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1 Introduction

By adhering to the concept of six-sigma and reducing variability in general, quality management processes can allow a company to reach more profitable markets. The case is true with Wasco Sales and Marketing. This report mainly documents one of the various deliverables that Wasco must produce to function in their environmental testing system to test their semiconductor-grade pressure switches. In other words, the problem is that Wasco does not have a quality management process advanced enough to qualify their product to be used in ultra-pure and environmentally-intense semiconductor manufacturing conditions. The deliverable that will be documented in the subsequent sections of this report is a manifold. The current manifold for these types of pressure switches is shown in Figure 1. Though functional, this manifold is inconvenient to use and incapable of fitting inside Wasco's Espec Platinous-series environmental chamber (Figure 2). When implemented into the environmental testing system, the manifold must be able to connect 100 semiconductor-grade pressure switches to an air supply of up to 1000 psi without exhibiting gross leakage while subject to varying humidity and temperature ranging from -70 to 180 degrees Centigrade. The objectives of this study are to:

- Conduct thorough research on critical aspects of the manifold and the functionalities that they must achieve
- Design iterative prototypes using CAD with the intention of testing specific qualities in each subsequent model
- Fabricate prototypes using CAM software and CNC machines
- Test each prototype for specific qualities that they were designed for
- Assess problems and generate solutions with each prototype

Many prototypes and design revisions will be produced using Autodesk Inventor for CAD work, Autodesk Inventor HSM for CAM work, and a Haas VF-2 CNC mill along with other various machines and tools as new problems arise. Sufficient context of the entire system, mainly concerning the software aspect, will be provided for understanding of the overall goal of the project; however, the scope of this report is directed towards the manifold. Objectives will be met by maintaining a Gantt chart denoting different sub goals to meet throughout the project, and coordinating with Wasco's Design Engineer, John Warren, and the industrially-experienced Cal Poly professor and technical advisor, Xuan Wang.

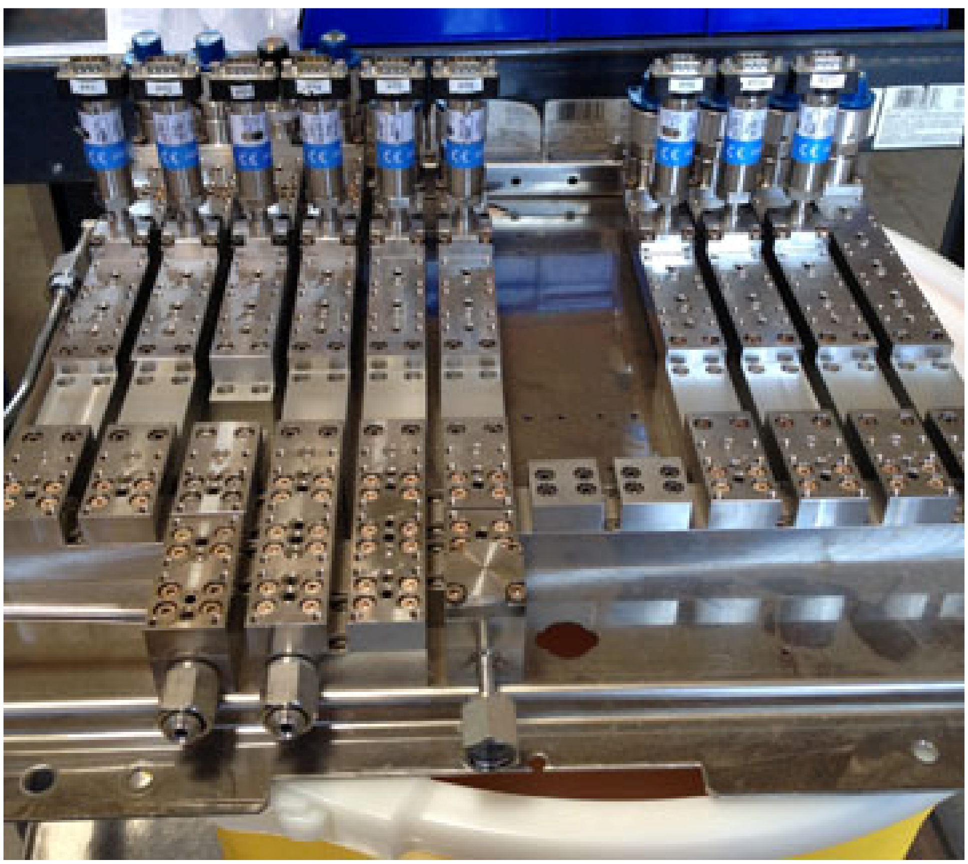


Figure 1: Old manifold – 4 screws required for each switch, stainless steel, weighs about 50 pounds

Figure 2: Espec Platinous-series environmental chamber

2 Background

This section of the report covers the background of Wasco as a company, the development and application of pressure switches, and a literature review concerning important aspects of completing the project. The literature review covers a broad spectrum of topics because the approach to this problem from Wasco's standpoint was unclear until more research was conducted.

2.1 Wasco Sales and Marketing

Wasco started as a screw company and eventually transitioned into production of pressure and vacuum switches, transducers, and transmitters. Established by the Way family, the company's name actually stands for "Way Automatic Screw Company." In addition to its name, Wasco still uses some of the machines and equipment purchased for screw manufacturing when the company first began. To improve product quality and open itself to new markets, Wasco purchased an Espec environmental chamber with the intent of eventually developing a process to validate their product against higher standards. Since then, Wasco has decided to reach a higher quality and performance market in the semiconductor industry. The environmental testing process, once designed and validated, will provide Wasco with more opportunities to satisfy customers who require similar environmental testing procedures for the quality of products that they order. This environmental chamber project is expected to expand Wasco's customer base and provide growth to the company as a whole.

2.2 Environmental Testing System Vision

Environmental testing shall be defined as triggering pressure and vacuum switches within an environmental chamber at varying temperatures and relative humidity proportions as specified by the customer. The system for environmental testing requires an environmental chamber, a manifold for pressure and vacuum switch units, a pressure controller, a gas booster, a pressure cylinder, pressure transducers, data acquisition devices, a computer with a specialized program to control variables and output data into a database, and plumbing and wiring throughout the system as its main components. Rough schematics of the system and its plumbing and wiring are shown in Figures 3 and 4 respectively.

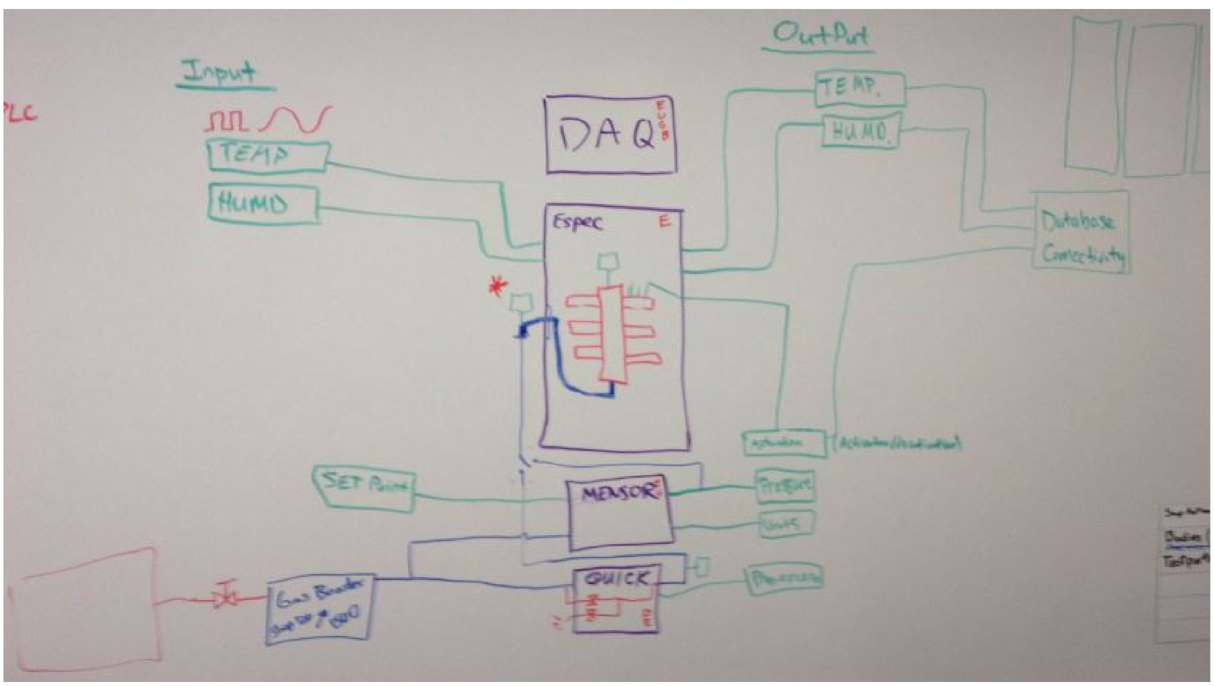


Figure 3: Rough schematic of environmental testing system

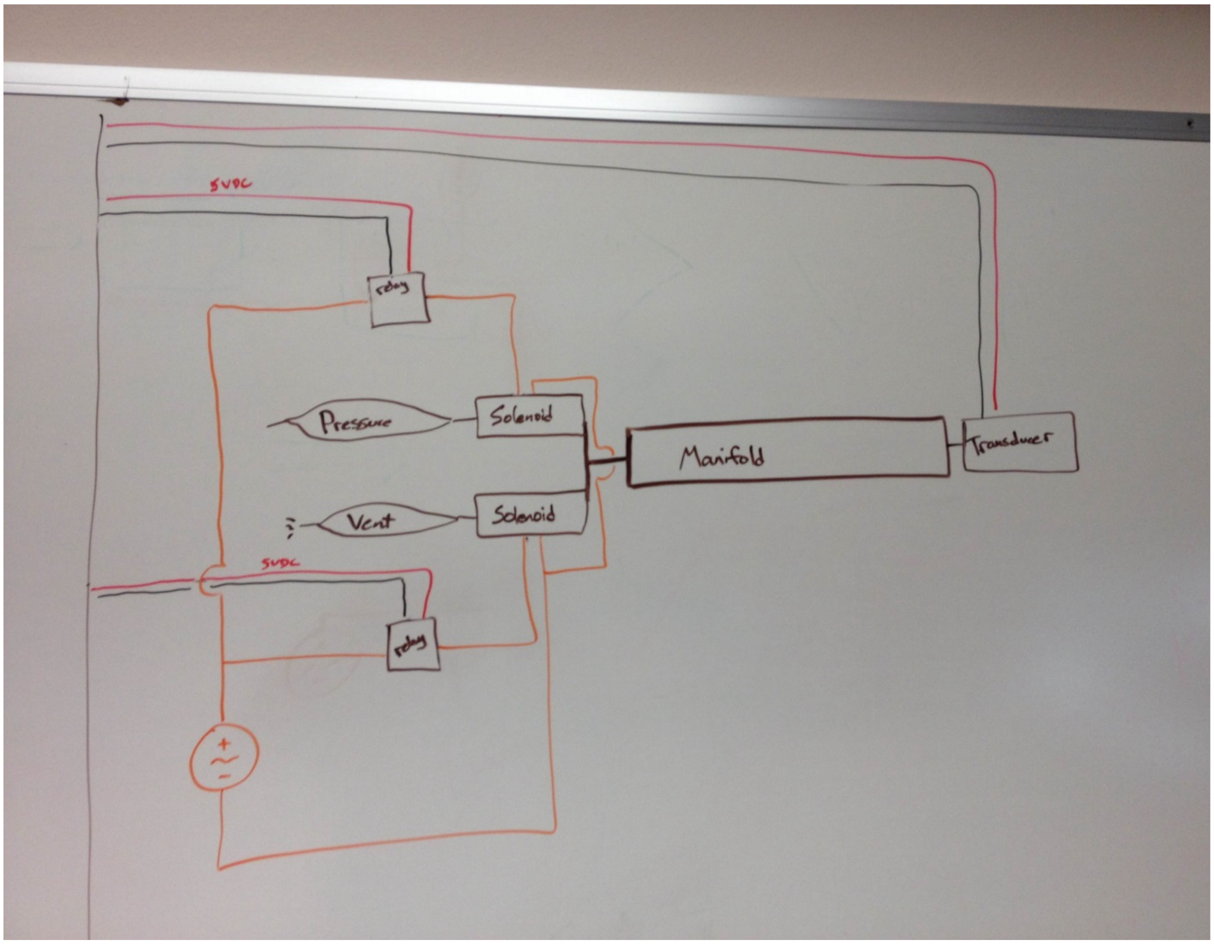


Figure 4: Rough schematic of wiring and plumbing of pressurize/vent functionality using two solenoid valves

2.3 Literature Review

Regarding LabVIEW programming and Computer-Aided Design and Manufacturing using Autodesk's Inventor software, this literature review will detail information gleaned from different books, articles, and case studies. Excerpts that relate to the task of establishing, programming, and adapting Wasco's Espec environmental chamber to strict semiconductor industry standard testing procedures for pressure and vacuum switches will be expanded upon and explained as to how it will be important for this project. This report outlines research into

four categories: *National Instruments LabVIEW*, *Autodesk Inventor*, *Environmental Chamber* and *Miscellaneous*. Each heading contains sub-headings pertaining to the main topic.

2.3.1 National Instruments LabVIEW

LabVIEW is a visual programming language known for its capability to acquire data and control instruments and machines in real-time (Turley et al., 1997). A user creates software using a block diagram and front panel in LabVIEW. The front panel is what displays to an operator of the created program while the block diagram shows controls, constants, and indicators that are wired to different functions and structures. The visual layout of the block diagram is easy to follow and learn, especially if a new LabVIEW user has experience with text-based programming. This programming environment will allow Wasco to create different programs for the environmental chamber which alter temperature, humidity, and pressure on 50 to 100 parts simultaneously. Since LabVIEW is such a crucial part of Wasco's environmental chamber project, it is the subject of the majority of the following pieces of literature.

In Turley and Wright's journal from 1997, I was able to learn of LabVIEW's power nearly two decades ago. In this case study, the authors' company, CACI International Inc., was contracted to construct a program to test Air Force engines. This single program in LabVIEW replaced three aircraft engine test systems and the out dated software and hardware that went along with them. The major problem was that the three test systems were very hard to maintain because each system was different from another. Turley and Wright outline their process while explaining why LabVIEW is superior to text-based programming. . The paper describes the major advantages of using LabVIEW, including reuse for developing related applications, immediate operator feedback, and optimization of processes. Also, LabVIEW is modular in the

way that it organizes a program. There is one main Virtual Instrument (VI), with subVIs within it and subVIs within those. This association forms a hierarchy that is easy to follow and organizes the process of developing software with LabVIEW (Figure 5).

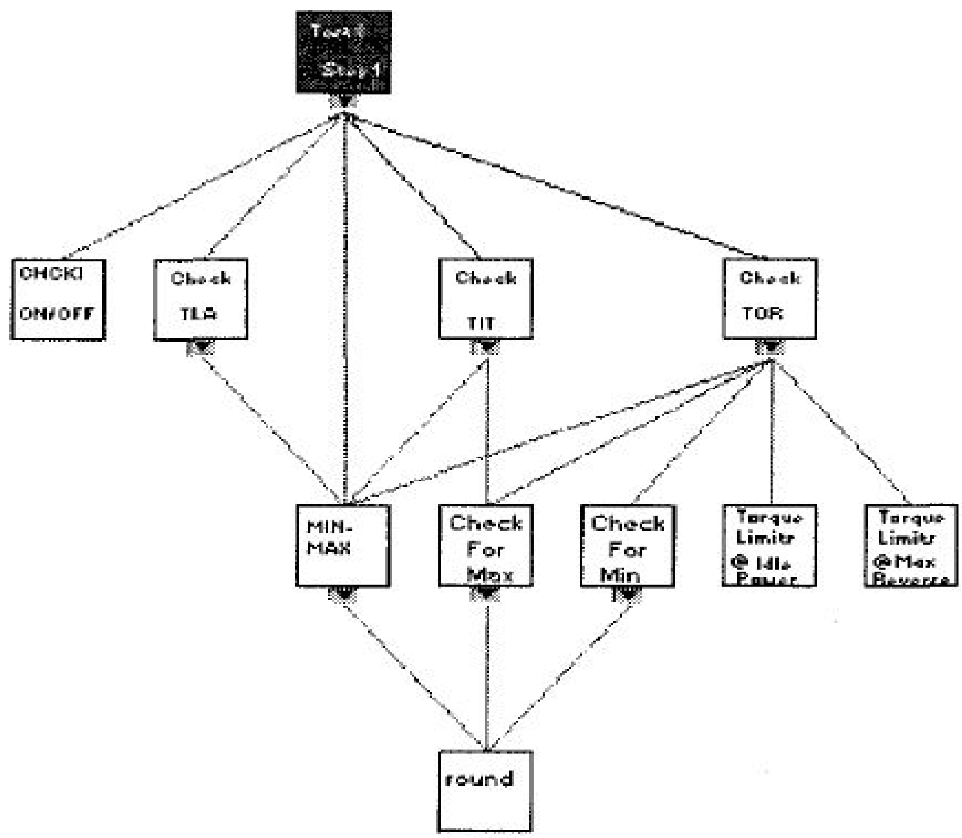


Figure 5: LabVIEW File Association Hierarchy Diagram (Turley et al., 1997)

Along with explaining the functionality of LabVIEW 1997, the case study's authors give a screen shot from their project – a check RPM VI and how they modeled the test system in LabVIEW. In the conclusion, they mention the drivers that can be downloaded into LabVIEW that are specific to whatever device that a programmer wants to control virtually. This is important for the environmental chamber because there are drivers online that will hopefully make the process of developing programs for it much easier.

The following case study from 2008 stuck out because it involves monitoring a pressure transducer through a LabVIEW environment, which is what Wasco must accomplish to receive real-time data from the pressure and vacuum switches. Though helpful, the article goes into a lot of detail concerning how they developed a system with remote access using an Object Linking and Embedding for Process Control (OPC) Server called HART. The authors list every piece of hardware that was used in their project and give a block diagram from LabVIEW. It is interesting to see another successful application of LabVIEW, but since the block diagram is unclear and the authors' focus is more on remote control using HART, this article may not be too helpful for the environmental chamber project.

Learning to build programs through LabVIEW is not something that someone can be trained on once and then that person is a proficient LabVIEW programmer. There will always be problems that require more research and referencing to come across a solution. In our week-long training class at Wasco, even the instructor had to check his references before answering a question or concern. Also in that class, we were provided with a *Lucid LabVIEW Fundamentals* manual which contains exercises and general information about the basics of LabVIEW (Spears, 2014). When starting practice projects, I also found *Hands-on Introduction to LabVIEW for Scientists and Engineers* by John Essick and *Labview Graphical Programming Cookbook* by Yik Yang. As new LabVIEW programmers, Wasco's engineering department can find solutions in these references along with Google searches when designing the block diagram and front panel for the environmental chamber interface.

2.3.2 Autodesk Inventor

One of the deliverables of the environmental project is a manifold designed and machined to meet Lam Research standards. The manifold must not damage or contaminate the parts in any way. No matter how much experience a CNC machinist or CAM-designer has, he or she must continue to use verified references to find solutions to new obstacles that will occur. Thom Tremblay, in his textbook titled *Autodesk Inventor 2014 and Inventor LT 2014 Essentials.*, provides general information about the program. Autodesk gives free student versions for its CAD software (Inventor) and CAM software (Inventor HSM) which is integrated into the main user interface. The program allows users to design a solid model part, and then seamlessly switch to the CAM interface to design coordinate systems, tool paths, and the rest of manufacturing procedures for a CNC Mill. Wasco uses two different CAM software packages, Inventor HSM for milling on the Haas VF2 and InventorCAM for mill-turning on the Haas DS-30SSY. Tremblay's textbook goes over all the basics of Inventor along with the technical aspects that will definitely be required when designing the manifold. It will be very easy to access the textbook file on a computer and search for a specific topic that might be hard to understand in the moment.

2.3.3 Espec Environmental Chamber

In the article, "PLC Based Automation of Grain Dryer" the authors use a PLC to automate the process of drying grains. The result is a more efficient and uniform process. This is applicable because humidity is an important factor to be controlled in the Espec environmental chamber that Wasco's project will be based on. The three Indian authors, who are electrical engineers by profession, clearly explain their objective and the steps that they took to achieve it.

When working on a big project with multiple aspects, it is important to start with a broad overview of the "moving pieces" and then move into more and more detail. In this article, the engineers did a good job of this. They first diagrammed the functionality of their grain dryer, and then analyzed inputs and outputs of the PLC along with the functions it will compute, as seen in Figure 6. For the environmental chamber, Wasco's engineering department should go about the end-goal in the same manner.

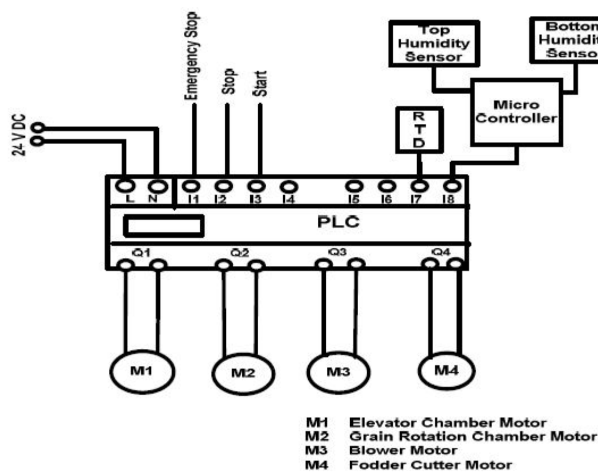


Figure 6: Diagram of PLC inputs and outputs (Singh et al., 2013)

2.3.4 Deciding on the most feasible programming environment

This project has been planned for over a year at Wasco. Upper-management of the company purchased the Espec environmental chamber at the end of their fiscal year after noticing that they had a budgetary surplus and that a groundbreaking contract between Wasco and a big semiconductor manufacturing company was in progress. When confronted with the decision to continue programming using programmable logic controllers (PLCs) using ladder-logic or transitioning to LabVIEW, both options must be analyzed for benefits and drawbacks.

For PLCs, single-core or multi-core systems may be used with several hardware and software options (Farzaneh et al., 2013). Modeling these options helps obtain a better perspective for someone who has never worked with PLCs before (Figure 7).

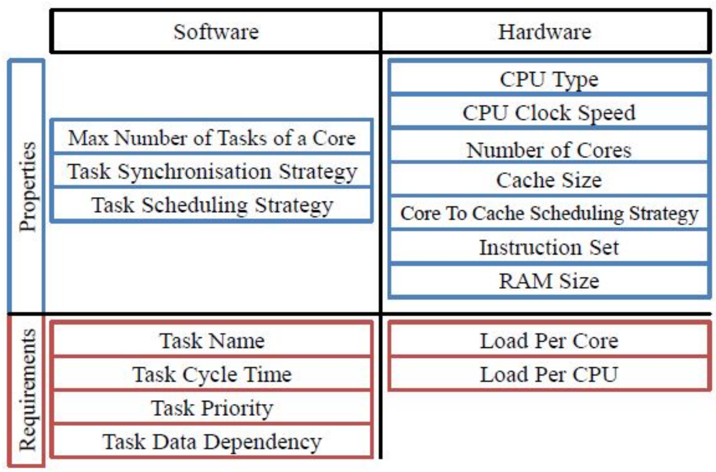


Figure 7: Software and hardware options of multi-core PLCs (Farzaneh et al., 2013)

Farzaneh details the PLC model for a hydraulic press used in the wood industry. The press incorporates up to 500 sensors which must be monitored and controlled by a multi-core PLC to press fiber board together with glue to obtain a specific thickness. Although the detail seemed overwhelming, it was helpful to read about a real and complex situation and its solution.

Mallik and Gupta from SRM University in India provided a simple and understandable LabVIEW example to be contrasted with the PLC example explained previously. Basically, the researchers used real-time monitoring of a temperature microelectromechanical sensor (MEMS) to easily notice if a part was being operated on outside of a specified temperature range. Production engineers could pinpoint the time and machine that needed attention (Mallik et al.,

2009). As seen in Figure 8, the authors also provided their work in LabVIEW: pictures of the front panel interface and block diagram (where the programmer "wires" inputs, functions, and outputs).

Figure 8: LabVIEW front panel and block diagram (Mallik et al., 2009)

They go on to write about the many benefits of LabVIEW – most of which can be referenced in Figure 9.

CONVENTIONAL CONTROLLER	LabVIEW
Vendor defined	User-defined.
Function –specific, stand-alone with limited connectivity.	Application –oriented system with connectivity to networks, peripherals and applications
Hardware is the key	Software is the key.
Closed, fixed functionality,expensive	Low- cost, reusable.
Slow turn on technology (5-10 years life cycle).	Open, flexible functionality leveraging off familiar computer technology
Minimal economics of scale & High development and maintenance costs	Maximum economics of scale Software minimizes development and maintenance costs.

Figure 9: Comparing and contrasting LabVIEW to conventional controllers such as PLCs

This is extremely helpful to learn just how easy LabVIEW can be incorporated to virtually control a machine. With regards to Wasco's environmental chamber, Mallik and Gupta's example seems much more relevant than Farzaneh's article about using PLCs to control a hydraulic press and monitor sensors. Having no experience with either programming method, LabVIEW seems like the most logical path that the engineering department should follow for this project. If this project is successful, LabVIEW has the potential to boost the performance of Visual Basic programs that Wasco uses if they are re-coded with LabVIEW.

2.3.5 Pressure Switches

The concept of pressure switches must be explained so that the type of testing Wasco requires for their product will make sense. Raymond Williams in his 1998 article "Optimizing Pressure Switch Selection" goes into detail about the function of a pressure switch, the different

types, and their strengths and weaknesses. "In its simplest form, a pressure switch is a device capable of detecting a pressure change and opening or closing a contact at a predetermined level" (Williams, 1998). Without going into more detail than necessary, assume that all switches for this report are the single-pole, double-throw (SPDT) variety. This means that the switch operates using a common terminal, a normally open-terminal, and a normally-closed terminal (Figure 10).

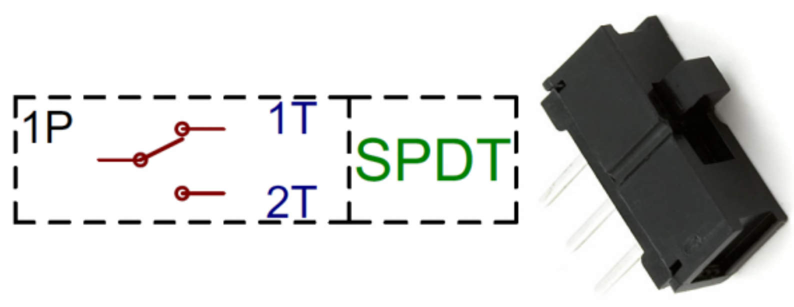


Figure 10: Single-Pole, double-throw switch schematic ("Switch Basics")

The switch that Wasco aims to improve on and adapt for a specific application is a diaphragm-sealed piston pressure switch. This type of pressure switch operates at pressures from full vacuum to 500 psi, exhibiting 2% accuracy and a life of around 2.5 million cycles with a low cycle rate compared to solid-state pressure switches (Williams, 1998). The units that the manifold will be used for have 1.125" square, stainless steel bases that are ¼" high (Figure __). The pressure inlet and exhaust are located on the bottom face of this square base. The manifold should connect to the square base without scratching the surface or contaminating the unit throughout its testing.

In Teschler's short article about pressure switches titled "Piston/diaphragm Pressure Switches," he explains the basics about pressure switch components and materials used under

different conditions. For example, Teschler lists different materials used to manufacture various diaphragms depending on the condition that the switch will be subject to. "EPDM is a typical choice when the diaphragm may see synthetic oils. It is also widely used outdoors in extreme cold because it stays flexible at low temperatures. On the other hand, Viton diaphragms are compatible with a wider variety of oils but are too stiff at low temperatures to work well in the cold" (Teschler, 2005). This is important and relevant because Wasco's goal is to test their switches under different temperature conditions that would be suitable to specific semiconductor applications. A possible result of testing could be that Wasco must redesign their switch's diaphragm material to perform better under certain temperatures or humidity instances. A diagram that Teschler provides to accompany his article can be seen in Figure 11. The article also briefly introduces the concept of solid-state switches. Solid state pressure and vacuum switches actuate at specific set points more precisely, endure long-term cycling, and cost much more than piston-diaphragm switches.

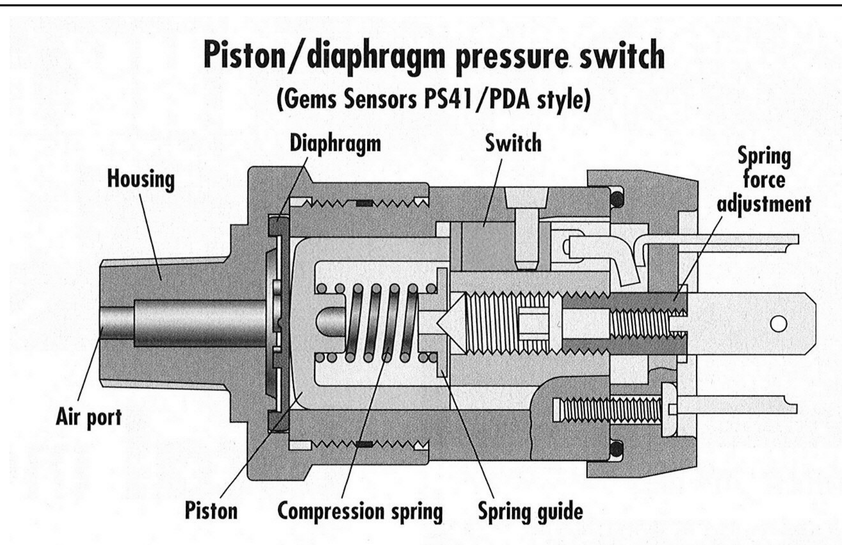


Figure 11: Piston/diaphragm pressure switch diagram (Teschler, 2005)

3 Methodology

To ensure steady progress and an economic use of time and materials, this project will abide by the DMAIC methodology of problem-solving. DMAIC stands for define, measure, analyze, improve, and control. In the defining phase, research must be conducted on critical aspects of the manifold and its role in the environmental chamber system. These critical aspects include O-ring selection, O-ring gland design, part locating method, part clamping method, air supply connection interface design, and the effect of extreme environmental conditions and internal pressure on the manifold assembly. During this phase is also an opportune time to ask as many questions as needed to upper-level management and experienced engineers on the subjects of machining, programming, and environmental testing. Iterative prototyping will fill the measure, analyze, and improve stages until all desired functionalities are accomplished. Each prototype will be designed and produced with the intention of testing one or two aspects of the design to evaluate design options and determine the most optimal solution. The control stage will include monitoring the manifold throughout environmental testing to verify that it is functioning as it is designed to function. The Gantt chart in Figure 12 shows the progress of the project in December 2015 along with soft deadlines for the deliverables.

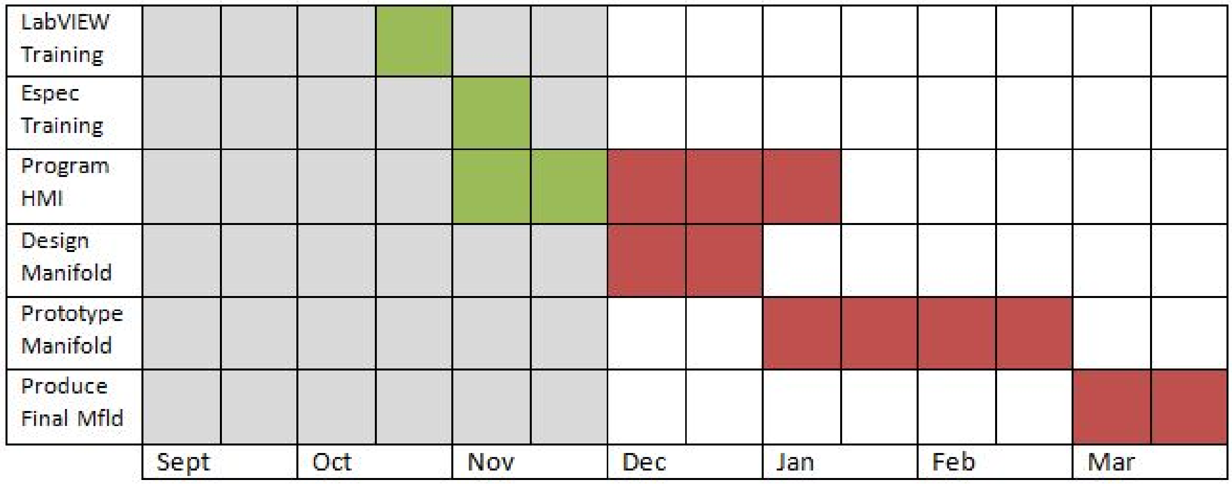


Figure 12: Gantt chart showing project progress at the beginning of December, 2015

4 Design

This section will document the progress achieved through developing each prototype leading to the final manifold design and fabrication. As mentioned in the previous section, Methodology, the critical design aspects of the pressure switch manifold are as follows:

- O-ring selection
- O-ring gland
- Part locating method
- Part holding method
- Air supply connection interface
- Number of units per manifold

Evaluated against

- Extreme environmental conditions
    - Varying humidity levels and temperature range between -70 and 180 degrees Centigrade
- Internal pressure up to 1000 psi
    - Manifold channels airflow into each pressure switch
- Necessary minimal damage/contamination to parts
    - Testing procedures and equipment must not damage or contaminate the parts
- Cost
- Operator convenience
    - Ease of loading and unloading parts for testing
- Reliability

  - Manifold and its components must remain functional over a reasonable amount of time
- Functionality
  - Manifold should not introduce a bias between the parts being tested

4.1 Prototype 1

The first prototype was created mainly to evaluate three different O-ring gland designs. Using the O-ring manufacturer, Parco's, O-ring Information book, a correct face seal under internal pressure should meet certain guidelines. In Figure 13, the dimensions of each O-ring gland can be seen in the partial engineering drawing. After testing with the manual pressure generator up to 1000 psi (Figure 14-D), the first prototype maintained its seals with no signs of leakage or damage to the parts. One of the main drawbacks to this design is the unbalanced clamping plates on the right and left edges of the manifold. When clamped, the plates tilt, possibly scratch the switches, and put unnecessary stress on the camping screws. Also, it seems inconvenient to have to tighten two screws for each part. These factors have been considered for the subsequent iterations of the manifold.

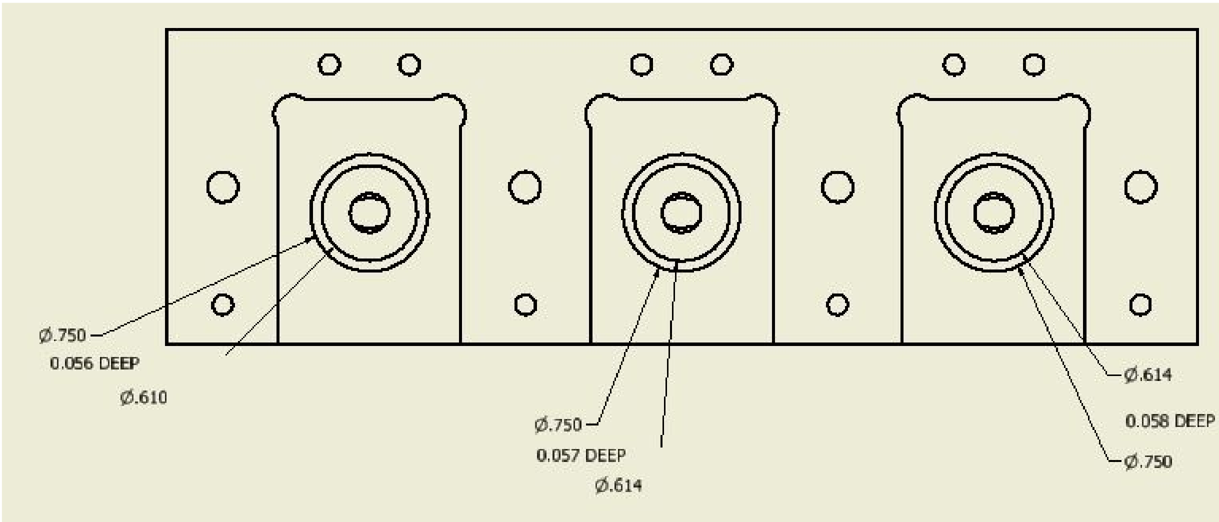


Figure 13: Prototype 1 O-ring gland design

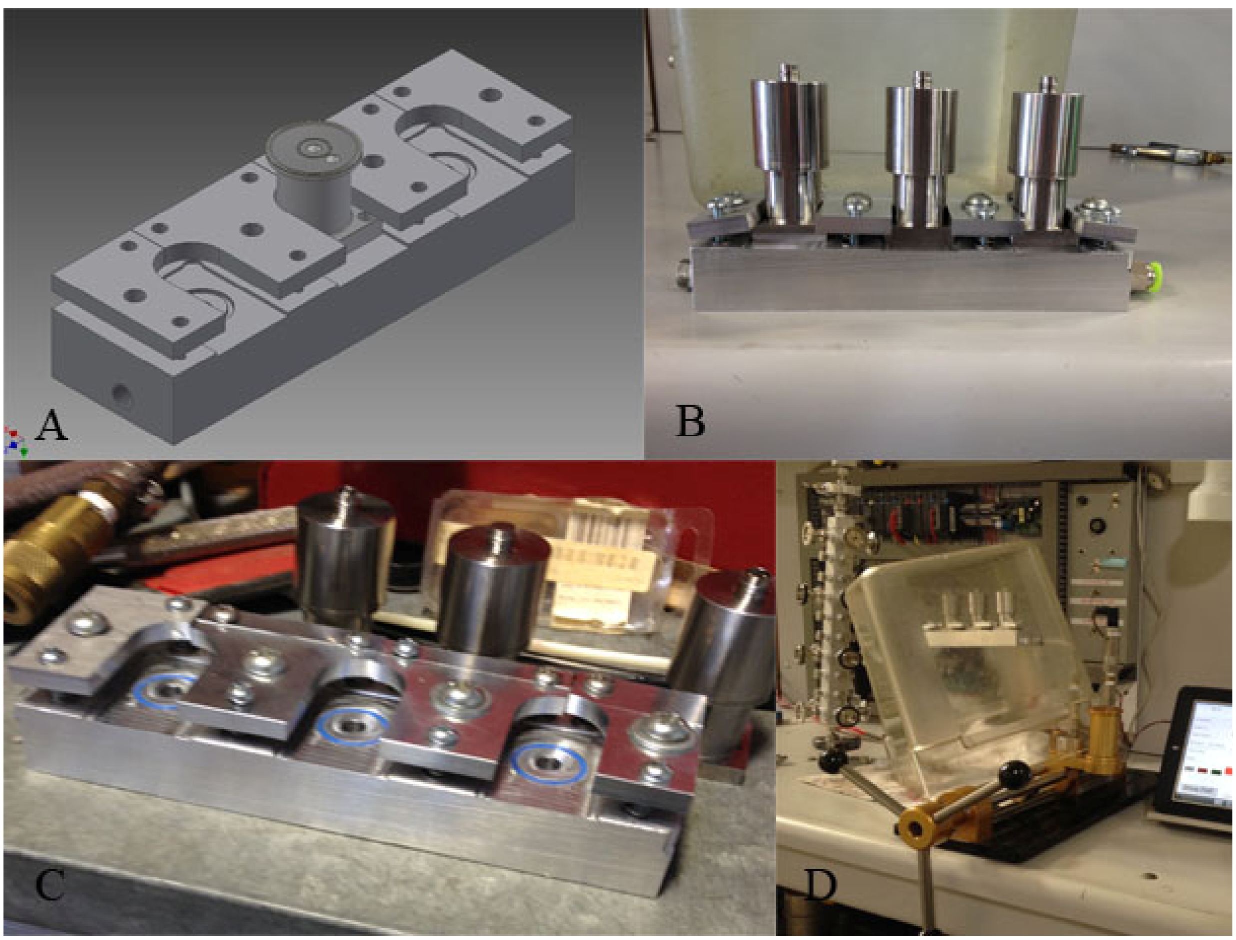


Figure 14: Prototype 1. A – Solid model, B – Parts attached, C – Parts unattached, D – Testing pressure limit with manual pressure generator

4.2 Prototype 2

The changes made in the second prototype are: a tighter outer diameter for the O-ring gland to compensate for internal pressure, a better fitting ¼-18 NPT air supply connection on the bottom, and a 0.010" deep groove around the edge of the part location pocket to provide relief for any burrs that might be present on the bottom of a switch's square flange base. Also, a small ledge was added to the sides of the manifold to balance the plates that clamp onto the square base of the switch. Pictures of the prototype are shown in Figure 15, and detailed explanations will follow in the next subsections.

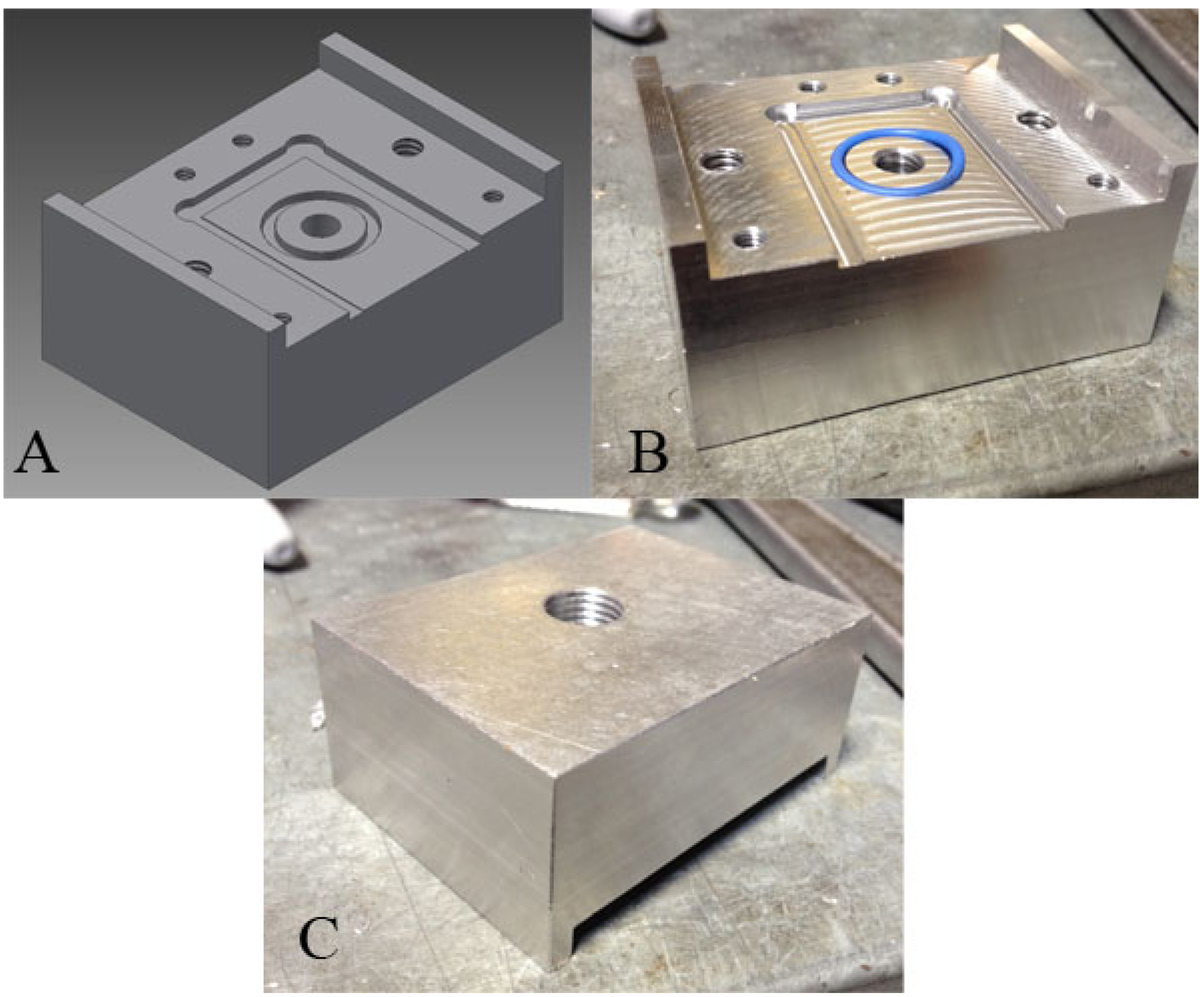


Figure 15: Prototype 2. A – Solid model, B – Top of single-port manifold, O-ring gland

4.2.1 O-Ring Gland

The O-ring gland redesign was an attempt to incorporate the internal pressure and extreme temperature factors. With high axial internal pressure, the rubber O-ring will have a tendency to expand outwards, so it is best practice to design the gland so that the O-ring will already be in 100% contact with the outer diameter of the gland. After machining the prototype, the O-ring did not stay in the gland because the interference was too severe. Also, high temperature will cause the rubber to expand. The gland must be designed so that there is room in the cavity for the material to fill. This concept is measured by gland fill percentage, which should optimally be 80-90% ("Static Axial Internal Pressure: O-Ring Gland Design"). The first prototype had a conservative design but this prototype's gland outer diameter was too small and did not allow the O-ring to sit in the gland.

4.2.2 Air Supply Connection

Quarter-inch NPT fittings are common in Wasco's operating facility, so ¼-18 NPT threads were chosen as the appropriate female connection to an air supply. Since taps vary to such a great degree, good online resources detailing proper depth of an NPT tapping were hard to find, so a trial-and-error method was used. Starting at a shallow, conservative tapping depth, the tapped hole was checked with a plug gauge in between step-downs to a deeper thread depth until the operator could hand-tighten the gauge until the flat on the gauge was flush with the top of the hole. For the tap used, a proper depth to tap was 0.6345".

4.2.3 Burr Relief Groove

This feature would allow relief for any small burrs that might be present on the bottom of the square base of the pressure switches, however, the switches usually do not enter the testing stage if post-processing is still required. Therefore, the groove would later be removed from the manifold design.

4.3 Prototype 3

Prototype 3 (Figure 16) has a deeper switch location pocket to make loading parts easier for the operator while eliminating a possibility of incorrectly clamping the part or parts. This iteration was also tested to 3000 psi using a manual pressure generator. This was to test the strength of the ¼-20 clamping screws and the tapped holes. Because the screw holes were only tapped to a depth of 0.35”, only seven threads of each of the two screws were holding against about 663 pounds of force at 3000 psi. The internal threads were tapped with a forming tap in aluminum. Since the threads held, the tapping depth can be considered adequate. Over the course of time, however, it would be wise to have deeper tapped holes to increase the lifespan of a functional manifold.

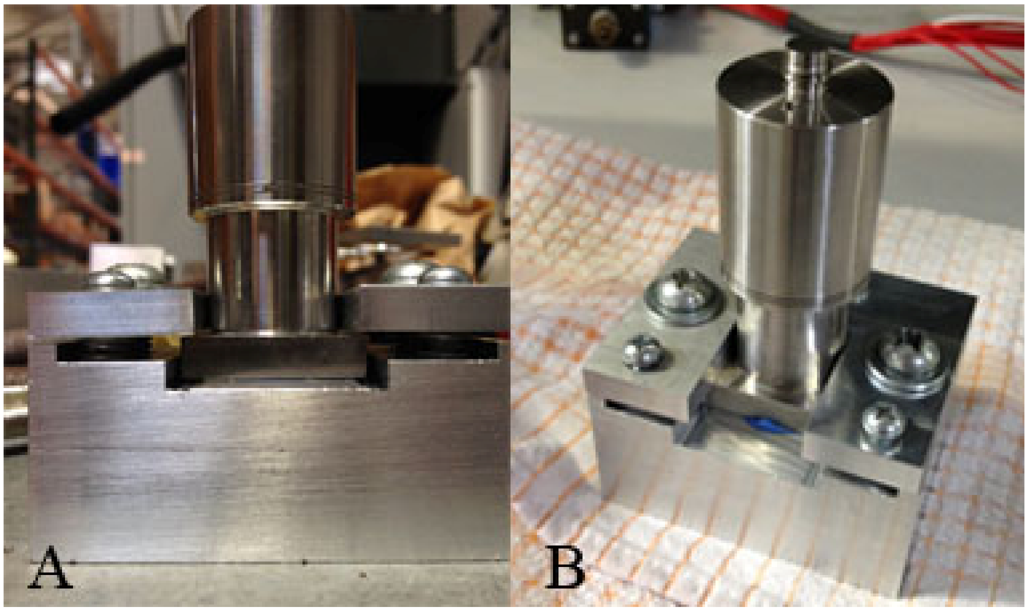


Figure 16: Prototype 3, A-with switch loaded, B-failed O-ring

4.4 Final Manifold

Figure 17 and 18 show the machined manifold and its engineering drawing, respectively. Only a small number of changes were made to the final prototype other than extending the design to house 10 switches. Firstly, small curves on the opening edges of the pockets allow less operator effort to load parts onto the manifold. Also, the tapped screw holes are deeper to accommodate more load than the previous prototypes. There are now 6 screws for 10 switches instead of 2 screws for 1 switch. When pressurized to 1000 psi, each part exerts about 442 pounds of force upwards against the clamping plate, which is held down by 6 screws. Therefore, each screw hole, now tapped to a depth of 0.5”, must be able to bear about 736.67 pounds of force. Additionally, the clamping plate is singular in this iteration of the manifold, allowing for much faster loading and removal of parts. The air supply pathway is designed so that the screw holes do not interfere, and only one connection to the air supply is required. The five ¼” NPT screw holes along the long edge of the manifold could not be avoided during machining to

achieve the desired “cross-hatched” design and must be plugged with NPT fittings. Lastly, 3/8” dowel pin holes were added at 0.003” interference for a 3/8”-diameter, steel dowel pin. These pins will help maintain a squared alignment between the manifold and clamping plate.

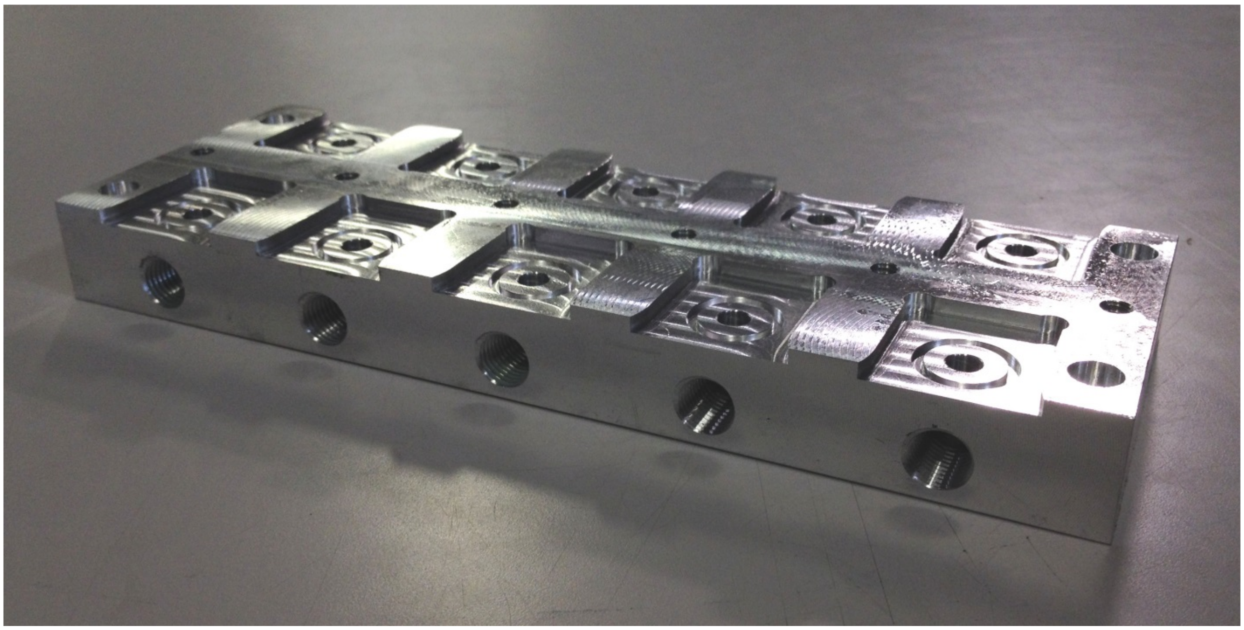
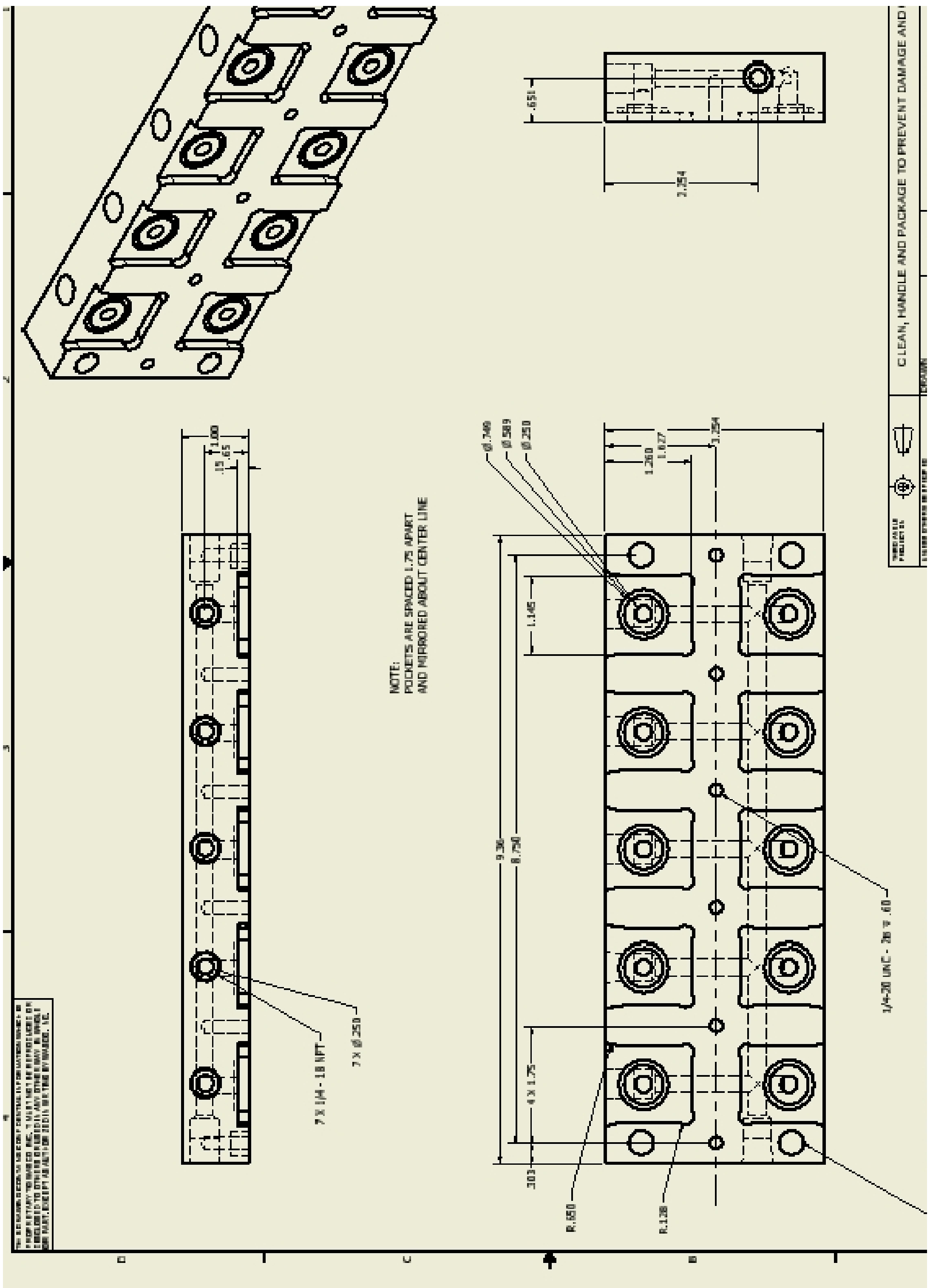


Figure 17: Final manifold


NOTE:
POCKETS ARE SPACED 1.75 APART
AND MIRRORED ABOUT CENTER LINE
CLEAN, HANDLE AND PACKAGE TO PREVENT DAMAGE AND
7 X 1/4 - 18 NPT
7 X Ø.250
4 X 1.75
Ø.749
Ø.589
Ø.250
1.260
1.627
3.254
2.254
.651
8.750
1.145
R.650
R.128

5 Results

The final assembled manifold, shown in Figure 19, was machined successfully on March 2, 2015. Reducing the number of clamping screws per pressure switch, adding four alignment pins, creating one clamping plate, and designing a "hatched" air supply connection to each part were the main changes to this version of the manifold.

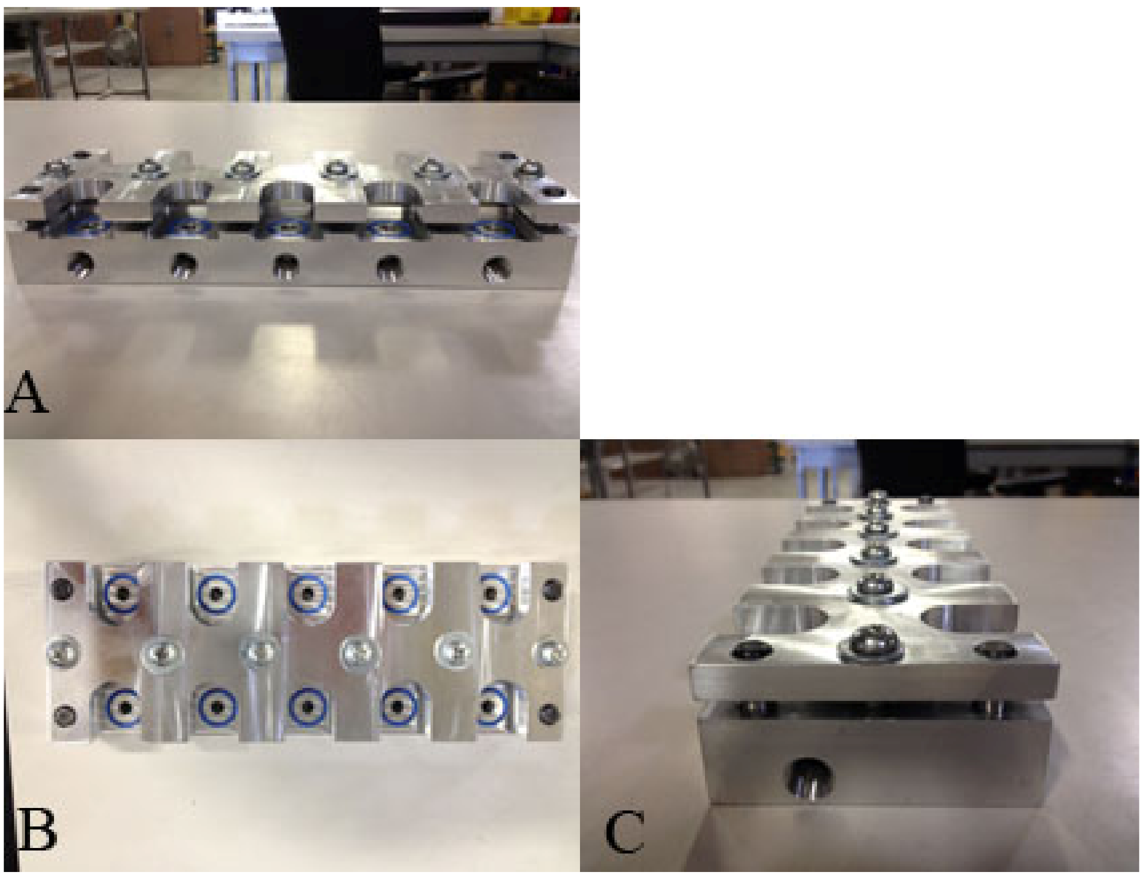


Figure 19: Final manifold assembly, A - Front view, B - Top view, C - Side view

5.1 Load on Clamping Screw Holes

At 1000 psi of internal pressure, the clamping plate is subject to about 352 pounds of force for every switch- 3520 pounds of force for all ten switches. Since only six ¼-20 screws hold the clamping plate, each screw hole must bear a load of approximately 587 pounds of axial force.

When testing the third prototype, the tapped holes were found to hold 663 pounds of force at 3000 psi of internal pressure when tapped in the aluminum manifold at a depth of only 0.35” (see section 4.2- Prototype 3). Because of these previous findings, one can be confident that the six screws should be able to easily hold the clamping plate at variable internal pressures up to 1000 psi. Also, the two screws on the furthest ends of the part are spring-loaded so that the clamping plate is in the raised position by default and parts are easier to load and unload from the manifold.

5.2 Alignment Pins and Clamping Plate

Four 3/8 hardened-steel alignment pins were press-fit into 0.372”-diameter holes for a three thousandths-inch interference. Mating holes on the clamping plate were drilled with an end mill using a helical toolpath to a diameter of 0.390” for a 15 thousandths-inch clearance fit to the alignment pins. Pressing the pins 0.265” deep into the manifold using an arbor press gave adequate perpendicularity and a smooth, linear clamping range-of-motion with the previously-stated clearance to the clamping plate.

5.3 Air Supply Routing

The air supply was routed in a “hatched” fashion seen in the engineering drawing in Figure 18. The benefit to this design is that only one inlet connection is needed while the drawback is that the manifold requires six ¼”-NPT plugs. When pressurized, switches that are furthest from the inlet will be actuated negligibly later that the switches close to the inlet. This potential problem can be considered negligible due to the fast rate at which the manifold will be pressurized and vented.

5.4 Evaluation of Success Criteria

Extreme environmental conditions	Will be tested once environmental chamber system is set up. Effort was made to accommodate these conditions during design. For example, the O-ring gland was designed for the percent of cavity filled to be low enough to account for high temperatures causing O-ring expansion. Tolerances on the manifold are loose enough to function through thermal expansion.
Internal pressure up to 1000 psi	By testing each prototype leading up to the final manifold, one can be confident that the manifold will hold up to 1000 psi with no problems.

Necessary minimal damage/contamination to parts	The manifold provides enough space between the bottom of the manifold pocket to the bottom of the clamping plate for a part to be loaded and unloaded without damaging the part.
Cost	The cost is easily within Wasco's budget for this project because all prototypes were made from aluminum, and all processes and tools used for the project were routinely cleaned and serviced.
Operator convenience	By adding a radius to the opening of the switch pocket, reducing the number of screws per part from 4 to 0.6, and reducing the weight of the manifold from 50 pounds to 2 pounds, operators can load and unload parts much quicker while also being able to transport the manifold easily.

Reliability	Reliability is still a concern because humidity will accelerate corrosion on manifolds made out of aluminum. Stainless steel is a consideration, but a decision will be made once the lifespan and cost of aluminum and stainless steel manifolds is known.
Functionality	The biggest bias that the manifold introduces is the time that each switch actuates will be slightly different as a result from varying distances between the ten switches and the one air supply inlet. This difference can be considered negligible in the context of Wasco's environmental testing and the generally high rate of pressurization of the manifold and switches they will use during testing.

5.5 Cost of Project

Since there is no projected date when environmental testing will be discarded as a quality assurance process at Wasco, the following cost analysis aims to estimate the added cost to each unit requiring environmental testing due to the addition of the environmental testing system over the next 10 and 20 years. Also, this analysis assumes that tool wear, collateral, and overhead are negligible costs.

Approximate Environmental Testing System Costs:

Epec Platinous-series environmental chamber + maintenance + training	$25,000
Mensor pressure controller	$20,000
Gas booster	$10,000
Gas cylinder	$500
Plumbing/wiring/fittings/regulators/solenoid valves	$3000
DAQ devices	$10,000
Transducers	$2,000
Aluminum for 10 manifolds	$85
O-rings, dowel pins, screws	$40
Intern hourly pay	$12,800
TOTAL	$78,925

Wasco plans to produce 1,000 units every year for customers along with approximately 2,000 R&D units requiring environmental testing. The result is 3,000 units every year requiring environmental testing- 30,000 over the course of 10 years, 60,000 in 20 years.

Over 10 years, an estimated cost of $2.631 is added per unit and $1.315 per unit over 20 years due to environmental testing. The cost of this project is fairly economic compared to the ultimate return on investment from including new environmental testing processes in Wasco's quality-assurance repertoire.

Aluminum $1.86/lb bulk price

Total volume of Al for 10 manifolds: ~160 in^3 (clamping plates) + ~305 in^3 (manifolds) = 465 in^3

Density of Al: 0.0975 lb/in^3

Weight: 465 * 0.0975 = 45.34 lb

Cost: ~$85.00

Intern hourly pay

2 interns

~$20/hr/intern

~2 days/wk working on the project, 20 weeks = 40 days

8 hrs/day = 320 hours

320 hours/intern * 2 interns * $20/hour = $12,800

6 Conclusion

The manifold for Wasco's environmental testing system is expected to function as designed once the quality assurance system is established. Approaching the project with a mind set on learning and refining the manifold design through iterative prototypes proved successful as verified by the evaluation of success criteria in section 5.4. The last stage of the DMAIC methodology of problem solving, control, will include careful monitoring of the manifolds before, during, and after environmental testing. Aiming for continuous improvement in all aspects of their business, Wasco's engineering department will strive to adapt their products and processes to different customer applications- soon including the capability to environmentally test their products for the quality the customer expects.

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