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4040C Universal Tester Backup

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4040C Manual Tester Backup

Swagelok Company (Solon, OH) - University of Akron

4600:402-461 Senior Design Project
4600:402-497 Honors Project

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Abstract:

The 40 Series ball valve is one of Swagelok's highest volume part families of which 60,000 parts per year are multi-ported. The multiport configuration requires a unique tester to ensure proper assembly & quality of upstream processes. Due to the age of the equipment and complexity of the valve array that this piece of equipment uses (see appendix for view of previous tester's valve array) this machine is prone to PLC and faulty component related downtime. This means maintenance must spend significant hours repairing broken logic as well as fixing parts of the valve array and other aging parts.

The bottleneck that the tester causes when undergoing maintenance has made the need for a backup tester for which the parts can flow through imperative. Due to the multiport configuration of these valves no alternate testing option exists, resulting a high rate of customer disappointments per day should the equipment fail. In addition to the tester's criticality, it has also been ranked as one of Swagelok's most unhealthy assets and is probable to experience extended downtime in the future. This project proposes to design and build a manually actuated test station to maintain the flow of multi-ported 40 series parts in the event of tester downtime.

It is important that the tester the team is designing be manually controlled. This eliminates the need for PLC control and the complexity and money that is involved with controlling pressure and flow sensors with all the different valve configurations that Swagelok's catalog contains. This tester is a low cost "mid-point" solution that will ease the bottleneck that is the legacy tester while Swagelok's equipment team creates an entirely new next generation automated solution to the problem. But that could be a $100k+ project that could take a team of engineers a year or more to develop and put into the production environment.

This manual controlled tester will use the same air cylinders found on the legacy tester with changes to the test end receiver (see appendix). The air cylinders are used to actuate the test ends on to the part and provide the clamping force necessary for a seal to be made. Once the seal is created pressure and flow testing is performed on the part using manual flow meters and regulators. A successful part will be determined by comparing the flow numbers charted in the standard documentation that already exists within the organization. By keeping the manual version as close as possible to the legacy version the fluctuation in the test results between the two machines can be minimized.

SWAGELOK INSTRUMENTATION BALL VALVES

The 40 series one-piece instrumentation ball valve has performed reliably for nearly 40 years in multiple industries. Swagelok modified the valve construction and developed an innovative assembly process.

The result is the 40G series ball valve which features an expanded operating temperature rating, improved thermal cycling capabilities, and reduced potential for leaks.

- On-off, switching, and crossover flow paths (see below)
- Working pressures up to 3000 psig (206 bar)
- Temperatures from -65 to 300°F (-53 to 148°C)
- 1/16 to 3/4 in. and 3 to 12 mm end connections
- All 40 and 40G valves have a panel mount nut standard

Feature	Valve Series		
	41G, 42G, 43G	41, 42, 43	44, 45
Valve Body Materials	Stainless steel	Brass, alloy 400	Stainless steel, brass, alloy 400
Packing Materials	Modified PTFE or UHMWPE	PTFE, PFA①, or UHMWPE①	PTFE or PFA①
Working Pressure psig (bar)	Up to 3000 (206), depending on valve size. See page 5.		
Temperature Rating °F (°C)	Modified PTFE packing −65 to 300 (−53 to 148) UHWMPE packing −65 to 150 (−53 to 65)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA or UHWMPE packing: −65 to 150 (−53 to 65)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA packing: −65 to 150 (−53 to 65)
Flow Coefficients (C_v)	0.08 to 2.4	0.05 to 2.4	1.5 to 12
End Connection Sizes	1/16 to 3/8 in.; 3 to 8 mm		3/8 to 3/4 in.; 8 to 12 mm
Flow Patterns	On-off (2-way); switching (3-way)	On-off (2-way); switching (3-way, 5-way and 7-way); crossover (4-way and 6-way)	On-off (2-way); switching (3-way and 5-way); crossover (4-way)

① Live-loaded PFA and UHMWPE packing materials. See **40T and 40E Series for Low-Temperature Service**, page 3.

40 Series Ball Valve Overview

Table of Contents

Abstract: 2

Introduction: 6

Conceptual Design: 7

Objective: 7

Design Brief: 7

Constraints: 8

Function Structure Diagram: 9

Objective Tree: 10

Weighted Decision Matrix: 11

Concept Sketches: 11

Embodiment Design: 14

Product Architecture Design: 14

Lay-Out & Connection Drawings: 15

Application of Embodiment Rules and Principles: 16

1. Unambiguous 17
2. Simple 17
3. Reliable 17

Failure Mode and Effects Analysis: 18

Materials and Manufacturing Processes: 18

Relevant Codes and Standards: 19

Air Cylinder Selection: 20

Detail Design: 21

Load Paths: 21

Component related analysis: 22

Calculation of cross-sectional dimensions: 22

Part Drawings: 23

Finalized Cabinet Design 24

Exploded-View Drawing 25

Functionality: 26

Cost: 26

Verification: 28

Results and Conclusion: 29

References: 30
Appendix: 30
Previous Tester Photos: 30
New Tester Photos: 34
40 Series Technical Information (Available to Consumers): 35
Statement of Contribution: 43

Introduction:

Swagelok started when a businessman named Fred Lennon bought the rights to Cullen Crawford's invention for a leak tight fitting "swage" which clamped a fitting onto pipe (hence the name "Swagelok") in 1947. Back then, the only leak-tight method of attaching tubing or other fluid systems components was welding or brazing. This revolutionary mechanical connection between fittings and tubing is what initially kicked off the company's success.

Swagelok is a large fluid systems company that manufactures high quality parts for the oil and gas, petrochemical, semiconductor, general industrial, nuclear, transportation, agriculture, and pharmaceutical industries. The company sells anything related to fluid systems (valves, fittings, tubing, ferrules, actuators, filters, components, tools, custom fluid direction panels, etc.). The main facilities are in Solon, and Highland Heights OH, with hubs on every major continent (Solon is the North American hub). Our products can be found anywhere from deep sea drilling sites to the international space station. The range of Swagelok's products is wide and diverse.

The main activities that go on domestically at Swagelok is manufacturing, machining, raw material processing (forging), chemical processing (coatings, case hardening, etc.), assembly, testing, R&D, storage, customer service / custom solutions, and shipping. Most proprietary components are manufactured and assembled 100% in the United States and then shipped out all over the world. These US-manufactured components constitute over 75% of the company's sales. Certain products lines such as regulators, or non-proprietary products are manufactured overseas.

The project covered in this report is related to the quality assurance aspects of the 40 series ball valve, specifically their multiport configuration(s). The 40 Series valve is one of Swagelok's highest volume part families of which 60,000 parts per year are multi-ported. This valve comes in many different configurations, actuation methods, alloys, and flow patterns (see appendix for more details). The multiport configuration requires a unique tester to ensure proper assembly & quality of upstream processes. The current tester has a high volatility and often causes excess downtime and loss of production. All Swagelok valves have very strict seat and shell leak testing parameters as well as flow rate parameters that need to be met to green light the part to be boxed up and sold.

The tester being designed will handle 41-45 (body designation) sized parts and X, Y, Z, and straight pattern configurations. It is also included in the project scope that along with the design, fabrication, and implementation of this tester that the testing process and procedure be fully documented for all different configurations, as well as all designed components have full standard work write-ups along with Bill of Materials (will be referred as BOM's in the remainder of the report), and any supplementary documentation.

Conceptual Design:

Objective:

The objective for this project is the complete implementation of a manually actuated test station capable of testing 41, 42, 43, 44, and 45 size parts with X, Y, Z, and straight pattern configurations. "Complete implementation" can be defined as Swagelok having ownership of a tester that has all the necessary, fully completed standard work documents, bills of materials, 3D models, and drawings necessary for its operation and maintenance.

Design Brief:

The project began with gaining an increased familiarity with the 40 series product line and the method Swagelok uses to test these valves. From this launching point, all the 40 series valves and their testing parameters will be evaluated. This will help the team generate the conceptual design for a tester that is a "one size fits all". A tester will need to be designed to accommodate all the end connection sizes and port configurations that Swagelok has commercially available. This evaluation of configurations and sizes will take up a considerable amount of time and will be vital to the success of the design.

Pressure and flow tests are performed on all manufactured parts to meet Swagelok's quality standards. This ensures every part is put together correctly and functions as it should. Pressure tests verify that the packing and all the handle components seated and were properly assembled. Flow testing ensures that all components that control the direction of flow are working correctly.

After the evaluation of configurations is completed, the old design was looked at for weaknesses to improve the new test fixture. A generation of design concepts began, with the knowledge of customer requirements and engineering characteristics. After selecting a final design concept, the team will begin assembling a 3D model to build/create detailed drawings and a bill of materials (subject to change until a final design is selected by Subject Matter Experts (SME's) at Swagelok).

Using in-house expert knowledge, we made use of components that are already well known within the building. This aided in shopping for actuators and hardware that fulfil the customer (being Swagelok) requirements. This way when hardware and certain components are purchased, the brands and components will have already been validated within the company. The biggest challenge in the design process was taking these hardware components that are being controlled by a PLC and coming up with a manual system that energizes these components when manual switches/levers/controls are added.

The same test ends used on the old model of actuator to make a seal against the parts will be used in this new design as well (see below). It would be a simple task to manufacture more test ends in the event they are deemed necessary for both machines, however that is not in the scope of our project. As of today, the idea is that the backup will only function if the current tester is down for maintenance, this means the test ends can be taken from the old tester and used on the manual one, therefor creation of more is not necessary.

The test end receiver (see component breakdown for a representation of what part is being discussed) however, needed to be redesigned. This is mostly because the old Eaton actuators and Swagelok test end receivers were so dated that part numbers and prints were unable to be found. This involved taking one of the test end receivers off the original actuators to measure overall length, important features, thread pitches/depths, and compiling all of these details into a solid model, and then creating a machining drawing so they can be manually turned by one of the machinists on site out of round stock. The test end receiver is the part that holds the test end. And the test end is the machined part that clamps over the end connection, pressurizes, and conducts the test. Pressure and flow meters are used to verify proper testing parameters are reached (testing parameters and internally controlled and specified in the standard work).

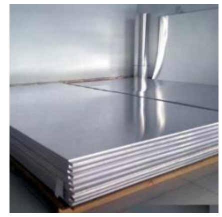
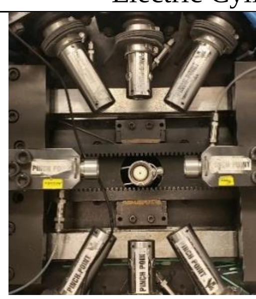
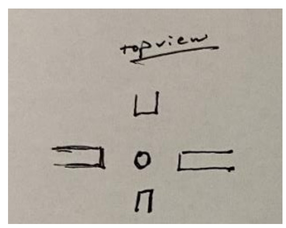
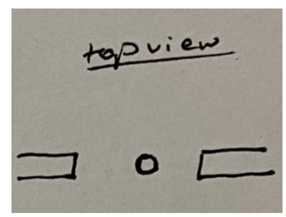
The cabinet itself needed to be constructed as well. It was decided early on that the footprint of the old tester would be copied because the testers would be located on the floor facing back-to-back from each other. Measurements were taken of the existing frame and a concept was made up from these dimensions using the updated MBKit materials available to us. MBKit also discounted the team some aluminum plate that we used to make the table base out of along with the fixture blocks that function as risers to get the parts away from the bottom of the table and inherently the bottom actuator. After the group is done with the design, sourcing, and testing, Swagelok will oversee the remainder of verification process with on-site assistance from group member Devan Keeling, if necessary. The overall cost of this project, including air cylinders, Swagelok components, tester framing material, labor, and miscellaneous expenses is to be within the given budget of $10,000.

Constraints:

There are many constraints that the group had to deal with while considering the vast amount of detail that is in each of the many subsystems in the design. There was obviously a limited amount of money that could be spent on this tester, and that amount of money could not be exceeded (the budget for the project was 10,000$). There was a limited amount of space on the shop floor that the tester could take up as well. So, the cabinet needed use its space very efficiently and ergonomically, as this is a piece of equipment that has a high amount of associate interaction during the workflow. Safety was also a large concern regarding the constraints that were placed on our design.

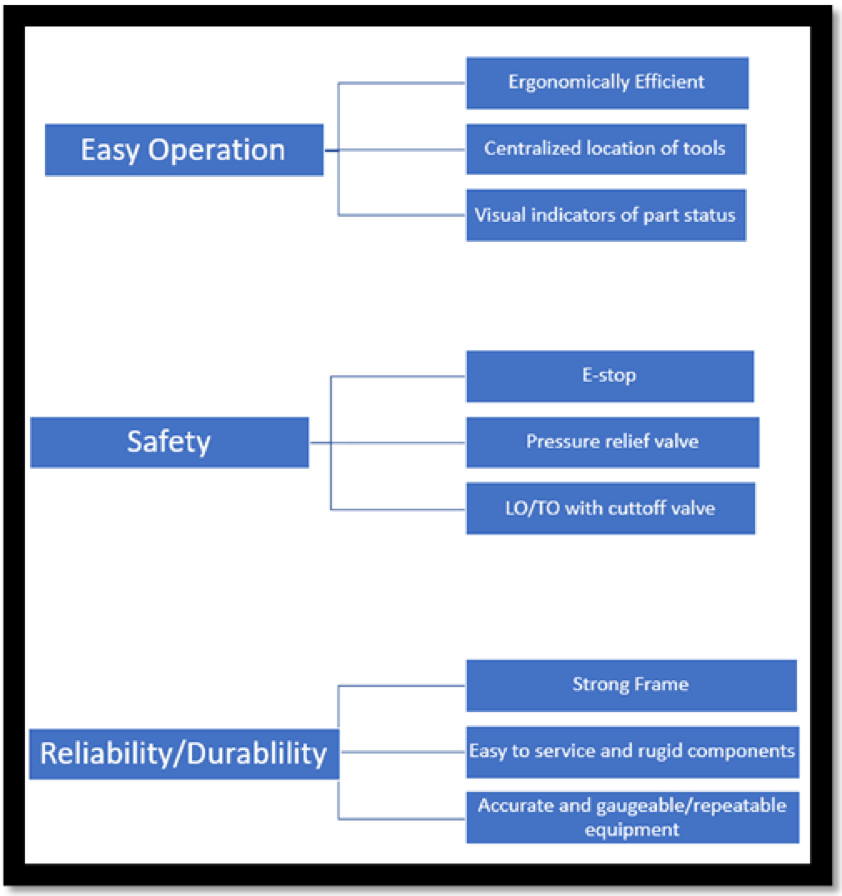
One of the largest constraints was regarding how the system was powered. Being that the tester had to be completely manually controlled, as well as pneumatically powered. This also ties into another constraint, being that the new manual tester had to be very similar to the original tester in shape, form, function. They need to run the same tests in very different ways. The sameness of their design was largely considered when custom parts needed to be made. Custom parts such as the test end receivers were often based off parts on the old machine, so they had the same leak down rates, sealing methods, and mechanical connections (as well as tolerances), between the two machines.

Function Structure Diagram:

Concept	Sketch
Frame	   Extruded Al Hardware Al and Steel Plate
Pressure / Force Transmission	  Electric Cylinder Pneumatic Cylinder
Cylinder Configuration	   Full XYZ Compat. 4-way Compat. 2-way Compat.
Interface	  PLC / User Interface Manual
Regulator Configuration	  Central Location In-Line

Safety	 Emergency Stop  Relief Valve  Shutoff Valve

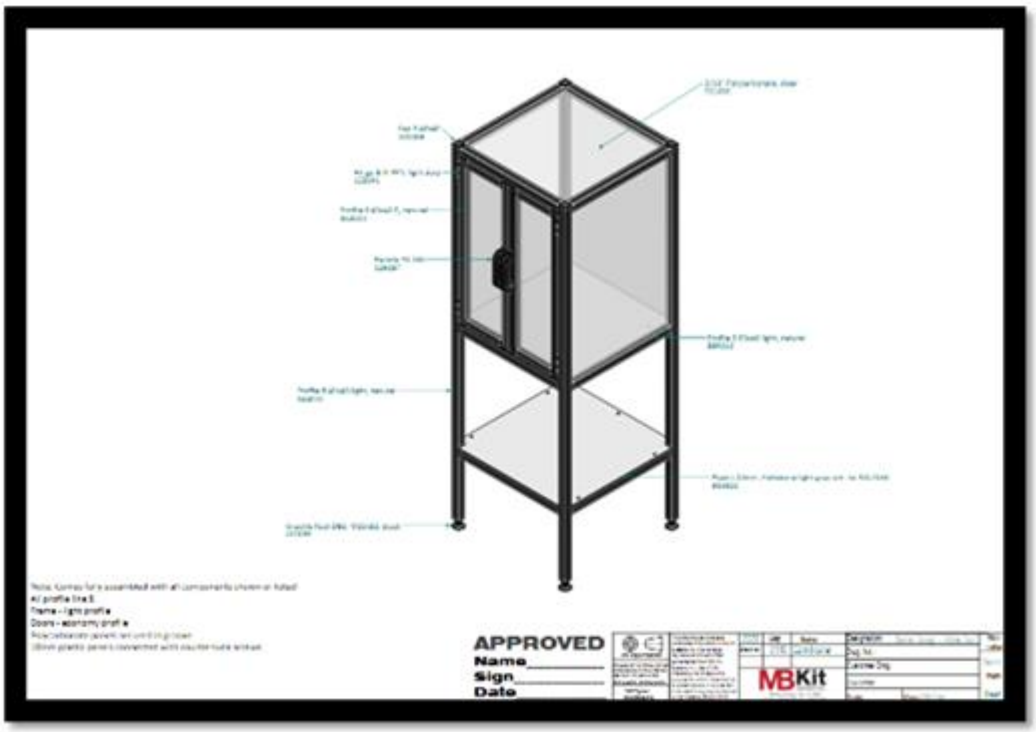
Objective Tree:



Weighted Decision Matrix:

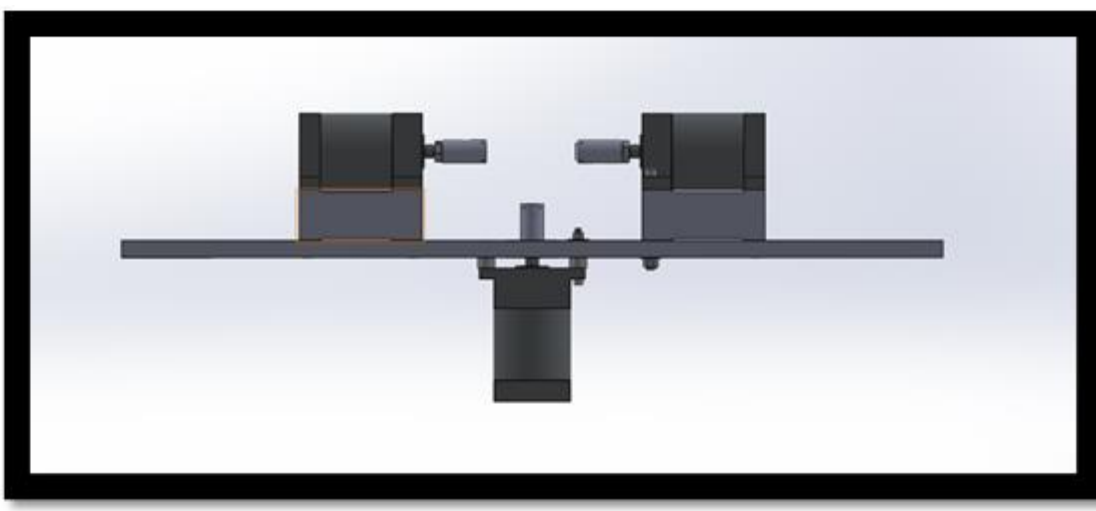
Weighted Decision Matrix for Cylinder Configuration							
Design Criterion	Weight Factor	Full XYZ Compatibility		90 degree XYZ Compatiblity		90 degree XY Compatiblity	
		Score	Rating	Score	Rating	Score	Rating
Material Cost	0.1	5	0.5	6	0.6	8	0.8
Manufacturing Cost	0.1	4	0.4	5	0.5	7	0.7
Reparibility	0.15	5	0.75	5	0.75	8	1.2
Durability	0.3	9	2.7	9	2.7	9	2.7
Reliability	0.3	5	1.5	7	2.1	9	2.7
Time to Manufacture	0.05	4	0.2	4	0.2	6	0.3
			6.05		6.85		8.4

Concept Sketches:

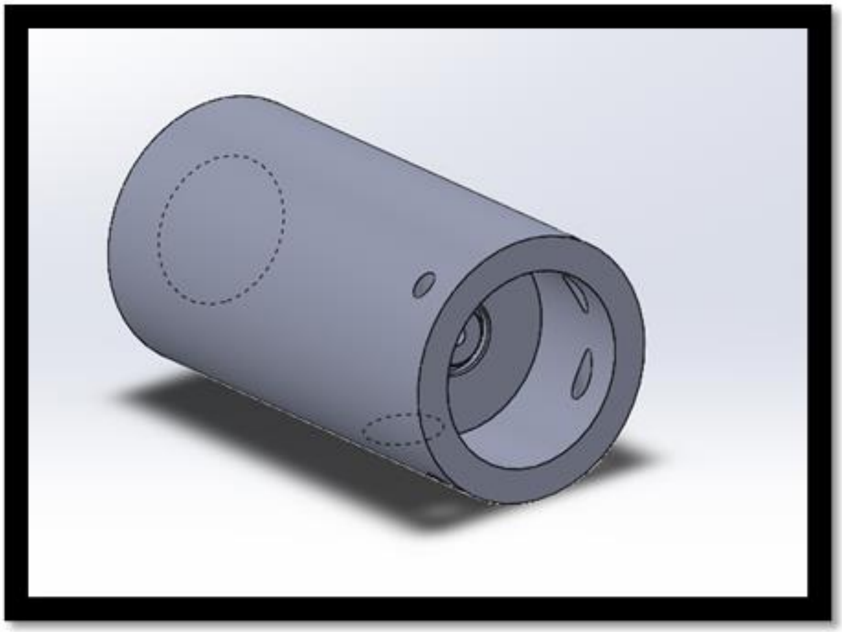


Cabinet Design 1 Concept

Cabinet Design 2 Concept



Actuator Location Concept 1
(Created after reviewing all design inputs from tech sponsors, and design of OE)



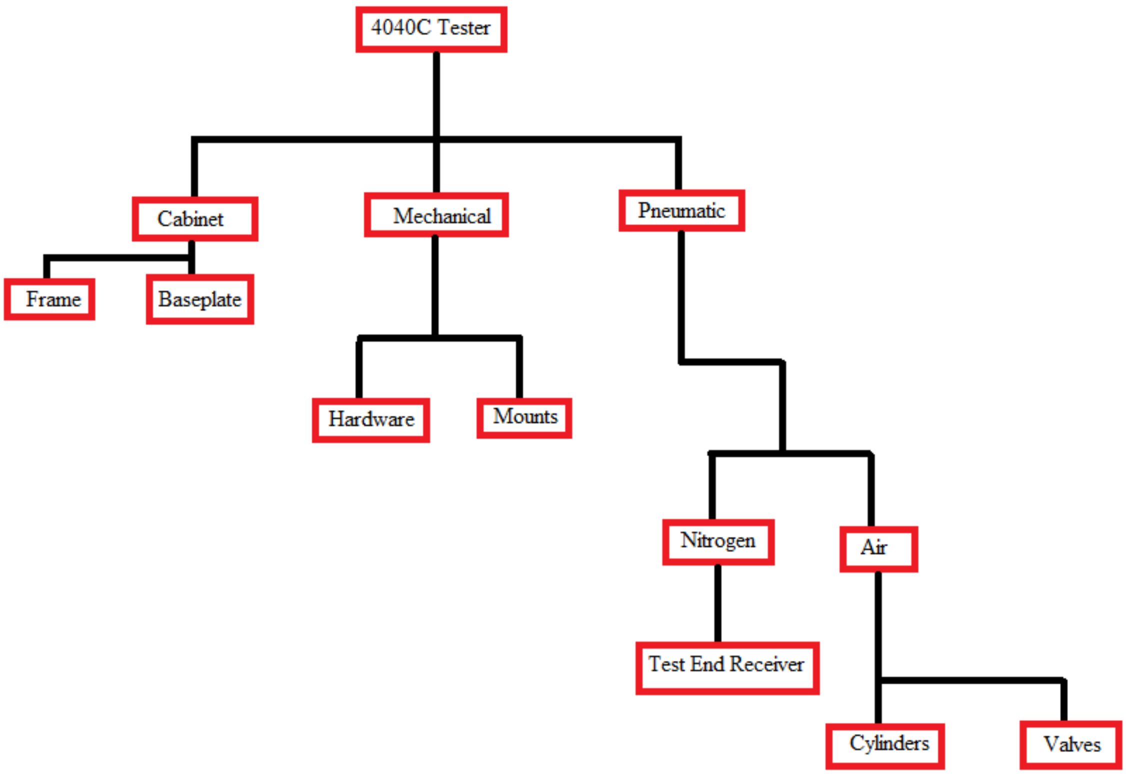
Revised Test End Receiver Design (screws into actuator shaft)
See embodiment design for all part and machining drawings.

Embodiment Design:

Embodiment design entails the explanation of the process in which the conceptual design was built upon. In the project scope there are three major categories that must be developed in greater detail: the cabinet, the mechanical pieces, and the pneumatic circuits. The embodiment design covers selection of parts for final/detail design and the general process of arriving to said design conclusions.

The embodiment design covers the following topics: product architecture, embodiment rules and principles, failure mode and effect analysis, layout configuration, ANSI or ISO standards, material selection, manufacturing processes, and cylinder selection.

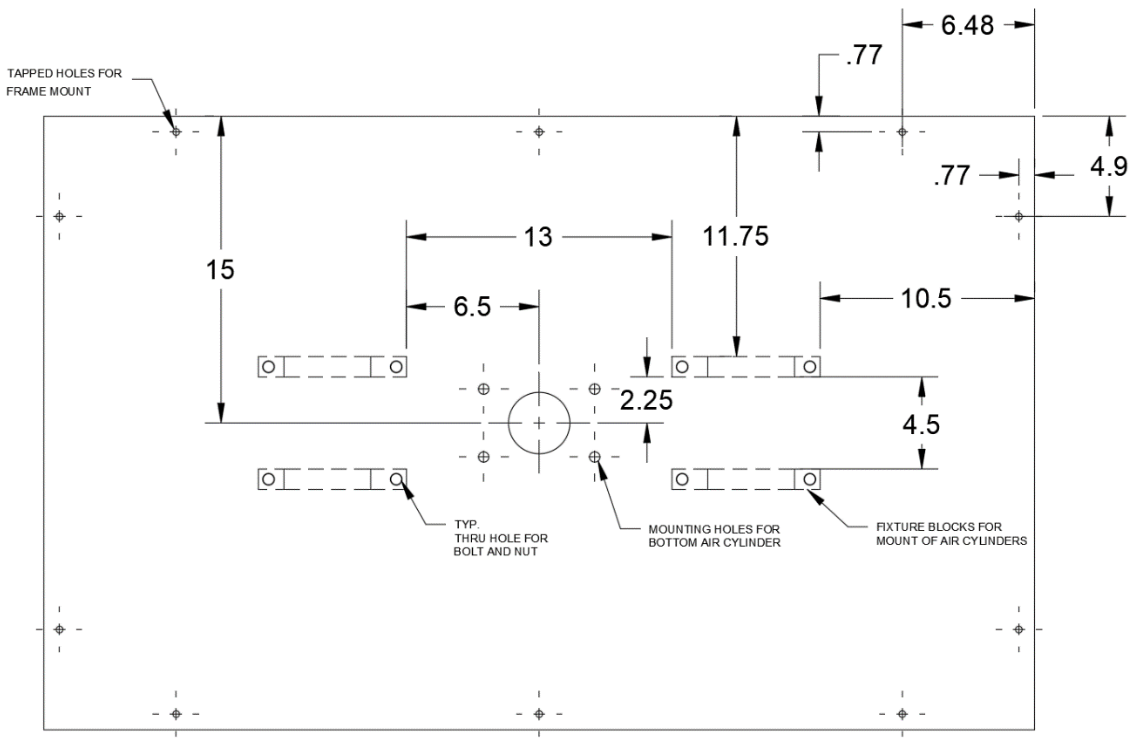
Product Architecture Design:



As described in the picture above, the product architecture design help shape the framework of the project. This simple image laid the groundwork of the finer details. Since the concept was well known, the graphic allowed for the division of the work to the group members who were strong in those areas. The assembly of the tester was broken down into 3 sections: the cabinet, the mechanical pieces, and the pneumatic circuits.

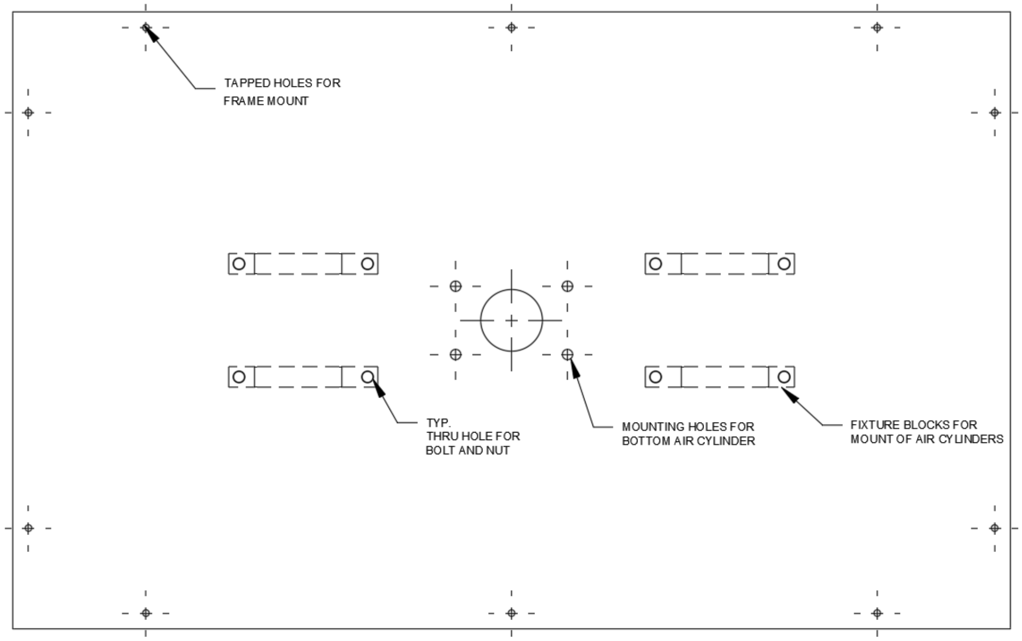
The cabinet initial concept remained as it was sufficient for the scope of the project. The mechanical side includes all the drawings for the machined parts, which includes the cylinder mounts, and all the hardware needed for assembly. The pneumatic side could also be broken up into a control side, but for simplicity is grouped on the assembly side since the control side needed to be determined before the assembly could be discussed. The pneumatic was broken up into the two different fluids required for operation: air and nitrogen. The nitrogen side was needed at the test end receiver for the verification of the product. The air side was necessary for moving the actuators and holding the part into place for safety and testing. Collaboration between the division of work was necessary for the final design.

Lay-Out & Connection Drawings:



The assembly lay-out, pictured above, gives general dimensions for the placement of parts relative to the fixed baseplate. The baseplate is a flat 1-inch-thick aluminum plate, which is fixed to a frame with the holes shown in the picture. The fixture blocks will be placed as shown to mount the air cylinder on top of. This acts as a riser for the air cylinders, so that the assembly can accommodate all the 40 series valves for testing.

The placement of these air cylinders was determined using the different valves and testing the extreme versions of the valves, meaning the largest and smallest, to see if they will work with the setup. Once the location of the air cylinder was fixed, the way that the cylinders could be fixed to the baseplate was discussed. It was determined that it would be best for the baseplate to have no tapped hole for the air cylinders, which requires nuts to hold the cylinder to the baseplate. The exact connection of all the systems will be discussed later in a simplified drawing.



The image above is a simplified top view of the baseplate. The image depicts all the holes used to fix the systems together. The holes that go around the perimeter are tapped 8mm holes that hold the baseplate to the frame. The remaining holes all are through holes. The large hole in the middle is a cutout for the air cylinder to be mounted to the underside of the plate and still be able to function. The four holes in a rectangular pattern that go around the large, bored hole for the air cylinder are derived from the faceplate of the air cylinder and allow for the cylinder to be mounted flush to the plate and be bolted with a nut to the baseplate.

The fixture blocks that are labeled on the image allow for the air cylinder to be raised off the baseplate, which is necessary to the function of the system. The fixture blocks are sandwiched between the air cylinders and the baseplate. The air cylinders that mount to the fixture blocks have a bolt that pass through a hole in the fixture blocks and are held to the baseplate with a nut on the underside of the baseplate.

Keeping the design and machining operations simple was the main priority during the design phase, this philosophy also influenced the groups choice of the bolt/nut/nylock washer connection method employed for affixing the air cylinders to the baseplate effectively and safely. All loads and stresses on the components were pre-determined and designed around to make sure the design would never fatigue or be unsafe to infinite cycles.

Application of Embodiment Rules and Principles:

There are three governing rules of embodiment design as discussed in the University of Akron's Concepts of Design course. Those governing principles and how they affected the thought process of our design are explained below.

1. Unambiguous

The tester is designed to physically hold a valve in place using multiple pneumatically actuated double-acting cylinders. The cylinders have manufactured test end receivers, so when they are pressurized, will gradually interface with the valve's end connections to create an air-tight seal. Nitrogen at the valve's rated pressure is then released into the valve via a user-controlled piping system. A flow meter detecting the gas interprets the pressure and sends a signal to a visual indicator light to determine if the part is leaking or not.

2. Simple

The tester frame is made from aluminum T-slot extrusions, making the construction of the frame straightforward and adjustable if required. The piping system controls are condensed into a panel layout to make operation more visually and ergonomically efficient when adjusting and venting pressure. All miscellaneous hardware components were purchased in bulk so that replacements can be easily obtained if necessary. The hardware components are also widely supplied by various manufacturers, such as McMaster and Grainger, if extra components become a concern.

The manufactured risers for the cylinders are made almost entirely of basic shapes from aluminum sheets that can be easily manufactured. The test end receivers are reverse engineered from the current models used in production with the current tester. This means all tooling, such as the Delrin cones used to create the seals, can be interchanged between the two machines. The bore of the cylinders is also the same, therefore all previous sealing pressure calculations can be used on the manual tester.

The tester's operation is manually controlled rather than through a PLC-integrated system. The design can test most X and Y configurations of the 40 series. These make up the majority of product tested in the cell currently, therefore minimizing the repercussions of the current tester being offline. It also greatly simplifies the piping system and requires less steps for operators when in use.

3. Reliable

The tester frame is constructed out of aluminum and therefore will not rust under normal conditions, as well all the high purity stainless used for the test end receivers. The metal was chosen for its availability and durability. All piping components, apart from the air cylinders, are Swagelok-manufactured products. Every valve, tube, hose, fitting, regulator, and gauge is customer-facing product. It has therefore been tested rigorously and is rated to operate at pressures well above the requirements needed for the manual tester. This also allows for easy replacement of any components, in the unlikely event that a component related failure does occur.

The air cylinders being used in the system have also been tested and validated per Robeck's product requirements. In the event of any loss of pressure or over-pressurization, emergency relief valves bleed pressure from the system automatically to acceptable design limits. The design also aligns with Swagelok's Lock-Out / Tag-Out procedures when the tester is offline or under maintenance to avoid any risk.

Failure Mode and Effects Analysis:

A FMEA or Failure Mode and Effects Analysis is extremely important when considering the design of any equipment or part in an engineering environment. It is important to brainstorm worst case "what-if" scenarios to see how bad potential failures in certain areas of the equipment would be. Thinking of these scenarios ahead of time could help prevent the issue from ever arising or allow a mitigation/avoidance strategy to be pre-prepared if anything does go wrong.

Failure Mode	Severity	Occurrence	Detection	RPN	Preventative
Pinched Finger	6	3	1	18	Pinch point stickers to draw attention and hand guards around moving components.
Loss of Pressure / Leak	7	5	3	105	High quality components at sealing points and clear assembly instructions. Specify o-ring clearance in standard work and always store extra at workstation.
Over-pressurized Line	3	2	4	24	Bleeder system that relieves pressure in the event of over-pressurization
Failure to Seal	4	7	1	28	Specify tight machining tolerances and proper O-ring sizes for seals and connections.
Cylinder Unable to Extend / Retract	2	4	2	16	Design with the minimum number of connections and length of hose. Make sure there are no kinks or bindings.
Flowmeter Malfunction / Misread	8	2	4	64	Pre-allocated good and bad parts to verify tester is operating before each shift begins using. Validation testing before production use.

Materials and Manufacturing Processes:

There are only a few parts that are being manufactured in the design, which would require specification of manufacturing methods and material. The parts are the baseplate, test end receiver, and cylinder fixture blocks. The baseplate was fabricated by MBKit on their CNC routing machine: first the thru holes and pilot holes for the threads to attach the base to the frame are machined, and then the perimeter is cut. The threads for frame connection are later added by hand. The tolerance to which the CNC machines to is ±0.001mm. This piece also has fixed overall dimensions to fit into the assembly. The baseplate consists of inch thick aluminum cast plate and was chosen because of the stock available at MBKit. A drawing was made for the necessary holes to fix the rest of the parts to the baseplate. The need for accurately drilled holes in the flat baseplate makes a CNC machine the ideal piece of equipment for this job.

The fixture blocks for the air cylinder are a simple design with a general shape of a rectangular prism and will be machined to specification from the same inch thick aluminum cast plate. The fixture blocks will require a rough cut and then be machined down for flatness. Lastly, through holes will be added to the fixture blocks for hardware that fixes the air cylinder to the baseplate. This process will be easily achievable, once the rough cut is complete on a mill.

The test end receiver has a general shape of a cylinder. Because of this general shape the test end receiver will be made of stainless-steel round stock. The part can be easily turned down on a lathe, along with a few holes that will need to be made using a mill after all the turned features are made, such as the NPT tap and the holes the hold the test ends in place with pins. All of this can be easily made and manufactured by Swagelok associates following the notes and callouts in the machining drawing the group created and gave to the machining team.

Relevant Codes and Standards:

Speaking of drawings and manufacturing. Swagelok is a highly organized company regarding how they want things designed, manufactured, cataloged, and documented. This is largely because it is an ISO certified company, meaning that Swagelok holds itself all ISO standards as well as several ANSI and ASME standards. A large part of ISO standards that helps Swagelok in the day-to-day operations is the traceability standards. If a quality issue every arises it is so helpful to be able to trace the routing back to the specific machine or the material lot the part came from and investigate why the quality issue has arisen. That is just one example how standards are helpful to companies like Swagelok.

Standards such as ISO and ANSI are essential on the global stage that Swagelok operates in. With so many people doing work for one collective group, certain rules need to be followed so everyone can be aligned and progress together. This is a large reason as to why standards were formed by groups made up of industry leaders and individuals in the first place.

Some important standards that we used throughout this project include the ASME standard for Dimensioning and Tolerancing (Y14.5). Using this standard ensured that whenever we included specific dimensions, callouts, decimal places, and icons that people with a drafting and manufacturing background could easily interpret our drawings and make parts accurately.

Another relevant and important standard involved with our project considering there are multiple pneumatic circuits in the design (shop air and nitrogen at pressures up to 1000 psi) is the NFPA Reliability analysis, field data reporting format and database compilation standard (T2.12.11-1). This standard lays out how data should be recorded when a reliability analysis is being conducted. This was used along with some internal standards as well as some of the ISO standards that Swagelok uses regarding required safety factors of certain parts as well as the criticality of certain components in pneumatic circuits. A topic of extreme concern regarding this equipment.

Air Cylinder Selection:

The decision to keep the cylinder bore the same as existing comes from the known air pressure values required to seal the fittings for testing. If the air cylinder bore were changed this would require a change in procedure for air pressure required to maintain a seal. This change in procedure for testing complicated matters to a degree that the group decided to stay with similar air cylinders. So, the air cylinder bore remained the same between the existing test fixture and the new backup fixture. With this knowledge, clamping forces required to maintain this seal during testing could be calculated as shown below.

Keep in mind also that certain part families require different clamping pressures to be applied. This is changed on demand with the current tester's coding. With our manually controlled clamping pressures controlled via regulators so as different batches of parts are tested standard work will have to be referred to so that the correct clamping pressure is being applied.

$$Air\ pressure: P_{air}\ (psi), Cylinder\ Bore: D_{cyl}\ (in) = 4.00\ in$$

$$Rod\ Size: D_{rod}(in) = 1.00\ in, Stroke: L\ (in) = 3\ in$$

$$Clamping\ Force = \frac{\pi}{4} * D_{cyl}^2 * P_{air}$$

$$Retraction\ Force = \frac{\pi}{4} * \left(D_{cyl} - D_{rod}\right)^2 * P_{air}$$

$$Volume\ of\ air\ required\ for\ Extension\ per\ cylinder\ (in^3)$$

$$= \frac{\pi}{4} * D_{cyl}^2 * L = 37.7\ in^3$$

$$Volume\ of\ air\ required\ for\ Retraction\ per\ cylinder\ (in^3)$$

$$= \frac{\pi}{4} * \left(D_{cyl} - D_{rod}\right)^2 * L = 21.205\ in^3$$

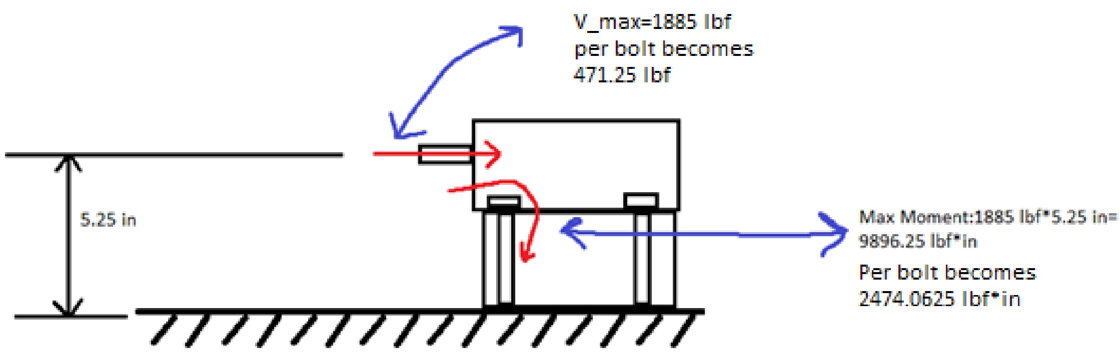
	Air Pressure [psi]	Cylinder Bore [in]	Rod Size [in]	Max Clamping Force [lbf]	Max Retraction Force [lbf]
Max Shop Air	150	4	1.00	1884.96	1060.29
Max for Test Fittings	100	4	1.00	1256.64	706.86

Detail Design:

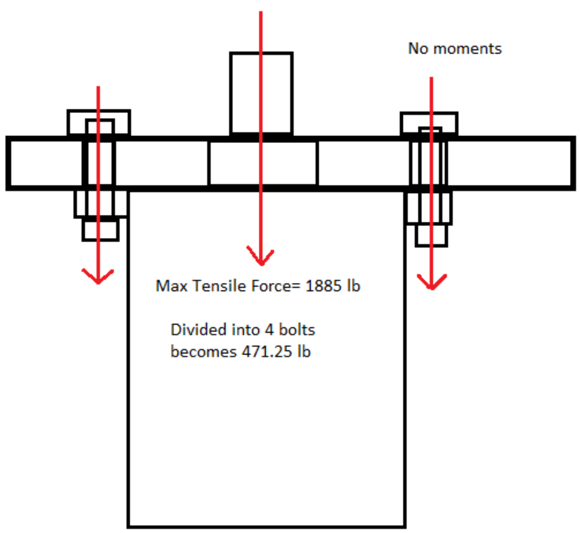
Within the detailed design, we will further expound on the conceptual and embodiment design sections. This includes part and assembly drawings that were used for part fabrication and assembly of the frame as well as an exploded view to show how the fasteners are used in assembly. Also included in this section are more calculations used for part selection and descriptions of different types of components used in the design.

Load Paths:

Side Mounted Cylinders



Top Mounted Cylinder



Component related analysis:

Many of the components used in this project are standard components of Swagelok, MBKit, and Grainger. This means that they are stocked and readily available for installation and use by the team. These components include hardware components like the bolts and hex nuts used to fix the air cylinders and riser blocks to the aluminum table base. Standard components from MBKit do require a small amount of machining is required; for example, the vertical aluminum posts are stocked in 6-meter lengths, and to be used it must be cut down (±0.1mm) to the desired length as well as clearance holes added to allow the use of fastening sets. Some components required the team to assemble a large percentage of tester assembly to accurately gauge quantity and size, like the lengths of hoses for the air supply.

Calculation of cross-sectional dimensions:

Strength of Bolts:

1/2-20 x 6" Black Oxide Socket Head Screw ASTM A574:

Min Tensile Strength=28792 lbf

Min Shear Strength=16051 lbf

3/8-24 x 2.5 Black Oxide Socket Head Screw ASTM A574:

Min Tensile Strength=15809 lbf

Min Shear Strength=8731 lbf

Part Drawings:

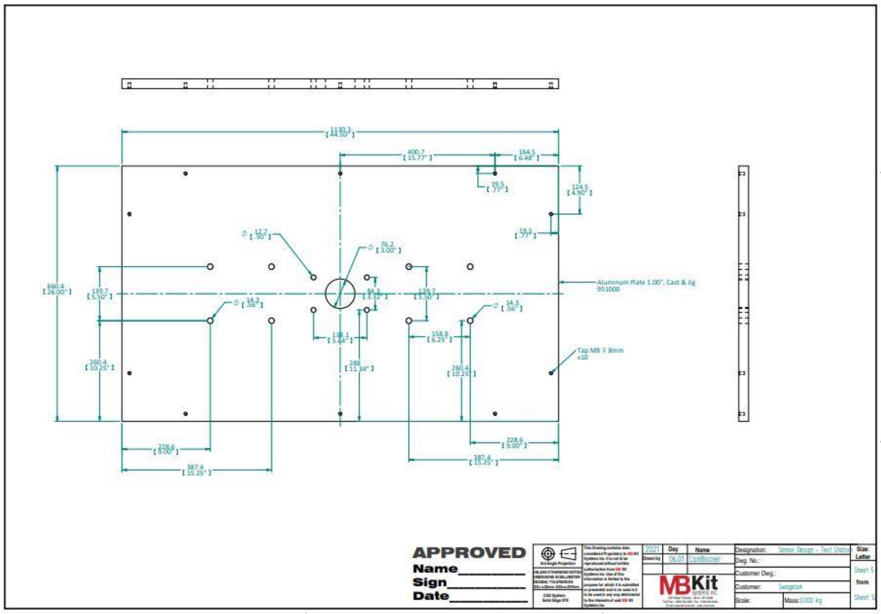
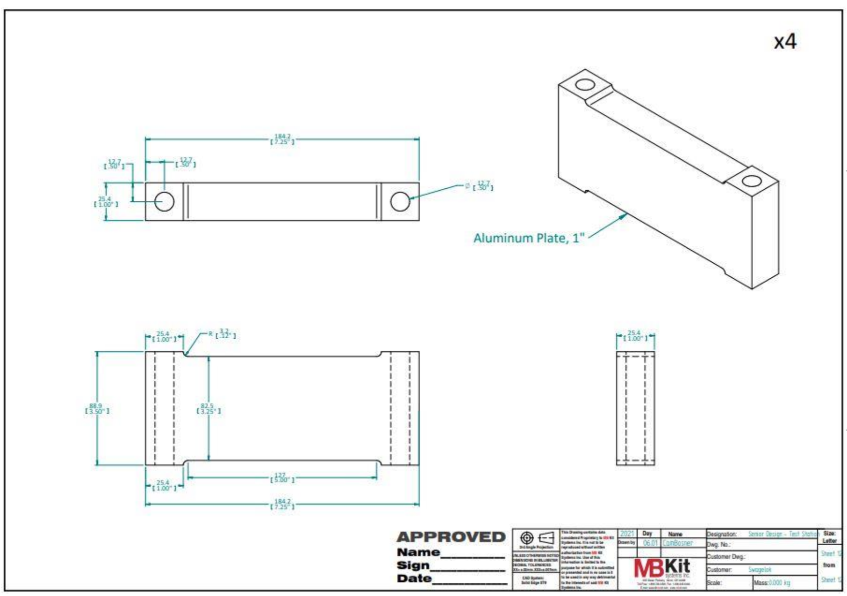
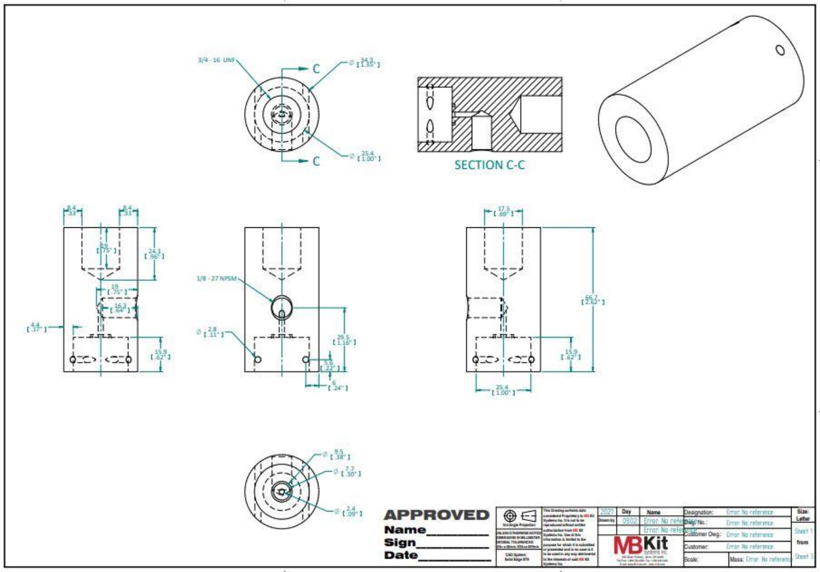


Table Base (see embodiment design as well)

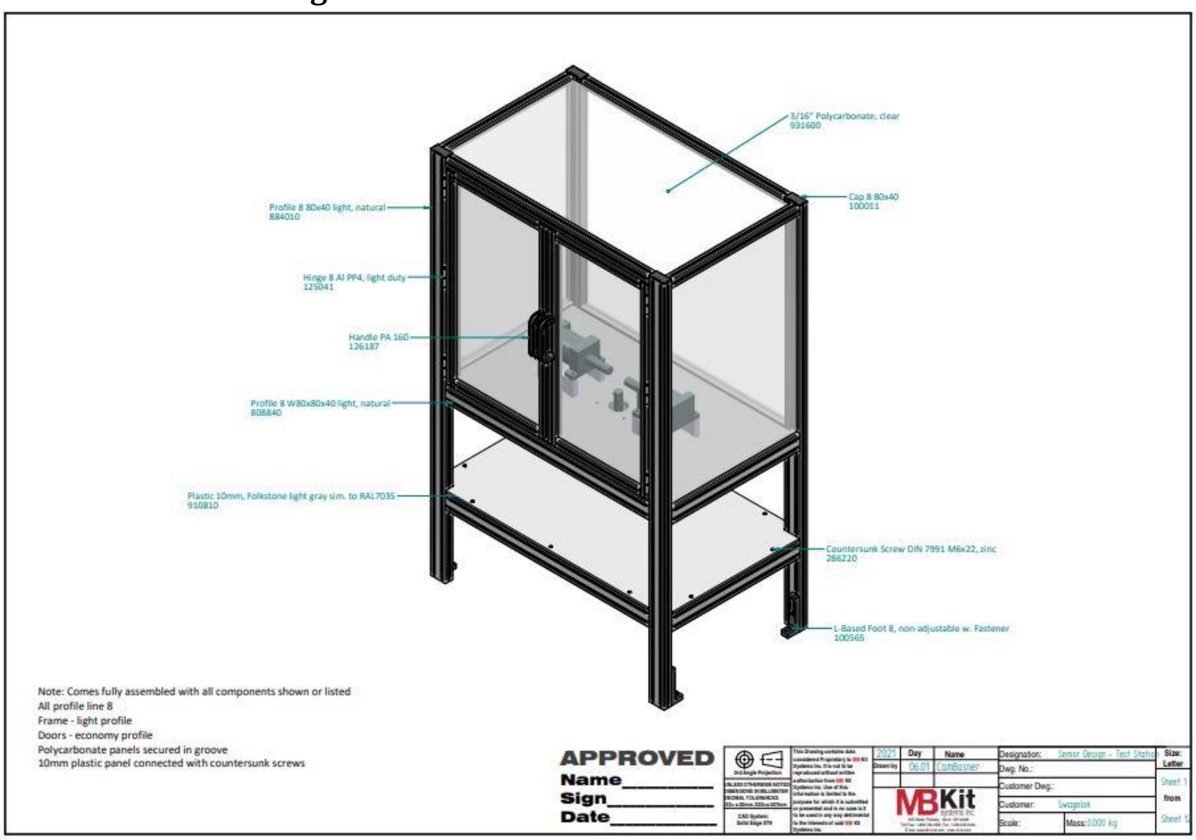


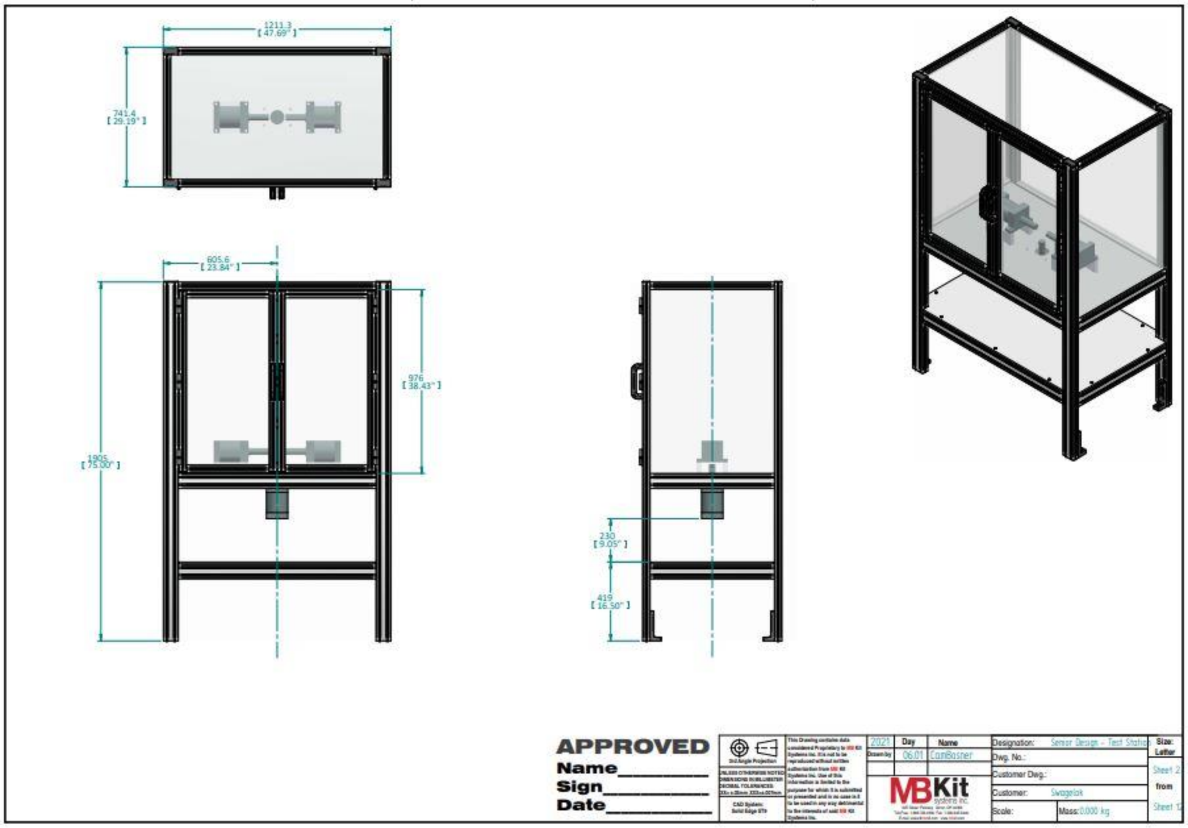
Riser Block



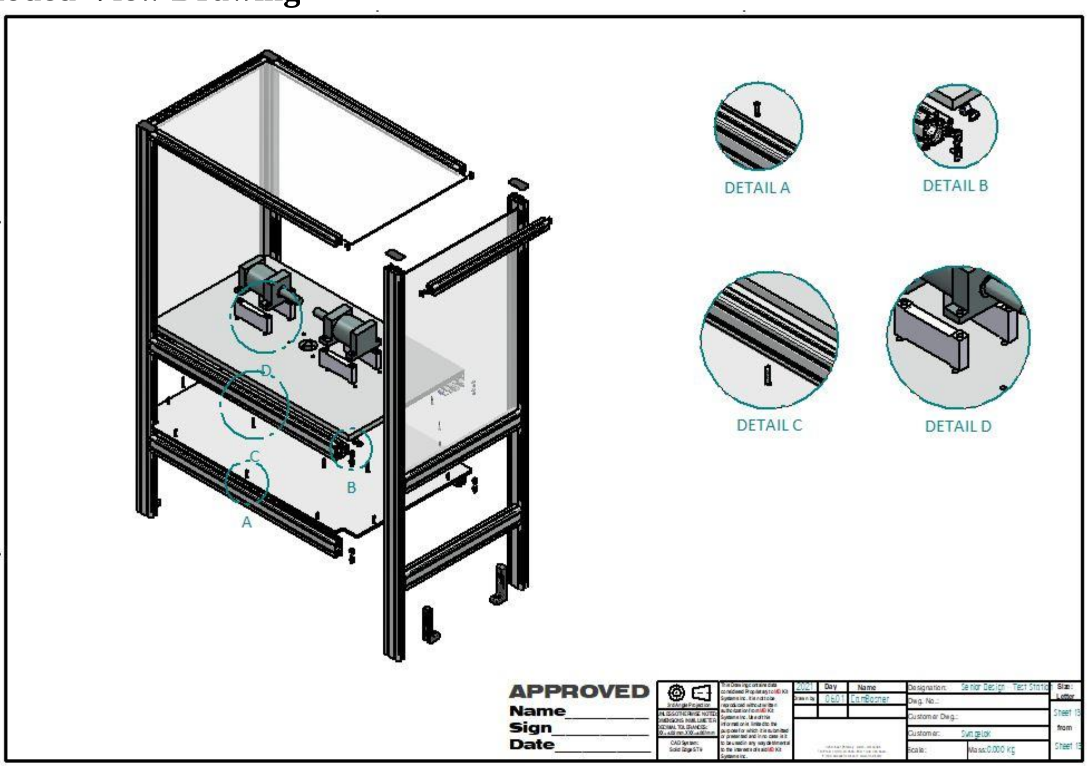
Test End Receiver

Finalized Cabinet Design





Exploded-View Drawing



Functionality:

This section is just explaining the testing process that a typical part will undergo for explanations sake. First a part would be held in place where the actuators would come in and clamp down on the part. The test end would be pressurized in the direction of flow indicated on the body of the part and flow rate would be tested against and internally set parameter. If that parameter is met, the part passes the flow test, if the part fails, the part fails and is set aside.

Next, the handle would be turned to the “closed position” so nothing would flow through the valve anymore. Then, the ends would be pressurized to the specified pressure while one end is monitored for leaks (done with flow meters). If the part meets the required pressure level while no leaking is observed at the other port, the part passes the test. If the minimum flow level is exceeded, the part fails and is set aside.

Cost:

Swagelok allocated the team $10,000 dollars to go towards the capital needed to complete this project. This money is for the use of purchasing the necessary components to complete the tester.

Components necessary for the tester included a cabinet to house all the moving parts of the tester, the Swagelok components necessary for the Tester to do its designed function.

Item	Quantity	Unit Price	Price	Notes
Cabinet and Baseplate	1	$2,600.00	$2,600.00	MBKit
Fixture Block	4	$15.00	$60.00	
Air Cylinder (Side Mounted)	2	$455.97	$911.94	Robeck
Air Cylinder (Head Mounted)	1	$451.51	$451.51	
Test End Receiver	3	$100.00	$300.00	All Swagelok Internal Components from Stock
SS-PB6TA6TA6-36 (Blue Swagelok Hose @ 3' long)	6	$50.00	$300.00	
SS-600-2 (600 Series with NPT)	6	$50.00	$300.00	
Clear 1000PSI Hose	1	$100.00	$100.00	
SS-200-6 (200 Series Unions)	6	$50.00	$300.00	
KPR1GJC412A20000	3	$100.00	$300.00	

(Regulator for Air)				
KPF1NWC8A8P2000 (Regulator for Nitrogen)	1	$100.00	$100.00	
Test Fittings	3	$0.00	$0.00	
SS-43GF6 (Ball Valve for E-Stop)	2	$266.61	$533.22	
PTFE Tape	1	$0.00	$0.00	
S-2F-90 (Filters)	3	$0.00	$0.00	
SS-45YF8 (4-Way Ball Valve)	1	$100.00	$100.00	
3/8-24 x 2.5 Black Oxide Socket Head Screw (Pack of 25)	1	$16.70	$16.70	Grainger
3/8 Steel Washer (Pack of 100)	1	$5.35	$5.35	
3/8-24 Steel Nylock Hex Nuts (Pack of 25)	1	$8.30	$8.30	
1/2-20 x 6" Black Oxide Socket Head Screw (Pack of 5)	2	$21.68	$43.36	
1/2-20 Steel Nylock Nut (Pack of 25)	1	$3.78	$3.78	
1/2 Steel Washer (Pack of 50)	1	$7.14	$7.14	
3/4-16 Steel Thin Hex Nut (Pack of 20)	1	$14.69	$14.69	
1/4" NPTF Flow Control Valves	3	$39.99	$119.97	
1/4" NPT Exhaust Mufflers	6	$3.08	$18.48	
4-Position/2-Way Valves	3	$177.74	$533.22	
Total Cost			**$7,127.66**	

Verification:

The nature of this project is risk management, as mentioned previously throughout this document. The tester currently in production is verified under Swagelok standards and undergoes multiple routine checks with test valves. These valves are visually marked as a passing or failing part, respectively.

To verify the new 4040C testing unit, we will be conducting experiments with all valve configurations that could be processed in the cell now. Some of these valves will purposely be assembled defectively to ensure that the tester will not read a false positive as this is our main quality concern. The valves will be tested by way of internal pressurization. The operator will actuate the required cylinders to seal the interior of the valve. Then Nitrogen gas will be released into the valve at its working (advertised) pressure. Through this process, the new 4040C tester will help in verifying the new tester as valves will be placed in both rigs to ensure the quality it maintained regardless of the machine used. It is unknown how many valves will be processed through the testers at this time, as Swagelok has unique verification testing procedures for each of its machines.

To verify the pressure being administered as well as the clamping force, in-line regulators are planned to be used as well as various pressure and force sensors to ensure the tester stays within the tolerance of the given valve in the system. We do not need to worry about the tolerance/accuracy of the pressure seen out of the regulator because the gauges used as well as the Swagelok regulators have fluctuations of less than 1% when compared to the pressures seen by the tester and part. The other main tolerance concern is our dimensioning of the tester components (actuators, end connections, etc.). As we have a limited footprint for this project, the goal is to keep, if not all, necessary hardware, and accessory components within the allotted space.

Results and Conclusion:

This was a very long project that required a vast amount of technical information as well as administrative organization to be carried out all from a remote setting. All while group members were full time with other obligations such as work and school as they prepared for graduation and movement into the workplace. The group members were left with a positive feeling after working on this project and it was good work experience to have before graduation and it only built on our co-op experiences.

Currently the project is in the testing and validation phase where after it can move into the production environment and start having product moving through it when deemed necessary. All components that needed to be sourced early in the year due to vastly increased lead times during peak COVID-19 impacts have been received by Swagelok, as well as the custom pieces that we have opted to have machined in house are made as well.

There were many things that went well during the early phases of the project. When meeting with Swagelok associates the objective of the project was clearly stated and a game plane quickly generated. The workload was quickly divided among the group and individual objectives were easily defined and the big picture was kept in sight as the students tackled their individual extremely technical subsystems.

Things slowed down slightly after the design phase. Shopping and specifying/quoting parts were a long and arduous process that took up significant time in the project timeline. Talking about packaging issues, dimensions, physical geometries, and concepts was a major challenge when doing it all through a computer screen. Sometimes other production responsibilities would make our Swagelok contacts difficult to get a hold of and that is just the nature of our project in relation to the everyday production environment, related to that the group also had varying workload with work and school and dealing with extremely busy times during the project timeline as well as large periods of downtime were a challenge to pick right up were it was left.

Overall, the group designed and sourced everything to create a piece of equipment that meets all the technical requirements that was asked of the system. When assembled, this tester will be able to run tests on the required parts with manual controls to reduce the criticality of its automated big brother. The group is left with a positive feeling overall and is thankful for the opportunity to work with Swagelok on this project. The next step is visiting the site for some assembly, and then the tester will be handed over to the project team on site and Devan will still be available as a contact for wrapping up whatever is left on the tester.

References:

Load Calculator. (n.d.). Retrieved January 15, 2021, from https://www.fastenal.com/en/84/load-calculator

Swagelok internal documentation (not specifically referenced due to confidentiality)

Appendix:

Previous Tester Photos:

4040C Testing Cell.

Previous Tester Work Area

Top View of the Testing Ports

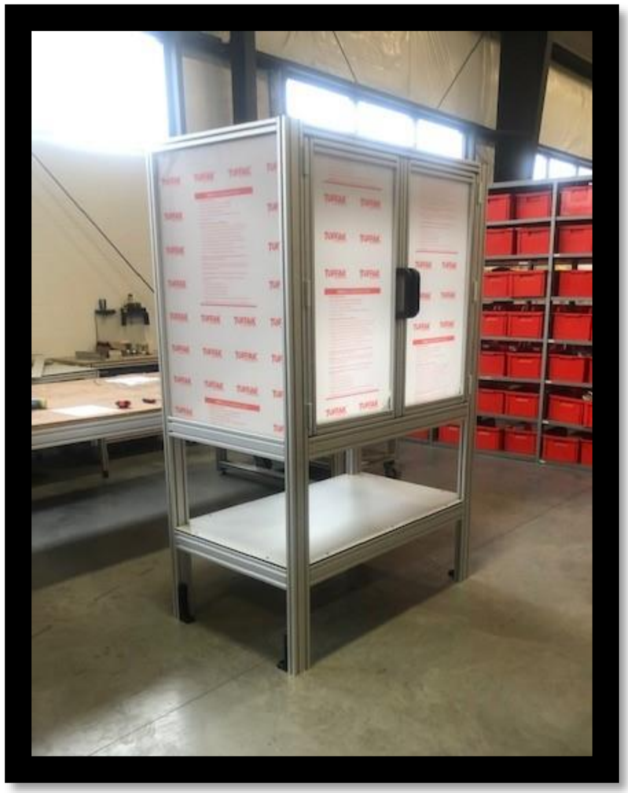
Fitting Adapter. Visible in the Top View.

Test End Receiver. Visible in the Top View.

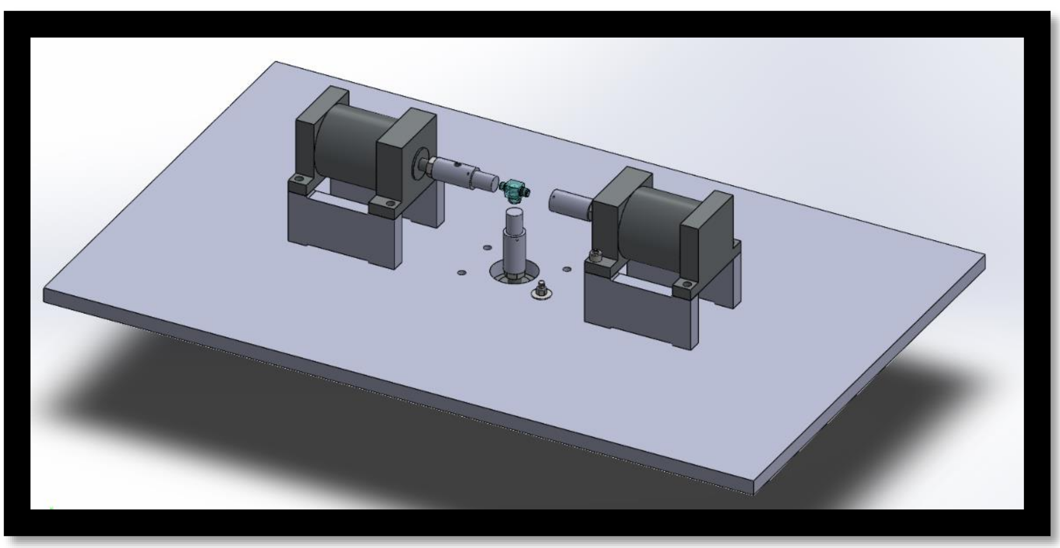
Under Table area of Tester. Note the large valve array and actuator bank with controllers.

Original Air Cylinder with barbed push in style connecting hose.

New Tester Photos:



New Tester Design Cabinet



New Table Base with Actuator Layout

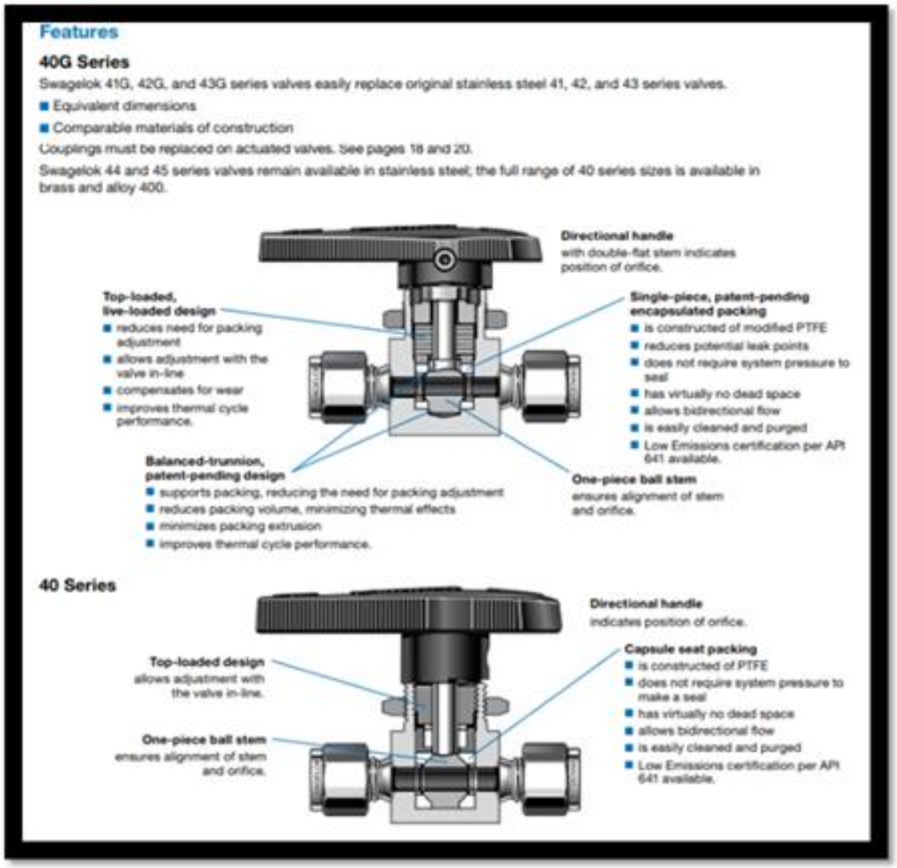
40 Series Technical Information (Available to Consumers):

40G Series and 40 Series Comparison

Feature	Valve Series		
	41G, 42G, 43G	41, 42, 43	44, 45
Valve Body Materials	Stainless steel	Brass, alloy 400	Stainless steel, brass, alloy 400
Packing Materials	Modified PTFE or UHMWPE	PTFE, PFA[1], or UHMWPE[1]	PTFE or PFA[1]
Working Pressure psig (bar)	Up to 3000 (206), depending on valve size. See page 5.		
Temperature Rating °F (°C)	Modified PTFE packing –65 to 300 (–53 to 148) UHWMPE packing –65 to 150 (–53 to 65)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA or UHWMPE packing: –65 to 150 (–53 to 65)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA packing: –65 to 150 (–53 to 65)
Flow Coefficients (C_v)	0.08 to 2.4	0.05 to 2.4	1.5 to 12
End Connection Sizes	1/16 to 3/8 in.; 3 to 8 mm		3/8 to 3/4 in.; 8 to 12 mm
Flow Patterns	On-off (2-way); switching (3-way)	On-off (2-way); switching (3-way, 5-way and 7-way); crossover (4-way and 6-way)	On-off (2-way); switching (3-way and 5-way); crossover (4-way)

[1] Live-loaded PFA and UHMWPE packing materials. See **40T and 40E Series for Low-Temperature Service,** page 3.

41-43G, and 41-45 Series Comparison



Features

40G Series

Swagelok 41G, 42G, and 43G series valves easily replace original stainless steel 41, 42, and 43 series valves.

- Equivalent dimensions
- Comparable materials of construction

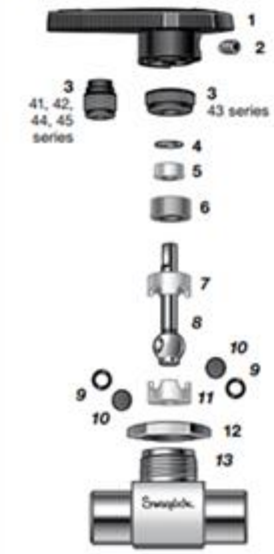
Couplings must be replaced on actuated valves. See pages 18 and 20.

Swagelok 44 and 45 series valves remain available in stainless steel; the full range of 40 series sizes is available in brass and alloy 400.

40 Series

Series Specific Features

40 Series



Component	Valve Body Materials		
	Stainless Steel	Brass	Alloy 400
	Material Grade/ASTM Specification		
1 Handle	Nylon with brass insert		
2 Set screw	S17400 SS/A564		
3 Packing bolt	Powdered metal 300 series SS or 316 SS/A276, A479	Brass CDA 360/B16	Alloy 400/B164
4 Upper gland	316 SS/A240	41, 42, 45 series: brass 260/B36; 43, 44 series: 316 SS/A240	Alloy 400/B127
5 Bushing	PTFE/D1710		
6 Lower gland	Powdered metal 300 series SS	Brass CDA 360/B16	Alloy 400/B164
7 Upper packing	*PTFE/D1710*		
8 Ball stem	*316 SS/A276*	*Brass CDA 360/B16①*	*Alloy 400/B164*
9 Side rings / *10 Side discs*	*Fluorocarbon-coated powdered metal 300 series SS/B783*	*Fluorocarbon-coated brass powdered metal①*	*Fluorocarbon-coated alloy 400 powdered metal*
11 Lower packing	*PTFE/D1710*		
12 Panel nut	Powdered metal 300 series SS/B783	Brass CDA 360/B16	Powdered metal 300 series SS/B783
13 Body②	*316 SS/ A276, A479*	*Brass CDA 356 or 360/B16*	*Alloy 400/B164*
Wetted lubricant	*41, 42, 43 series: silicone-based; 44, 45 series: silicone- and fluorinated-based*		
Nonwetted lubricant	Molybdenum disulfide with hydrocarbon binder coating		

Wetted components listed in italics.

① 4-way, 5-way, 6-way, and 7-way valves contain stainless steel stem, rings, and discs.

② Bodies with VCO end connections have fluorocarbon FKM O-rings.

Swagelok

40 Series BOM

Materials of Construction

40G Series

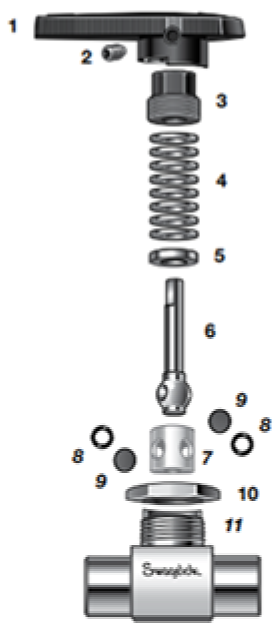
Component	Stainless Steel Valve Body Material
	Material Grade/ASTM Specification
1 Handle	Nylon with powdered metal 300 series SS insert
2 Set screw	S17400/A564
3 Packing bolt	Powdered metal 300 series SS
4 Springs①	S17700/A693
5 Gland	Powdered metal 300 series SS
6 Ball stem	*316 SS/A276*
7 Packing	*Modified PTFE/D1710 type 1, Grade 1, Class B or UHMWPE/D4020*
8 Side rings / *9 Side discs*	*Powdered metal 300 series SS/B783②*
10 Panel nut	Powdered metal 300 series SS/B783
11 Body③	*316 SS/A276 and A479*
Wetted lubricant	*Silicone-based*
Nonwetted lubricant	Molybdenum disulfide with hydrocarbon binder coating

Wetted components listed in italics.

① 41G and 42G series: 8 springs; 43G series: 6 springs.

② B783 specification not available on 41G and 42G series; standard on 43G series.

③ Bodies with VCO® end connections and modified PTFE packing have fluorocarbon FKM O-rings; bodies with with VCO end connections and UHMWPE packing have ethylene propylene O-rings.



40G Series BOM

Valve Series	40G		40		
Packing Material	Modified PTFE UHMWPE①		PTFE		
Valve Size (Configuration)	41G, 42G (Straight, Angle, 3-Way); 43G (Angle, 3-Way)	43G (Straight)	41, 42 (Straight, Angle, 3-Way); 43 (Angle, 3-Way); 44, 45 (Straight)	43 (Straight)	44, 45 (Angle, 3-Way)
Temperature °F (°C)	Working Pressure, psig (bar)				
–65 (–53) to 50 (10)	2500 (172)	3000 (206)	—	—	—
50 (10) to 150 (65)	2500 (172)	3000 (206)	2500 (172)	3000 (206)	1500 (103)
200 (93)	2500 (172)	2800 (193)	—	—	—
250 (121)	2500 (172)	2650 (182)	—	—	—
300 (148)	2500 (172)	2500 (172)	—	—	—

Valve Series	Temperature °F (°C)	Working Pressure psig (bar)
43Z (5-way)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA or UHWMPE packing: –65 to 150 (–53 to 65)	2500 (172)
45Z (5-way)		1500 (103)
43Z6 (7-way)		500 (34.4)

Pressure ratings for valves with Swagelok tube fitting ends may be lower due to the tubing pressure rating. Refer to *Tubing Data* catalog, MS-01-107, for additional information.

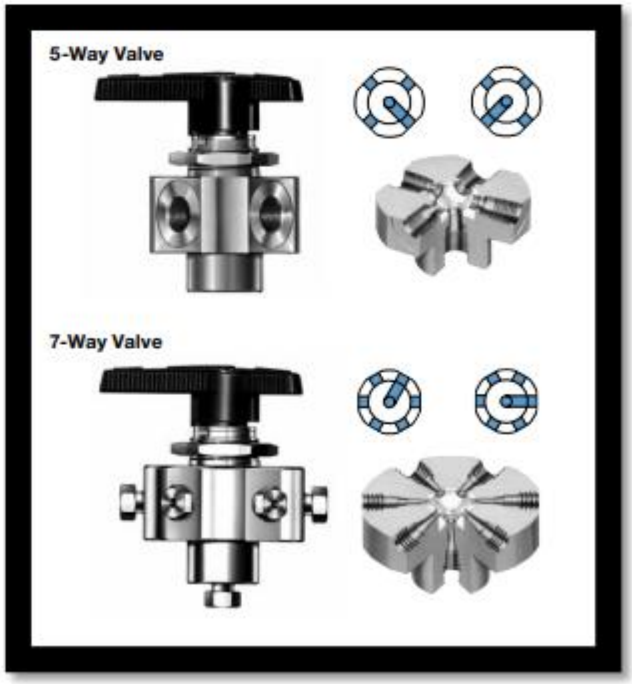
Valve Series	Temperature °F (°C)	Working Pressure psig (bar)
43Y (4-way)	PTFE packing: 50 to 150 (10 to 65) Live-loaded PFA or UHWMPE packing: –65 to 150 (–53 to 65)	2500 (172)
45Y (4-way)		1500 (103)
43Y6 (6-way)		500 (34.4)

Pressure ratings for valves with Swagelok tube fitting ends may be lower due to the tubing pressure rating. Refer to *Tubing Data* catalog, MS-01-107, for additional information.

Pressure and Temperature Ratings for all different series and directional patterns

Flow Patterns for 2-Way Valves

Flow Patterns for 3-Way Valves



Flow Patterns for 5 and 7-Way Valves

Flow Pattern for 4 and 6-Way Crossover Valves

Flow Data at 70°F (20°C)

Flow Coefficient (C_v)	Pressure Drop to Atmosphere (Δp), psi (bar)					
	10 (0.68)	50 (3.4)	100 (6.8)	10 (0.68)	50 (3.4)	100 (6.8)
	Air Flow std ft³/min (std L/min)			Water Flow U. S. gal/min (std L/min)		
0.05	0.6 (16)	1.5 (42)	2.6 (73)	0.1 (0.3)	0.3 (1.1)	0.5 (1.8)
0.06	0.7 (19)	1.8 (50)	3.2 (90)	0.2 (0.7)	0.4 (1.5)	0.6 (2.2)
0.07	0.8 (22)	2.1 (59)	3.7 (100)	0.2 (0.7)	0.5 (1.8)	0.7 (2.6)
0.08	0.9 (25)	2.4 (67)	4.3 (120)	0.3 (1.1)	0.6 (2.2)	0.8 (3.0)
0.10	1.1 (31)	3.0 (84)	5.3 (150)	0.3 (1.1)	0.7 (2.6)	1.0 (3.7)
0.15	1.7 (48)	4.5 (120)	8.0 (220)	0.4 (1.5)	1.0 (3.7)	1.5 (5.6)
0.20	2.3 (65)	6.0 (160)	11 (310)	0.6 (2.2)	1.4 (5.2)	2.0 (7.5)
0.30	3.4 (96)	9.0 (250)	16 (450)	0.9 (3.4)	2.1 (7.9)	3.0 (11)
0.35	4.0 (110)	10 (280)	19 (530)	1.1 (4.1)	2.4 (9.0)	3.5 (13)
0.50	5.6 (150)	15 (420)	27 (760)	1.6 (6.0)	3.5 (13)	5.0 (18)
0.60	6.8 (190)	18 (500)	32 (900)	1.9 (7.1)	4.2 (15)	6.0 (22)
0.70	7.9 (220)	21 (590)	37 (1000)	2.2 (8.3)	4.9 (18)	7.0 (26)
0.75	8.5 (240)	22 (620)	40 (1100)	2.3 (8.7)	5.3 (20)	7.5 (28)
0.80	9.0 (250)	24 (670)	42 (1100)	2.5 (9.4)	5.6 (21)	8.0 (30)
0.90	10 (280)	27 (760)	48 (1300)	2.8 (10)	6.4 (24)	9.0 (34)
1.2	14 (390)	36 (1000)	64 (1800)	3.8 (14)	8.5 (32)	12 (45)
1.4	16 (450)	42 (1100)	74 (2000)	4.4 (16)	9.9 (37)	14 (52)
1.5	17 (480)	45 (1200)	80 (2200)	4.7 (17)	11 (41)	15 (56)
1.6	18 (500)	48 (1300)	85 (2400)	5.0 (18)	11 (41)	16 (60)
1.7	19 (530)	51 (1400)	90 (2500)	5.3 (20)	12 (45)	17 (64)
2.0	22 (620)	60 (1600)	100 (2800)	6.3 (23)	14 (52)	20 (75)
2.4	27 (760)	72 (2000)	120 (3300)	7.6 (28)	17 (64)	24 (90)
2.6	29 (820)	78 (2200)	140 (3900)	8.2 (31)	18 (68)	26 (98)
3.0	34 (960)	90 (2500)	160 (4500)	9.5 (35)	21 (79)	30 (110)
3.5	39 (1100)	100 (2800)	180 (5000)	11 (41)	25 (94)	35 (130)
3.8	43 (1200)	110 (3100)	200 (5600)	12 (45)	27 (100)	38 (140)
4.6	52 (1400)	140 (3900)	240 (6700)	15 (56)	33 (120)	46 (170)
6.0	68 (1900)	180 (5000)	320 (9000)	19 (71)	42 (150)	60 (220)
6.3	71 (2000)	190 (5300)	330 (9300)	20 (75)	45 (170)	63 (230)
6.4	72 (2000)	190 (5300)	340 (9600)	20 (75)	45 (170)	64 (240)
12	130 (3600)	360 (10 000)	640 (18 000)	38 (140)	85 (320)	120 (450)

Testing

Every 40G series and 40 series ball valve is factory tested with nitrogen at 1000 psig (69 bar) or at its maximum rated pressure if less than 1000 psig (69 bar). Seat tests have a maximum allowable leak rate of 0.1 std cm³/min.

Low Fugitive Emissions

The American Petroleum Institute's API 641 tests for fugitive emissions to atmosphere for quarter-turn ball valves. The tests are conducted at a third party lab and certify that at no point in the test did the valve leak in excess of 100 ppm of methane. Certificates stating that the valve is certified for Low Emissions service are available for the following 40 series valves: 40, 40G and 40T. For more information, contact your authorized Swagelok sales and service representative.

Cleaning and Packaging

All 40G series and 40 series valves are cleaned in accordance with Swagelok *Standard Cleaning and Packaging (SC-10)* catalog, MS-06-62.

Special cleaning and packaging in accordance with Swagelok *Special Cleaning and Packaging (SC-11)* catalog, MS-06-63, to ensure compliance with product cleanliness requirements stated in ASTM G93 Level C, is available as an option. See **Process Options,** page 23.

Flow Data

1 SS - **2** 43G **3** E **4** V **5** L **6** S4 **7** -LL-RD

1 Body Material

B = Brass (40 series only)
M = Alloy 400 (40 series only)
SS = 316 stainless steel (40G series, 44 series, 45 series)

2 Valve Series

On-Off (2-Way) *(page 6)*
41G, 42G, 43G,
41, 42, 43, 44, 45

Switching (3-Way) *(page 8)*
41GX, 42GX, 43GX,
41X, 42X, 43X, 44X, 45X

Switching (5-Way) *(page 10)*
43Z, 45Z

Switching (7-Way) *(page 10)*
43Z6

Crossover (4-Way) *(page 11)*
43Y, 45Y

Crossover (6-Way) *(page 11)*
43Y6

3 Packing Material

40G Series
E = UHMWPE
None = modified PTFE

40 Series
None = PTFE

40T and 40E Series
E = Live-loaded UHMWPE (41, 42, 43 series sizes only)
T = Live-loaded PFA (all sizes)

4 Optional Vent Port

V = Vent port (page 15)

5 Optional Flow Path

H, L, HH, HL (page 24)

6 End Connections, Size

Swagelok Tube Fittings

Fractional, in.
S1 = 1/16
S2 = 1/8
S4 = 1/4
S6 = 3/8
S8 = 1/2
S12 = 3/4

Metric, mm
S3MM = 3
S6MM = 6
S8MM = 8
S10MM = 10
S12MM = 12

Female NPT
F2 = 1/8 in.
F4 = 1/4 in.
F6 = 3/8 in.
F8 = 1/2 in.

Female ISO/BSP Tapered
F4RT = 1/4 in.
F6RT = 3/8 in.
F8RT = 1/2 in.

Male NPT
M4 = 1/4 in.

Male NPT to Swagelok Tube Fitting
M4-S4 = 1/4 in.

VCO Fittings
VCO4 = 1/4 in.

Integral Male VCR Fittings
VCR4 = 1/4 in.
VCR8 = 1/2 in.

7 Options and Accessories

Add multiple designators in *alphanumeric* order. Not all options available for all valves. See pages cited below.

-A = Angle-pattern body (page 6)

-BL, -GR, -OG, -RD, -YW = Nylon directional handle colors (page 13)

-K, -SHD, -SH, -BKB, -NH, -NHS, -LH, -LL, -LLC = Handle options (pages 13 and 21)

-WVS2, -WVS4, . . . -WVS8M = Swagelok tube fitting vent port connections (page 15)

-WV4T49-2, -WV6MT10-50M = Tube stub vent port connections (page 15)

-SE2, -SE4, -SE6 = Stem extensions (page 15)

-WN1, -WN2 = Directional name plates (page 15)

-PT, -W20, -W31 = Production tests (page 23)

-SC11 = Special cleaning and packaging (page 23)

-1466 = No lubrication/special cleaning and packaging (page 23)

Part Number Guide

Statement of Contribution:

Devan:

- Report Sections
    - Abstract, Abstract file, introduction.
    - Appendix
    - Constraints
    - Codes and Standards
    - Overall editing
    - Conclusion
- Administrative communication with Swagelok
- Designed test end receiver and coordinated manufacturing.
- Helped John design regulator panel.
- Helped spec out hardware for mounting the air cylinders and fixtures to the table.
- Large portion of solid modeling.
- Communicated with Swagelok to coordinate buying of materials and parts.

Signature: *Devan Keeling*

John:

- Helped take meeting notes during weekly team meetings.
- Specified and ordered all miscellaneous hardware for tester.
- Researched and specified all Swagelok components for piping system.
- Designed piping architecture for both Nitrogen and Air systems to actuate the tester.
- Helped in designing the regulator panel.
- Edited promotional video for University of Akron's Final Presentation.
- Helped write Detailed Design, Embodiment Design, Design Brief, Cost, and Introduction sections of the final report.

Signature: *John Bowen*

Cameron:

- Designed/manufactured/assembled testing cabinet.
    - Solid model of cabinet
    - Cut and machined aluminum profiles
- Helped coordinate shipping of test cabinet.

- 2D drawings of test-end receiver for fabrication
- Helped write the Detailed Design section as well as added supporting information in other report sections.
- Editing and formatting of final report

Signature: *Cameron Bosner*

Jacob:

- Picked and quoted appropriate air cylinders.
- Designed and modeled fixture blocks for air cylinders
- Collaborated with others on picking out valves for manual conversion.
- Helped write Detailed Design and Embodiment Design sections of the report.
- Made simplified drawings for connection explanation.
- Made path-load drawings and calculations for detail design.

Signature: *Jacob Lenart*

Date: May 3, 2021