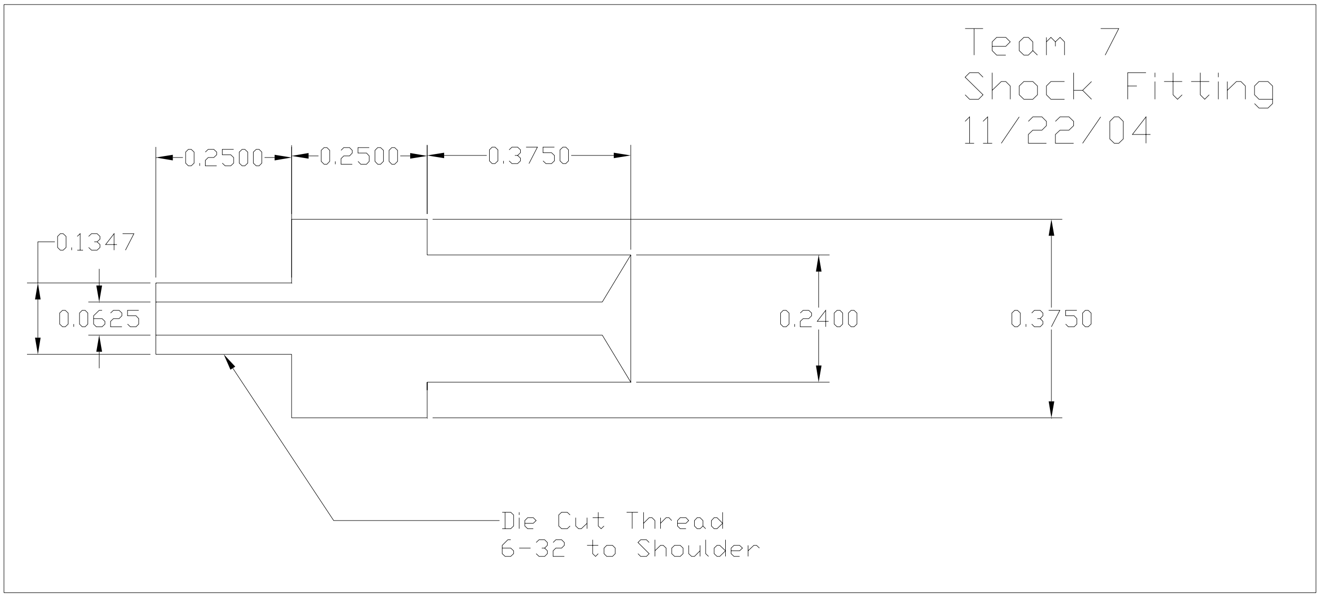


Figure E-1: Shock Fitting Diagram