CRANE ChemPharma & Energy: Plug Measurement System

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Hunter Gastineau

April 2022

Thesis Advisor:

Dr. Ahmed Elgafy, PhD

TABLE OF CONTENTS

ABSTRACT

As a capstone senior design project for the College of Engineering and Applied Science at the University of Cincinnati, I have endeavored to work with CRANE ChemPharma & Energy to solve a design problem. This unique problem and subsequent design, uses sections of the knowledge I have gained during my time at the University of Cincinnati. By designing a part from concept, to design, to prototype, to model, and finally to implementation, all the supporting concepts of my degree program will be utilized.

PROBLEM STATEMENT

CRANE ChemPharma & Energy (Crane CP&E), which manufactures large industrial valves, has found the need to obtain a non-deforming measurement device for its valves' interior plugs. A system to accurately hold and measure a plastic-covered part without altering its dimensions is required.

RESEARCH

Background of the Problem

The valves that Crane makes essentially have two different parts: the plug and the waterway. A diagram of a completed assembly is contained in Figure 1 (1):

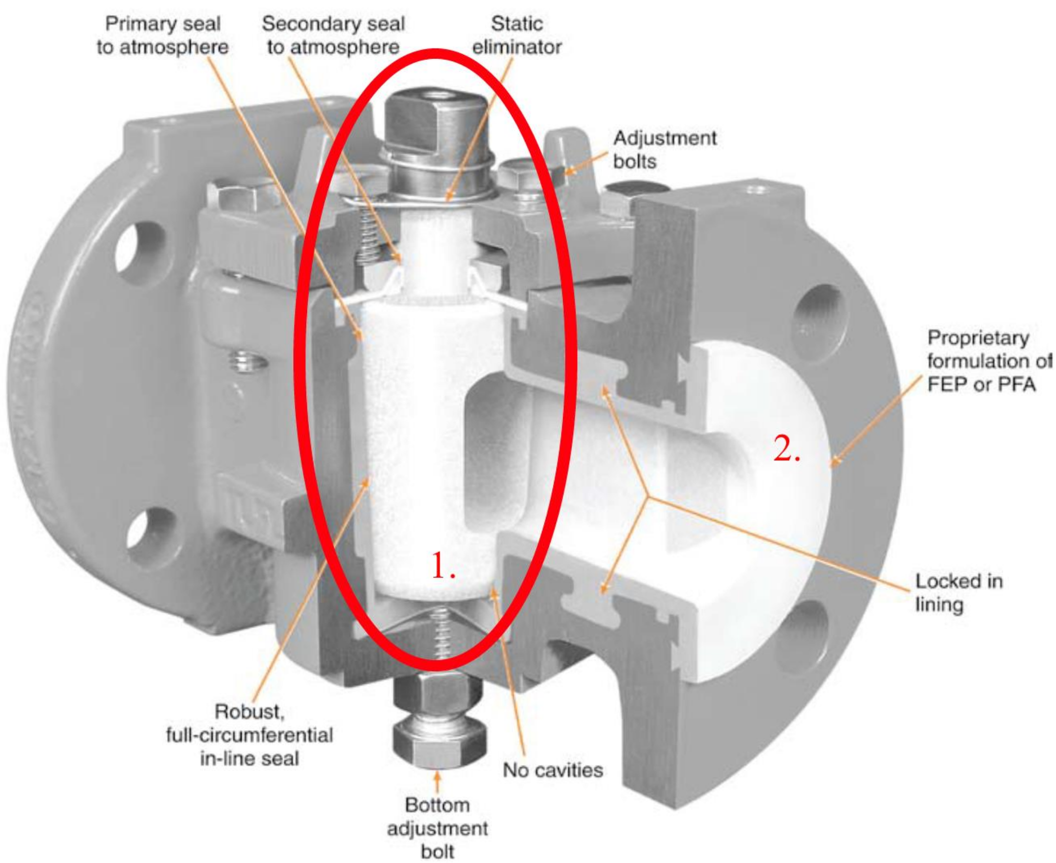


Figure 1: XOMOX Valve: 1.) The plug (circled). 2.) The waterway.

The plug has a hole through the bottom side, and a flat attachment point on the top. By turning the plug inside the waterway, the fluid flows through, and the valve is allowed to be open and closed (2). The application for this product is corrosive material transfer. Therefore, both of these parts are lined with FEP or PFA plastic (2). In order to maintain a precise seal, the plastic must be machined to a tight tolerance, and therefore requires measuring at multiple stages.

This product line is one of the main value streams at Crane CP&E. As such, any change in the process has the ability to massive increase or decrease efficiency. Currently, this is being measured using a height gage placed on a granite plate. An example of a typical cell setup can be seen in Figure 2:

Figure 2: Granite plate (bottom) and height gage with indicator (left), along with other necessary tools.

Crane CP&E has found that this means of measurement for the plug section of this value assembly is inaccurate and slow. This, as well as lacking a granite plate at critical machines has also caused certain plugs to be measured with nearby calipers or micrometers. These readings are known to be even further from actual, and hold the possibility to deform the edge that is being measured. Crane CP&E has conducted Measurement System Analysis (MSA) and Key Performance Indicators (KPI) studies that have shown that getting consistent measurements is not easy or consistent (1). These studies, which take in the inputs of multiple operators and tools, are a standard test of Crane CP&E's precision measurements (1). Improving upon the measurement process will save a great deal of time in money in both operator time, research, and precision tool expense.

Of course, with a product of this nature, there are risks to failure to create a good part. Ultimately, if a product is pushed out the door with a flaw in it, the customer is at risk for a possible life-threatening occurrence as a result of part failure. This is the worst-case scenario, especially considering the application of corrosive-resistant valves. Before that, however, it is likely to be caught by Crane CP&E's Quality program. For the time until a better process is implemented, the Quality department has been reviewing every plug with a Coordinate Measuring Machine (CMM). However, this is not a good long-term solution. This problem is using time from three to four different operators, and multiple added hours to what should ultimately be a simple measurement for a single line operator to perform.

Applicable Standards

For the proposed project, there are many constraints that are variable, and will change as the project progresses. Many of these items can be seen in the House of Quality (HoQ) in the Quality Function Deployment (QFD). However, there are a few constraints that must be adhered to. The final product must be able to accept more than one size of plug, as creating a range of sizes would be too costly. The final product must also have a means of tightly securing the angled face of this plug to itself, to ensure an accurate measurement can be gathered.

In order to ensure that these requirements are met, certain industry standards must also be adhered to. This includes general machinery standards, as per OSHA 1910.212. As well as minimizing pinch point hazards, as per OHSA 1910.211. For any fittings, “M” thread designations and standards will be used, as per ISO 68-1. These standards will make certain that any final product will be able to be used in a safe and standardized manner.

State of The Art

Granite and Height Gages

The solution that is currently in place, which Crane is using, is a height gage placed on a granite plate. At each relevant machining cell, there is a placed a granite table with a height gage. The part is removed from the machine and inspected after its final operation. Unfortunately, this way of inspection has been known to cause to cause problems. The operators cite the difficult of using a vertical height gage on a part with such complex geometry; gathering an accurate reading is near impossible. The geometry of the part in question can be seen in Figure 3:

Figure 3: XOMOX Lined Plug.

Barring this, as well as lacking a granite plate at critical machines has also caused certain plug to be measured with straight caliper or micrometers. These measurements are known to be even further from the actual. It can be seen that the problem is not being addressed adequately, as the measurements of these tools hold the possibility to deform the edge that is being measured.

Air Gaging

Crane's Quality department has put a great deal of time and research into a ring/air gage from Universal Gage Corporation, which measures diameters via air (4). The gage is a ring gage made slightly larger that the measurement diameter, with two air sensors which pump air in between the part and test the resistance. A similar system can be seen in Figure 4:

Figure 4: Universal Gage's Outside Diameter Air Ring gage.

This air gage, although fantastic in theory, arrived with a slew of issues. In its testing phase, which was conducted between multiple operators in varying conditions, it was determined to have a wildly inconsistent measurements (±0.050") gleaned from operator to operator. On top of this, the physical process of slowly moving the ring over the part multiple times, and constantly getting inconsistent results was time consuming and ineffective: it could take anywhere from two to three minutes per part, with a shoddy reading.

Ring Gages

A ring gage from Dyer Gage, which uses a slight touch indicator to infer measurements was also tested (3). This ring gage was far easier to use than the air/ring gage. However, the nature of using it resulted in a worse reading due to the human factor. Due to the geometry of the plug being measured, the operator would have to hold the ring gage in the air to get the reading. The small inserts on the indicators made this extremely difficult to do well, often needing reset. Also, if the ring was not level relative to the part, the resulting measurement would be oblong, invalidating it. This resulted in measurement error much greater than even the air/ring gage (±0.075”) This ring gage was certainly better than past devices, but it certainly would not hold up to the rigorous environment of a machine shop.

End User

The main user of the proposed gage is a machine/assembly line operator. This operator’s main job is to run the machine (in this case a lathe) through all its operations and then inspect their part. Through inspection, they will use a variety of tools. They have training on how to operate every tool within their cell, and the proposed solution would be no different. However, once implemented, this gage will take the place of all their affected tools, making inspection one simple step.

Any other user for the gage would be a facility supervisor, quality engineer, or calibrator. These employees would be able to ensure that the gage is operating correctly and does not pose issues for the operator to overcome. They would also be able to make any changes to the operating procedure or physical changes to the device itself.

Summary of Research

From the various testing and other products Crane has reviewed, we have not found valid a solution to our problem. Although products with similar goals exist, one that effectively meets Crane's goals does not. Therefore, an adaptable product that is built to Crane's own specifications should be created. This device will be able to look at the failures of similar products and overcome them, while still being viable for use for multiple sizes of plugs, and other applications.

QUALITY FUNCTION DEPLOYMENT

Customer Features

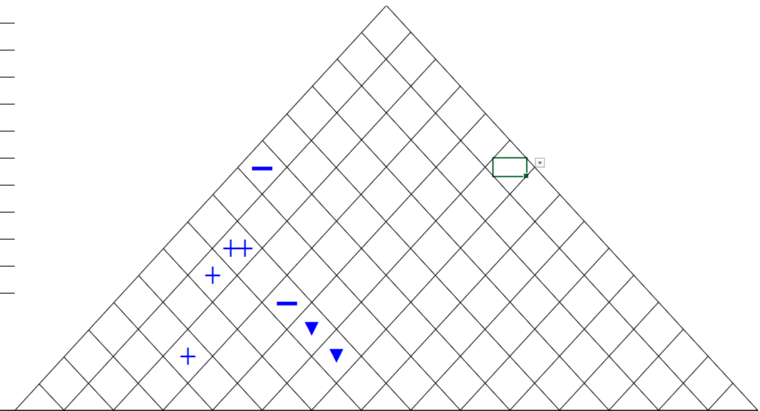
- Worker Safety
- Cost Savings
- Ease of Use
- Size (Volume)
- Time to Use
- Mobility
- Adaptability

Engineering Characteristics

- Pinch Points
- Weight
- Material Cost
- Machining Cost
- Number of Controls
- Size Adjustment
- Size Range
- Volume
- Mounting Points
- Grip Strength
- Accuracy

House of Quality

Title:	Crane ChemPharma & Energy Plug Measumrent System
Author:	Hunter Gastineau
Date:	10.1.21
Notes:	These points will be adapted as time goes on.

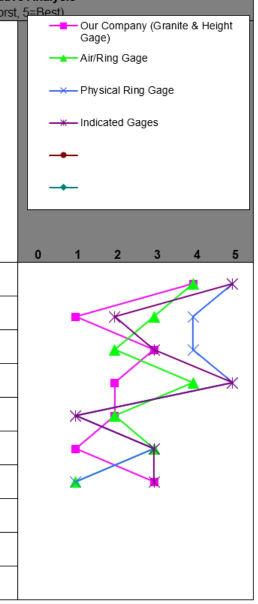


Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	▼	▼	▲	▲	▼	▼	▼					
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Pinch Points	Weight	Material Cost	Machining Cost	Number of Controls	Size Adjustment	Size Range	Volume	Mounting Points	Grip Stregnth	Accuracy				

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality	1 Pinch Points	2 Weight	3 Material Cost	4 Machining Cost	5 Number of Controls	6 Size Adjustment	7 Size Range	8 Volume	9 Mounting Points	10 Grip Stregnth	11 Accuracy	12	13	14	15	Our Company (Granite & Height Gage)	Air/Ring Gage	Physical Ring Gage	Indicated Gages
1	9	25.0	6.0	Worker Safety	⊙	⊙			○	▲	▲	○	⊙	○						4	4	5	5
2	9	16.7	4.0	Cost Savings		▲	⊙	⊙	○	○	○	⊙		▲	⊙					1	3	4	2
3	9	12.5	3.0	Ease of Use	○	▲			⊙	⊙	⊙	▲		○						3	2	4	3
4	9	8.3	2.0	Size (Volume)		▲	○		▲	⊙	⊙	⊙	○	○						2	4	5	5
5	9	12.5	3.0	Time to Use	○	▲			⊙	⊙	▲	▲		⊙	○					2	2	1	1
6	9	4.2	1.0	Mobility		⊙	▲		⊙		○	⊙	⊙							1	3	3	3
7	9	20.8	5.0	Adaptability		⊙				⊙	⊙	⊙	⊙		▲					3	1	1	3
8																							
9																							
10																							

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value	<2	<50 Lbs.	$500	$500	<3	10 Size Positions	10 Sizes	<0.125 m^3	4	<200N	±0.0005"				
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	5	3	7	8	9	9	5	1	4	7				
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9				
Weight / Importance	300.0	500.0	179.2	150.0	395.8	562.5	475.0	550.0	475.0	266.7	208.3				
Relative Weight	7.4	12.3	4.4	3.7	9.7	13.8	11.7	13.5	11.7	6.6	5.1				

Competitive Analysis (0=Worst, 5=Best)



Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Powered by QFD Online (http://www.QFDOnline.com)

Product Objectives

Worker Safety - (25%)

The safety of the assembly line worker is paramount. Any implemented design must first have all safety considerations in mind.

Accuracy & Precision - (20.8%)

Ultimately, this product is built to measure a finely machined edge. The accuracy of that measurement, and its repeatability it critical to this overall design.

Durability - (16.7%)

In the busy work environment of a machine shop, accidents are bound to happen. A design and material that can shrug off the occasional accidental impact is required.

Adaptability - (12.5%)

The proposed device must be able to accept many different sizes of plugs in order to be effective. A (or many) device(s) with too little variability in this regard would be cumbersome.

Ease of Use - (12.5%)

Since the operator using the proposed device will be an operator with little training, the device should be simple enough to use with minimal instruction. This will require a quicker time to use than the height gage counterpart. This will partially involve cost savings, as the quicker the labor goes, the cheaper the process is.

Cost Savings - (8.3%)

Part of the reason that this project was started was that the current tools Crane uses in their process are far too expensive for how inaccurate they are. The proposed device must meet their needs without breaking the bank.

Mobility - (4.2%)

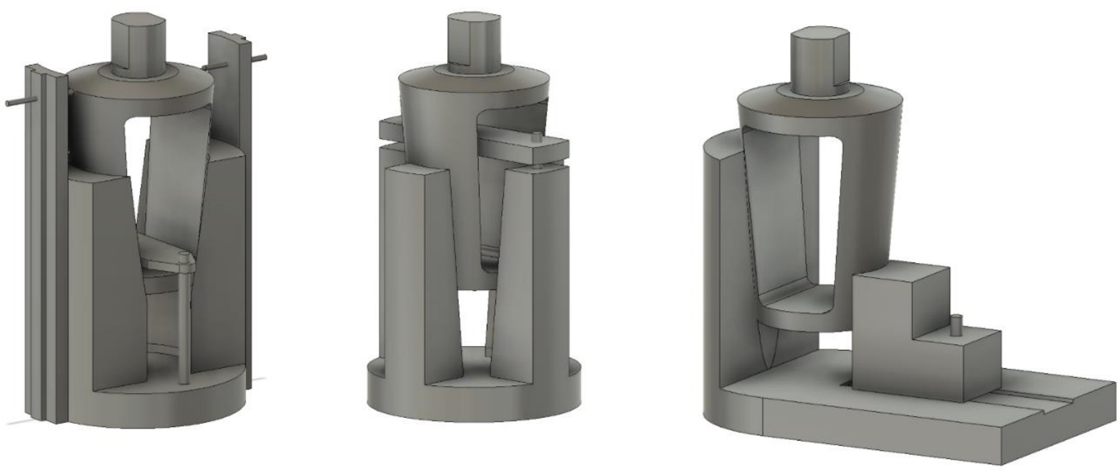
Crane's machining cells are prone to moving around a lot. The proposed device must be secure, while still being allowed to move without the use of extensive time or machinery requirements.

DESIGN

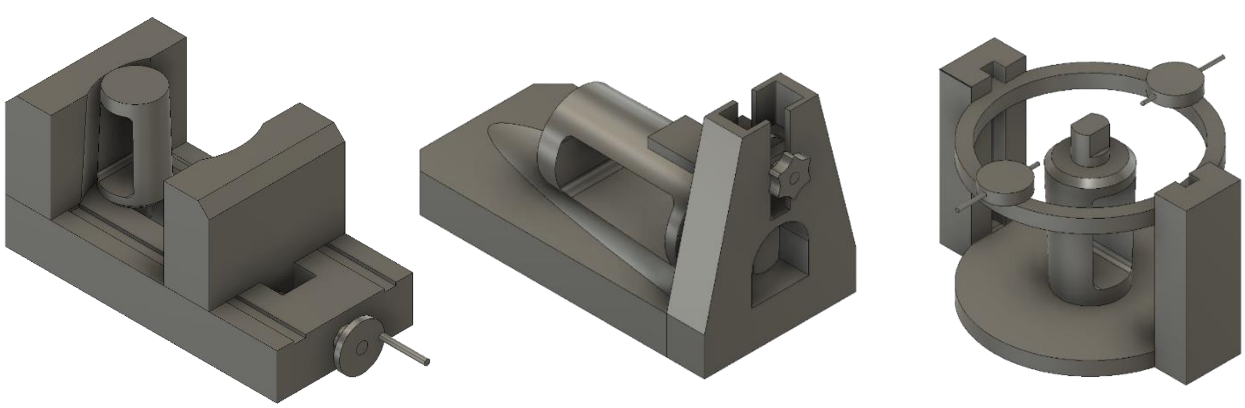
Design Alternatives and Selection

In the concept designs, there were multiple stages of designs that were proposed, and discussed with Crane engineers.

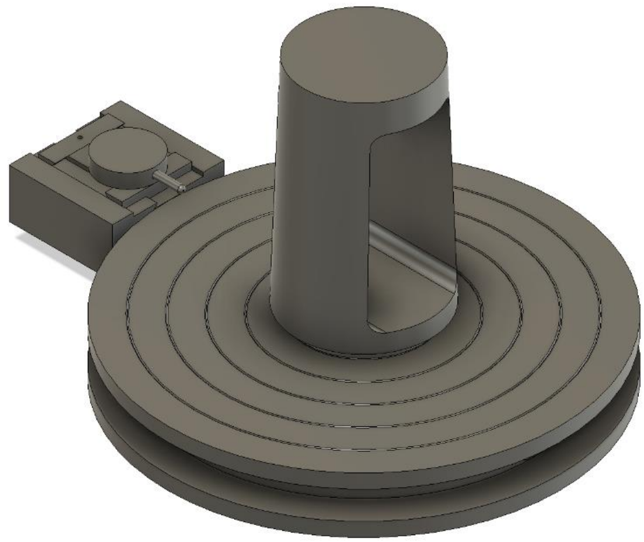
Concepts #1-3: These were very simple, rough designs which were made to start certain topics of discussion. These included things like, "What should the mounting surfaces look like?", "How should the plug be held in place?", "How large should the assembly be?", etc.



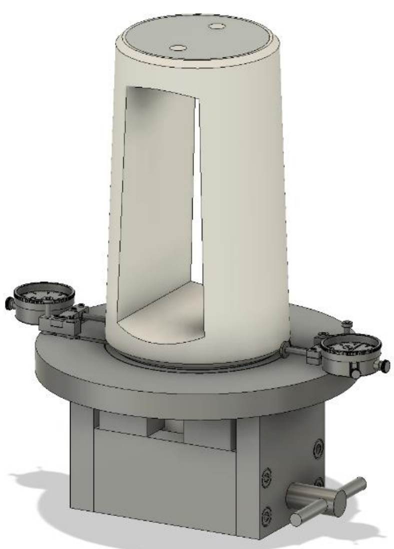
Concepts #4-6: These were the first revision of the general design ideas. On the left and middle, we have a vise-type mechanism which would be able to both hold the plug tightly, and glean the measurement. On the right, a double-indicator setup was proposed in order to be able to get a measurement along the entire side face of the plug.

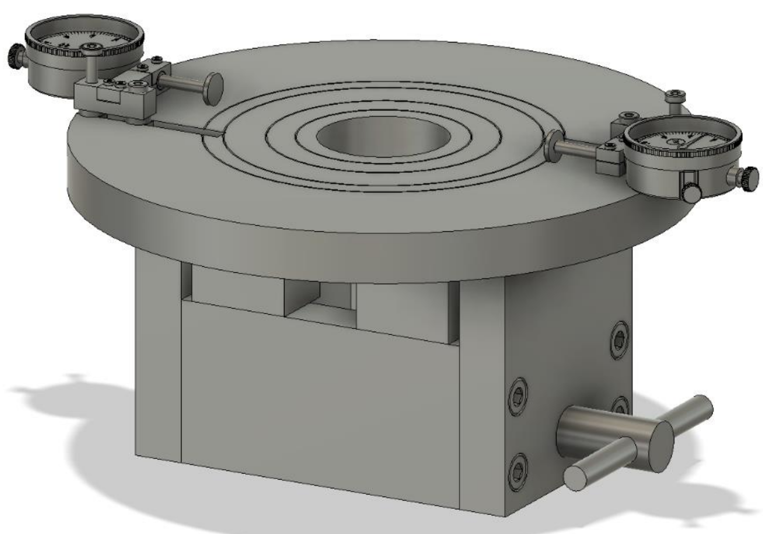


Concepts #7-8: The next revision of designs chose the indicator setup, and proposed different layouts. The left retained the dual-indicator setup, but with 3-axis adjustment. The right, a single indicator that would rotate around the entire part.



Final Concept: The final iteration of the concept phase would combine the important points from every revision. An adjustable, dual-indicator setup, as well as a secure vise that is adaptable, to ensure that the part does not move.





Loading Conditions

Heaviest Use Case

For the safe loading of the assembly, the heaviest use case of the finished part was to be determined. For Crane, this would be their 10” plug. The plug, partially comprised of steel and PFA plastic, weighs at a max, 17.7 kg. This results in a 173.6N static load on the top face of the part. The calculations are as follows:

$$Volume_{steel} = 2.012 * 10^6\ mm^3$$
$$Density_{steel} = 0.007 g/mm^3$$
$$Volume_{PFA} = 1.431 * 10^6\ mm^3$$
$$Density_{PFA} = 0.002 g/mm^3$$

$$Volume_{steel} * Density_{steel} = 14.8\ kg$$
$$Volume_{PFA} * Density_{PFA} = 2.9\ kg$$
$$Weight_{total} = 17.7$$
$$Force_{total} = 17.7 * 9.81 = 173.6N$$

Simulation

From this data, we were able to input the models, volumes, and densities into Fusion 360's simulation program. This program, which utilizes the CAD and simulation workspaces together, is able to tell many different things about loading conditions. The following is a snapshot of the simulation, and some associated figures:

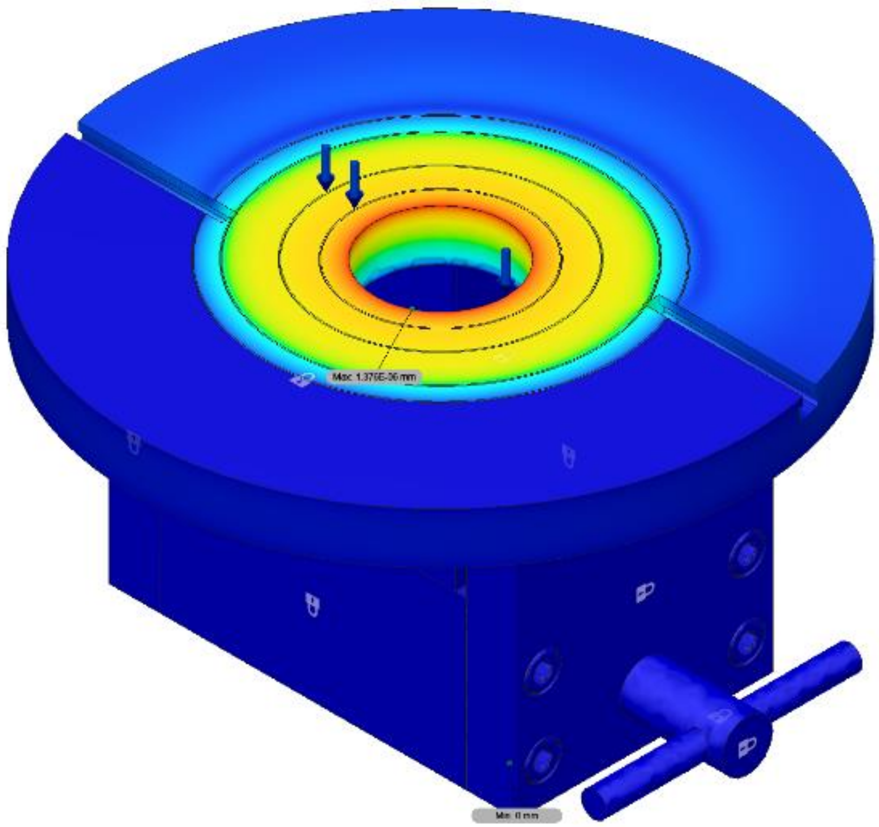


Figure 5: Fusion 360 Displacement Simulation (Exaggerated)

$Max\ deformation$: 0.000001376 mm

$Max\ stress$: 0.01454 Mpa

$Max\ strain$: $9.472 * 10^{-8}$

$Factor\ of\ Safety$: 15

Specifications and Standards

Screws

ISO 68-1 - General Purpose Screw Threads - Profile

ISO 262 - General Purpose Metric Screw Threads – Screws, Bolts, and Nuts

DIN 6912/7984 - Socket Head Cap Screws

DIN 508/787 - T-Slot Nuts/Bolts

Materials

AISI 1020 Grade Steel

ASTM D6867-19 - Perfluoroalkoxy Alkane

General Tolerances

ISO 2768 - Level: Coarse

Material Selection

Raw Materials

For the raw metal materials used in this assembly, we have found via the simulation, that there will not be a large focus on strength. Ultimately, robustness over time is our main goal. As such, we have found that AISI 1020 grade steel for the overall assembly would be a good fit. It is cheap, and easily machinable, while still being plenty strong enough to support our load and fending off accidental impacts.

PROOF OF DESIGN & TESTING

Rapid Prototyping

In order to quickly verify the fit and finish of the parts that the CAD model proposed, a rapid prototype of the model was manufactured on a 3D printer. Using the industrial-grade 3D printers at the University of Cincinnati’s 1819 lab, and supplemented by my own Ender 3 small-scale 3D printer, a prototype was furnished within a week of the drawing’s conception.

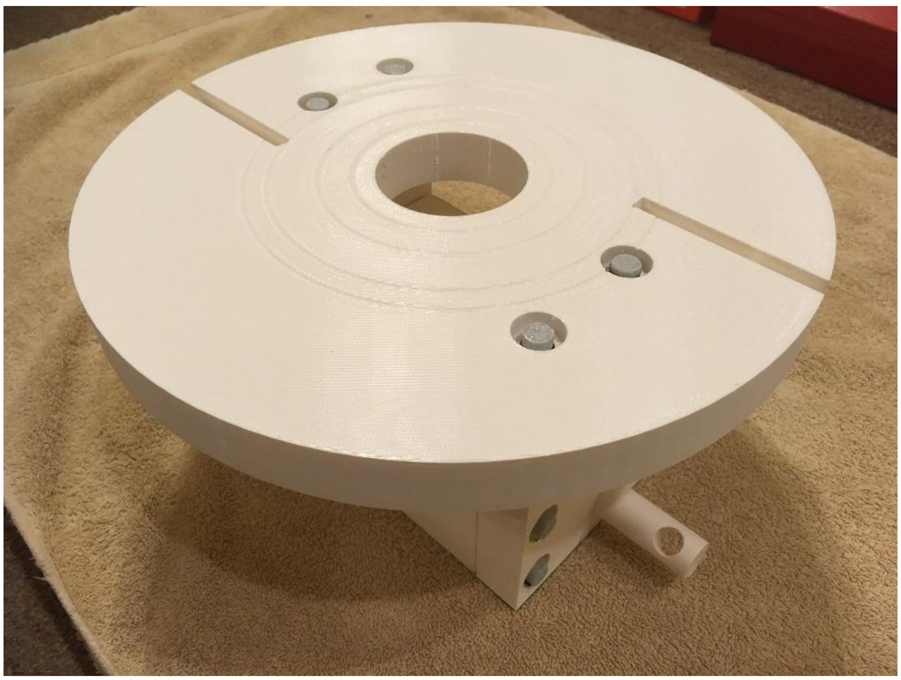


Figure 6: Completed 3D-Printed Prototype

Machining Processes

From the conception of the design, this model has been meant to combine simplicity and cost effectiveness, in order to be easily implemented into a shop floor's face-paced environment. As such, the machining of the parts was very simple. Conducted via Crane's Tool & Die department, the majority of the machine work was done on a vertical mill. This includes the top plate, vice walls, and vice jaws. On a lathe, the double-threaded self-centering vice screw was machined.

Practical Testing

For the testing period of this assembly, various actual manufactured parts were used for testing. This, as well as industry standard gage blocks will be used to ensure that the assembly has a suitable accuracy for the application. By placing a gage-plug hybrid inside the vice and tightening it, the indicators can be calibrated. Then, without moving the indicators, a part to be test can be placed into the vice, and a measurement gleaned from the largest diameter of the plug.

PROJECT MANAGEMENT

Budget, Proposed/Actual

After discussing the project with the plant and quality managers at Crane CP&E, a budget target of $1000 is to be hit. After prototyping and machining, I am proud to say that the budget was not exceeded. This is broken down in the following table:

Proposed Budget	Actual Budget
$500 – Materials	$200 – 2x Mitutoyo 2416S
$500 – Machining	$50 – Misc. Hardware
	$212 – 3D Printing
	$500 – Machining
TOTAL: $1000	**TOTAL: $962**

Schedule, Proposed/Actual

There were a few delays, when comparing the proposed and actual schedules. The biggest delay was scheduling conflicts with Crane's machine shop. However, this is why I made the proposed schedule very optimistic, with large break between the events.

Proposed Schedule		Actual Schedule	
Item	**Date**	**Item**	**Date**
Design Concept Model	**1.10.22**	Design Concept Model	**1.17.22**
Concept Refinement	**1.20.22**	Concept Refinement	**1.31.22**
Construction of prototype	**1.31.22**	Construction of prototype	**2.25.22**
Construction of final	**2.25.22**	Construction of final	**4.13.22**
Implement into Crane's Process	**3.25.22**	Tech Expo Day	**4.14.22**
Tech Expo Day	**4.11.22**	Implement into Crane's Process	**4.18.22**

CONCLUSION

At the end of the day, the final product has accomplished what it set out to do. The setup can easily measure a wide array of plugs (from 4" to 10") without a fuss or wasted time. However, there are still improvements that could be made. After machining completion, I was in awe of how heavy the practical model was. Although in our research survey we found that mobility was not an issue, moving around this 60lb. mass proved to be very difficult. We also found that the geometry of the t-slots for the indicators lacked the ability for smooth movement. A tighter lubricated, or perhaps even a slider system should be implemented into the final product in order to make for a smoother measurement experience. However, the model we made is one that emphasized our main goals without compromising our budgets, schedule, or other constraints.

REFERENCES

1. **6SigmaStudyGuide.com. 2021.** Measurement Systems Analysis (MSA). [Online] August 11, 2021. https://sixsigmastudyguide.com/measurement-systems-analysis/.
2. **Crane ChemPharma & Energy. 2021.** XOMOX® Lined Plug Valves. [Online] August 11, 2021. https://cranecpe.com/product/xomox-lined-plug-valves/#tab-id-0.
3. **Dyer Gage. 2021.** 283 Series Full or Part Circle O.D. Gages. [Online] August 11, 2021. http://www.dyergage.com/categories/283-series-full-or-part-circle-o-d-gages/.
4. **Universal Gage Corporation. 2021.** Universal Gage Corporation. [Online] August 11, 2021. https://www.universalgage.com/.