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Hardware Development And Testing For LOX/LCH4 Rocket Engine

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HARDWARE DEVELOPMENT AND TESTING FOR LOX/LCH4 ROCKET ENGINE

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Dedication

I would like to dedicate this thesis and all the work that was put behind it to my family and friends. They all have always supported this dream.

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by

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Abstract

The University of Texas at El Paso (UTEP) Center for Space Exploration and Technology Research (cSETR) has focused its research efforts on developing LOX/LCH4 propulsion systems. As part of the Janus Sub-orbital vehicle program, UTEP is developing a 2000 lbf throttleable rocket engine (Chrome X). The first iteration of this engine design will be geared for further optimization towards a flight engine. Components like electric motors, valves, and sealants have been selected to achieve throttle ability and sealing of the engine. These components play a crucial part on the engine to be able to have a successful firing. As part of the overall engine system integration, the components will be tested at conditions meant to simulate expected operating conditions during main engine firings. These tests will ultimately give insight regarding component performance, thereby allowing for evaluation, verification, and validation of the selected components. This work will primarily focus on the description of components selection and will present performance elevation test data meant to assess component operation.

The actuation system is composed of a valve, electric motor, gearbox, thermal standoff, and frame. These components were selected and or manufactured using the requirements set for the injection. The injection requirements were the first set of requirements where every other set of requirements was derived from, for the other components. The injection requirements are chamber pressure / injection pressure, flowrates, and upstream pressure. These requirements were used to size the valve. The injections system has some other operational requirements, but the described parameters are the only set necessary to size a valve. Once a set of valves were selected, the breakup torque and response time were obtained. The breakup torque is the torque a valve requires to start moving. The response time is the time from close to open or inversely for the valve to operate. These requirements that were derived from the valves were used to select the electric motor. The electric motor comes with a gearbox, encoder and a digital controller. For the valve and motor to work together a couple of more parts needed to be spec out. The thermal standoff was designed and manufactured to serve as an insulator for the motor and be a connection between

the valve and motor. This part has some special features to improve its insulating capabilities. However to be able to manufacture it under conventional methods seemed difficult because of the lattice design and titanium was the material picked for manufacturing. For these reasons, it was decided to do additive manufacturing for this part. The final component that is needed to make this system work is a frame to hold the aforementioned components together. The frame was made out of cylindrical plates where the valve and motor were mounted onto. Studs were used to connect the plates together. This whole system was built for the throttling valves that the engine needs.

There are many forms a component can be inspected for verifications of design. The reaction control engine (RCE), throttling system, and the sealants went through a verification test. The reaction control engine after it was manufactured, some of its features like the injection orifices and the throat went through dimension validation. For these tasks, precision tools were obtained**.** After all of the dimensions were validated. A none destructive test campaign went underway to validate assumptions. This test series consisted of flowing water and monitoring the pressure, flow rate, and temperature upstream and downstream of the engine. The actuation system had a similar test as the RCE. Where a set up meant to be used with water was built and monitored the performance of the valve. Finally, the prospect sealants that would be used in the engine had a performance test. The purpose of the sealant test was to replicate the kind of environment the sealants would be in an engine fire test. From the data gathered it was determined that the gasket sealant had a better performance than the tape type.

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Chapter 1: Introduction

The Center for Space Exploration Technology Research (cSETR) has the interest of developing propulsion systems that would operate with the use of liquid oxygen (LOX) and liquid methane (LCH4) as their main propellants. These systems are composed of propellant feed lines, injection system, ignition system, combustion chamber, and a converging-diverging nozzle. The propellant feed lines are all the tubing and components (filters, flow meters, pressure transducers, thermocouples, valves, tanks, etc.) that comes upstream of the injection system. These components need to be picked carefully using the requirements set by the injection system. If these components are inadequate, it may cause the propellant not to arrive at the desired conditions to the injection system and ultimately cause failure in the engine. The injection system for a rocket engine has a design dependent on the kind of propellants, pressure in the chamber and machining limitations. For example, the chamber pressure and propellant properties were used to size a pintle injection and impinging injection for the same rocket. The impinging injection was scrapped because the prices to manufacture were too high. For this reason, the pintle injection was picked over the impinging injector. Also, an early version of the ignition system has already been tested in the university facilities. The necessary adjustments to the engine system were made to adapt this injector. The combustions chamber and nozzle design are very closely related because they must deal with the combust gases and how these gases allow for the rocket to produce thrust. For the chamber and nozzle, it's hard to validate their design without firing propellants. The only validation tests these components go through is dimensioning and geometry. Most of these systems and components can be tested with non-destructive means to assure they will perform as design. For example, water was used to test the flow rates at the injection system and valves. The focus of this paper is to explain the development of the hardware, verification testing of the different critical components to the performance of the engine. This paper will focus on the verification and validation of critical components for the engines being developed at the Center for Space Exploration Technology Research (cSETR).

1.1 Why Liquid Oxygen (LOX) and Liquid Methane (LCH4)

The interest to use liquid oxygen (LOX) and liquid methane (LCH4) comes from the many advantages that this propellant combination brings, a relative lower toxicity, acceptable performance parameters (specific impulse (Isp), and thrust) and the possibility to be harvested in the surface of Mars. Hydrazine is an example of a good propellant due to its ability to ignite by just being mix with oxygen. However, being exposed to hydrazine causes problems with the central nervous system, lungs, and liver. [14] Exposure to methane (not advisable due to its flammability) may cause a person to have a mild headache and in extreme cases suffocation. Liquid hydrogen and liquid oxygen are among the propellant combinations with the highest Isp having a value of 388s. LOX and LCH4 have a value of about 299s, after doing the calculations of thrust coefficient and C* have deemed this acceptable combination values for a thruster. The values of thrust coefficient and C* will be explained in later chapters. The high levels of carbon dioxide and minor amounts of other elements and compounds in the surface of Mars will allow for a process to manufacture methane and oxygen that will be used as a fuel for the rocket. LOX and LCH4 is a new propellant combination that has many advantages when it comes to deep space exploration, and many resources are being used for research.

The MIRO Center for Space Exploration Technology Research (cSETR) of the University of Texas at El Paso (UTEP) has the interest in using LOX-LCH4 technologies to develop research opportunities for students to work on. The projects currently being developed at cSETR are the LOX-LCH4 5-8 lbf, 500 lbf, 2000 lbf propulsion engines, the suborbital vehicle Daedalus and the robotic lander Janus. The 5-8 lbf engine will be used on both Daedalus and Janus as a reaction control engine. This means that this engine will give any necessary adjustment needed on the vehicles' orientation while flying. The 500 lbf engine will be the main propulsion system for Daedalus. This engine should be able to throttle a 1:4 ratio depending on the mission statement. The purpose of Daedalus is to assess the performance and interaction of the propellant system when is under microgravity. The 2000 lbf engine will be the main propulsion system for Janus. Like the 500 lbf engine, the 2000 lbf should be able to throttle. The other requirement this engine

has is to be able to integrate a gimbal system, that in part will help the Janus vehicle maneuver as need. The Janus vehicle purpose is to demonstrate the performance of the LOX and LCH4 propulsion system in take-off and landing maneuvers. These projects have an end goal to integrate a functional LOX LCH4 propulsion system in different environments. The primary focus of this thesis is the hardware and component development for the engines. The different components were tested for validation of design using non-destructive means like flowing water through them or just validating the geometry.

Chapter 2: Overview of engine projects

The three engines that are being developed at cSETR the pencil thruster, Centennial Restartable Oxygen Methane Engine (CROME) and CROME X share similar design processes and some requirements. All three engines must use LOX.LCH4 as the propellant combination. This brings the first parameter to look at, that is the specific impulse (I_{sp}). Then from there, a number of parameters can be calculated depending on the mission of the respective engine.For example, the thrust coefficient, C*, flow rates, chamber pressure, injection pressure, etc. can be derived using some relations that will be later explained. These parameters are needed to start designing the geometry that will be required to achieve the initial requirement. The geometry consists, but it's not limited to the chamber diameter, throat diameter, nozzle type and length, injection system, etc.

2.1 Basic rocket equations

To start calculating any of the parameters to design a rocket engine. The understanding of how a rocket engine starts moving is imperative. Newton's third law of motion states that every action has an equal and opposite reaction. This helps explain how the production of hot gases when combusting inside the chamber, propel the engine in the opposite direction from which they were expelled. This principle was used in the Rocket Equation:

$$F = \dot{m}v_e + (P_e + P_a)A_e \tag{2.1}$$

In this equation F stands for the thrust of the vehicle, $\dot{m}$ is for the mass flow rate, v_e is the exit velocity of the gases, P_e and P_a are the exits and ambient pressure, and A_e is the exit area of the nozzle. This equation is composed of a momentum exchange of the fluid and a pressure imbalance at the exit of the nozzle. [16] From this equation only, the force (thrust) is known because it is one of the first requirements that were given to each engine. To be able to move forward some other thermodynamic conditions need to be set. First, since the chamber has a converging-diverging nozzle at the throat, there needs to be choke flow. This means that at the throat the Mach number is one or sonic flow. This assumption was used for the isentropic flow, with some simplification

since at the throat the Mach number is one. For the flow to be able to reach sonic conditions, the ratio between exit and chamber pressure needs to be lower than the critical pressure ratio. The critical pressure ratio is obtained by using this equation:

$$\frac{P_t}{P_c} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \tag{2.2}$$

P_t is the pressure at the throat, P_c is the chamber pressure, and k is the specific heat ratio of the gas. The specific heat ratio is a value gotten by using Chemical Equilibrium with Applications (CEA), by setting a chamber pressure, temperature and combination of chemicals. If the pressure ratio is greater than the critical pressure ratio, sonic conditions will not be met. Meaning that the velocity of the gases will be slowed down through the diverging nozzle. [16] The theoretical exit gas velocity can be obtained using this thermodynamic equation:

$$V_e = \sqrt{\frac{2kgRT_c}{k-1}\left(1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right)} \tag{2.3}$$

In this equation R means the specific gas constant of the exhausted gas, g is the gravitational constant and T_c is the total temperature of the chamber. As already mentioned, another parameter that is used to relate the performance of an engine is the Isp. This can be used to get a rough estimate of the flow rates that an engine might require. The definition of this term is

$$I_{sp} = \frac{F}{\dot{m}g} \tag{2.4}$$

A relatable way to use this term is to compare it to gallons per mile like on a car. Having a low mass flow rate means a higher performance value.

The mixture ratio (MR) is a very important parameter that helps size tanks for each of the propellants, helps determine the mass flow rate for each of the propellants, and with the use of another solver like CEA or RPA the temperature of combustion can be determined. The equation for MR is

$$MR = \frac{\dot{m}_{ox}}{\dot{m}_f} \tag{2.5}$$

The numerator term is the oxidizer mass flowrate, and the denominator is the fuel mass flow rate. This MR equation is the same equation used for the car industry to rate if an engine is flowing fuel rich or fuel lean. Also, it is worth noting that when an engine is flowing fuel lean, the temperatures are hotter than when running fuel rich. Depending on the requirements the ration of this MR value is very important when dealing with a materials temperature limit. For all the engines the MR value is about 2.7. This value should allow for equal consumption of propellant and have equal size tanks. These different relations described were used to design and set the requirements of all the three engines.

2.3 MATERIALS AND ADDITIVE MANUFACTURING

The material selection of a rocket engine is an important parameter to analyze because it will set the maximum temperature and pressure that the combustion should be allowed to achieve. Some of the material properties to look for while analyzing different possibilities are the temperature limit, tensile and yield strength and the young modulus. A widely used material in the aerospace industry is Inconel 718 and 625 (Nickel base alloy). Both these materials have a high corrosion resistance, and they are compatible with pure oxygen use. Oxygen is a very ignitable fluid. A particle smaller than the thickness of a hair could be enough to ignite a pure oxygen environment. Also, some materials like carbon steel and aluminum among others are very reactive to oxygen. These advantages plus the knowledge that this material has been used before on similar applications lead to it being picked as the material for the engine.

Inconel 625 is a slightly weaker variation of Inconel 718. However, the 718 variation is very difficult to machine because of its work hardening properties [10]. Work hardening or strain hardening is a property of certain materials that make the material harden whenever there is plastic deformation. Work hardening is the reason for this material to have to be continuously machined and make it harder for a machinist to work with. Also, the machinability rating for both Inconel 625 and 718 is 0.12. (values of 1 mean that material is easy to machine). Inconel 625 still has the issue of work hardening however its slightly weaker stats make it simpler to machine compared to

the 718 variations, and it can be 3D printed. These are the reason for using the 625 variations on the injector. The injector has a tolerance of about 0.002” on most of its features. Table 2.1 shows all the some of the properties of Inconel 625 and 718.

Table 2.1 Inconel 718 and 625 Properties

	Inconel 718	Inconel 625
Tensile Strength	180 ksi	120 ksi
Young Modulus	29 ksi	30.1 ksi
Melting Temp	1,300˚	1,800˚

2.4 Pencil Thruster

A reaction control system (RCS) is used on large space vehicles like shuttles, lander, and missiles as a mean to readjust trajectory. This system consists of various engines placed in strategic position in a vehicle. Propellants are feed through a small connection out of the main propulsion system or at times will have their own propellant tanks. The difference between a reaction control system and the main propulsion system (MPS) is that the RCS has to pulse when firing and the MPS is a continuous firing. Also since the RCS is meant for adjusting trajectory or positioning, the thrust requirement is much less than the MPS of the same vehicle.

Table 2.2: Pencil Thruster Requirements

Requirements	
Propellant	LOX/LCH4
Operation	Pulsing Thrust
Material	Inconel 718
Thrust	5-8 lbf
Chamber Pressure	100 ±5 psi
Specific Impulse	182 sec
Mixture ration	2
Fuel Film Cooling	≤30% of LCH4 flow rate

Table 2.2 show some of the requirements and specifications for this engine design. This engine design has passed through several iterations of the design. This engine will work on both Daedalus and Janus. Figure 2.1 shows the last design that was manufactured.

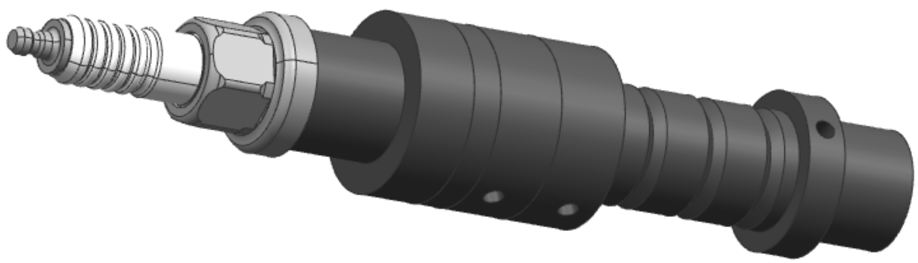


Figure 2.1: Pencil Thruster Final Design

2.5 CHROME X 2000 ENGINE

The 2000 lbf engine CROME X has a much bigger thrust requirement compared to the pencil thruster. One of the major requirements for this engine is that it needs to be throttleable. As already mentioned this engine is meant to propel and maneuver the Janus lander. The way that this engine will maneuver the vehicle is by installing a gimbaling system. The gimbal system will be used to hover the vehicle to a predetermined location.

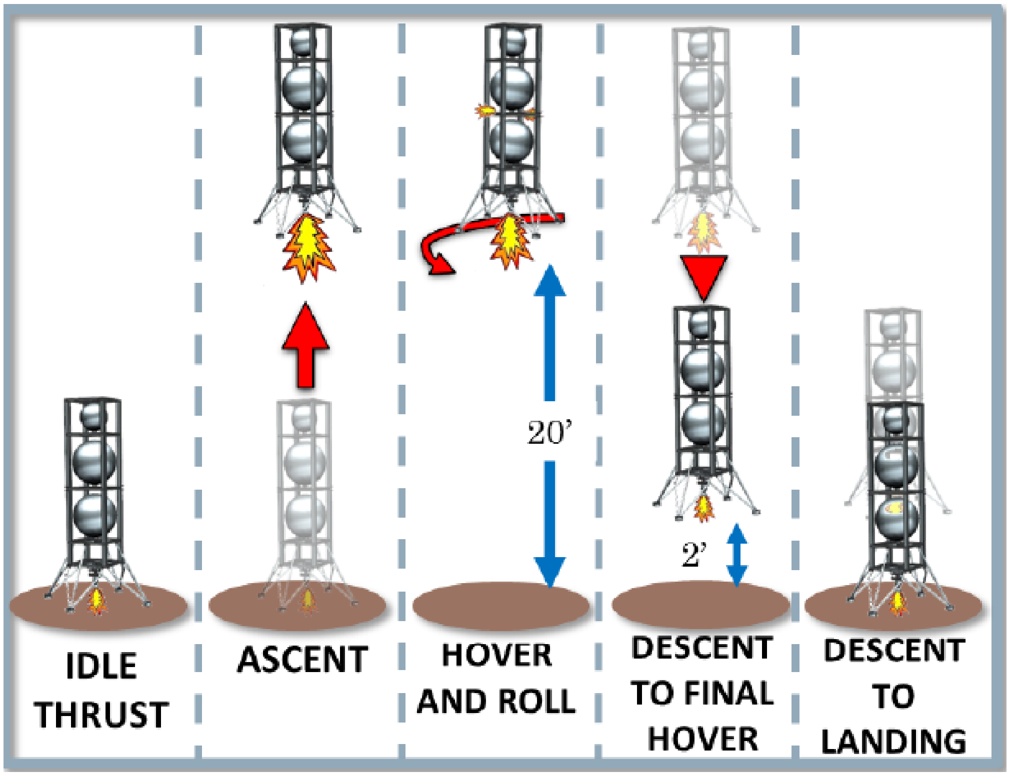


Figure 2.2: Janus Expected Flight Profile

The RCS will be integrated into Janus to aid the gimbal system move to position that on its own it would achieve. Figure 2.2 shows a schematic of the mission for the Janus vehicle that the engine needs to achieve. The way a gimbal will achieve maneuvering is by tilting the engine to a certain degree. The Gimbal system is yet to be developed. Some basic components to start to look at are some hydraulic system that will adjust the engine. Depending on how complex the gimbal system is a vehicle might not need to have an RCS system. However, having an RCS on the vehicle can be used as means for an extra measure to prevent the vehicle from tilting too much and cause any catastrophic problems for the vehicle. The CROME X engine is in its final phase for the first iteration and is about to be quoted to be machined.

2.6 CROME 500 LBF ENGINE

The Centennial Restartable Oxygen Methane Engine (CROME) was designed to have 500 lbf of thrust and to be used on Daedalus. Like CROME X is a throttled engine with a 1:4 ratio. The mission of both Daedalus and the CROME is to reach suborbital altitude and record data for various thrust levels. [15] Figure 2.3 shows the expected flight path that the vehicle will take when testing.

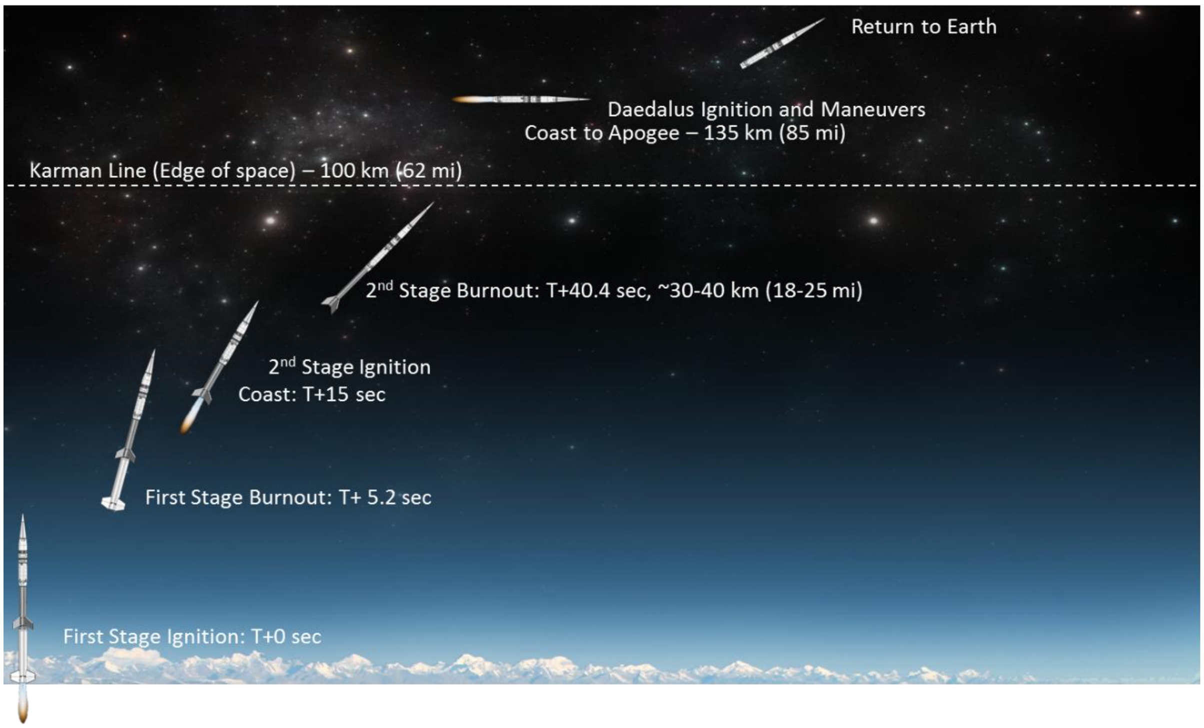


Figure 2.3: Daedalus Flight Profile

This engine is already in the process of being manufactured. When its ready it will undergo a series of validation test. This test will be performed to make sure that the manufacturers met what was agreed on the blueprints. On later chapters, this process will be explained in greater detail.

Chapter 3 Hardware selection

In every project, there is hardware that needs to be selected or designed to achieve any set requirements. Some of this hardware is off the shelf products. Like seals, valves, actuators, fittings, etc. These objects are necessary to try and lower the total price or to save time when to build a complex system. For all three engines, there were certain items that needed to be selected. Also, several components needed to be designed, and manufactured since the industry does not have a product that complies with a set of requirements. The RCS needed a reliable sparking system and valves that would allow for the pulsing functionality. Both the CROME and CROME X have similar requirements like having to throttle thrust, and on the assembly, there are several sections that require a seal. For these reasons, some of the hardware of both these engines is very similar. The selection of the hardware is very dependent on requirements set during the design process and also the design of components. Further discussion on these requirements will be discussed in later sections.

3.1 RCE HARDWARE

The 5-8lbf pencil thruster has two major components to be picked to be able to achieve pulsing fire; these are the injection valves and the ignition component. The valves for the pencil thruster only require to open and close at a fast rate since this is a pulsing engine.

Figure 3.1: Gems D-Series Cryogenic Solenoid Valve

For the ignition component, it was determined to use a spark plug. It was selected because is a widely used component in the industry to start up cars and some radio-controlled planes. The spark plug needed some modifications since the spark that it creates does not reach the desired distance. How well the valves and spark plug work plus the whole engine response time could be all summarized by the minimum impulse bit. Minimum impulse bit means the operational precision of a thruster system [2]. In other words, this means the minimum impulse of the system can achieve when the thruster starts and the stops rapidly. The valves and the spark plug are components critical to the functionality of the of the reaction control engine.

Table 3.1: Gems Valves Specifications

D- Series Solenoid Valves	
Open/Close Time	10-20 ms
Temperature	-320°F
CV	0.7
Power	15 Watts

The valves that were picked for the ignition system in the RCE were manufactured by Gems Sensors and Controls as shown in Figure 3.1. Table 3.1 shows all the details on these valves. The three reasons that these valves were picked was because of the temperature range that was within the temperature values for liquid methane (-305F) and liquid oxygen (-296F). These valves are made from 316 stainless steel making them compatible with oxygen. Any material that is not compatible with pure oxygen like aluminum could ignite as soon as the oxygen contacts it. When looking for valves another parameter to look at is the CV coefficient. This is a value mostly used by industry to express the valve's flow capacity. This coefficient is defined as the flow of water at a 60 F temperature with a certain pressure drop in psi across the valve. The values for CV on the selected valve were very low at about 0.7. For the RCE since the flow rate required to achieve the 5lbf of thrust is 0.007 ft^3/s the CV value required for the valve is more than enough to achieve

what is desired. Also with the flow rate and CV values using the flow coefficient equation the value of pressure drop is also not very significant.

The ignition system of the Pencil Thruster consists of a commercially available automotive spark plug. This spark plug is located upstream of the injection orifices. It was placed there for ease of installation and functionality, by having it there as shown in Figure 3.2.

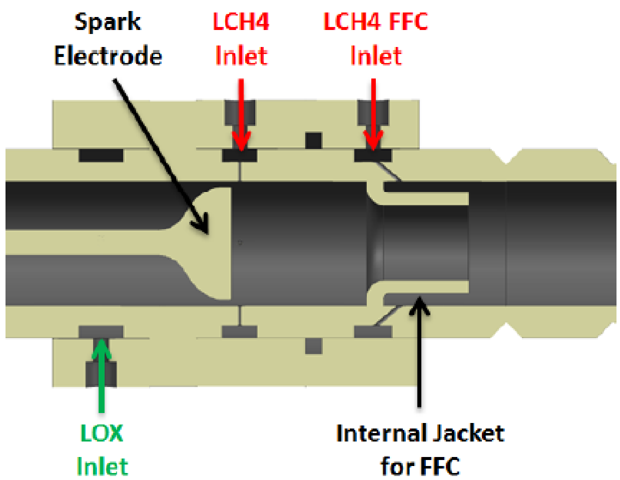


Figure 3.2: Spark-Plug Positioning and Injection Labels

The spark plug has an ideal position in the middle of the chamber. The layout spark plugs usually must be able to spark does not favor the ignition of propellants very much since proportionally is far from the mixture zone in the chamber. This is the reason the spark plug needed some modifications. The spark plug was modified by removing the tip and adding a custom-made electrode made from tungsten. Tungsten has the highest melting point of any metal at 6,170 F. It is also very commonly used for welding tools.

Figure 3.3: Manufactured Spark-Plug with Modified Tungsten Tip

Figure 3.3 shows the spark plug with the tungsten tip. The length and shape of the tip were designed to allow a spark arc to be formed with the wall of the chamber and to be position in a zone with an ignitable mixture. Using these modifications on the spark plug allowed for a spark to occur in an area with a good mix of propellant.

3.2 CROME AND CROME X HARDWARE (THROTTLING SYSTEM)

The CROME and CROME X share a lot of similar hardware the major difference is size and layout. As mentioned before these engines need to throttle thrust as a requirement for this an actuation system need to spec out. The components that they have in common are the seals and the actuation system. Since both engines are modular, there are many matting parts that needed a form of sealant to be placed. Our NASA Johnson Space Center (JSC) mentors for their modular engines they used Teflon Gore seal to prevent any leaking of mating parts. They claimed that this seal gave an acceptable performance and the ease of installation and replacement made it worth it. For CROME and CROME X it was chosen to achieve throttling by placing valves upstream of the injection. The derived requirements for this actuation system are to be able to flow LCH4 and LOX effectively; they should be able to move from closed to open in 5 seconds and have a vertical length no longer than 36 inches. There aren't many commercially available systems that could achieve these requirements. The major setback to find a system in the industry was the required

velocity to open the valve. The speed of most system was around 30 seconds to open the valves fully. Also, the size of the system was too big and heavy from what it was required. For these reasons, a custom-made system needed to be designed. First a set of valves needed to be picked. Using the information from these valves an electric motor was sized to be able to open the valves in the required time. These components will allow the engines to achieve the requirements once the full assemble engines are available for fire testing. To be able to pick a type of valve suitable for the engines requirement to throttle, there are a couple of things to look for. Also, whenever sizing a valve, many companies use the CV coefficient. This value is obtained by using a variation of the Darcy formula. The CV coefficient is a way company characterize a valves capacity and flow coefficient.

$$CV = Q\sqrt{\frac{SG}{\Delta P}} \tag{3.1}$$

In this equation Q is the mass flow rate in gallons per minute (GPM), SG is the specific gravity of the fluid and ΔP is the pressure change in psi across the valve. The flow rates were obtained by setting what the optimum expansion and the throat area of the engine will be. The decision to use 1250 lbf as the thrust for optimum expansion was made because as throttling down to 500 lbf would cause the nozzle to over-expand. The opposite would happen if the optimum expansion was considered for 2000 lbf, where the nozzle would under expand as shown in Figure 3.4.

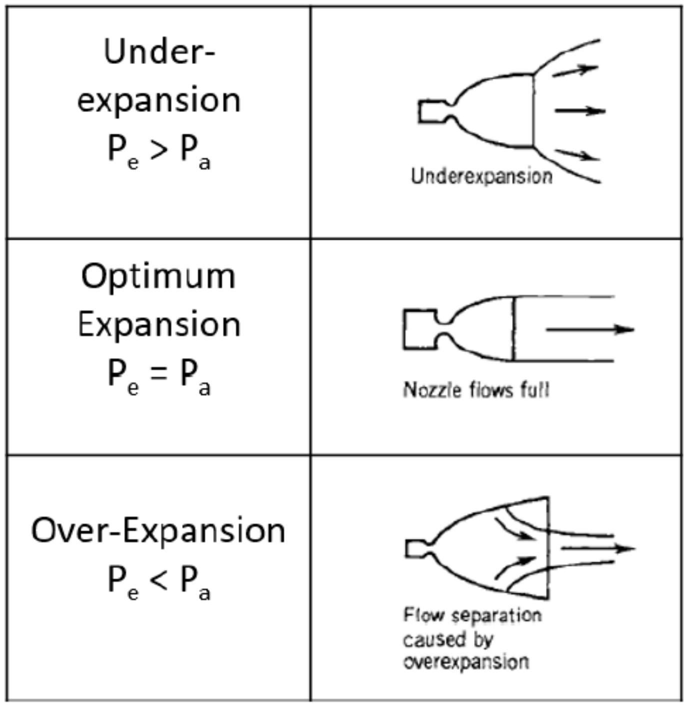


Figure 3.4: Visual Representation of Nozzle Performance

Then the mass flow rate and the pressure at injections were calculated. This information was used plus the respective density and specific gravity of LOX and LCH4 to size the valves. Equation 3.1 calculated that at 2000lbf the CV coefficient that was needed was 14.7. Any valve with a CV coefficient less than 14.7 meant that the flow capacity of the valve was not enough to accommodate the desired flow rate. On the other hand, having a CV greater than 19 meant for a coarse control over the flow rate as the valve approaches full open. Figure 3.5 shows a graph of % open vs. flow rate for LOX. In this comparison it was assumed a ΔP of 7.2 psi for a fully open valve with a resulting CV of 14.7. Figure 3.6 shows a graph of % open vs. flow rate for LCH4. In this comparison it was assumed a ΔP of 5.4 psi for a fully open with a resulting CV of 14.7. For both fluids as the valves moves to a new position or % open. The values for ΔP, volume flow rate, and CV changed. These values and graphs were used to find an adequate throttle valve. Habonim Industrial Valves and Actuators was the company from which the valves were sized and bought.

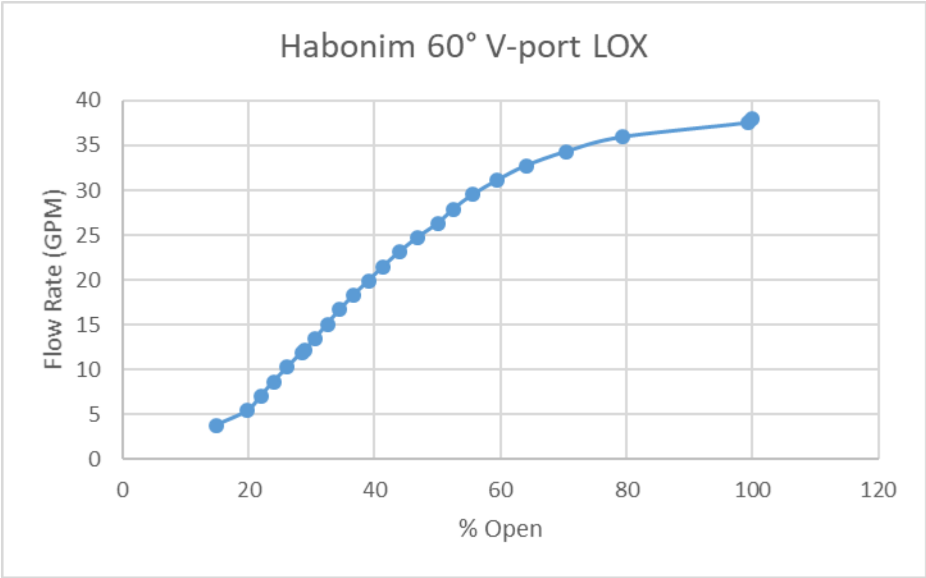


Figure 3.5: Habonim Valve % Open vs. Flow Rate with a CV of 14.7

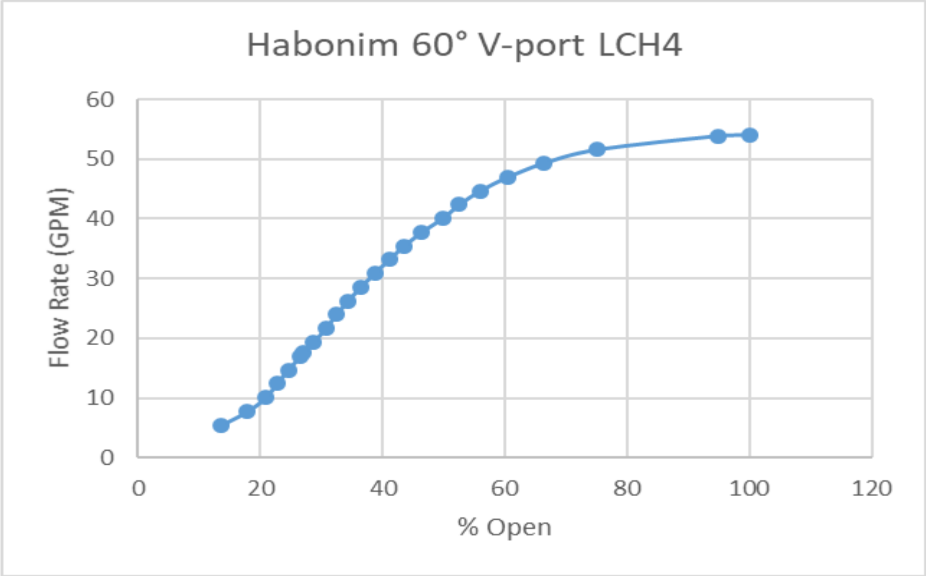


Figure 3.6: Habonim Valve % Open vs. Flow Rate with a CV of 14.7

A round port for a throttle application is highly unadvisable. The circular area as seen in Figure 3.7, makes the flow control very difficult. The difficulty comes from, as the valve is opened or closed and reaches the middle section of the circle with a small rotation a lot of areas is either exposed or blocked, allowing or blocking the flow. Then the flow rate recorded would be very sporatic. For the engine to be able to throttle this type of response does not work. Many companies including Habonim Industrial Valves and Actuators have the option to switch the circular port to

a V-shaped port as shown in Figure 3.7.

Figure 3.7: Valve V-port comparison (30°, 60°, 90° and Round Port)

For the V- port Habonim offered 3 variances a 90, 60, and 30-degree size port, as seen in Figure 3.7. As previously mentioned a CV coefficient of more than 14.7 was required. The 60˚ variance offered a 15.2 value for CV. Table 3.2 shows a comparison of %open vs. CV for the LOX and LCH4 valves and comparing it to the manufacturers values for a 60˚ v-port. These information's would be useful when the valve system is ready to be tested.

Table 3.2: Theoretical CV values and the manufacturers 60˚ port values at different % open

LOX Valve		LCH4 Valve		60˚ V-port manufacturer values	
% Open	CV	% Open	CV	% Open	CV
20	0.3	20	0.4	20	0.4
30	0.8	30	1.0	30	0.9

40	1.7	40	1.8	40	1.7
50	2.7	50	2.6	50	2.6
60	4.1	60	4.1	60	4.1
70	5.8	70	6.0	70	5.8
80	8.4	80	8.5	80	8.2
90	11.7	90	11.4	90	11.0
100	14.7	100	14.7	100	15.2

The CV values between the theoretical desired and the manufacturers ports were very closed. For this reason, the green light to buy the 60˚ v-port valves was given.

Habonim offered a distinct valve for the liquid oxygen and liquid methane. In appearance, they both were 3-piece ball valves with a V-port and safety features. The inside components like the seats and seal were made from different materials to accommodate the fluid that was going to flow through. The seats are the seal that are placed next to the ball port. The valve that is going to be used to flow the liquid methane has a carbon filled polytetrafluoroethylene (CF PTFE). This seal is used for valves that transport flammable fluids because in the case there is a fire inside the pipeline they can allow a few moments before the fire comes out of the valve. The oxygen valve has a modified polytetrafluoroethylene (TFM PTFE) seal. This seal is known to be inert or compatible with pure oxygen making it safe to transport the liquid oxygen. TFM PTFE offers a temperature range of -328°F to 448°F. -328°F is 8° colder than what has required the valve to handle. Also since the valve is not directly in touch with the combustion chamber, the heat from combustion should not reach the valves after firing. Another property that these valves have is that they are anti-static. This feature prevents the valves from building electricity and causing a spark that could ignite these highly flammable materials. The different components and properties the valves have the transport of both the liquid oxygen and liquid methane should be manageable.

There was a modification from the manufacturer that was made of these valves by request of cSETR. Cryogenic service valves come with a bonnet as shown in figure 3.8.

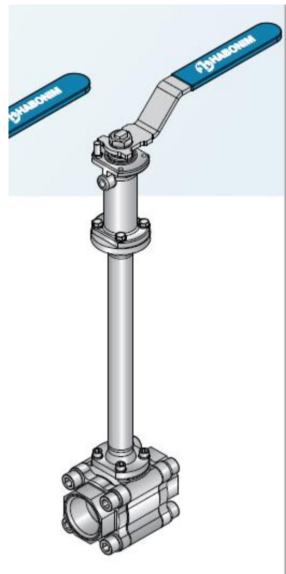


Figure 3.8: Cryogenic Service Valve

The bonnet was designed to put some distance between the seals and the cold fluid usually 9" away. This is to prevent the seal from getting frozen. Inside the bonnet, the gases also act as an insulator to give the seal extra protection. The modification that was requested was to remove this bonnet because there is a limited space where the valves are going to be placed. Also, a separate actuation system is going to be added to the stem of the valve for autonomous open and closing of the valve further adding to the length. Assuming the risk of damaging these seals and leaking propellant the valves were bought without the bonnet. However, the valves are going to have the same seals that valves with bonnets have. Before, fully relying on these valve for the injection system a couple of tests will be performed. These tests are fully discussed in later chapters.

From the start, it was said that a pneumatic type of motor would not be used because of the cryogenic conditions. Since this kind of motor relays in the air to move, exposure to -320F environment could further compress the air inside the cylinder. Since the engine is going to get

above 500 F, this sudden change in temperature can cause a rise in pressure and destroy the pneumatic system. For this reason, the decision to use an electric system was made.

The valves that were selected have some properties that were used to size an electric motor. One of them is the amount of torque required to open the valve. The other is the amount of time that is desired to fully open a valve from 0 % to 100% open.

Table 3.3: Valve Requirements for Motor Selection

Autonomous Valve Requirements	
Torque	187 lbf-in
Response Time	0.5 sec
Power	144 watts

Table 3.3 shows the values necessary to size the electric motor. Using the torque and time some algebraic manipulation was used to get the power required to operate the valve. The power value was used to find a suitable electric motor. The speed that the motor should operate at is about 30 RPM. From the Habonim, it was said that the valve used for methane has a breakout torque of 187 lb-in. Then using the diameter of the stem that is 7/16" the force required to open the valve is 524.84 lbf.

The motor that was picked is a Maxon Motors stepper electrical motor. The model for the motor is a 200 watt with graphite brushes. Maxon offered a combination of an electric motor and a gearbox.

Table 3.4 Electric Motor specifications

Maxon Motor and Gearbox Specifications	
Power	200 Watts
Torque	3.7 lbf-in
Speed	5,420 RPM
Gear Ratio	71:1

Max Amperage	7.07 amps

Table 3.4 shows the specifications of the motor and gearbox. The voltage and current are parameters that can be adjusted depending on the speed and torque desired. The motor and gearbox combination give a max speed of about 76 RPM and a max torque of 262 lbf-in. Maxon also provided some relations to help calculate the torque and velocity the motor will output depending on the amount of voltage and current. Figure 3.9 shows an illustration of the motor and gearbox.

$$M_{act} = A_{Av} * M_{Cons} \tag{3.2}$$

$$V_{act} = \left(V_n * V_{supp}\right) - \left(M_{act} * \frac{S}{T}_{Grad}\right) \tag{3.3}$$

Figure 3.9: Electric Motor, Gearbox, and encoder assembly

Equation 3.2 is used to calculate the torque the motor generates depending on the current the motor can grab. M_{act} is the amount of torque the motor generates, A_{AV} is the amount of current available for the motor to grab and M_{cons} is the torque constant of the motor (this value is found in the motor's spec sheet). Equation 3.3 calculates the velocity of the motor where V_{act} is the velocity if the motor, v_{supp} is the voltage supplied to the motor, V_n is the speed constant of the motor found

in the spec sheet, M_{act} is the actual torque of the motor as previously mentioned and (S/T)grad is a constant found in the spec sheet of the motor. The spec sheet of the motor is found in the Appendix . As a note, these values are for the motor only no gearbox. The motor is rated for 36 VDC; this is the maximum voltage that the motor needs to operate.

Table 3.5: Expected performance parameter for motor

A_{AV}	6.06 Amps
M_{cons}	60.4 mNm/Amps
V_{supp}	24 V
V_n	158 RPM/V
(S/T)grad	0.638 RPM/mNm
M_{act}	366 mNm /3.24 lbf-in
V_{act}	3558 RPM
Power Supplied	145 W
With Gearbox Speed	50 RPM
With Gearbox Torque	25986mNm / 230lbf-in

If the full voltage can not is supplied, the motor is able to operate in a range of 12 to 36 VDC this would only affect the velocity of the motor. A similar thing happens with the current if the max amount of current cannot be made available for the motor. The motor would only grab the max amount of current that is available by the system.

Table 3.5 show the expected speed and torque the motor will delivered having a supply of 24 V and 6.06 amps. The torque with the gearbox is expected to be at around 230 lbf-in. This value exceeds the required 187 lbf-in, giving assurance that the actuation system would be able to move the valve. The speed the motor would deliver is at about 50 RPM. If this speed is attainable when operating the valve, the time for the valve to go from fully closed to fully open reduces to 0.3 sec. Since the values for torque and speed are greater than what it was required, it gives confidence that the system will work for the throttling purposes and even achieved more than originally desired.

The components that are going to allow for the communication between the motor and a computer are the encoder and the EPOS 70/10. Figure 3.10 has an illustration of the encoder and EPOS 70/10. The encoder is the primary communication between the stepper motor and the computer. In simple terms, this piece of equipment counts the steps of the shaft of the motor. Then the EPOS 70/10 is the modular controller that sends the position of the motor and receives the signal from the computer to the encoder then to the motor.

Figure 3.10: Epos 70/10 (Left) and Encoder (Right)

Since the actuation system (motor, gearbox, and encoder) and the valve is a custom-made system made to comply with the requirements. Some additional parts needed to be manufactured. The connection between the actuation system and the valve needed to be made. This part is going to be referred as the thermal standoff. The standoff should not allow heat from the actuation system to be absorbed to the point where the temperature at the shaft of the actuation system be -4˚F. This temperature was gotten from the low-level temperature limit of the actuation system.

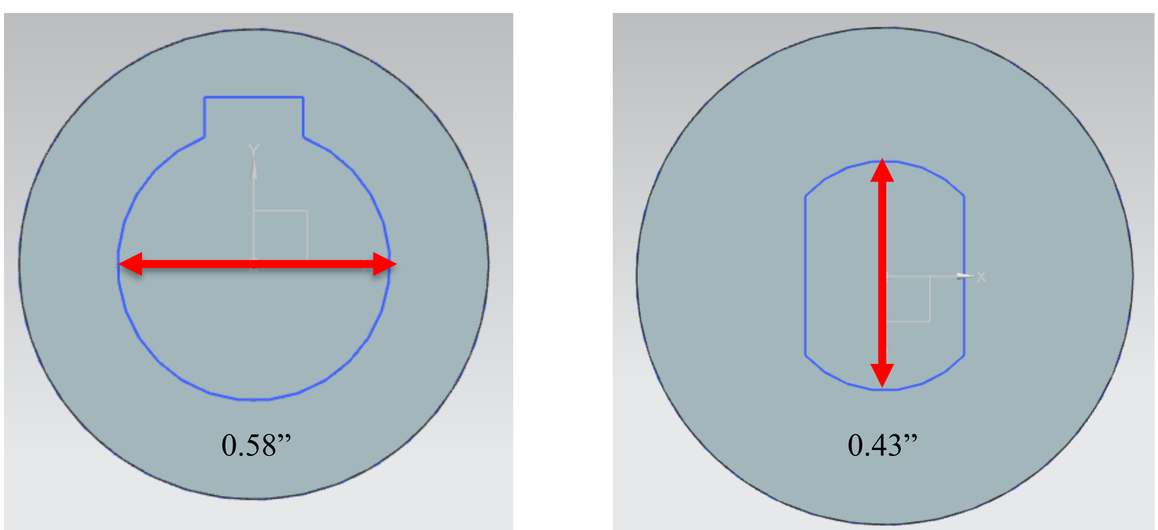


Figure 3.11 Thermal Standoff Motor connection dimensions, motor (Left) and valve (Right) connection

The stem on the valve where the handle is and the shaft of the motor was used to design the interfaces of the standoff that connects the valve and actuation system. A simulation of the Thermal Stand-off will be further discussed in a later chapter. Figure 3.11 shows the connection of both the actuator shaft and valve stem. The section for the stem has a diameter of 0.43" and to straight features to allow for a shaft with a similar shape to rotate the stem. The other connection with a diameter of 0.58" was made for the motor shaft. The key groove is the part of the shaft that allows it to rotate whatever is attached to it, to help with the transfer of torque. One of the distinguishable features of the thermal standoff is that it has many holes in the middle section. It is pretty much a shell with holes. The idea behind this design is to allow air to pass through that section and act as an insulation to prevent heat absorption out of the motor. These features are to help prevent the actuation system from reaching its temperature limit.

The thermal standoff from the beginning it was chosen to be made from titanium. This decision was made because Titanium has a low heat transfer coefficient and a high strength value. Also, it was

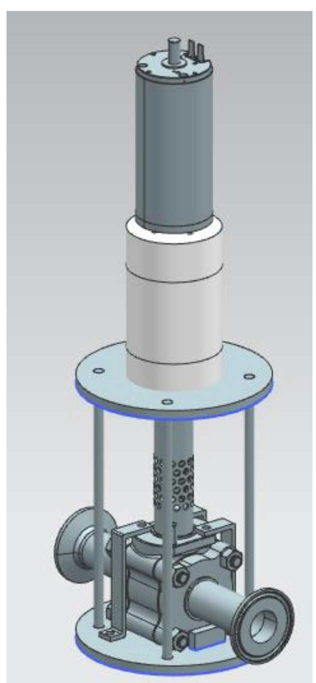


Figure 3.12: Full Frame Assembly with Valve and Motor Included

one of the materials that can be additive manufacture at the Keck Center. Also, thermal analysis was performed using Ansys Fluent. The process of how the boundary conditions were determined and the results will be discussed in a later chapter

Also, a frame was designed to hold together the valve, actuation system, and the thermal standoff. Without this frame, either the valve or the actuation system would spin out of control. This frame is going to hold I place the valve and the actuation system and only allow the thermal standoff to move. Figure 3.12 shows the CAD of the frame. The primary requirement is that it should hold the torque of 187 lb-in.

Figure 3.13: Manufactured Frame Assembly

Figure 3.13 shows the manufactured frame with the valve and actuator. The frame consists of 1/4" studs 9” long. These studs were picked over a rod because using nuts the positioning along the stud of any of the plate can be adjusted. Also, a longer stud could be employed to hold any other

component or to hold this frame on to any other structure of the engine. Two 5” diameter plates with a thickness of ¼,” were used. One of them is to hold the actuator from the already manufactured holds on the gearbox. The other plates were used to place the valve. A set of three S shape brackets are going to be used to hold the valve in place attaching it to a plate. These components make part of the autonomous injection valves that will allow the CROME and CROME X engines throttle.

3.2.1 Finite Element Analysis On Thermal Standoff

As previously mentioned the thermal standoff was designed to be a connection between the actuator and the valve. The requirements that this component needed to accomplish are to be able to withstand the torque and speed of the actuator. Also, it had to act as an insulator for the actuator that had a low-temperature limit of about -30˚C and not let the temperature on the side of the actuator drop below the limit. On the other side of the thermal standoff is the valve. When flowing the propellants, the valve would have a temperature of about ≤-151˚C. For this reason, the actuator needs protection from the low temperatures. The overall design of the thermal standoff is a cylindrical rod with a hollow mid-section with a lattice. The purpose of the mid-section lattice is to increase the thermal resistance and by result increase the thermal gradient between the actuator and the valve. Thermal analysis was performed to find the optimal length for the thermal standoff. Since the large thermal gradient of 120˚C, more than likely will affect the mechanical properties of the thermal standoff a stress analysis was done in parallel with the thermal analysis. These analyses were performed using Ansys Workbench. Also, the thermal standoff required a safety factor to yield of at least 3.0. The material of the valve is stainless steel 316 and for the thermal standoff is a titanium alloy (Ti6Al4V ELI). Titanium was selected for the thermal standoff because it had a low thermal conductivity. Table 3.6 shows the properties of Ti6Al4V ELI.

Table 3.6: Ti6Al4V ELI Material Properties used for Analisis

Ti6Al4V ELI Material Properties

Yield Strength	930Mpa/134.9 ksi
Ultimate Tensile Strength	970Mpa/140.7 ksi

For the simulations, a couple of different lengths and lattices arrangements were designed for comparison. The changes went from changing the quantity of hole and arrangement of the lattice to doing different length. Figure 3.14 shows a couple of examples of the different designs that were used for the simulation.

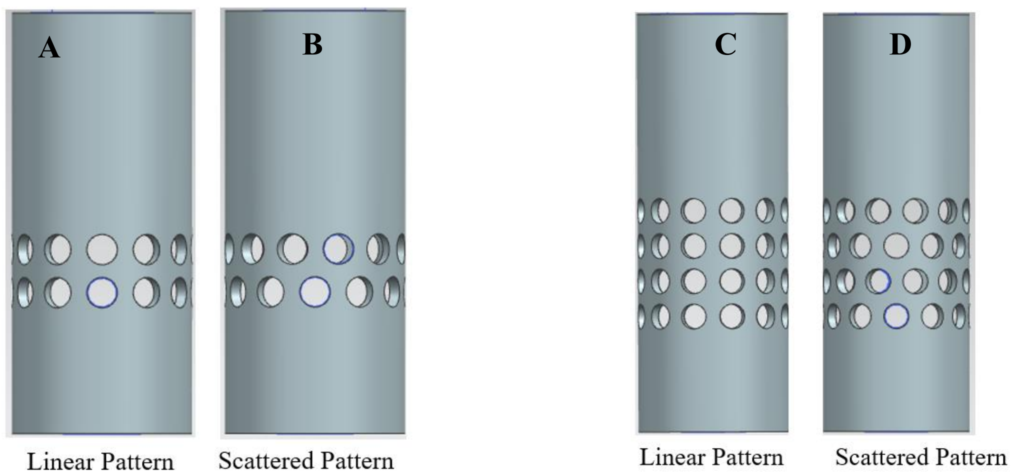


Figure 3.14: Thermal Standoff Lattice Iterations, (A) 2 Row Linear Pattern, (B) 2 Row Scattered Pattern, (C) 4 Row Linear Pattern, (D) 4 Row Scattered Pattern

For the thermal and mechanical analysis, there are a couple of boundary conditions that were used for the simulation these are shown in Table 3.7.

Table 3.7: Thermal Properties used for Simulation

Methane Convection (Inside Valve) (A)	
Heat Transfer Coefficient	16,012 W/m^2*˚C
Temperature	-162˚C
Oxygen Convection (Inside Valve) (A)	
Heat Transfer Coefficient	14,560 W/m^2*˚C
Temperature	-183˚C
Ambient (Around the Rod) (B)	
Heat Transfer Coefficient	10 W/m^2*˚C
Temperature	10 ˚C

These conditions were applied in a certain section of the valve assembly as seen in Figure 3.14.

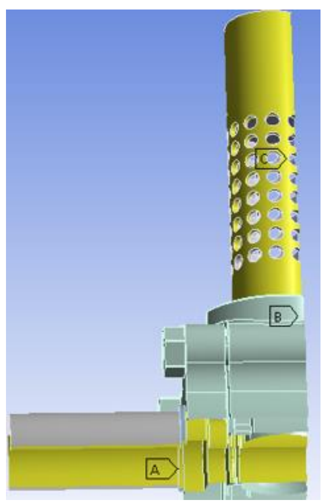
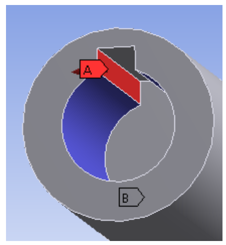


Figure 3.15: (A) Location where the Oxygen/Methane convection was applied, (B) Location where Ambient conditions were applied

As seen in Figure 3.15, the values for the oxygen conditions were applied there over the methane conditions because oxygen is colder in cryogenic conditions. For the mechanical analysis, the boundary conditions that were used were to apply a force of about 524.8 lbf where on the side of the thermal standoff where the actuator will be connected. On the opposite side, a frictionless

support was placed in all the faces inside the connections for the valve is. Figure 3.16 shows the location of these boundary conditions. Table 3.8 a comparison of all the designs results and helped decide of which design was better.



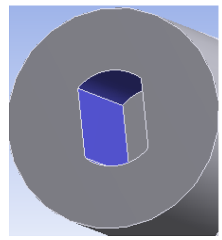


Figure 3.16: (Left) Actuator Connection Side the red mark shows the location where the load was applied, (Right) Valve connection side.

Table 3.8: Simulation Results for The Different Designs

Length (in)	Pattern	Temperature (LCH4)	Status	Stress (LCH4) psi	Safety Factor (LCH4	Temperature (LOX)	Status	Stress (LOX) psi	Safety Factor (LOX)
3.80	Linear	12.3˚C 54.2˚F	Success	Max: 31,600 / Min:40.0	3.6	11.2˚C 52.2˚F	Success	Max: 35,100 / Min: 6.81	3.3
3.35	Scattered	5.8˚C 42.5˚F	Success	Max: 31,400 / Min: 30.4	3.7	4.0˚C 39.2˚F	Success	Max: 35,000/ Min: 35.5	3.3
2.85	Linear	-11.3˚C 11.5˚F	Success	Max: 30,100 / Min: 585	3.7	-15.2˚C 4.7˚F	Success	Max: 34,600 / Min: 504	3.3
2.85	Scattered	-9.6˚C 14.6˚F	Success	Max: 33,400 / Min: 412	3.3	-13.3˚C 8.13˚F	Success	Max: 38,700 / Min: 521	3.0
2.60	Linear	-22.5˚C -8.5˚F	Failure	Max: 31,800 / Min: 460	3.6	-27.6˚C 17.7˚F	Failure	Max: 35,600 / Min: 566	3.2

Looking through the different designs, all of the tested configurations had passing values for the stress even with the big thermal gradient. These results show that the titanium alloy is a very good when dealing with the stresses and the temperature gradient. The 3.80" design had the largest thermal gradient registered,but the length does not work.In the other end the design with the length of 2.60" has a temperature too close to the limit of the actuator causing the design to fail. The design that was ultimately selected was the one with the length of 3.35". This design had

the second highest thermal gradient, and the length is within the boundaries that were set by the vehicle team. Figure 3.18 shows where the stresses concentrated in the rod having both the thermal and stress analysis performed at the same time

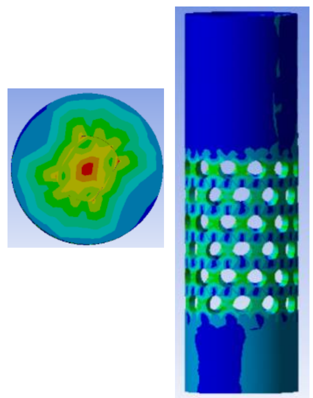


Figure 3.17: Visual Representation for Stress Concentration, (Left) Valve Connection Side, (Right) Lattice View

Most of the stress is located on the side where the valve is connected because in this section is where the highest thermal gradient is. Some of the stress also gets distributed through the lattice because of its one of the weakest sections of the thermal standoff. However, the values of stress in this section is not big enough to cause issues unless the stress gets to high. This scenario seems unlikely because the force that was used for the boundary conditions is the maximum torque the actuator system can deliver. An outside force needs to come in to cause any damage. The 3.35" long design was selected to be the design to be used as the thermal standoff because it's thermal gradient and stress concentration are adequate to work under the conditions that were set.

3.2.2 Finite Element Analysis in Frame

The frame was designed to keep the actuator-valve assembly together without any physical rotation of neither of the valve or actuator. The frame is made from two cylindrical plates. One

would hold the valve by latching to it using some Z shaped brackets. The other plate is going the hold the actuator by using the bolt circle included in the actuator. This will prevent the actuator from spinning out of control. For the pillars, it was decided to use studs because they would allow for adjustment of the frame and also if need be other components could be bolted into the frame. These studs could also be

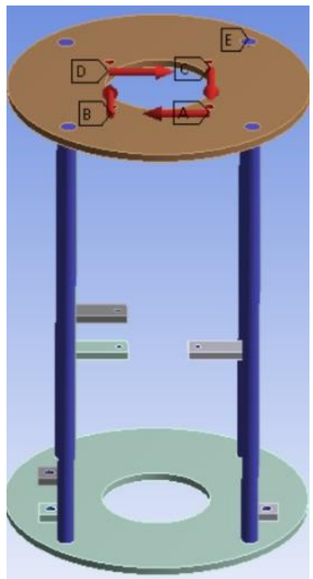


Figure 3.18: Location of Boundary Condition In The Frame

used for hooking the frame to any other structured that would allow it. All of these components were made out of stainless steel 316. Figure 3.13 shows the full manufactured frame design. To be sure that the frame was going to be able to handle the stress of the actuator an FEA was done and to determine the adequate diameter of the studs and thickness of the plates. Figure 3.19 shows the location of the boundary conditions that were applied. The red arrows represent the torque applied. The value of the torque was 187 lbf-in. The pillars were fixed. Figure 3.20 Shows the results of the FEA.

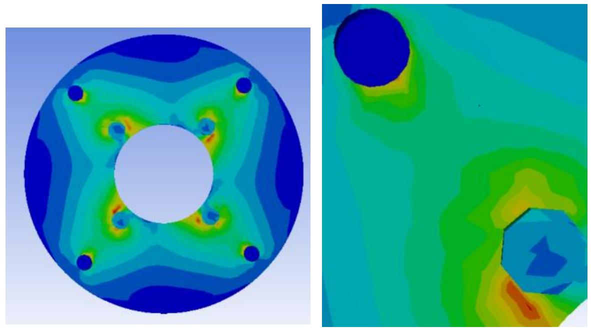


Figure 3.19: FEA Results in Plate Holding Actuator

From the results, it can be concluded that the max stress was located near the holes where the actuator is going to be held with bolts. The max stress was about 5,700 psi making the safety factor 7. These results showed that the frame should not have any issues with the torque that the actuator delivers, and the design conceptually works.

3.3 CROME AND CROME X HARDWARE (SEALS)

The first iterations of the CROME and CROME X engines have many mating parts. Certain sections have either propellants or combustion products running on one side of them. The engine was made modular to allow ease of dissembling because the first iterations of both engines are only meant for testing purposes. For example, if there is any catastrophic incident where a component of the engine like the nozzle was destroyed. The damaged nozzle and the sealant that's in the injector could be removed and replaced with

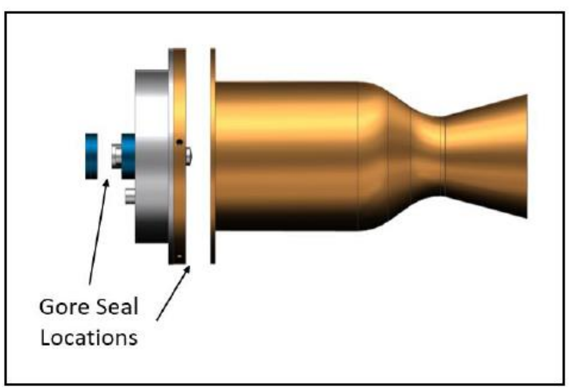


Figure 3.20: Teflon Sealant Locations within The CROME X

a new nozzle, and sealant. Figure 3.20 shows the mating parts that required seals in the engine. On the left side is the connection between the injector tubing into the injector body. This junction will have to pass through liquid methane at temperatures of around -280˚F at a pressure of about 300 psi. On the right is the connection between the injector body and the chamber. Ignition is going to happen inside the junction between the injector body and the chamber. Through this junction, the combusted material is going to pass by at temperatures of around 5,000˚F without film cooling and pressures of 200 psi. These junctions need a seal that will contain the cold fluid and the hot combusted products.

The seal that was picked for this task was a Teflon type seal from GORE. Johnson Space Center (JSC), engineers/mentors, uses this material regularly on their test engines with no major incident. JSC mentors explained that they used this material and brand because of its easy installation to almost any surface. The seal performance at the harsh conditions was acceptable. They said that they indeed saw some leaks however they had to fail-safe around the delicate section to prevent further damage to the equipment. This fail-safe consisted of running nitrogen an inert fluid through sensitive to leaks sections of their system. They also mentioned that they rarely had to replace a seal after a fire. The only occasion they replaced any of the seals was when they had taken apart the chamber from the injector body. This was because as the Teflon was compressed between the interfaces, and it went through a plastic deformation making it unusable after compressed. Also as time passed and the harsh conditions, the Teflon start flowing/creeping through the surfaces where it was placed. Also, Teflon is a material that is safe to use with pure oxygen and methane because it is inert to any of these fluids. The only requirement that the seal has is that it requires an installation pressure of about 2,500 psi evenly distributed. The low-end temperature limit of -400˚F the seal makes it adequate to be used on the propellant system. The lowest expected temperature for this system is -320˚F. The -320˚F value was obtained from the boiling temperature of liquefied nitrogen that is -320˚F at atmospheric pressures. The high-end temperature limit of the Gore seal is 600˚F. This limit brings doubt because the expected temperature for combustion is at around 1000˚F. Even though JSC engineers recommended the

use of this type of seal and this brand a test was developed to assure the use of this seal is safe when firing. On a later chapter, the test for this seal will be further discussed. One thing to understand is that the Teflon seal is not an adhesive that holds together any two mating parts. The Teflon is more for filling up any possible leak path that is left from uniting two solid surfaces. For this reason, this seal has an installation pressure requirement. The max pressure in the system and installation pressure work hand in hand with how good the seal was. For example, if the seal is placed in a flange to unite piping. The pressure inside the piping will mostly be along the walls of the piping not affecting the way the seal was connected. Another case is when the Teflon is used to seal two hemispheres. When pressurizing, part of the pressure will try to pull apart the flanges where the Teflon was installed. In this circumstance, the amount of pressure used when installing the Teflon become very critical to the success of it preventing any leaks. Some other factors come to play too with type and grade of the bolts used.

Chapter 4 Injector Sealants

4.1 Seal Test

As previously mentioned, the Gore Teflon sealant has a high-end temperature limit of 600˚F that causes concern, because when the engine starts combusting the liquid methane and liquid oxygen the flange might reach temperatures of about 1000˚F. There is a possibility that the sealant my get burned to the point where it's sealing capabilities is depleted. This temperature is about 60 % higher than what the seal limit is. A test campaign was started to reassure that the Teflon will keep a good seal even after being cycled through temperatures of about -200˚F to 600˚F, having a temperature gradient of 800˚F. A flange was developed using similar dimensions as the 500 lbf engine chamber to test the temperature parameters. Another objective to test is how bad is the creep for the seal when undergoing a big temperature change of about 1,700˚F. Creep, in this case, means that over time as the sealant has a constant pressure being applied. The sealant starts flowing, and the initial pressure that was applied at first will start to decrease. This behavior might cause the sealant to stop sealing properly and cause leakage in the system. The decreased pressure can be quantified by measuring the change in length of the bolts after they were tightening by a certain torque.

$$F = \frac{E * A_T * \Delta L}{L_E} \tag{4.1}$$

Equation 4.1 was used to calculate the amount of force applied to each bolt. In this equation E is Young's modulus of the bolt, A_T id the tensile area of the bolts, ΔL is the elongation the bolt gets when putting force and L_E is the effective length of the bolt. The effective length of the bolt is the section that is a stretch when applying a torque. The section of the bolt that remains outside the nut that is not considered within what is being stretched. A_T or the tensile area of the bolt is the cross-sectional area that falls in between the pitch diameter and the minor diameter of a bolt. The value for A_T is a very standard that it comes in charts where the information of the bolt sizes and grades come. However, equation 4.2 is another method of finding the tensile area of a United Thread Coarse (UNC) bolt.

$$A_T = \frac{\pi}{4}\left(\frac{d_m+d_p}{2}\right)^2 \tag{4.2}$$

In equation 4.2, D_m is the minor diameter, and D_p is the pitch diameter of a bolt. Figure 4.1 shows an illustration of all the measurements of a bolt. The effective length can be calculated using equation 4.3.

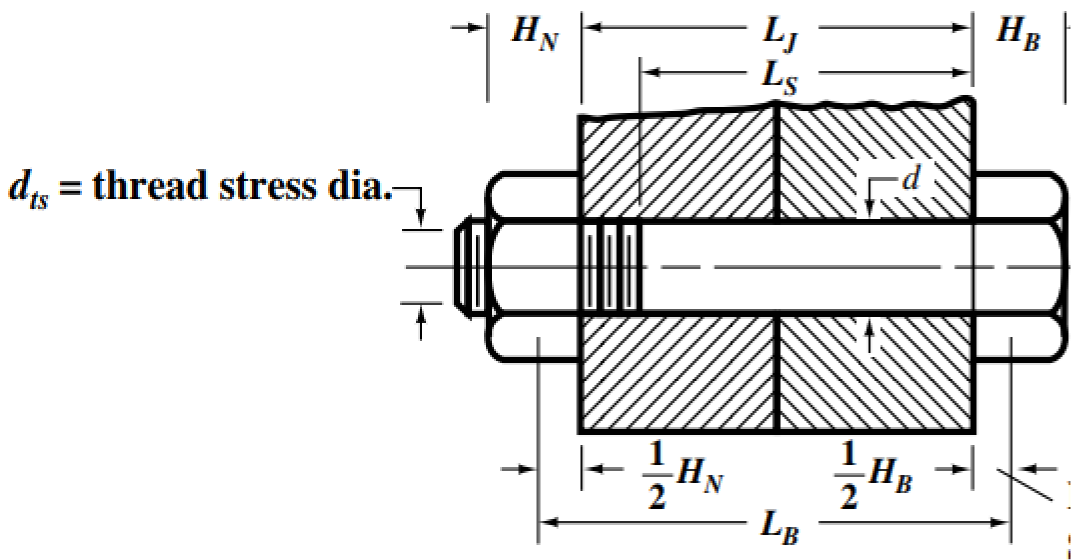


Figure 4.1 Bolt Measurements Illustration

$$L_E = \left(\frac{d_{ts}}{d}\right)^2 * \frac{H_B}{2} + L_J + \frac{H_N}{2} \tag{4.3}$$

Table4.1: values used to calculate pressure applied to sealant

E	28000000 psi
A_T	0.05 in^2
ΔL	0.003
L_E	1.46 in
H_B	0.19 in
H_N	0.26 in
L_J	1.35 in

D_{TS}	0.25 in
F/bolt	2876 lbf
Pressure on sealant	3,600 psi

Where d_{ts} is the diameter of the tensile area or the mean between the pitch diameter and the minor diameter, d is the diameter of the bolt, H_B is the height of the bolt's head, L_J is the overall length of the bolt and H_N is the height of the nut used. As a note, the height of the washer was taken added to the height of the head of the bolt and nut. This equation considers the section of the bolt inside the nut and the head of the bolt that gets stretched. A factor that affects the way the force in the bolt is calculated is if the bolt is fully or partially threaded. This affects the bolt calculations because when calculating the force that can go through the bolt. The cross-sectional area of the bolt is different. The fully threaded bolt cross-sectional area need to be calculated using equation 4.3 is different. In this case, there would be two different tensile areas one for the threaded and the other for the solid section. On the other hand, the cross-sectional area of the bolt that is not fully threaded is just the area of a circle using the diameter of the bolt. The force will need to be calculated using a combination of both cross-sectional areas. For these tests, a fully threaded bolt was used, and equation 4.3 stands as it is.

Table 4.1 show the values used in the equations to calculate the pressure administered to the sealant. The force per bolt is also known as preload. The sealant needs an installation pressure of 2,500 psi. However a safety factor of 1.5 was included to assure that the sealant had enough pressure to be considered sealed.

Figure 4.2 Gore Seal Tape Variety

4.1.1 Gore seals used

For these tests, there were two kinds of Gore Teflon sealant used. There is the tape; this sealant has adhesive on one side to prevent it from moving when installing it on a surface. There is also a set of tips on how to cut the ends of the seal to have the best seal possible. Figure 4.2 shows the Gore tape seal

Figure 4.3: Tape Sealant Installation

variety. Figure 4.3 shows how to lay down the seal into a surface and how to cut and connect both ends. For this type of sealant, there were many widths to choose from. The way that a width for the tape was picked was through Mcmaster Carr selection criteria. When going through the selection of the different widths, there is a column that says different flange sizes. The pipe sizes were used as a reference to get a width for the Teflon tape. For the 500 lbf engine, the flange that connects the injector body and the chamber is approximately 5 ½", This size corresponded with a width of 3/8" for the sealant. Also, the ¼" wide tape was obtained to have a comparison of the different widths. The other kind of seal that was tested was a gasket type. This gasket comes in squared sheets; the picked size was a 6" by 6" with a thickness of 1/8". Unlike the tape Teflon, the gasket needs to be cut out from the gasket sheet.

Figure 4.4 Gore Gasket Sheet

Figure 4.4 shows the gasket before being cut out to fit into the test article. The only requirement for the dimension of the cut-out gasket was that the inner diameter needed to be slightly bigger than the diameter of the hole in the test article (will be discussed on a later chapter). The width of the gasket was decided to be 3/8” like the Teflon tape to have a comparison of their performance when comparing both. These configurations of seals will go through to temperature cycling using temperatures as low as -200˚F and go up to 600˚F and be pressurized to about 100 psi. This data is meant to be used to gain confidence in the use of either the Teflon gasket or the Teflon tape on the actual fire test of the CROME or CROME X engines

Figure 4.5: Manufactured Test Article Plates, Base (Left) and Top (Right)

4.1.2 Test article

A test article was developed to represent the method of how the injector body and the chamber of the 500 lbf engine were designed. Figure 4.5 shows the two pieces that were manufactured for these test. It consists of two plates of the same thickness of about an. One of the plates has hole 0.5” in depth, this plate was called base, and the other that only has the bolt circle is called the top. This hole acts as a chamber to hold pressurized nitrogen when both plates are bolted together. The diameter of the hole is about 5 1/2”. This diameter is not the same diameter

of the 500 lbf engine chamber diameter as seen in the comparison if the plate and the actual engine chamber as seen in Figure 4.6.

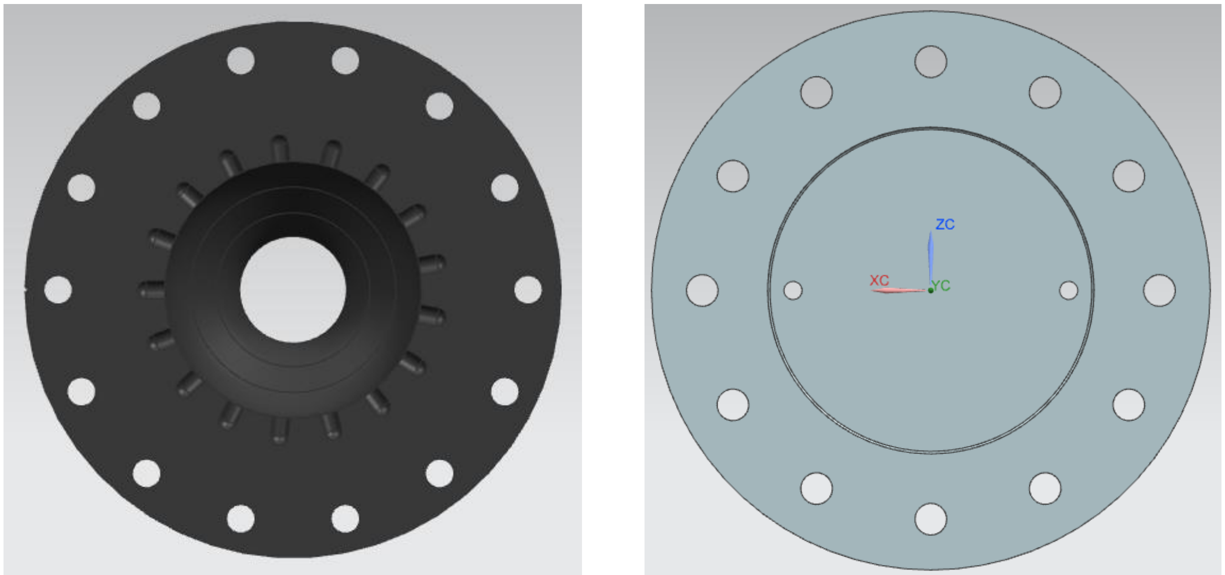


Figure 4.6: 500 lbf Chamber (Left) and Test Article (Right)

The larger diameter of the test article was done that way to accommodate the grooves of the acoustic cavities within where the sealants are going to be placed. Also, this chamber design is meant to hold 100 psi of nitrogen. Both plates had a simulation done using FEA to validate that indeed having pressurized nitrogen up to 100 psi was going to be safe.

Table 4.1 SS 316 Properties

SS 316 Properties	
Tensile Strength	84 ksi
Young Modulus	28000 ksi
Melting Temperature	2,500 ˚F

Table 4.1 shows the properties of stainless steel 316. A simulation was performed on the plates to assure that they will work under pressure. To start the simulation, the boundary conditions that were set are to put a fixed condition in the area where the washers would be. This condition was set because that is the area that will hold the flange from being taken apart as the chamber is being pressurized. Both plates had the same kind of boundary condition. Then the base and top had a pressure of 100 psi on the inside to simulate the pressure trying to take apart the plates when in pressure. Stainless steel was picked since it's a material that is very commonly used when dealing with cryogenic fluids for tubing, fittings, and any critical component. Ansys Mechanica was used to

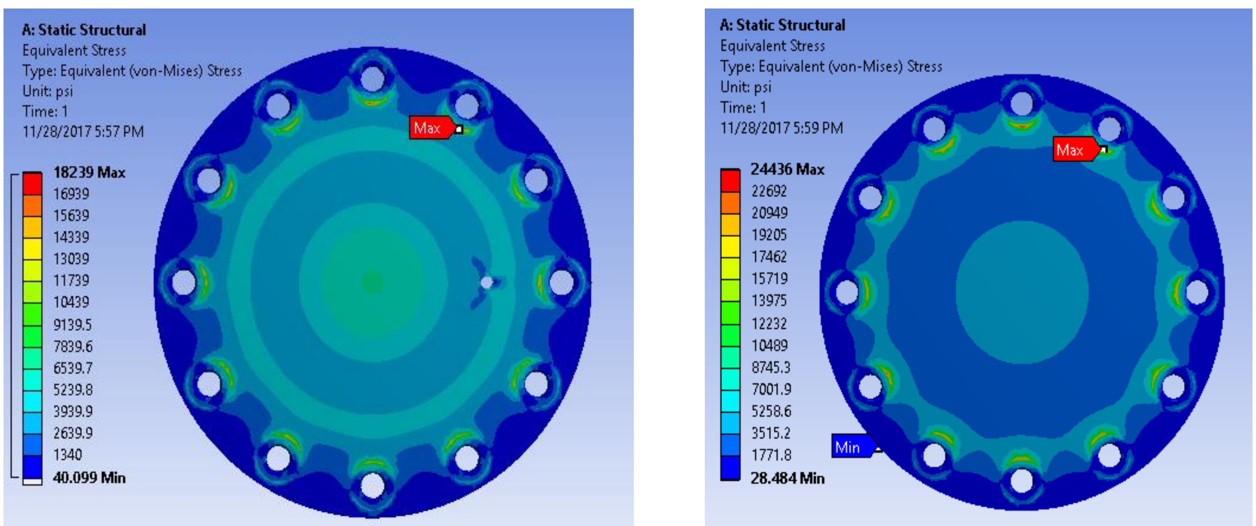


Figure 4.7: Stress simulation for Test Article Components Base (Left) and Top (Right)

perform the FEA of both plates. Figure 4.7 shows the results of the simulation for both plates. From Figure 4.7 the max stress is in the area close to the bolts circles for the base plate. The value of this stress is about 18,200 psi. This gives the design to have a factor of safety of about 4.6. The top plate showed a similar behavior near the bolts in the stress distribution, and the stress still has a high safety factor. The results from this FEA showed that the plates are going to be able to work under the conditions set for this test.

The bolt circle load distribution and bolt selection are important because the Teflon gasket and tape depend on the amount and equal distribution of the load administered during installation to seal properly. The fasteners in the bolt circle should be able to evenly distribute and deliver a pressure of 1,500 psi to the sealant. These criteria were used to size and set the number of bolts for the test. As a rule of thumb, the bolts should be tightening to a minimum of 75% of their material tensile strength (proof strength). The term proof strength is used for the bolts maximum strength before there is any plastic deformation. In other words, this value stays within the bolts elastic deformation spectrum. This value is to assure that the bolt is tightened enough that it would not come loose on their own. Another parameter that was considered when sizing the bolts was the pressure inside the chamber when pressurizing the system. This pressure was added to the forces the bolts should be able to handle when testing. The reason for adding this force was because as the test article is being pressurized. The pressure will remove 100 psi from the installation pressure the sealant has from installation. This could generate a leak as the test article is being pressurized.

For the bolt design, it was decided to use 18-5/16" diameter bolts. Also, when picking bolts, they have force grading going from 1 to 8, varying in their proof strength and material composition. For this project, it was chosen to use grade 8 bolts.

Table 4.2: Properties Used for Force Calculations

Grade 8 Bolts Properties	
Tensile Strength	150 ksi
Material	Zinc Yellow-Chromate Plated Steel
Young's Modulus	28,000 ksi
Thread Type	UNC
Thread Spacing	Coarse

Table 4.2, shows the properties of the bolts used. The length of these bolts was picked to be 2.5". Since both the plates were 1" in thickness and a section of the bolts needed to stick out to be able to use washer and nuts to tighten them properly. Since each bolt have a tensile strength of

about 150,000 psi and a proof load of about 6,800 lbf. The proof load is the maximum amount of load the bolt can handle. The number of bolts can be obtained by using equation 4.4.

$$3 \leq \frac{\pi D_b}{Nd} \geq 6 \tag{4.4}$$

D_b is the bolt circle diameter, N is the number of bolts within the circle and d is the nominal diameter of the bolt. This equation is used to obtain the optimal value of the bolt circle diameter. The parameters that need to be followed are that if the equation has a value of 3 or less the bolt circle is too small that a wrench does not fit and makes it almost impossible to tighten the bolts. On the other hand, if the value is greater than 6. The bolt circle diameter is too big, causing the force distribution not to be evenly spread out when tightening the bolt circle. Using the force that each bolt will have and the diameter the torque can be calculated. In a number of mechanical design books, it is suggested to add a stiffness factor when trying to calculate the torque because almost every torque wrench has a plus or minus 20% of error when applying a torque. The calculated torque for each bolt was 225 lb-in. The total elongation of the bolt was calculated too to proof that the bolt was applying an approximate load of 2,500 psi to the seal. This bolt patterned calculations were used to prove that the quantity and type of bolts picked are adequate to be used in this test.

4.1.3 Seal Installation requirement

The Teflon gasket and tape have different methods of installation, but both have the same pressure requirement of 2,500 psi at installation. The Teflon tape has a very simple process of installation. Since in one side of it has adhesive the application in a surface become very simple. In the

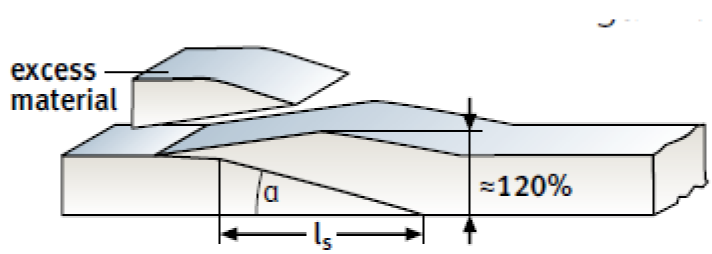


Figure 4.8: Illustration of How to Place Ends of Tape Sealant

gore website it is suggested to cut both tips at a 45-degree angle as shown in Figure 4.8 to improve the seal in that area. As mentioned before the gasket must be cut from the 6” by 6” sheet. The Teflon tape layout and dimensions were used as a reference to cut out the gasket. Since the gasket does not have any sort of adhesive the assembly of both plates has to be done carefully. Once of plates are assembled together, and the bolts are placed in each hole with their nut and washer. The bolts will be torqued using a torque wrench.

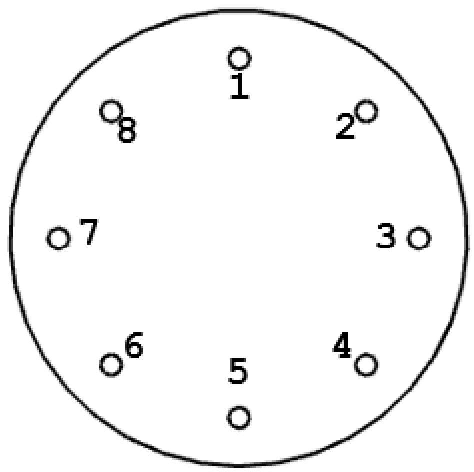


Figure 4.9: Test Article Bolt Labeling

Figure 4.9 was used to arrange a pattern to try an equally tightened the sealant. The order of the pattern followed was 1, 4, 7, 2, 5, 8, 3, and 6 at increments of 40 lb-in with the torque until 185 lbf-in was achieved.

Figure 4.10: Fully Assembled Test Article, Test Ready

Figure 4.10 shows a fully assembled test article. For both the sealant types, the test article was assembled the same way. After all the bolts have been fully loaded, a micrometer was used to measure how much displacement the bolts went through. This same instrumentation was used to record the length of the bolts before they were put in the test article. Equation 4.1 was used to get the total force in each bolt.

4.1.4 Testing Results

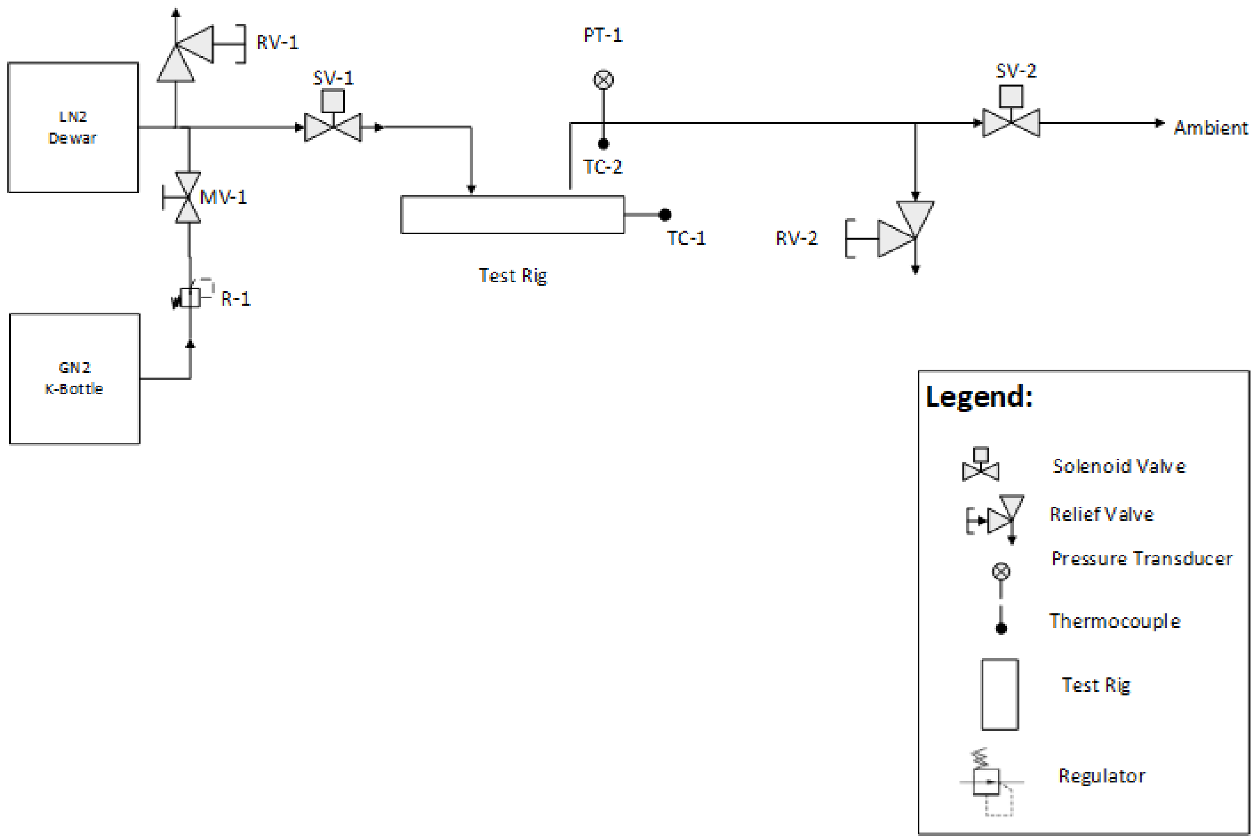


Figure 4.11 Seal Test Pipe and Instrumentation Diagram

Figure 4.11 shows the pipe and instrumentation diagram for this test. This schematic shows an overall picture of how the test looks like on paper. Figure 4.12 is the actual test set up fully assembled with the required torque in each bolt. For the first results, the Teflon tape was used. As the Teflon tape was applied, the location where both ends meant was noted. To have a better measurement of the force

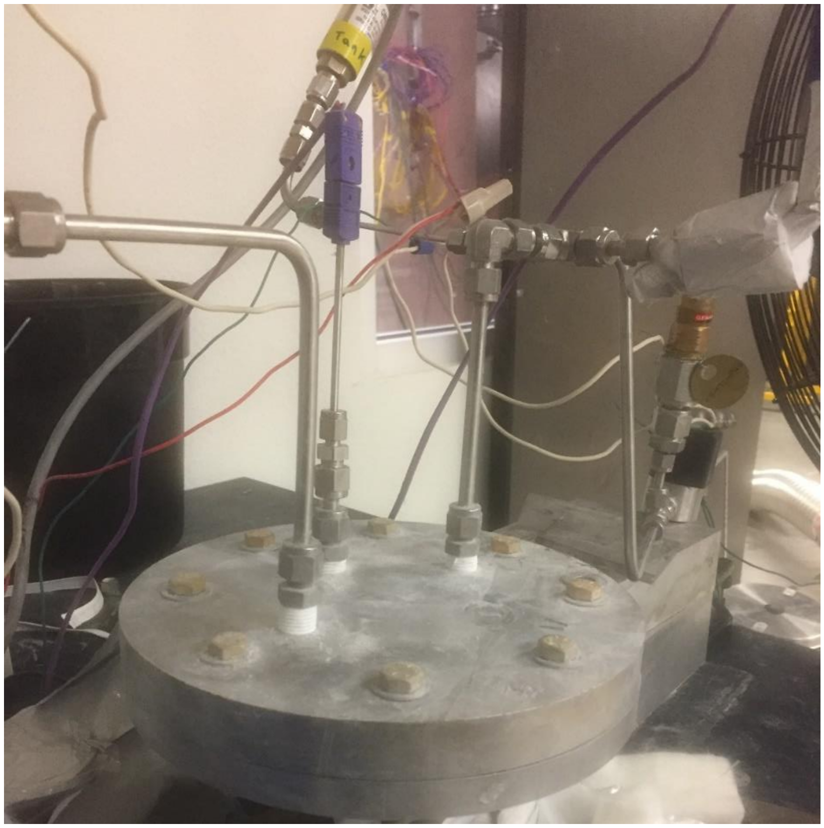


Figure 4.12: Physical Representation of Seal Test

in each bolt, the elongation of the bolts was recorded. The elongation of the bolts was done by measuring the original length of the bolts and after applying the torque with a torque wrench. The length of the bolt was measured once more, and the difference between both measurements is the elongation. The test article and the bolts used were labeled as shown in Figure 4.9 to keep track of the measurements of each bolt and the location where both ends of the sealant tape met. The figures previously mentioned can be used to follow what happened during testing as far as flowing the LN2 and pressurizing the test article with gaseous nitrogen (GN2). Following the procedures document that was drafted for this test, the liquid nitrogen (LN2) was flowed through to get the test article cold to -200F. Having the test article at this temperature meant that neither water nor snoop was adequate to check for any possible leaks. The test article was warmed up to room ambient temperatures to be able to measure the elongation of the bolts and leaks check the system.

Table 4.3: The Total Force and Pressure Before and After Installation Applied to the Sealant Tape

	Measurements at Installation	Measurements after Cold Treatment
Total Force (lbf)	22,093	20,214
Total Pressure (psi)	2,975	2,722

Table 4.3 shows the total force and pressure before and after the test article was put through the cold treatment. Also, the measurements were taken when the test article was at room temperature. Once the flange was taken back to room temperature, it was placed in a bucket full of water to inspect if there was any leak visually. A pressure of 100 psi using gaseous nitrogen (GN2) was put through the flange. This visual inspection showed a very small bubble if any throughout the flange. Overall, this leak check, it was concluded that the sealant did not leak or that it passed the leak check. Then the flange bolts were retightened to have 185 lbf-in. The 185 lbf-in showed to be a leak-tight torque quantity for the flange. This procedure was done several times to see if there was any fatigue in the sealant to cause any major leakage. After each cold cycle and checking for leakage using water. Every time there was either a small bubble that sporadically floated up or no bubbles were showed. Through this test, it was shown that the Teflon tape is very effective when dealing with low temperatures.

The next step was to place it in a heat treatment. The equipment that was readily available and that was big enough to fit the 5” diameter flange had a high-end temperature limit of 480˚F. The time for the test article to achieved 480˚F is about 45 minutes. The decision was made to leave the flange inside the oven for 2 hours. After letting the flange cool down to room temperature the force was measured.

Table 4.4: The Total Force and Pressure Before and After Installation Applied to the Sealant Tape

	Measurements at Installation	Measurements after Heat Treatment
Total Force (lbf)	25,581	14,814

Total Pressure (psi)	3,445	1,995

Table 4.4 shows the results of the force of each bolt after it was heated up. The results showed that there was a drop of about 11,000 lbf in the force. Then the test article was placed in the bucket of water and pressurized to 100 psi. The sealant leaked from almost half of its circumference. Also in between the circumference where it leaked was the part of the sealant where both ends meet. Then the flange was retightened to 185 lbf-in and successfully passed the leak check. The test article was placed once again in the oven under the same conditions that were previously mentioned. Once more the test article leaked from the same location leaking at a constant rate. The location where both ends of the sealant meet where located in the area where there was leaking. It can be concluded that the zone where the two ends of the tape meet are very susceptible to losing its sealing capabilities because more tests were conducted, and similar results were obtained.

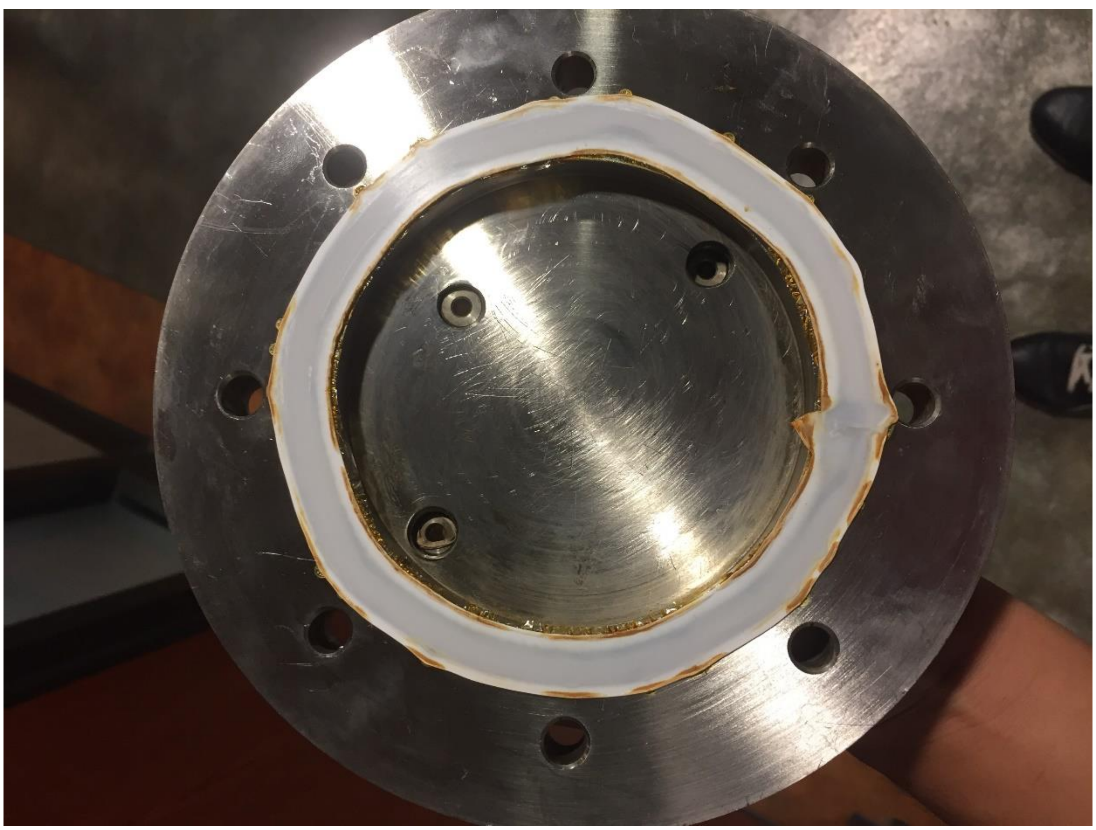


Figure 4.13: Sealant After Being Put in the Oven

Figure 4.13 shows the image of the sealant tape after it was put in the oven. The sealant was not too damage from being put through a temperature of 480 F. However, the adhesive that the tape had was left completely useless and probably affecting the performance of the sealant.

Figure 4.14: Teflon Gasket after being Cut off from the Sheet

Figure 4.14 shows the Teflon gasket. As previously mentioned the gasket dimensions were taken by using the tape sealant as a reference for the width inner and outer radius. The gasket has similar installation requirements as the tape sealant for this reason the pressure/torque values were the same as the sealing tape. The same process that was previously described for the sealant tape was followed for the sealant gasket. However, the decision was taken to double the amount of torque. As a result, the load doubled in the sealant. The results after cold treating the flange showed that the force placed in the gasket remains almost the same except for a few exemptions in some bolts. The leak inspection was successful as no bubbles formed. The next part was to place the test article inside the oven for two hours at a temperature of 480˚F like before. After, the flange had cooled down to room temperature it was leaked check. This gasket also leaked but the area where it did was much smaller. Figure 4.15 shows a representation of where it leaked. The red highlight in the circumference of the flange shows the location where it leaked. Then the flange was retightened to 185 lbf-in of torque, leaked check, and placed inside the oven. The results were identical to what was seen before for the gasket, however, the location where the leak happened changed. After, the flange was disassembled. The gasket had very few burned spots.

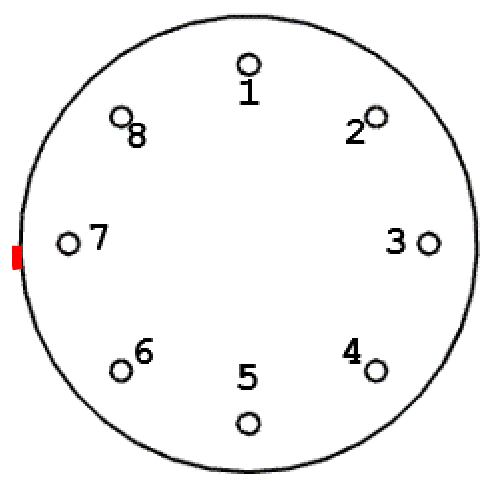


Figure 4.15: Representation of Leak Area in the Test Article (Red)

After these tests were done in the sealant tape and the gasket, both test subjects showed to be very reliable when dealing with temperatures of -200˚F. The leak rate was very minimal if none existent. The only occasion a leak was seen was for the sealant tape. The bubbles were almost the width of a quarter (.069") . Also, the time between each bubble was about 20 to 30 seconds between bubble. When retightening the test article, a torque of 185 lbf-in was sufficient to stop any leaking if it was spotted. The real difference between the sealants was shown when using the oven. The results showed that the gasket has a better performance when dealing with high temperatures. A probable reason for the gasket to have had better results could be since it is a solid piece without having an overlapping section like the tape sealant. The tape sealant had a few aspects going against it. Number one was the overlapping of the end tips, even though the manufacturer had suggestions on how to prevent a leak path through this section. The leak check showed that when put through the temperature of 480˚F the seal would not hold. The adhesive could have been another problem because after the flange was heated up. The adhesive would burn as seen in figure 4.13. The burn marks that are seen in the figure are mostly the burn adhesive. On the other hand, the gasket was damaged very little, and the leaks were not very big nor constant.

Chapter 5 RCS Validation

Whenever costume hardware is developed, there is a need to validate the features of the part as specified in the blueprints or any other requirement document after manufacturing. For example, on a rocket engine assembly one of the most crucial section of it, is the nozzle diameter. This diameter can be defined by using the thermodynamic relation for expansion ratio:

$$ER = \frac{A_e}{A_t} = \frac{\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}}{\left(\frac{P_e}{P_c}\right)^{\frac{1}{k}}\sqrt{\frac{2k}{k-1}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}} \tag{5.1}$$

In this relation A_e and A_t are the exit and throat area respectively, P_e and P_a are the chambers, and exit pressure and k is the specific heat ratio of the gas. This equation and a few others like the thrust coefficient were used to size different component of an engine. Table 5.1 shows the different

Table 5.1: Comparison Of Designed and Actual Dimensions

Engine Features	Designed Value (in)	Actual Nominal Value (in)
Chamber Diameter	0.500	0.499
LOX Injection Orifice	0.018	0.017
LCH4 Injection Orifice	0.016	0.016
FFC Injection Orifice	0.020	0.020
Throat Diameter	0.230	0.239
Chamber Wall Thickness	0.125	0.127

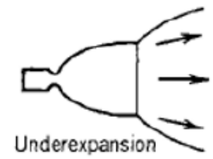
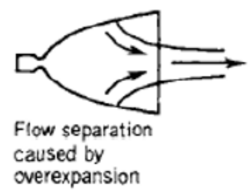
Measure area of Throat is Smaller than Theoretical Area	
Theoretical Area of Throat is the Same as the Measured Area	
Measured Area is Bigger than Theoretical Area	

Figure 5.1: Visual Representation of what the Throat Area could be

component names and dimension of the pencil thruster. The dimensions listed were used plus some other call outs for the manufacturer to machine the engine. These dimensions are important in the performance of the engine. For example, the throat area is very important for the thrust and/or performance of the engine. If the throat comes too big from the manufacturer, the combusted material would not flow at Mach 1 or choke. This phenomenon is called over-expanded nozzle. The other case where the nozzle is smaller than calculated. The pressure inside the chamber will be larger than expected causing an under-expanded nozzle. Figure 5.1 shows these performance parameters that occur within the engine depending on the throat size results from manufacturing. It also includes the image of an optimum expanded nozzle. For this kind of performance, the engine was designed, and the dimension of the throat come into play.

Figure 5.2: (A) Modified Spark Plug, (B) Chamber, (C) Nozzle

The engine assembly was divided into four different sections for ease of manufacturing and inspection. These four parts are a chamber, nozzle, injection rings and sparker.

Figure 5.2 shows all the different parts. After all the components were manufactured, an inspection process was performed for each part. The instrumentation used to be able to validate these values were go and no-go gauges, and a caliper.

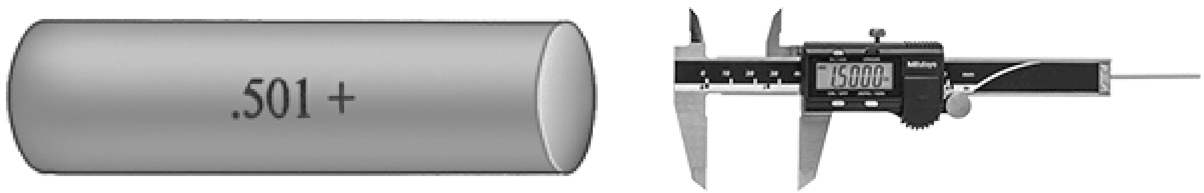


Figure 5.3: Go-No-Go Gauge (Left) and Caliper (Right) used for Validation

Figure 5.3 shows the go and no-go gauges and the caliper. The tolerance that the go and no-go gauge provide is ±0.0001”. This allowed for high confidence in the size of the injector holes that are

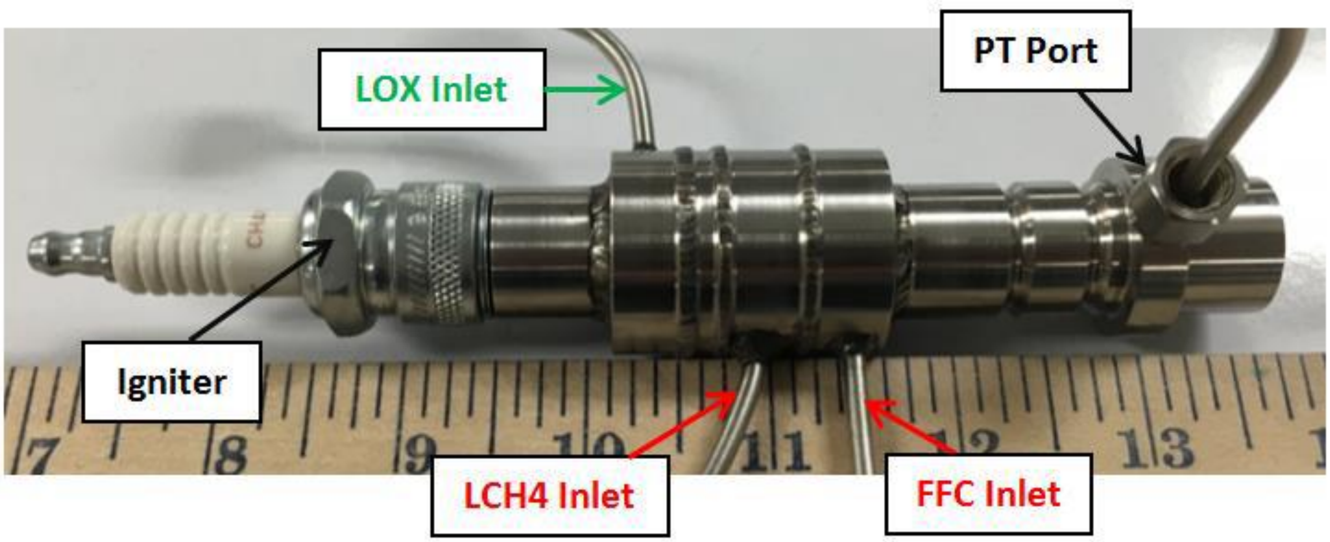


Figure 5.4: Fully Assembled and Welded Pencil Thruster

In the 0.001 magnitudes. With these tools, the engine was inspected, approved and ready to go into the final step of assembly. Figure 5.4 shows a fully assembled and welded pencil thruster.

5.1 WATER TESTING

After the dimensions of the RCE were inspected and deemed acceptable, the next step is to do validation of the injector flow rates using water. These tests series was used to understand the performance and design of the injector orifices. The injector performance parameters consist of the pressure drop across the injectors and volume flow rater leading to them. These test results were used to validate the theoretical values previously used to size the injectors. These comparisons and test experiences are also going to be very valuable when dealing with the hot fire testing of the engine and as experience for any future testing of any other system.

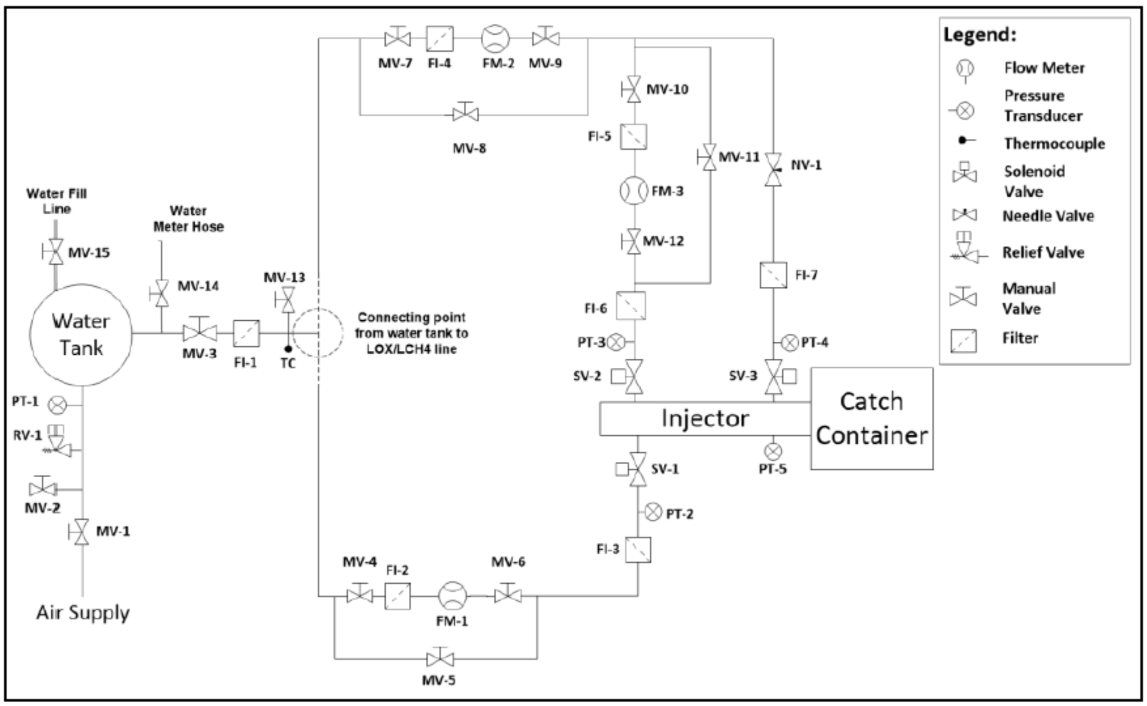


Figure 5.5: Pipe and Instrumentation Diagram for RCS Water Test Set Up

Figure 5.5 shows the piping and instrumentation diagram used to develop the water test. The sensors used in this set up were pressure transducers, flow meters, and thermocouples. These sensors plus valves (solenoids, needle, and globe valves) are shown in figure 5.6 within the test set up.

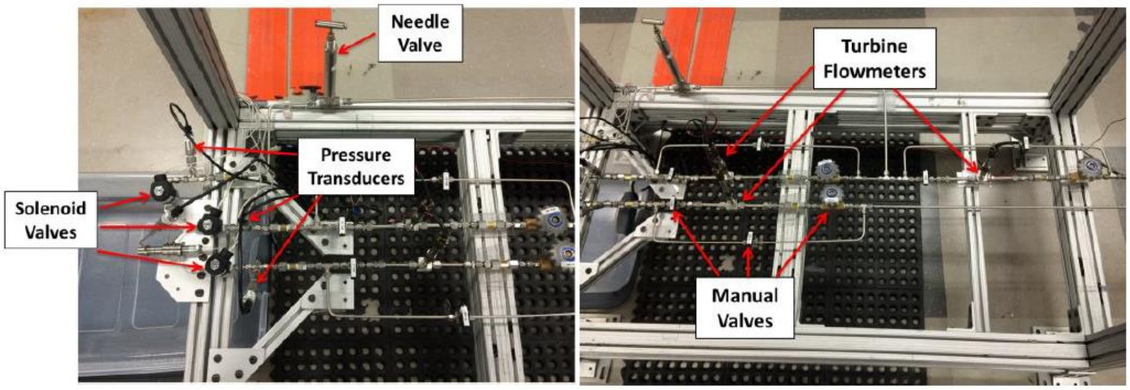


Figure 5.6: Physical Hardware with Sensor

The way this system is going to work is by filling the tank with water up to 20 gallons. Then the tank was pressurized with compressed air varying the pressure from 20 to 80 psi. The flow meters

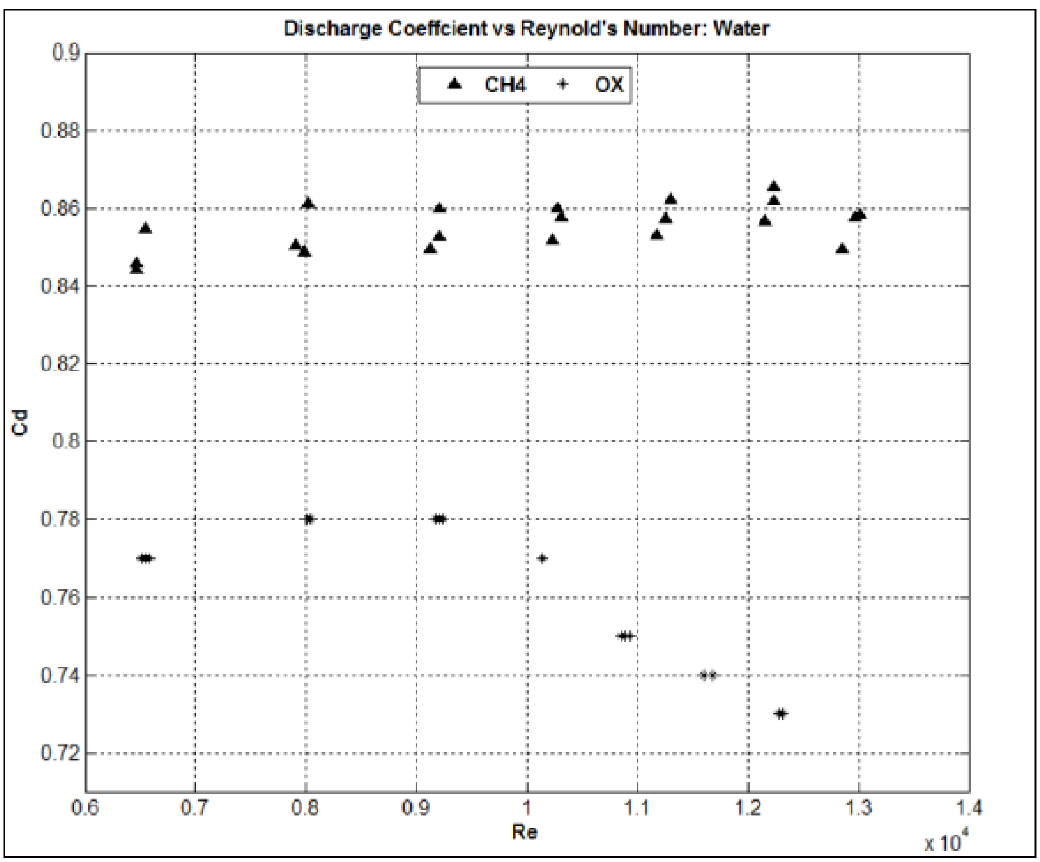


Figure 5.7 Discharge Coefficient vs. Reynolds Number

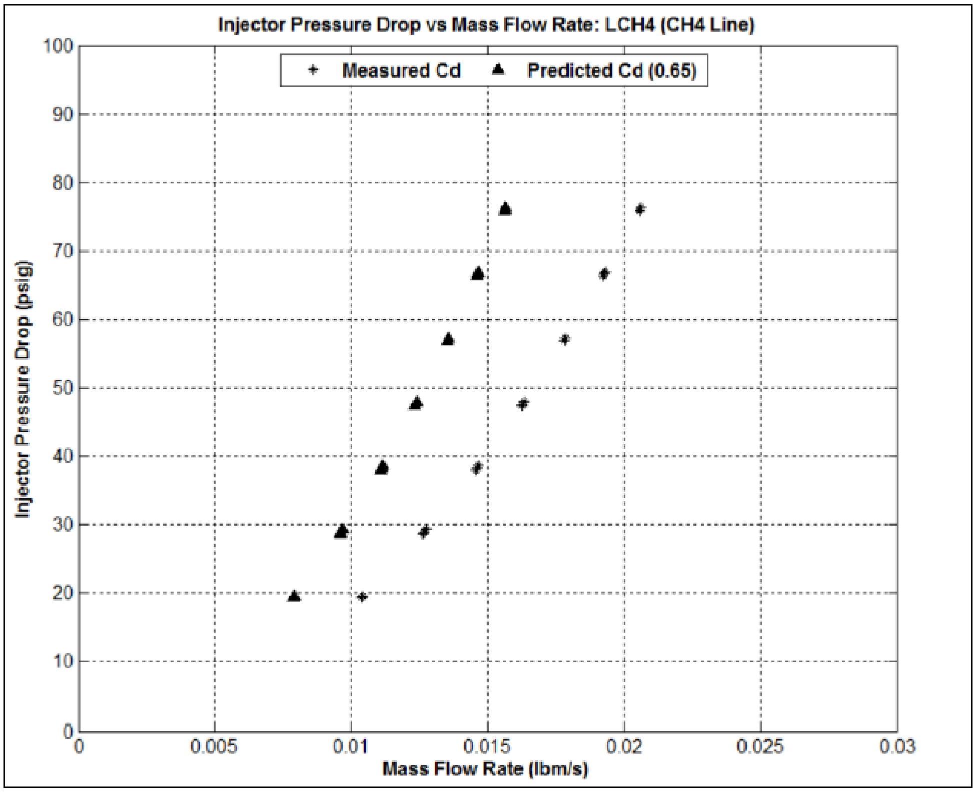


Figure 5.8: Comparison Between Theoretical and Measured Discharge Coefficient For LCH4

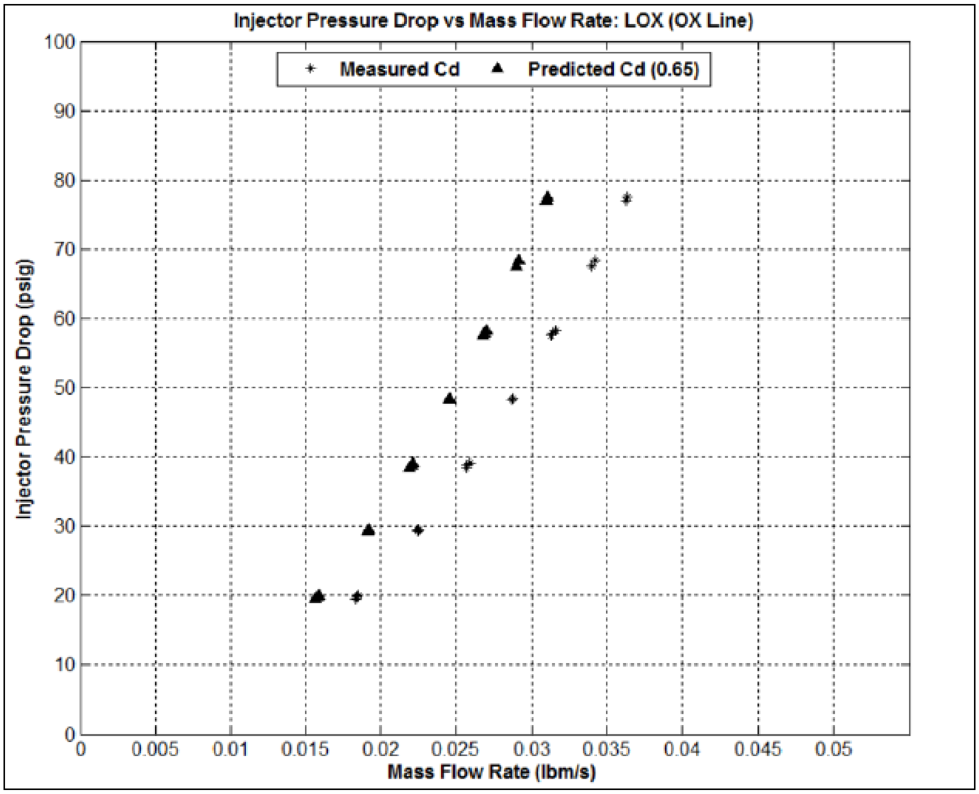


Figure 5.9: Comparison Between Theoretical and Measured Discharge Coefficient For LOX

required a bypass to protect them from over spinning because of a sudden increase in the pressure. This can be prevented by slowly pressurizing the flow meter. Once the tubing is filled with water up to the solenoid valves that are placed right before the injectors. The test is ready to commence. For this test, the injectors were tested separately and compared results to their respected theoretical values of flow rate and pressure drop.

Table 5.2: Tests Results for Water Test Validation for the RCE

Test Run	Tank Pressure [PSIG]	LOX Injector ΔP [PSIG]	LOX ṁ [lbm/s]	LCH4 Injector ΔP [PSIG]	LCH4 ṁ [lbm/s]
1	20±2	19.6	0.017	19.6	0.016
2	30±2	29.3	0.021	29.3	0.020
3	40±2	38.5	0.025	38.5	0.023
4	50±2	48.2	0.027	48.2	0.025
5	60±2	57.5	0.029	57.5	0.028
6	70±2	67.5	0.031	67.4	0.030
7	80±2	77.0	0.033	77.0	0.032
8	80±2	77.5	0.033	77.5	0.032
9	70±2	68.4	0.031	68.3	0.030
10	60±2	58.3	0.029	58.3	0.028
11	50±2	48.5	0.027	48.4	0.025
12	40±2	39.2	0.025	39.2	0.023
13	30±2	29.5	0.022	29.5	0.019
14	20±2	20.1	0.018	20.1	0.016
15	20±2	19.9	0.018	19.9	0.016
16	30±2	29.5	0.022	29.5	0.020
17	40±2	38.8	0.025	38.8	0.022
18	50±2	48.2	0.027	48.2	0.025
19	60±2	57.9	0.029	57.8	0.027
20	70±2	67.5	0.031	67.5	0.030
21	80±2	77.1	0.033	77.0	0.031

Table 5.2 shows the results of pressure drop and flow rate for the LOX and LCH4 sections separately. The uncertainties that were displayed for the pressure and flow rate for both sections were ±0.5 psi and ±0.0002 lbm/s. The results were used to obtain the discharge coefficient (C_D) for both injection geometries. The values that were obtained for the discharge coefficient were 0.86 for LCH4 and 0.76 for LOX. These orifices discharge more fluid than what was calculated. The theoretical values for both orifices were 0.65. To further analyze the discharge coefficient through the injectors, the values of C_D were plotted against the Reynolds number. Figure 5.7 shows C_D vs. Reynolds number for both LOX and LCH4. The C_D values of LCH4 can be seen to remain

constant as the Reynolds number changes, and it can be concluded that the C_D is dependent form the flow velocity. This trend is not followed by the LOX C_D, as the value for Reynolds number increased the C_D decreased. Equation 5.2

$$\Delta P = \frac{1}{2g_c\rho}\left(\frac{\dot{\omega}}{C_D A}\right) \rightarrow \dot{\omega} = C_D A\sqrt{2\rho g_c \Delta P} \quad (5.2)$$

was used to determine the values of flow rate using the calculated C_D and the ΔP across the injectors. Figure 5.8 and 5.9 are graphs that show the results for the mass flow rates based in the theoretical C_D and the mass flow rates based on the C_D obtained from testing. From these results, it was determined that the C_D difference for the LOX section is about 15 % and for the LCH4 section is 24%. For both injection orifices, the flow rates were higher than expected. These results are going to be used to adjust some variables of the fire test to be able to adjust to what the injectors are giving.

Chapter 6 Actuation System Water Test

As previously mentioned, the CROME and CROME X requires a custom-made throttleable system. There are various methods to be able to throttle a rocket engine one of them is through the valves or through the injection system. For both engines, it was decided to throttle using valves. Out in the market, there are many automated valves however none of these systems were able to achieve the time open requirement of 0.5 seconds. For this reason, an electric motor was size separately from the valves to be able to achieve the time open requirement. Then the valves had the v port feature to allow for a more linear control in the flow as the position of the port changes. Then for these components to be able to work together, two more systems were generated to couple the motor and valves together. These were the thermal standoff and the frame. The thermal standoff was designed to directly connect the valve and motor and transfer the required torque to open the valve from the motor. Also, it was designed thinking to protect the motor from the cryogenic temperatures the valves will get. The frame is meant to hold the motor, valve, and thermal stand-off together. The frame and the thermal stand-off will have a visual test to see if they are able to allow the motor to move the valve successfully. The valve will go through a verification test, to calculate how much flow or CV it will allow at every position and if the manufacturer values correspond to the actual valve. Another parameter that will be analyzed is the position vs. ΔP. The motor can only be as good as the frame and thermal stand-off if the frame and thermal-standoff are not stiff enough for the values and actuator not to move. This test will help understand how stiff the frame should be and what kind of redesign could need.

6.1 TEST SET UP

The system was constructed using pipes, some needle valves, quarter turn valves and a positive displacement pump.

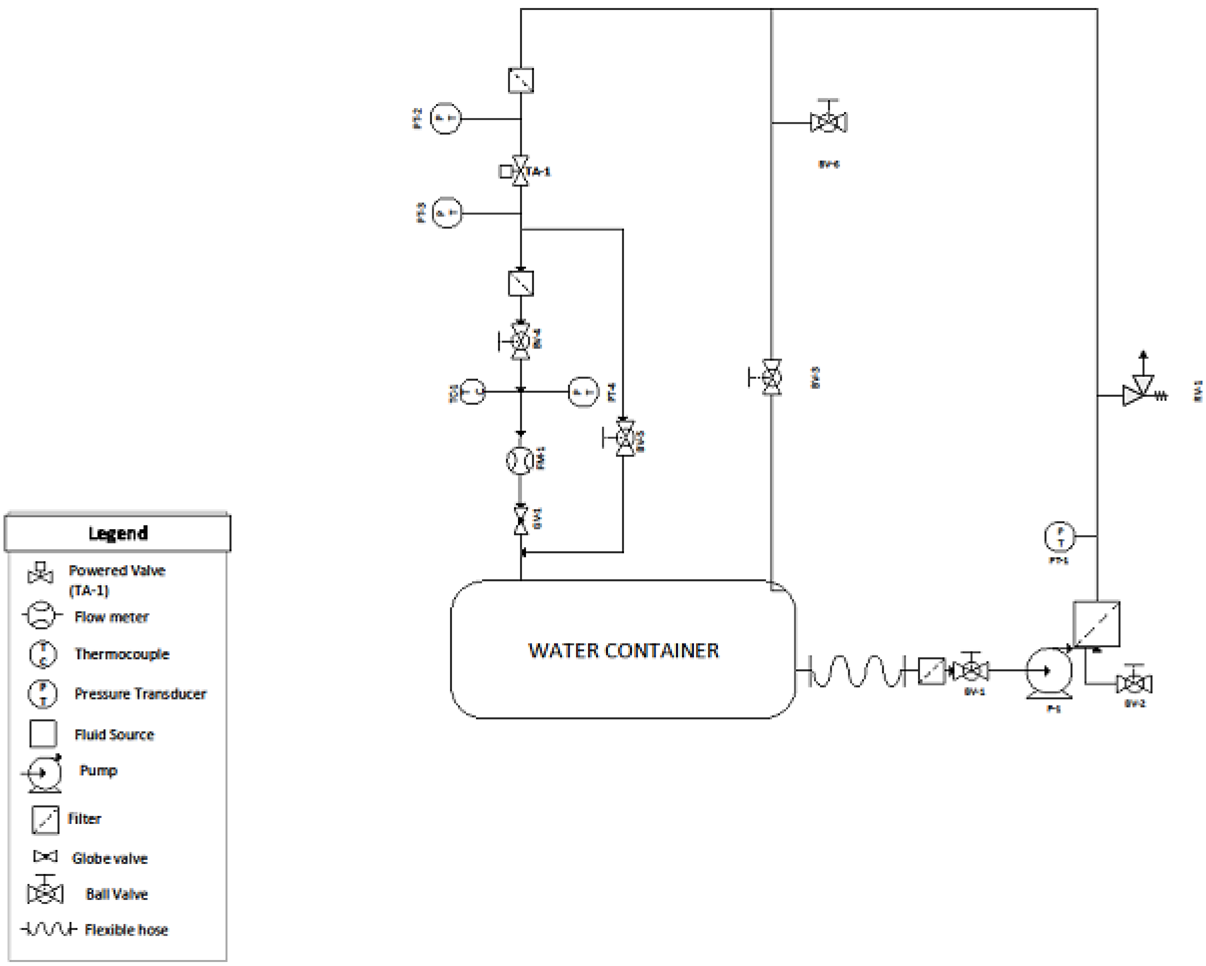


Figure 6.1: Pipe and Instrumentation Diagram of the Valve Water Test

Figure 6.1 shows the pipe and instrumentation diagram for the valve water test set up. This set up has two outlets. The system is configured this way because the pump should not be operated fully blocked by flowing water. For this reason, the outlet that does not have the flow meter should remain open as the pump is turned on. Like in the RCS system the flow meter is put through a bypass system to protect it. The water will be let into the flow meter slowly until the valves

upstream and downstream of the flow meter are fully open. Both these procedures are to protect the pump and flow meter.

The positive displacement pump is a kind of pump that is meant to always deliver the same amount of flow rate under a range of conditions. The operational requirements for the pump are that it has a pressure limit of 125 psi if this pressure was to be exceeded the risk of damaging the pump was great. Since for this system, the use of a GN2 k-bottle or an air compressor is not possible to pressurize the system. The pump was used to increase the pressure in the system, and that way get pressure change across the actuation system. The increase in pressure was achieved by adjusting both of the glove valves at the end of both outlets. As the actuation system switched positions, one of these valves would get adjusted until a pressure of around 55±5 psi, after the adjustment data would be obtained by the data acquisition. A further explanation of the procedures of how this system was operated is in the approved procedural document. Figure 6.2 shows the physical representation of the system.

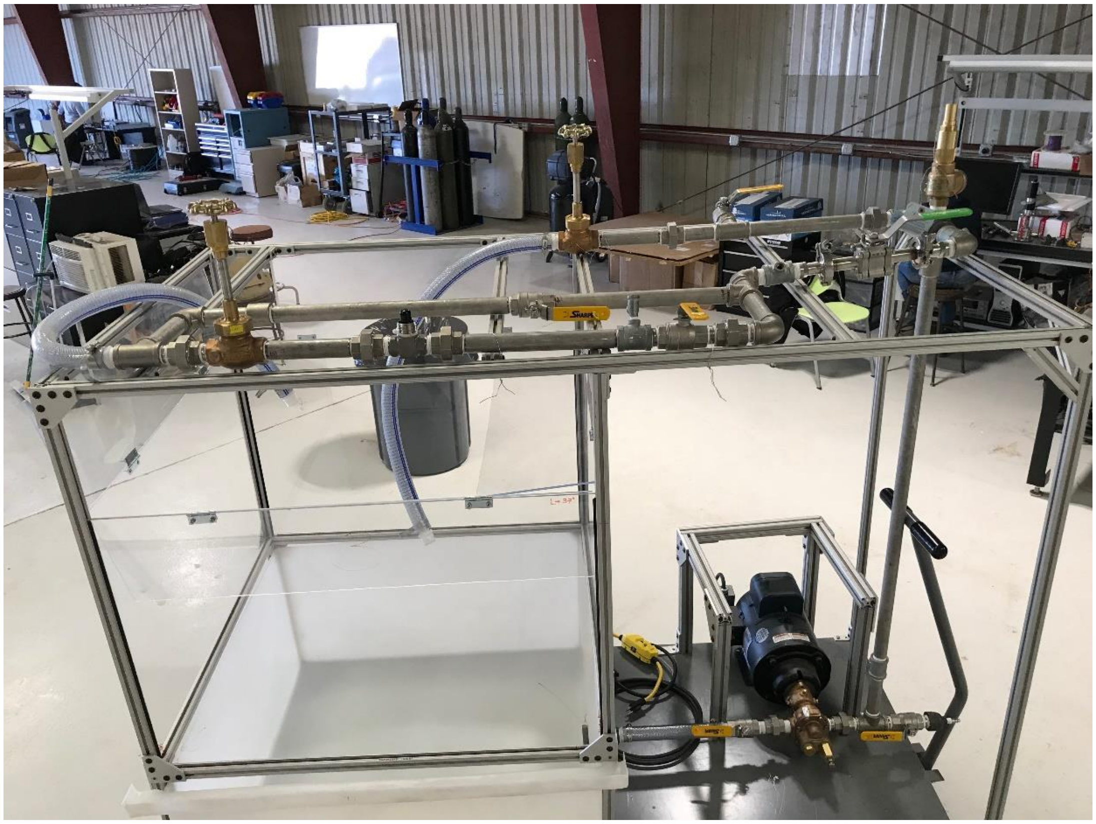


Figure 6.2: Physical Representation of Valve Water Test

6.2 RESULTS

During the test campaign, the desired pressure that wanted to be achieved was 100 psi. However, this was not possible because of power limitations. Every time the system at around 85 to 90 psi the transformer would jump the circuit inside it. For this reason, it was decided to only go up to 55±5 psi in the system. After the valve water test was fully operational, testing went underway. Table 6.1 shows the pressure change across the valve, flow rates and CV values from the test at every position.

Table 6.1: Valve Water Test Results

% Open	ΔP across Valve (psi)	CV	Flow Rates (GPM)
40	50.4	0.9	6.0
50	41.16	2.1	12.0

60	27.2	3.9	15.4
70	17.2	6.3	19.3
80	5.5	8.4	18.6
90	3.8	9.6	18.6
100	3.65	10.2	19.5

The Results of ΔP and flow rate were used to obtain the CV value at each position. However, by looking at the results. The values after 40% were not consistent. This was attributed to the fact that as soon as the actuation system was almost closed. The pressure control was difficult to achieve. Any small adjustment had a large pressure change. Also, the flow meter is only rated to read flow rates above 3 GPM. Any value below this should be considered useless. For these reasons, the data below 40% open was not considered.

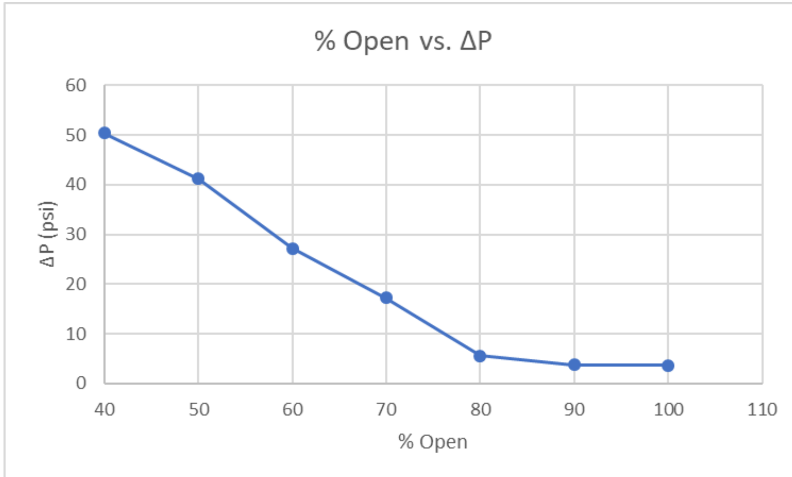


Figure 6.3: % Open v. ΔP Graph Experimental

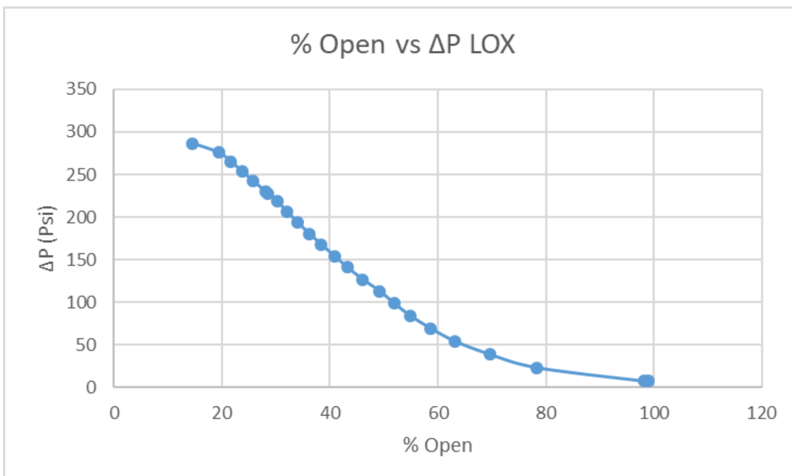


Figure 6.4: Theoretical % Open vs. ΔP Graph LOX

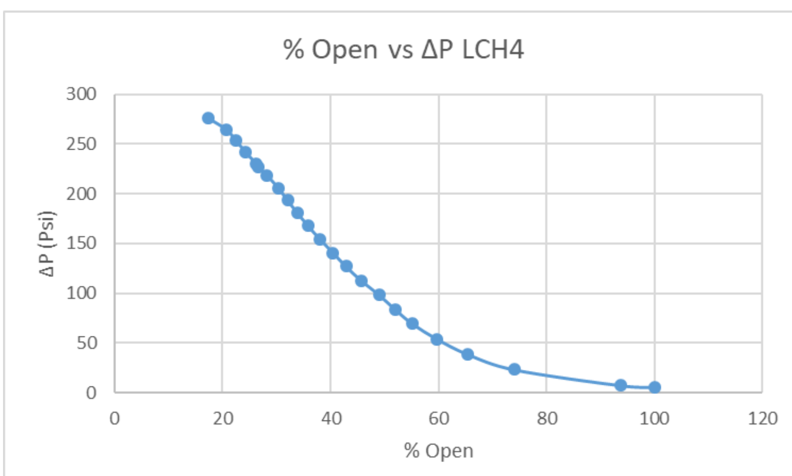


Figure 6.5: Theoretical % Open vs. ΔP Graph LCH4

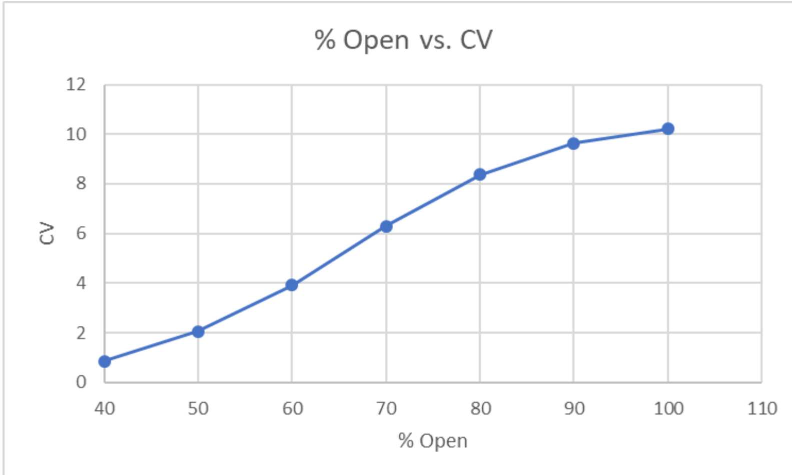


Figure 6.6 % Open v. CV Experimental

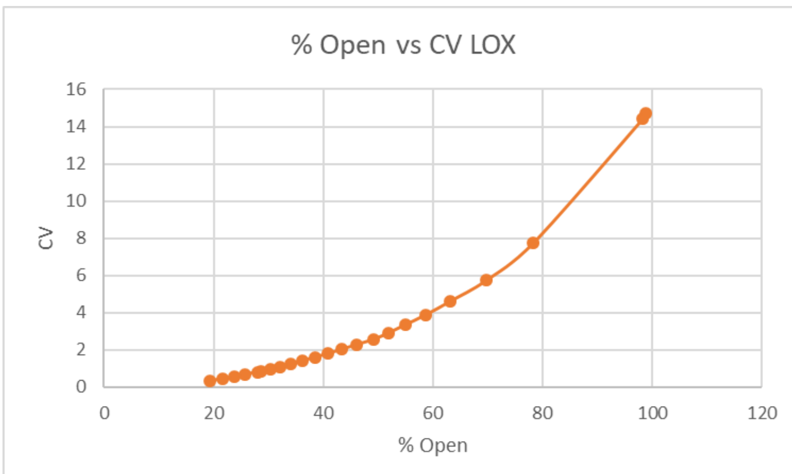


Figure 6.7: Theoretical % Open v. CV LOX

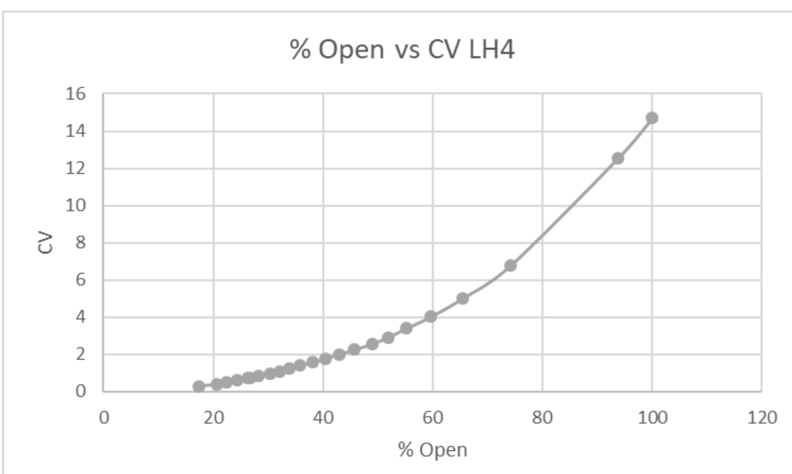


Figure 6.8: Theoretical % Open v. CV LCH4

Figure 6.3 shows the graph for % open v. ΔP. It can be seen that the values of ΔP decrease in a linear manner as the valve get opened more and more. As the % open get the 80%, the ΔP stops decreasing to the point where at 80, 90, and 100 the values are very similar. In this zone where the valve is almost fully open the pressure change should not be very significant. Since in the v-port, the round section of it should be most exposed allowing almost all of the flow rates to go through. Figure 6.4 and 6.5 the theoretical of % open vs. ΔP for LOX and LCH4 respectively The graphs were compared with the experimental graph , it can be seen that as the valve opens the pressure change decreases in a linear manner. This shows tha the valve operates as expected. However. The theoretical graphs show the results for a system that has a tank pressure of about 300 psi. The theoretical values need to be change so that they match the experimental system max pressure of 50 psi. The CV behavior follows a similar trend as the ΔP. This can be seen in Figure 6.6. The CV value maxes out at around 10.2 making it a problem.Figure 6.7 and 6.8 show the theoretical values for LOX and LCH4 resulting CV calculations. In the theoretical graphs for the valve, it was seen that a value less than 14.7 for the CV would not allow the sufficient flow rate the engine requires.the solution to this problem is to contact Habonim and get a 90˚ port. The replacement of the port is not very difficult and easy to do.

Chapter 7 Conclusion and Future Work

The nondestructive testing and validation procedures are important when dealing with hardware. This kind of procedures could prevent any kind of surprised or accident during a system test. If there is any parameter that does not fit was first required. This kind of procedure gives an assessment and possible solution for a problem. For example in the case of a manufactured part, if any feature of a part does not meet what was stipulated in the blueprints. The part could be returned to the manufacturer for it to be corrected. The water flow testing for the RCE and the actuation system helped to get familiar with each of the system and in a certain way is risk-free. For example, both of these systems will be used in a rocket engine where very dangerous propellants would be used. Doing a water test before a fire test is very convenient to correlate the values of the water flow with the propellants at a low risk but a high learning experience. The next step for the actuation system is to undergo low-temperature shock testing. This test is to see the insulating capabilities of the thermal standoff.

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Appendix

Appendix A

2K-TP-001

Center for Space Exploration Technology Research
University of Texas at El Paso

Engine (Janus & Daedalus): Seals Test

Center for Space Exploration Technology Research-UTEP

APPROVALS

Israel Lopez ______________________ ______________________

2000 lbf Team Lead **Date**

Charles Hill ______________________ ______________________

cSETR Safety Approver **Date**

Luz Bugarin ______________________ ______________________

cSETR Safety Manager **Date**

Contents

1.0 Introduction

1.1 Experimental Objective

A mock-up flange that represents typical flange connections on the CROME and CROME-X engines will be built to test the Teflon seal that will be used. The mock-up will be subjected to a temperature cycle going between -185°F and ambient temperature several times.

After each cycle, the performance of the seal will be evaluated by measuring any change on the bolt preload. A leak check will also be performed to test whether the seal can still hold the internal pressure applied to the flange.

1.2 Theory

This experiment measures the preload on each of the bolts to determine if the preload changes as the flange is cycled from room temperature to -185°, and over time. The elongation of each bolt will be measured and the force per bolt calculated. The calculation will use equation 1 where F is the bolt preload, l_B is the bolt's effective length, δ is the bolt elongation, A_s is the bolt's tensile area (defined by eq. 2) and E is the bolt's modulus of elasticity. Each bolt should have a preload of about 3120 ± 6% lbf. Then the summation on all the forces will be calculated. To be able to approximate the amount of pressure the Teflon seal will experience. A crushed sample of the Teflon will be measure for its thickness and length and have the effective area the pressure will act.

$$\delta = \frac{F * l_B}{A_S * E} \quad (1)$$

$$A_S = \frac{\pi}{4}\left(\frac{d_m + d_p}{2}\right)^2 \quad (2)$$

The bolt's effective length that is determined using equation 3, this variable includes the contribution of the bolts' area and head and nut ends. Where d_{ts} is the thread stress diameter, d is the bolts diameter, H_B is the height of the bolt head, H_N is the height of the nut, ls is the length of the unthreaded length of the bolt and l_J is the overall joint length. All of this values are going to be measured during testing with the exception of the d_{ts} because this value is the average between the bolts minimum diameter and pitch diameter.

$$l_B = \left(\frac{d_{ts}}{d}\right)^2 * \left(l_s + \frac{H_B}{2}\right) + l_j - l_s + \frac{H_N}{2} \quad (3)$$

1.3 Seal Test Rig

The seal test rig consists of two 304 stainless steel plates. One of the plates has a groove that will act as a chamber to allow for nitrogen to be contained and pressurized. On the surface where the Teflon is going to be placed, the material has a flatness of .005” and a surface finish of 125 micro-inches. The other plate does not have any special feature other than the bolt circle. Also on the side where the Teflon is going to be placed, the material also has a surface flatness of .005” and a surface finish of 125 micro-in.

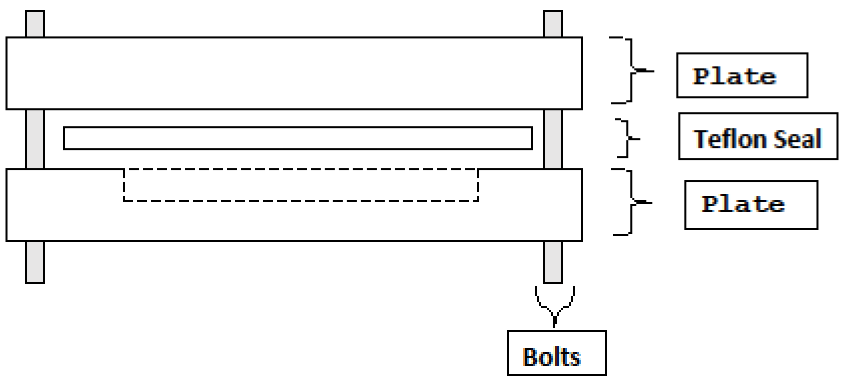


Figure 1. Side view schematic of test rig labeling the bolts, plates and teflon seal.

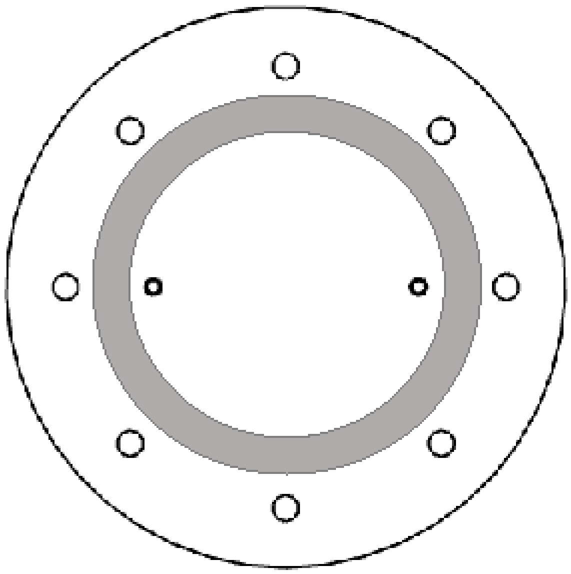


Figure 2. Image shows the possible view of the position of the seal within the flange.

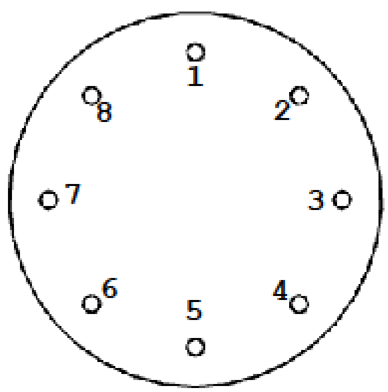


Figure 3. Bolt labeling

Bolt &Torquing sequence					
Sequence	1	2	3	4	5
1	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolts
4	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
7	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
2	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
5	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
8	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
3	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt
6	50 lb-in	100 lb-in	150 lb-in	200 lb-in	measure length of bolt

Table 1. Bolt tightening sequence

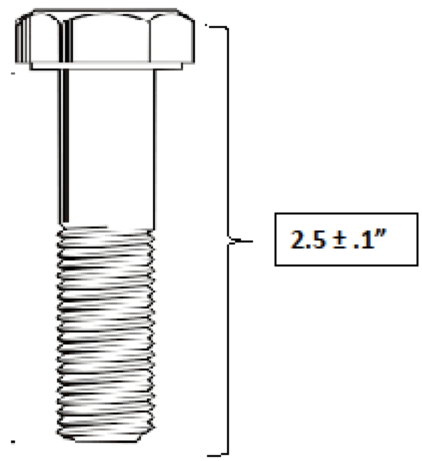


Figure 4. Bolt length after grinding approximately

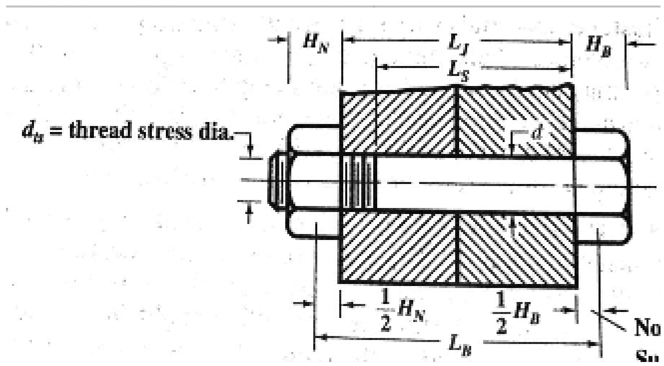


Figure 5. Bolt dimensioning diagram

1.4 Properties and Requirements Tables

Gore Teflon seal requirements & properties	
Compression stress	2500 psi
safety factor	1.5
force required per bolt	3122 lbf
Compression growth factor	1.2
Mean diameter	5.3 in.
seal length	16.3 in.
force required	28000 lbf
thickness	0.375

Table 2. Gore Teflon seal requirements & properties

Bolts Properties	
Bolts Grade	8
Minimum proof strength	120,000 psi
material	medium carbon steel
elastic modulus	28,000,000 psi
Tensile diameter	.058 in^2

Table 3. Bolts Properties

Flange Properties	
Material	304 SS
Bolt circle diameter	6.3"

Table 4. Flange properties

2.0 Test Configuration

2.1 Test Personnel

Project Lead: Pedro Nunez

Location:

Engineering Building Room E105: cSETR Goddard Laboratory
University of Texas at El Paso
El Paso, TX 79902

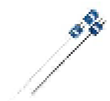
Personnel breakdown and contact info:

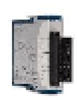
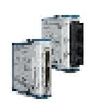
Person	**Role**	**E-mail**
Israel Lopez	Research Engineer	Ilopez7@miners.utep.edu
Pedro Nunez	Research Engineer	pnunez5@miners.utep.edu
Raul Ponce	Research Engineer	rponce4@miners.utep.edu
Charles Hill	Safety Supervisor	scotthill125@gmail.com
Luz Bugarin	Safety Engineer	libugarin@miners.utep.edu

- **Test Conductors** – *Pedro Nunez*
  - The test conductor is responsible for monitoring the test via the LabVIEW Graphic User Interface. This includes but is not limited to:
    - Opening/Closing Valves during system check
    - Running test sequence
    - Ensuring the LabVIEW program is reading and recording at the desired times
- **Test Technician** – *Israel Lopez*
  - The test technician is responsible for the test setup. He/she is responsible for:
    - Initial pre-test set-up of instrumentation
    - LN2 tank pressurization; This includes setting the tank to the desired test pressure and opening the valve prior to testing
    - Preforming leak checks and hardware adjustments before and during the test
    - Turning on the fan to disperse LN2 exhaust
- **Test Supervisor** – *Pedro Nunez*
  - The test supervisor must oversee the team and ensure the test procedure and matrix are being followed
  - Also responsible for initiating the manual emergency stop in the event of an emergency

2.2 List of instrumentation

Instrumentation Devices				
Device (Provider)	**Visual**	**Input**	**Output**	**Description**
PX1005L1-500AV Pressure Transducer (Omega)		Excitation Voltage: 10VDC	Signal Output: Millivolt analog signal	This transducer is capable of outputting an analog voltage that is proportional to pressure
		Excitation Voltage: 120V 60 Hz	Signal Output: 0-5V analog signal	This device amplifies the analog signal from the Cryo-PTs and displays the pressure

Thermocouple k-type (Omega)		TC Probe	Signal Output: Millivolt analog Signal	This device turns a temperature gradient into a voltage gradient and converts this value into a temperature using a CJC value.
Solenoid Valve (Gems Sensors & Controls)		Excitation Voltage: 12VDC	This device will open whenever the excitation voltage is applied	This device is used to electronically control the flow of propellant.

Data Acquisition (DAQ) Devices				
Device (Provider)	**Visual**	**Input**	**Output**	**Description**
NI 9211 (National Instruments)		4 differential thermocouple connections	Serial connection to chassis	This module can take up to four differential thermocouple measurements
NI 9205 (National Instruments)		32 RSE connections or 16 differential connections	Serial connection to chassis	This module can read up to 16 PTs

2.3 Piping and Instrumentation Diagram (P&ID)

Below in Fig 3 the schematic for the degradation test is shown. This includes the LN2 tank with valves, pressure transducers, thermocouples, and relief valve.

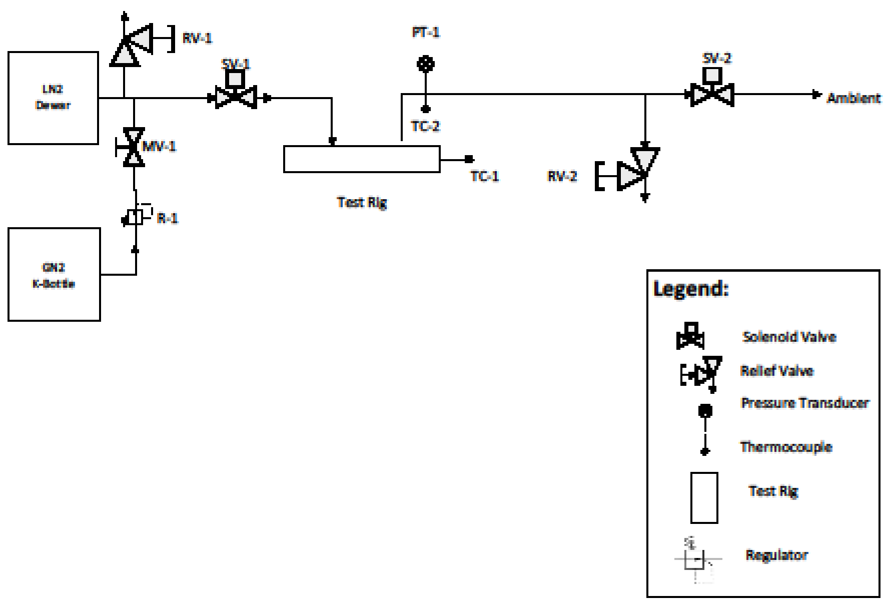


Figure 6. Pipe and instrumentation diagram

2.4 Test Matrix

bolt & nut measurements	
	Inches
d pitch	
d min.	
dts	
Bolt Diameter (d)	
Unthreaded Length (ls)	
Head Bolt (HB)	
Head Nut (HN)	
Joint Length (lJ)	

*Note, Figure 5 could be used as a visual aid to determine what each component are on Bolt & nut Measurement matrix

Unloaded Bolts (new bolts)				
Bolts #	Length 1	Length 2	Length 3	Average
	inches	Inches	Inches	inches
1				
2				
3				
4				
5				
6				
7				
8				

bolt Elongation	
	Elongation Estimate to achieve 3120 ± 6% lbf
Bolts	inches
1	
2	
3	
4	
5	
6	
7	
8	

Temperature Cycling																									
# Cycles From -185° to ambient		Bolt 1			Bolt 2			Bolt 3			Bolt 4			Bolt 5			Bolt 6			Bolt 7			Bolt 8		
1	Elongation (in.)																								
2	Elongation (in.)																								
3	Elongation (in.)																								
4	Elongation (in.)																								
5	Elongation (in.)																								

Teflon strip dimensioning	
length	
thickness	
width	

- The ambient temperature would be taken the day of the experiment
- Using the average for the initial length of each bolt the elongation will be determine

3.0 Experimental Procedure

The following section outlines the various tests procedures used. Moreover, the section outlines the specific roles of all test personnel.

3.1 LabView Operation

1. Turn on Power Supplies and ensure all wires are connected
2. Plug in PT amplifiers and allow ten minutes for them to warm up
3. While on the desktop of the testing computer, open the LabVIEW file titled "seal_test.vi"
4. Switch operation mode to manual

3.2 Test Set-Up Preparations

The following section outlines the steps/actions needed prior to testing.

I) Initialization (instrumentation test)
   - A) Measure length, thickness and width of teflon strip (write it on TEFLON STRIP DEMENSIONING matrix)
   - B) Measure required components specified on BOLTS AND NUTS MEASUREMENTS matrix and on figure 5.
     - 1) Duplicate BOLTS AND NUTS MEASUREMENT matrix for all the bolts
     - 2) Using equation 1 and 3 determine the amount of elongation each bolt should have to achieve *3120 ± 6% lbf* and record on BOLT ELONGATION matrix. An excel File will be generated to do calculation
   - C) Place it on the marked surface of the flange.
     - 1) When placing the strip on to the flange and forming the circle be sure that only ¼" of both ends of the strip is overlapping.
   - D) Align both flanges one on top of the other.
   - E) Be sure that all bolts and holes are marked from 1 to 8 in if not do so.
     - 1) When making the holes on the flange be sure to follow figure 3 to marked them.
     - 2) Numbering should be place on both flanges on the side where the seal won't be place.
   - F) Place bolt with corresponding hole.
   - G) Using table 1 and figure 3 start tightening bolts.
     - 1) Follow the order of the bolts specified table 1.
     - 2) Once the torque of 200 lbf-in is reach. Start measuring the elongation of each bolt using the micrometer.

(a) Using the values noted on BOLT ELONGATION matrix. Start trying to tighten or loosen bolts to achieve elongation with a tolerance of ±0.0002"

(b) When tightening or loosening the bolts and measuring the elongation with the micrometer, go with increments of 0.005" and then move on to the next bolt still following the tightening sequence.

3) Once all bolts are tightened to desire preload. They would not be tighten or loosen during the duration of the test.

H) Open Labview and be sure that PT-1 and TC-1 are reading ambient conditions (~12.7 psia and ~70°F).

1) If the values for the PT are not met go back to the PT-1 calibration data and be sure that input is correct on Labview

2) For the TC-1 check the connectivity and evaluate if the equipment needs to be replaced.

3) In the case that an instrument needs to be replaced, repeat step H; otherwise continue to next section.

I) Open and close SV-1 and SV-2

1) If they don't respond evaluate connectivity and try again or replace

II) Leak check

A) Connect line to tee fitting on the LN2 and k-bottle source.

B) Keep LN2 Dewar Close

C) Open GN2 regulator to 50 psia

D) Open SV-1 and keep SV-2 close

1) Solenoid valves are normally closed unless signal is transmitted

E) Starting from SV-1 to SV-2, place a drop of the Snoop leak detector on every fitting attached on the set up

1) Wait 2 minutes to see if bubbles form at any location on the line

(a) If no bubbles form on the line, proceed to step E

(b) If bubbles do form anywhere on the line, proceed by tightening the respective fitting until there are no visible bubbles forming proceed to step E.

(c) If bubbles form on the anywhere on the flange where the Teflon could seal. Disassemble flange remove seal and go back to section I A. If not continue to step F

F) Close GN2

G) Open SV-2 to depressurize system.

3.3 Test Procedures

A) Connect line to tee fitting on the LN2 and k-bottle source.

1) Be sure LN2 Dewar tank is pressurized at a pressure of 250 psia.

B) Open LN2 Dewar liquid valve

C) Open SV-1 and SV-2 (LN2 should start flowing through system)

D) Monitor TC-1 until a wall temperature of -185 ± 5 °F is reached.

E) Once desired temperature is reached close LN2 Dewar. Let the system warm up to room temperature. (leave SV-1 and SV-2 open)

F) Once TC-1 reads ambient temperature. Use a micrometer to measure each bolt elongation three times and on the TEMPERATURE CYCLING matrix.

G) Once the new lengths are recorded, completely open GN2 K-bottle supply valve and open the pressure regulator to a downstream pressure of 50 psi.

H) Close SV-2 and allow system to pressurize to 50 psia.

I) Close GN2 supply and SV-1.

J) Using the snoop check for any leaks on the test rig.

K) Repeat steps A thru J for another cycle

1) This process will be repeated for 5 more cycles or until a leak is spotted in the system using the snoop

L) Once the cycling is completed, do not tighten or loosen the bolts. Leave test rig and comeback in 2 days to measure the elongation of the bolts. (record if there was any change)

4.0 Hazardous Analysis

HA #	System	Hazard	Severity	Likelihood	HA Index	Mitigation
1	Nitrogen Delivery	Tank Regulator Failure	1 - Minor	1 - Unlikely	1	Close k-bottle manual valve depressurize line.
2	Nitrogen Delivery	Manual Valve Failure	1 - Minor	1 - Unlikely	1	Close k-bottle manual valve depressurize lines.
3	Nitrogen Delivery	Line Overpressure	3 - Significant	1 - Unlikely	2	Pressure relief valve will open allowing line to depressurize
4	Nitrogen Delivery	Relief valve pressure	3- Significant	1 - Unlikely	2	LabView redline will open all solenoid valves when a certain pressure is read.
5	Controls	Program Failure	1 - Minor	2 - Infrequent	1	Close tanks, depressurize line and restart program.
6	Controls	Power Failure	2 - Moderate	1 - Unlikely	1	Manual and pressure relief valves incorporated into system

Appendix B

2K-TP-001

Center for Space Exploration Technology Research
University of Texas at El Paso

Engine (Janus & Daedalus): Valve Test

Center for Space Exploration Technology Research-UTEP

APPROVALS

Pedro Nunez	10/12/17
2000 lbf Team Lead	Date
Charles Hill	10/12/17
cSETR Safety Approver	Date
cSETR Safety Manager	Date

Table of Contents

1 Introduction

1.1 Experimental Objective

The assembly of the actuators and the valves is an important component of the engines. This assembly will be used on both CROME and CROME-X engines to throttle the engine. The purpose of this experiment is to test the valves by measuring the volumetric flow rate at a specific open position and the overall flow coefficient value (CV).

After performing the necessary leak checks, water flow test will be performed. The purpose of the water flow test is to simulate the flow rates calculated of LHC4 and LOX. This is to assure we will get the required flow rates at the desired position. Thus, we will obtain a comparison between the calculated flow coefficient values and the values obtained by our experiment.

1.2 Theory

In a vehicle, changing the amount of propellant flow delivered to the engine dictates its thrust level. The main engine valves control the propellant flow to the engine. These valves throttle the rocket engine by controlling the valve position and consequently the amount of propellant delivered to the engine. Precise valve position control and repeatability are paramount to vary the thrust for vehicle dynamic control.

From the requirements, the required flow coefficient (CV) of the valve (an indicator of the pressure drop for a given flow rate) was calculated.

$$CV = Q\sqrt{\frac{SG}{\Delta P}} \tag{1}$$

This value serves as comparison criteria for the performance of different valves. The flow coefficient(CV) of a valve is defined as the flow rate (Q) of water at 60 F, with a pressure drop of one PSI across the valve. Also, the specific gravity (SG) of the fluid needs considered.

The minimum CV value required was 15. When comparing different valves, manufactures usually report the CV value of the valve at different open positions from fully open to fully closed (normally shown as a CV vs. % open of the valve). This information was used to compare different valves from several manufacturers and select the main valves.

2 Test Configuration

2.1 Test Personnel

Project Lead: Linda Hernandez

Location:

> **Engineering Building Room E105: cSETR Goddard Laboratory**
> **University of Texas at El Paso**
> **El Paso, TX 79902**
> **(Change Address – In progress)**

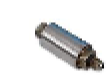
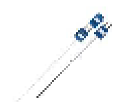
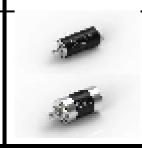
Personnel breakdown and contact info:

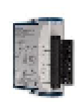
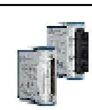
Person	Role	E-mail
Linda Hernandez	Research Engineer	lehernandez9@miners.utep.edu
Pedro Nunez	Research Engineer	pnunez5@miners.utep.edu
Jason Adams	Research Engineer	jradams2@miners.utep.edu
Charles Hill	Safety Supervisor	cshill2@utep.edu
Luz Bugarin	Safety Engineer	libugarin@miners.utep.edu

- **Test Conductors** – *Linda Hernandez*
  - The test conductor is responsible for monitoring the test via the LabVIEW Graphic User Interface. This includes but is not limited to:
    - Ensuring the LabVIEW program is reading and recording at the desired times
    - Running test sequence
    - Opening/Closing Valves during system check
- **Test Technician** – *Pedro Nunez*
  - The test technician is responsible for the test setup. He/she is responsible for:
    - Initial pre-test set-up of instrumentation
    - Preforming leak checks and hardware adjustments before and during the test
- **Test Supervisor** – *Jason Adams*
  - The test supervisor must oversee the team and ensure the test procedure and matrix are being followed
  - Responsible for initiating the manual emergency stop in the event of an emergency

2.2 List of Instrumentation

Component	Functional Description	Manufacturer	Model	Rated Pressure/Proof Pressure	Max Expected Operating Pressure	Size/Fitting Type
PT-1	Pressure Transducer	Omega			100 psi	
PT-2	Pressure Transducer	Omega			100 psi	
PT-3	Pressure Transducer	Omega			100 psi	
PT-4	Pressure Transducer	Omega			100 psi	
FM-1	Flow Meter	Omega	FTB-1424 021709A947	5,000 psi	100 psi	1" NPT
TC-1	Thermo couple	Omega			100 psi	
BV-1	Ball Valve				100 psi	1" NPT
BV-2	Ball Valve				100 psi	1" NPT
BV-3	Ball Valve				100 psi	1" NPT
BV-4	Ball Valve				100 psi	1" NPT
BV-5	Ball Valve				100 psi	1" NPT
BV-6	Ball Valve				100 psi	1" NPT
GV-1	Globe Valve				100 psi	1" NPT
RV-1	Relief Valve				Set at 125 psi	1" NPT
P-1	Pump	Pentair Shurflo	GMBN6VC7	125 psi	100 psi	
TA-1	Electric Motor & Gear Box	Maxon Presicion Motors	425032-1904642	no pressure will be put through this component		
TA-1	3-Piece Ball Valve	Habonim Valves	FN47W-666MPG/ETO-VB60	5000 psi	100 psi	1" Sanitary

Instrumentation Devices				
Device (Provider)	**Visual**	**Input**	**Output**	**Description**
PX1005L1-500AV Pressure Transducer (Omega)		Excitation Voltage: 10VDC	Signal Output: Millivolt analog signal	This transducer can output an analog voltage that is proportional to pressure
		Excitation Voltage: 120V 60 Hz	Signal Output: 0-5V analog signal	This device amplifies the analog signal from the Cryo-PTs and displays the pressure
Thermocouple k-type (Omega)		TC Probe	Signal Output: Millivolt analog Signal	This device turns a temperature gradient into a voltage gradient and converts this value into a temperature using a CJC value.
Maxon DC Motor		Excitation Voltage: 24 V / 6.7Amps	This device will open the valves at a desired position	This device is used to electronically control the flow of water

Data Acquisition (DAQ) Devices				
Device (Provider)	**Visual**	**Input**	**Output**	**Description**
NI 9211 (National Instruments)		4 differential thermocouple connections	Serial connection to chassis	This module can take up to four differential thermocouple measurements
NI 9205 (National Instruments)		32 RSE connections or 16 differential connections	Serial connection to chassis	This module can read up to 16 PTs

2.3 Piping and Instrumentation Diagram (P&ID)

Below in Fig. 1 the fluid schematic for the active water flow test is shown. This includes the water tank with a pump, valves, pressure transducers, thermocouples and flow meters.

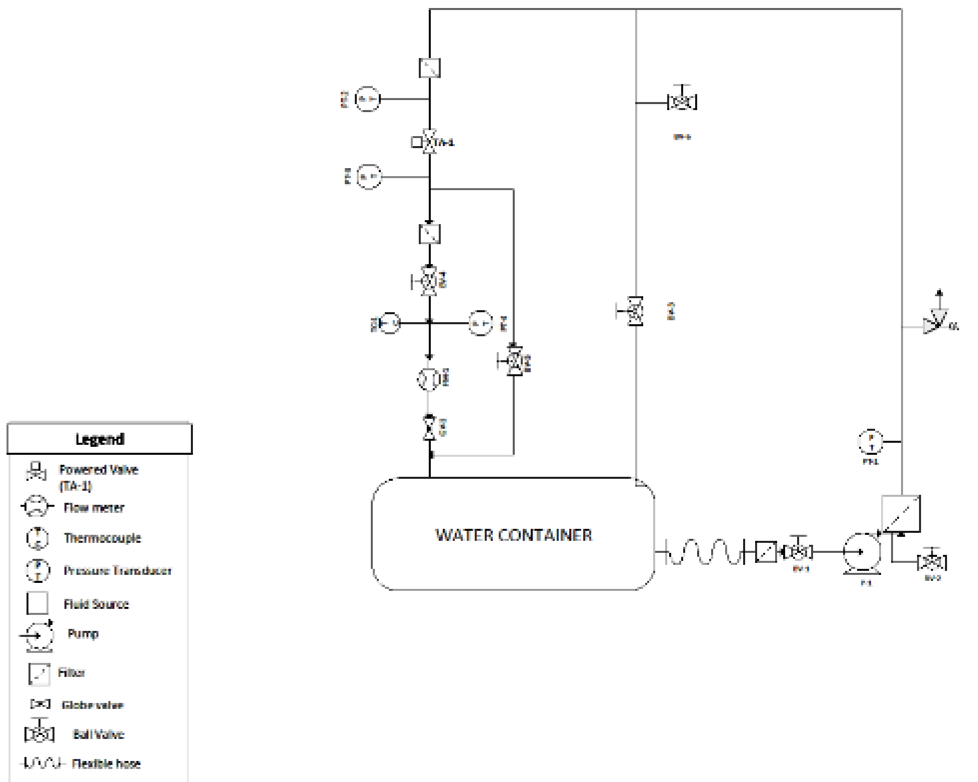


Figure 1: Water set up PI&D

2.4 Test Matrix

The objective of this test is to measure experimental flow coefficient (CV) values. These values will be calculated by obtaining the change of pressure that occurs as fluid goes though the actuated valve at a certain flow rate. The results of this test will be compared to the calculated flow rates.

To determine response time of the valve, the actuator will be tested first. The actuator will be programed to open and close the valve. While the actuator opens and closes the valve, at different positions, the current and the voltage used by the actuator will be recorded. Once is process is completed, the data will be extracted from LabVIEW to detect any changes in the voltage and current that occurred. From those results the response time will be estimated.

Use the table below to record the values throughout the test such as the inlet and outlet pressure going through the valve, pressure reference points and the flow rate of water at a specified position. Once all the values have been recorded, calculate the change in pressure (ΔP = P2-P3) and the flow coefficient (CV). **Record the pressure for a minute as the valve closes and opens. Also, record the inlet and the outlet pressure reference point. PT-1 is the reference point for the inlet pressure and PT-4 is the reference point for the outlet pressure. Which are located before the inlet pressure transducer (PT-2) and after the outlet transducer (PT-3).**

% Open	Degrees	Steps	PT1 Ref.	P inlet (P2)	P outlet (P3)	PT4 Ref.	ΔP (P2-P3)	Experimental Flow Rate	MFG CV	EXP. CV
	°		PSIG	PSIG	PSIG	PSIG	PSIG	lb/s		
100	90°	125							15.17	
90	81°	112.5							11.66	
80	72°	100							8.32	
70	63°	87.5							5.80	
60	54°	75							4.10	
50	45°	62.5							2.67	
40	36°	50							1.73	
30	27°	37.5							0.929	
20	18°	25							0.367	
10	9°	12.5							0.130	
0	0	0							0	

Table 1: Input table for water flow test (as the valve closes)

% Open	Degrees	Steps	PT1 Ref.	P inlet (P2)	P outlet (P3)	PT4 Ref.	ΔP (P2-P3)	Experimental Flow Rate	MFG CV	Exp. CV
	°		PSIG	PSIG	PSIG	PSIG	PSIG	lb/s		
0	0	0							0	
10	9°	12.5							0.130	
20	18°	25							0.367	
30	27°	37.5							0.929	
40	36°	50							1.73	
50	45°	62.5							2.67	
60	54°	75							4.10	
70	63°	87.5							5.80	
80	72°	100							8.32	
90	81°	112.5							11.66	
100	90°	125							15.17	

Table 2: Input table for water flow test (as the valve opens)

Compare the flow coefficient (CV) value obtained from the experiment with the CV value calculated. Use the table below to record these values. Record the comparison data percentage using equation 5.

$$Comparison\ data\ percentage = \left(\frac{\#experimental - \#Provided}{\#Provided}\right) * 100$$

Provided CV Value	Experimental CV Value (While opening)	Comparison Percentage	Provided CV Value	Experimental CV Value (While closing)	Comparison Percentage
0.130			0.130		
0.367			0.367		
0.929			0.929		
1.73			1.73		
2.67			2.67		
4.10			4.10		
5.80			5.80		
8.32			8.32		
11.66			11.66		
15.17			15.17		

Table 3: Comparison table for 2 Trials

Once the test is completed, with the values obtained in LabVIEW create a graph to show the change in pressure and flow rate. Also create a graph to compare the flow rate and the stepper motor settings (Open percentage).

The test will consist of closing (100% to 0%) and opening (0% to 100%) the valve. Repeat this procedure, three consecutive times to measure the accuracy of the obtained results.

3 Experimental Procedure

The following section outlines the test procedure used. Moreover, the section outlines the specific roles of all test personnel.

3.1 Labview Operation

3.1.1 Ensure all wires to PTs', TCs', flow meters, valves electric motor and pump are properly connected.

3.1.2 Turn on power supply to Pts' amplifiers and valves electric motors.

3.1.2.1 Allow ten minutes for PTs' amplifiers to warm up

3.1.3 While on the desktop of the testing computer, open the LabVIEW file titled "Water_set_up.vi"

3.2 Test Set-Up Preparation

The following section outlines the steps/actions needed prior to testing.

Gas Leak Test

3.2.1 All valves are closed.

3.2.2 Connect the air compressor to system through BV-6 with a quick connection, and turn on compressor, set regulated pressure to 40 plus minus 5, open valve.

3.2.3 Open TA-1

3.2.3.1 Pressurize system gradually.

a. Start around 40 PSI and gradually move to a higher pressure. (Max Pressure: 100 PSI) Monitor PT-1, PT-2, and PT-3.

3.2.4 Start adding snoop through all fittings.

Note: Downstream of BV-3, BV-6, BV-5, GV-1, and upstream of BV-1 are open to atmosphere. In these sections of the system there is no need to put snoop. Any leaks in these sections will be seen once water starts flowing. Also, the section between BV-4 and GV-1(flowmeter bypass) should never be open when pressurizing with air, any possible leaks in this section will be seen once water starts flowing.

3.2.4.1 If no bubbles form, proceed to next step **3.2.5**.

3.2.4.2 If bubbles start forming.

a. Close BV-6, and disconnect compressor.
b. Gradually open BV-6 to depressurize system.
c. Use a wrench to tighten any fitting that leaks.

d. Restart procedure from step **3.2.1**.

3.2.4.3 If after the fitting was tighten twice, bubbles don't stop forming.

a. Close BV-6, and disconnect compressor.
b. Gradually open BV-6 to depressurize system.
c. Remove the fitting that is leaking.
d. Replace fitting with a new one or replace Teflon.
e. Reinstall fitting into the system using a wrench.
f. Restart procedure from step **3.2.1**.

3.2.5 Looking at the TA-1 section.

3.2.5.1 If no bubbles start forming proceed to step **3.2.6**.

3.2.5.2 If bubbles form at the sanitary.

3.2.5.3 Disconnect sanitary fitting.

3.2.5.4 Replace seal with a new one.

3.2.5.5 Reconnect sanitary fitting.

3.2.5.6 Restart procedure from step **3.2.1**.

3.2.6 Close BV-6

3.2.6.1 Disconnect compressor.

3.2.6.2 Open BV-6 slowly and depressurize system. Monitor PT-1, PT-2 and PT-3 until they read ambient pressure.

3.2.6.3 Close BV-6

3.3 System priming, leak checking and test procedure

3.3.1 Fill up tank with water until it reaches the 90-gal mark.

3.3.2 Open BV-1 and BV-3 fully. All other valves should remain closed.

3.3.3 Open BV-6 until water starts coming out.

3.3.3.1 Close BV-6

3.3.4 Turn on pump. Water should be circulating the system.

3.3.4.1 If no water leakage is detected proceed to step **3.3.5**.

3.3.4.2 If water leakage is detected.

a. Turn off pump
b. Use a wrench to tighten fitting.
c. Restart procedure from step **3.3.2**.

3.3.4.3 If water leakage persists from previously tighten fittings after tightening it twice.

a. Turn off pump.
b. Close BV-1 and BV-3
c. Drain the water at the system by opening BV-2 and BV-6.

I. Put a clean bucket under both valves when draining.
II. After done draining put water back into the container.

d. Close BV-2 and BV-6.
e. Remove fitting.
f. Either replace fitting or re-do Teflon installation (depending on the type of fitting).
g. Restart procedure from step **3.3.2**.

3.3.5 Open TA-1 and BV-5

3.3.5.1 If no water leakage is detected proceed to step **3.3.6**.

3.3.5.2 If water leakage is detected.

a. Turn off pump
b. Use a wrench to tighten fitting.
c. Restart procedure from step **3.3.2**.

3.3.5.3 If water leakage persists from previously tighten fitting after tightening it twice.

a. Turn off pump.
b. Close BV-1 and BV-3
c. Drain the water at the system by opening BV-2 and BV-6.
   I. Put a clean bucket under both valves when draining.
   II. After done draining put water back into the container.
d. Close BV-2 and BV-6.
e. Remove fitting.
f. Either replace fitting or re-do Teflon installation (depending on the type of fitting).
g. Restart procedure from step **3.3.2**.

3.3.6 Gradually open BV-4 to protect flowmeter from over spinning.

3.3.7 Gradually open GV-1 to protect flowmeter from over spinning.

3.3.7.1 Flow meter should now be reading flow rates and system should be fully primed.

3.3.7.2 If no water leakage is detected proceed to step **3.3.8**.

3.3.7.3 If water leakage is detected.

a. Turn off pump
b. Close BV-1 and BV_3
c. Use a wrench to tighten fitting.
d. Restart procedure from step **3.3.2**.

3.3.7.4 If water leakage persists from previously tighten fitting after tightening it twice.

a. Turn off pump.
b. Close BV-1 and BV-3
c. Drain the water at the system by opening BV-2 and BV-swswe 6.
   I. Put a clean bucket under both valves when draining.
   II. After done draining put water back into the container.
d. Close BV-2 and BV-6.
e. Remove fitting.
f. Either replace fitting or re-do Teflon installation (depending on the type of fitting).
g. Restart procedure from step **3.3.2**.

3.3.8 Adjust the amount BV-3 is open until PT-1 and PT-2 starts reading 100±5 psi.

3.3.9 **RV-1 will open if the system pressure exceeds 125 PSI. If at any moment RV-1 opens.**

3.3.9.1 **Turn off pump and investigate why the system is over pressurized (Max pressure 100±5 PSI).**

3.3.9.2 **Restart procedures from step 3.4.1.**

3.3.10 Adjust positioning of TA-1 at the required percent open stated at the test matrix (table 1 and table 2).

3.3.10.1 Adjust the amount BV-3 is open until PT-1 and PT-2 starts reading 100±5 psi.

3.3.11 Start recording for 1 minute using PT-1, PT-2, PT-3 PT-4 and FM-2.

3.3.11.1 Adjust TA-1 to next position required from test matrix.

3.3.11.2 repeat step **3.3.10.1** until all positions and repetitions stated at the test matrix are complete.

3.3.12 Once test matrix is complete.

3.3.13 Open BV-5

3.3.14 Close GV-1

3.3.15 Close BV-4

3.3.16 Fully open BV-3

3.3.17 Turn off pump.

3.4 System Drainage

3.4.1 Close BV-1.

3.4.2 Open BV-2 and BV-6 to drain piping

3.4.2.1 Put a clean bucket under valves or connect hose to the valves.

3.4.2.2 Leave BV-2 and BV-6 open until water stops coming out.

3.4.2.3 Close BV-2 and BV-6.

3.4.3 Remove bypass.

3.4.3.1 Put bypass over bucket or drainage to dry.

3.4.3.2 Open BV-4 and GV-1 slowly to let water out of the piping.

3.4.4 Connect air gun to air compressor

3.4.4.1 Dry system (this does not include bypass).

3.4.5 Close all valves

3.4.6 Connect hose to BV-2.

3.4.7 Open BV-1 and BV-2.

3.4.7.1 Hose should be lead to specified drainage area for the water.

3.4.7.2 If water remains in the container.
a. Carefully place jack under the car and tilt system.

3.4.8 Using air gun and compressor.

3.4.8.1 Blow air through the system until dry.

3.4.9 On the Bypass section, close BV-4 and GV-1.

3.4.9.1 Reconnect bypass to system.

3.4.10 Test Completed

3.4.10.1 If test needs to be performed again start procedures form the gas leak check section.

4 Hazardous Analysis

HA #	System	Hazard	Severity	Likelihood	HA Index	Mitigation
1	Controls	Program 4Failure	1 – Minor	2 – Infrequent	1	Double check connections before the test begins.
2	Controls	Electric Shock	3 – Significant	1 – Unlikely	1	Ground electrical components. Check for disconnected connections. Keep wiring away from possible leak places.
3	Line	Water Spill	2 – Minor	5 – Highly likely.	1	Ensure water is at the limit line marked on the set up. Eliminate all possible leaks in the system.

Appendix C

HABONIM
Industrial Valves & Actuators

Inspired By Challenge

Technical Information
Valve torques

Standard soft seat

Metal seated (MTM)

Cryogenic

Trunnion

Introduction

The operating torque of the ball valve is influenced by a number of factors.
Some are design - related such as:

- Initial preload determined by the designer
- Production tolerance allowed
- Flexibility of the seat design
- Contact surface between the ball and the seat

Some are material - related, such as the COF (coefficient of friction) of the seat.
Others are application - related such as:

- System pressure
- Media (dry, lubricant, abrasive, etc.)
- Temperature
- Frequency of operation

The torque required to operate a ball valve is a function of friction between the valve's metal parts and its soft sealing materials.
The friction points in a floating ball valve are the stem and the ball/seat.

Stem torque

When tightening the stem nut to compress the stem sealing, the friction between the stem assembly parts is increased, which generates the stem torque.
Proper adjustment of the stem nut is important to valve performance and service life. If the nut is too loose, the probability of stem leakage is increased. If the nut is too tight, the stem torque will be higher and will increase the general torque of the valve – which might result in faulty actuator sizing.
Thus, it is very important to follow the stem adjustment instructions specified in each product IOM.
Since the friction area between the metal and soft parts in the stem is relatively low, the operating conditions will have a minor influence on the stem torque.

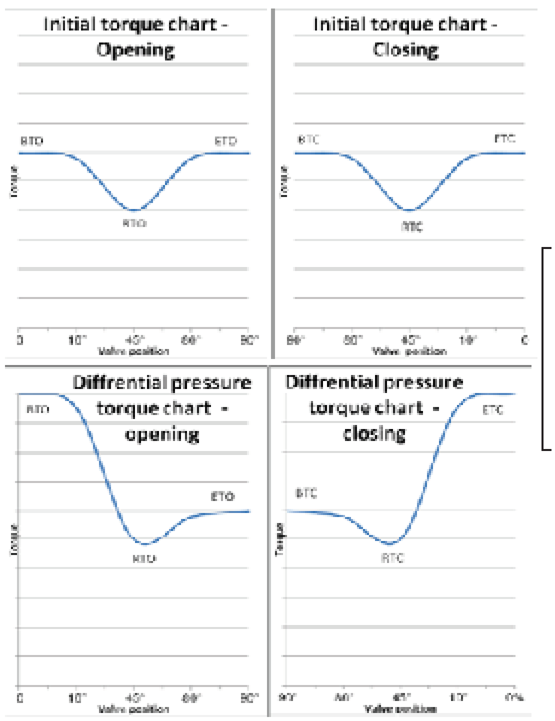
Ball / Seat torque

The friction between the ball and the seat is responsible for most of the valve torque.
The valve's initial ball/seat torque is a function of the seat preload (determined by the designer) and the seat material.
The relative high friction areas , together with the floating ball design concept that allows the system pressure to force the ball into the downstream seat, causes the ball/seat torque to be very sensitive to service conditions in general and to the system pressure in particular.

When analyzing the torque characteristics during valve operation it is common to distinguish between two different characteristics:

- **Initial torque characteristic**
  When low differential pressure or no pressure is applied on the valve.
  In this case, the Break To Open (BTO) torque and End To Open (ETO) torque are more-or-less the same and are estimated to be 40%-50% higher than the other positions.
  Opening and closing should be considered the same.

- **Differential torque characteristic**
  When differential pressure has a significant influence on the valve breakout torque. In general, Habonim recommends using this characteristic for applications with a differential pressure above 20bar (Class #150).
  In this case, the Break To Open (BTO) torque and End To Close (ETC) torque are more-or-less the same and estimated to be much higher than the other positions. The higher the differential pressure, the higher the BTO/ETC torque.
  The RTO/RTC and ETO/BTC are measured when the pressure is no longer forcing the ball into the seat hence the torque value in those positions will be considered the initial torque values.



BTO - Break To Open
RTO - Run To Open
ETO - End To Open
BTC - Break To Close
RTC - Run To Close
ETC - End To Close

Habonim pressure-torque curves

Before the actuator can be sized for any given valve application, the amount of torque required by the valve must be determined. The valve torque curves in this catalog show the breakout torque (BTO) requirements of Habonim ball valves as a function of valve size, seat material and differential pressure across the valve when the ball is in the closed position.
All pressure-torque curves herein are the result of both theoretical calculations and laboratory testing using water and nitrogen at ambient temperature.
Since the values on the pressure-torque curves are an average of several measures, 20% should be added as a safety factor for pneumatic actuators in standard services.
To enhance the accuracy of the torque values for specific service conditions, correction factors are applied for different applications. The correction factors are adequate for the vast majority of applications.
If your application is not on the list please consult with Habonim engineers.
Warning: The maximum torque shown in the below graphs correlates to the Material / Series limitation. Do no attempt to extrapolate it to higher torque figures.

Correction factors

Note: Use the correction factors below **instead** of the standard safety factor and not on top of it.

Corrections factors - special application

Emergency shut-down (ESD) service	1.8
IEC 61508 SIL complaint installation	1.8
Cryogenic applications (below -60 °C)	1.5
Valves operated less than once a day	1.5
Control valves	1.5

Corrections factors - Media

Gas, dirty (natural gas)	1.5
Gas , dry	1.3
Chlorine	1.5
Viscous slurry (cp>100)	2.0
Oil, thermal oil, lubricant	0.8

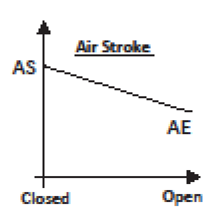
Actuator sizing instructions

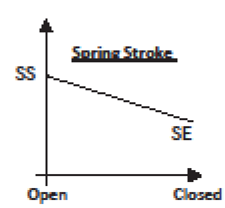
The sizing instructions below are suitable for Habonim's Compact actuator as well as for any pneumatic rack & pinion actuator.

- Given the valve size, differential pressure across the valve, and the seat material. look up the valve break-out torque (BTO) from the appropriate pressure-torque curves in this chapter.
- Consider this value to be T1
- Using the same curve, look up the valve torque at ΔP=0. Consider this value to be T2.
- If the application requires a correction factor then multiply T1 and T2 by the correction factor (according to the list above). If a correction factor is not required then add the standard safety factor (20%). The Values after factor addition will be T'1 and T'2.
- To size an actuator make sure that all the conditions in the table below are fulfilled.

	Condition 1	Condition 2
DA	$T > T'_1$	-
SR - Fail Close	$T_{AS}, T_{SE} > T'_1$	$T_{SS}, T_{AE} > T'_2$
SR - Fail Open	$T_{SS}, T_{AE} > T'_1$	$T_{AS}, T_{SE} > T'_2$

T_{AS} - Air Start Torque
T_{AE} - Air End Torque
T_{SS} - Spring Start Torque
T_{SE} - Spring End Torque





Valve torques	Actuator sizing	Standard soft seat	Metal seated (MTM)	Cryogenic	Trunnion

Example 1:

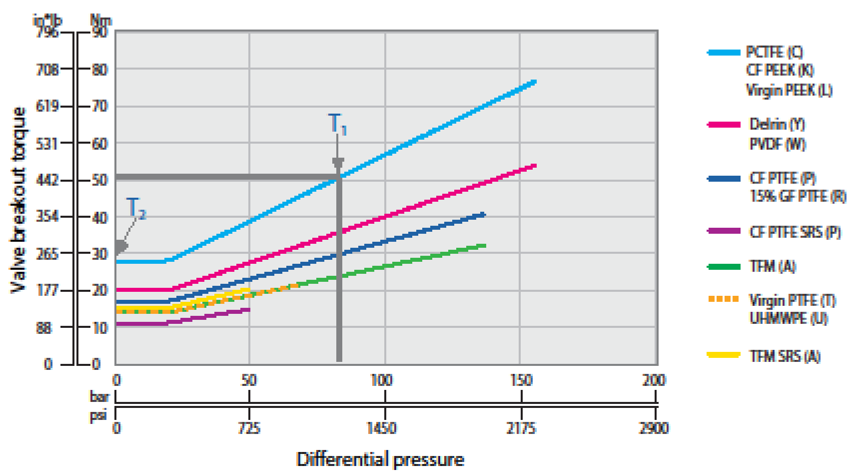
Given the following information:

- Application: Nitrogen
- Valve series 47X (Standard port)
- Seat: PEEK (K)
- Maximum differential pressure - 80 bar.
- Actuator type - SR (Spring return) - Fail Close
- Actuator air supply - 5.5 bar (80PSI)

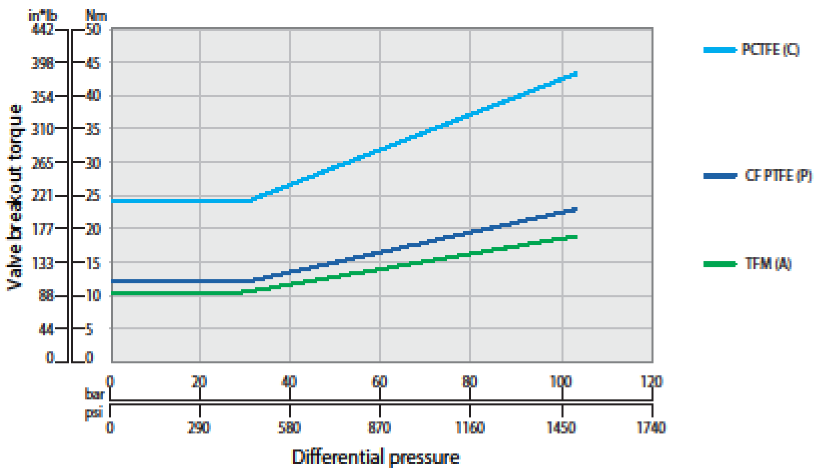
Sizing steps:

1. Determination of T_1 and T_2:
   According to the pressure-torque curve suitable for the series , size and seat:
   T_1 =50Nm ; T_2= 28Nm
2. Correction factor:
   Since the media is dry nitrogen a correction factor 1.3 should be added to the torque values Hence: T'1 =65Nm ; T'2= 36.4 Nm.
3. Actuator sizing
   Since this application require SR, FC actuator , the sizing criteria should be.
   $T_{AS}, T_{SE} > T'_1$
   $T_{SS}, T_{AE} > T'_2$
   a. Search the spring end (T_{SE}) column for the first torque greater than T'_1.
      In this example, the first actuator to meet $T_{SE} > T'_1$ (65Nm) is C30M SR-3.
   b. Once found, check the remaining parameters, If one of them is not fulfilled move to the next actuator.
      In this example, Other parameters on this actuator are not applicable (T_{AS} - N/A, T_{AE} - N/A) hence, the next actuator should be examined.
   c. Repeat stages a. and b. until you find the actuator that complies with all the required conditions.
      In this example, the next actuator to meet $T_{SE} > T'_1$ (65Nm) is C35 SR-2C.
      The parameters on this actuator:
      T_{AS}=133Nm, T_{SE}=73Nm both greater than T'_1 =65Nm
      T_{SS}=137Nm, T_{AE}=68Nm both greater than T'_2 =36.4Nm
      hence, C35 SR-2C will be the properly sized recomended actuator.

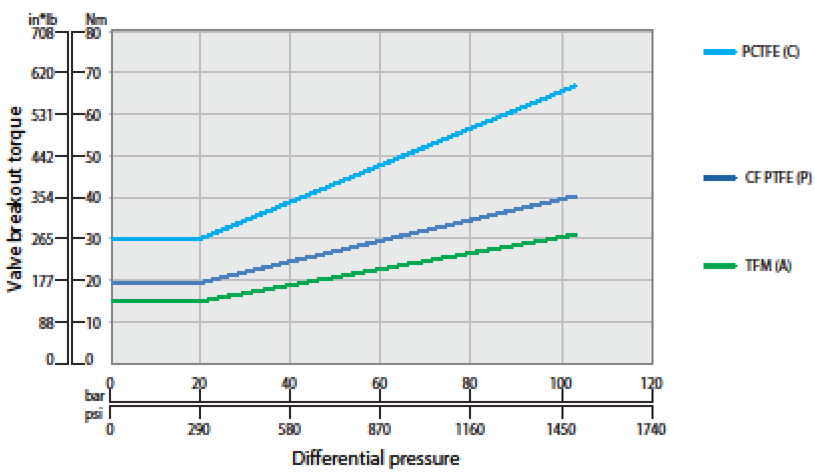
Pressure class: #900 | Standard port: 1½" (DN40) | Full port: 1¼" (DN32) | 47 Series



Pressure class: #600 | Standard port: 1" (DN25) | Full port: ¾" (DN20) | 47C Series



Pressure class: #600 | Standard port: 1¼" (DN32) | Full port: 1" (DN25) | 47C Series



Appendix D

HABONIM
Industrial Valves & Actuators

Inspired By Challenge

FN47W Series 3-Piece Ball Valves
Installation, Operating & Maintenance

Sizes Included:
½" - 4" (DN15 - DN100)

1. GENERAL

This Installation, Operating & Maintenance manual present the instructions required for safe use of Habonim 3-piece ball valves type FN47W series. The manual relates to reduce bore and full bore. Before using any of these series valves, read the entire IOM carefully and make sure you understand everything. Where in doubt, please consult with Habonim.

WARNINGS & SAFETY INSTRUCTIONS

Habonim cannot anticipate all of the situations a user may encounter while installing and using Habonim valves. The user **MUST** know and follow all applicable industry specifications on the safe installation and use of these valves. Misapplication of the product may result in injuries or property damage. Refer to Habonim product catalogues, product brochures and installation, operating and maintenance manuals for additional product safety information or contact Habonim.

1. Keep hands and objects away from the valve ports at all times. Actuated valves could be accidentally operated, resulting in serious injury or valve damage.
2. Before removing a valve from the line, always make sure the line has been depressurized and drained. Cycle the valve a few times to relieve any pressure that could be trapped in the body cavity.
3. Utmost caution must be taken when handling a valve that has toxic, corrosive, flammable or a contaminant nature media flowing through its pipeline. The following safety precautions are recommended when dismantling valves with hazardous media:
   d. Wear eye shield, protective headgear, clothing, gloves and footwear.
   e. Have available running water.
   f. Have a suitable fire extinguisher when media is flammable.
4. Do not try to operate a valve that exhibits any sign of leakage. Isolate the valve and either repair or replace it.
5. Do not use or substitute non Habonim components or parts in Habonim valves and assemblies.

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1. LIMITATIONS

The correct selection of materials of construction, seats and seals, internal valve components and pressure/temperature ratings determines the safe use of the valves and the particular performance requirements for the application. This information can be found on the nameplate welded to the valve body.

As the extent of applications that these valves can be used in, is large, it is not possible to cover all installation and maintenance instructions for service of the valves. It is the user's responsibility to use the valves as recommended and in accordance with the pressure and temperature limits as stated in this manual. Where in doubt, please consult with Habonim.

Any unstable fluid or gas should be identified by its manufacturer and must not be used with Habonim valves.

CAUTION:

The valves should be used in a well designed, adequately protected system to ensure that external and internal pressure and temperature limits do not exceed the valve limits.

The valve body rating can be higher than the seat rating.

Valve surface temperature may become extremely hot or cold due to ambient or operating conditions. Prevent any type of direct contact with the valve that may cause harm or injury .Avoid direct contact with the valve by wearing protective gloves.

The valves should be used in a well designed, adequately supported piping system such that it will not be subjected to undue forces, stresses or shock loads during service.

The valves are not designed to operate during or after earthquakes or under fatigue conditions. It is the responsibility of the owner to determine if fatigue conditions exist.

Do not allow dust layers to build up on the equipment.

The process fluid temperature shall not exceed the ignition temperature of the dust.

2. SIL

Under normal operating conditions the Habonim valve should be inspected for proper functioning and signs of deterioration every 50,000 cycles or 6 months (whichever comes first). Under severe operating conditions inspection should be more frequently; detected defects should be repaired promptly.

Severe operating conditions can be defined as:

- Application temperature less than -20 deg C
- Application temperature higher than +230 deg C
- Flow velocity higher than 5 m/sec for liquids, and 200 m/sec for gaseous
- Acidic media PH < 5 or alkaline media PH > 9

Habonim recommend a proof test interval of 12 months; in case of Fail to Open ESD system, a partial stroke is acceptable to confirm that the installation is functioning properly.

For ESD systems with a Fail-To-Close demand, it is necessary to plan a system shut-down; de-energize the system and inspect the valve turning to its fully closed position.

It is essential to log-in the following parameters on site QA records as a proof for preserving SIL capabilities: date, hour, name and signature of the responsible engineer, air pressure on site, time to close the valve, time to open the valve.

Habonim recommend valve full maintenance operation every 500,000 cycles or 4 years, whichever comes first (refer to Para. 7 in this IOM for maintenance instructions). The combined corrosion and erosion allowance for the valve body wall thickness is 1 mm. When this allowance has been eroded or corroded, mechanically removed or otherwise, the valve should no longer be used. Inspect the valve wall thickness every time the valve is maintained.

The estimated mean time to repair (MTTR) a valve, i.e. time net (line draining or cooling down time excluded from the valve MTTR) of replacing old valve with a new one is 60 minutes. Maintenance team must read and understand the Habonim product IOM before starting the operation. In case of a doubt please consult the Habonim engineering team.

When a valve has been repaired or any maintenance was performed, check the valve for proper function (proof testing). Any failures affecting functional safety should be reported to the Habonim factory.

Client should consult the Habonim factory in order to obtain the product assessment, FMEDA report, and other associated statistical data to satisfy SIL level.

Special condition for safe use

When connected to an actuator the maximum rubbing speed of any component within the valve must not exceed 1ms-1.

3. STORAGE

Prior to storage, inspect the valve for shipping damage. Keep all protective packaging, flange covers and end caps attached to the valves during storage. It is recommended to keep the valves in a clean and dry environment until ready for use.

Carbon Steel valves have a "black oxide" and oil dipped finish. This nontoxic process is performed to retard rusting during storage. It is not a substitute for paint or other means of protective coating to be applied to the valve once installed.

Stainless steel valves have their natural finish and do not require additional protection once installed.

4. OPERATING INSTRUCTIONS

Habonim Valves provide tight shut off when used under normal conditions and in accordance with Habonim's published pressure/temperature chart. If these valves are used in a partially open (throttled) position, seat life may be reduced. Consult with Habonim for the proper seat material selection.

Valve operation works by operating the valve handle 90° turn anti-clockwise to open, and 90° turn clockwise to close. On manually operated valves the valve is open when the handle or stem flats are parallel with the pipeline and closed when the handle or stem flats are perpendicular to the pipeline.

All standard valves are bidirectional and as such, can be installed for flow in either direction. Valves which are unidirectional will have a flow direction arrow welded to the body and separate assembly instructions.

A silicone-based lubricant is applied to assist valve break in. The lubricant, if unacceptable, may be removed by a solvent wash.

If a shut-off valve is installed for end of line service, it must be ensured that it is closed with a blind end connection and the valve is secured against being opened unintentionally.

WARNING: Never look into the valve bore while the valve is in a flowline. Pressure and fluids could escape from the valve causing bodily injury.

To prevent leakage, malfunctions resulting from internal

wear or seal degradation, the user must establish a preventive maintenance and inspection program. This program must

include:

a. Inspection of parts to detect loss of wall thickness which may result in decreased pressure capacity (see para. 2 for acceptable reduction of wall thickness).
b. Routine replacement of seals and inspection for proper operation (See **para. 7** for maintenance instructions).

Valve operating torques as published in the Habonim literature are the normal expected maximum break-away torques. These torques have been confirmed by laboratory testing of each valve under controlled conditions. Highly viscous or abrasive media, frequency of operation and temperature fluctuations could cause an increase in valve torque.

3. INSTALLATION

The installation procedure for ball valves is critical to ensuring both long life and satisfactory performance. Valves stored on site awaiting installation should be kept in their original packing, in dry conditions, where damage will not occur (see **para. 4**). Before carrying out the installation, it is important to follow the basic procedures described below:

5.1. General

5.1.2. Carefully unpack the valve and check valve nameplate for identification of materials (see **Figure 2**).

5.1.3. Remove any special packing materials, which were used for packing.

5.1.4. Check the valve for any flow direction indication marks. Appropriate care must be taken, to install the valve for proper flow orientation.

5.1.5. Inspect the valve interior through the end ports to determine it is clean and free from foreign matter.

5.1.6. Cycle the valve and inspect any functionally significant features.

5.1.7. Read all the literature and note any special warning tags or plates attached to the valve.

5.1.8. Before installation check to insure the ball is in the fully open position in order to prevent possible damage to the ball and seats. The valve performance depends on its original conditions. At any stage do not leave the valve in the partially open position.

5.2. Threaded End Valves

5.2.3. Valves with threaded ends should be treated as a single unit and should not be dismantled when installing to pipeline.

5.2.4. Before installing the valves, make sure that the threads on the mating pipe are free from excessive grit, dirt or burrs.

5.2.5. When tightening the valve, apply a pipe wrench or spanner to the end connector closest to the pipe being worked, using standard piping practices.

5.2.6. Use appropriate joining sealants material in correct quantities.

5.2.7. If "back-welding" is required on threaded end valves, refer to the instructions for Weld End valves or to the "Habonim Welding Instructions" bulletin.

5.3. Weld End Valves in-line

5.3.1. Welding of valves shall be performed by a qualified person according to the ASME Boiler Construction Code Section IX. For valves to be welded within the EEA, refer to the requirements of ESR 3.1.2 of the Pressure Equipment Directive 97/23/EC.

5.3.2. Valves with Delrin® or UHMWPE seats must be disassembled before welding in line. For more information on recommended welding procedures or seat materials, please consult with Habonim.

5.3.3. Valves that will be welded directly to the line must be in the fully open position to protect the ball and seats from excessive temperatures during the welding procedures (aside those mentioned in **Para. 6.3.2**).

5.3.4. It is recommended to remove the valve wrench during the welding procedure. Protect or remove actuators from weld splatter or arc strikes. Valves in the "Fail Close" position should be cycled to the open position.

5.3.5. Use a temperature stick and a wet cloth wrapped around the center section to prevent overheating. DO NOT heat the center section over 150°C (300°F).

5.3.6. Align valve to pipe line, ensuring proper fit to minimize pipe load. Tack weld only.

5.3.7. Complete welding in small segments. Allow enough time for cooling between each segment.

5.3.8. After completing the welds, wait for the valve to cool below 90°C (200°F). Tighten the body bolts to torque figures and tightening patterns according to **Figure 1**.

5.3.9. Replace the wrench or actuator. It is recommended not to rotate the valve to the closed position before flushing the line.

5.4. Weld End Valves not in-line

5.4.1. Welding of valves shall be performed by a qualified person according to the ASME Boiler Construction Code Section IX. For valves to be welded within the EEA, refer to the requirements of ESR 3.1.2 of the Pressure Equipment Directive 97/23/EC.

5.4.2. Valves that will be disassembled before welding carry a packet with replacement body seals. Follow steps 2 to 9 of the DISASSEMBLY section but to not discard of the seat rings.

5.4.3. Prior to welding the ends to the pipe, make sure their flats are aligned to the body flats (see **NOTE** in **page 6**).

5.4.4. Do not scratch or cut the seats and sealing surfaces of the valves as this will cause valve leakage.

5.4.5. Assemble the valve without the ball and seats and follow steps 1 to 7 for Weld End Valves.

5.4.6. After the valve cools down, follow again steps 2 to 9 of the DISASSEMBLY section and section 7 to 13 of the ASSEMBLY section.

6. MAINTENANCE

HABONIM valves have a long and trouble free life, and maintenance is seldom required. When maintenance is necessary, valves can be refurbished on site.

To extend valve performance and reduce possible plant problems, the following procedures should be followed:

6.1. If leakage at the stem is noted, tighten the gland nut about a 1/6-turn as a routine maintenance procedure. This will compensate for any wear or settling of the gland packing.

6.2. Caution: Excessive tightening of the stem nut can result in accelerated seal wear and high valve operating torque.

6.3. If the valve is removed from the line and disassembled, replacement of all seats and seals is recommended using the appropriate Habonim Repair kit. Examine all metallic sealing surfaces such as ball, stem, and the surfaces on the end connectors that contact the seats for wear, corrosion or damage.

6.4. Only Habonim's authorized spare parts should be used. Repair kits from Habonim consist of the following:

V-Ball Type:	V-Port Type:
2 x seats	1 x seat
1 x stem packing	1 x stem packing
1 x stem thrust seal	1 x stem thrust seal
1 x anti-abrasion ring	1 x anti-abrasion ring
2 x body seals	3 x body seals

6.5. In addition to repair kits, other spare parts available from Habonim are: valve balls, stems, screws and nuts. Should additional parts be required, it is recommended that the complete valve be replaced.

6.6. When ordering repair kits, please provide the valve size and full figure number code and series.

7. DISASSEMBLY

7.1. The following instructions are for disassembly of V-Ball valves sizes ½" to 2 ½" (DN15-DN65)

7.1.1. Cycle the valve with the line pressure fully relieved before attempting to remove the valve from the pipeline, to ensure pressure has also been discharged from the valve cavity.

7.1.2. Bring the valve to the open position. Warning: trying to remove the valve body from the line in the closed position will damage the ball.

7.1.3. With the valve in the open position, remove all 8 body bolts.

7.1.4. Bring out the body center section.

7.1.5. Remove and discard the seats and body seals. Be careful not to damage the sealing surfaces.

7.1.6. Support the ball to prevent it from falling out of body and turn valve to the closed position for its removal. Set the ball aside in a clean secure area for reuse.

7.1.7. Remove the locking clip, stem nut, disk springs, follower, slide bearing and anti-abrasion ring. Place all components removed in a clean secure area.

7.1.8. Push the stem down into the body and remove it. Discard the stem thrust seal, and stem packing. Care should be taken to not scratch or nick the stem bore area of the body. Clean the stem and stem bore area.

7.2. The following instructions are for in-line disassembly of V-Port valves sizes ½" to 2 ½" (DN15-DN65)

7.2.1. Refer to items 8.1.1 to 8.1.4

7.2.2. Remove and discard the soft seat, locating pin, V-Port seat and body seals. Be careful not to damage the sealing surfaces.

7.2.3. Refer to items 8.1.7 to 8.1.8

7.3. The following instructions are for disassembly of V-Ball valves sizes 3" to 4" (DN80-DN100).

7.3.1. Cycle the valve with the line pressure fully relieved before attempting to remove the valve from the pipeline, to ensure pressure has also been discharged from the valve cavity.

7.3.2. Bring the valve to the open position. Warning: trying to remove the valve body from the line in the closed position will damage the ball.

7.3.3. With the valve in the open position, remove all 16 body bolts.

7.3.4. Bring out the body center section.

7.3.5. Remove and discard the seat support, seats and body seals. Be careful not to damage the sealing surfaces.

7.3.6. Support the ball to prevent it from falling out of body and turn the valve to the closed position for its removal. Set the ball aside in clean secure area for reuse.

7.3.7. Carefully loosen the tab lock washer using a screw driver, and remove the stem nut, tab lock washer, disk springs, follower, slide bearing and anti-abrasion ring. Place all the components in a clean secure area.

7.3.8. Push the stem down into the body and remove it. Discard the stem thrust seal, and stem packing, taking care not to scratch or nick the stem bore area of the body. Clean the stem and stem bore area.

7.4. The following instructions are for disassembly of V-Port valves sizes 3" to 4" (DN80-DN100).

7.4.1. Refer to items 8.3.1 to 8.3.4

7.4.2. Remove and discard the soft seat, locating pin, V-Port seat and body seals. Be careful not to damage the sealing surfaces.

7.4.3. Refer to items 8.3.7 to 8.3.8

8. ASSEMBLY

The following instructions are for assembly of V-Ball valves, sizes ½" to 2 ½" (DN15-DN65)

8.1. Lubricate the new stem thrust seal, anti-abrasion ring and stem packing with an appropriate lubricant (Molykote 33 - thin smear). Place the stem thrust seal on the stem.
8.2. Insert the stem horizontally into the center of the body with the threaded side first and carefully guide it up through the stem bore.
8.3. Holding the stem up, insert the new stem packing over the stem and into the stem bore. Place the anti-abrasion ring, slide bearing, follower and two disk springs onto the stem. The first spring convex side down and the second spring convex side up.
8.4. Thread the stem nut onto the stem. Tighten the stem nut to the appropriate torque value (table 1).
8.5. Place the locking clip on the stem nut by adjusting the orientation of the nut (in the clockwise direction).
8.6. Bring the valve to the closed position to insert the ball.
8.7. Place the ball in the center of the body until the stem tongue is engaged and bring the valve to the open position to prevent the ball from falling out.
8.8. Place the new body seals and new seats in the body.
8.9. Ease the body assembly back between ends, taking care not to score faces or damage seals, and reinstall the body bolts.
8.10. To prevent galling of bolt thread, lubricate the threads with an anti-galling compound.
8.11. Tighten the body bolts to the appropriate torque values (table 2), and according to the tightening pattern illustrated in figure 1.
8.12. Leave the valve in the open position for flushing the line.

The following instructions are for assembly of V-Port valves sizes ½" to 2 ½" (DN15-DN65)

8.13. Refer to items 9.1 to 9.7
8.14. Place V-Seat, location pin, new body seals and new soft seat in the body.
8.15. Refer to items 9.9 to 9.12

The following instructions are for assembly of V-Ball valves sizes 3" to 4" (DN80-DN100)

8.16. For V-Ball valves, refer to items 9.1 to 9.3
8.17. Place the tab lock washer on the stem and thread the stem nut. Tighten the stem nut to the appropriate torque values (table 1).
8.18. Carefully secure the stem nut by bending tab lock washer while adjusting the orientation of the nut (in a clockwise direction).
8.19. Bring the valve to the closed position to insert the ball.
8.20. Place the ball in the center of the body until the stem tongue is engaged and bring the valve to the open position to prevent the ball from falling out.
8.21. Place the new body seals, new seats and seat support in the body.
8.22. Refer to items 9.9 to 9.12

The following instructions are for assembly of V-Ball valves sizes 3" to 4" (DN80-DN100)

8.23. Refer to items 9.1 to 9.3
8.24. Refer to items 9.17 to 9.20
8.25. Place V-Seat, location pin, new body seals and new soft seat in the body.
8.26. Refer to items 9.9 to 9.12

TABLE 1

Stem Nut Tightening Torque

Reduced Ball	Full Bore	Nut Thread	Tightening Torque	
			Nm	in.lb
1/2"	1/4",3/8"	3/8"-24 UNF	4	35
3/4"	1/2"	3/8"-24 UNF	4	35
1"	3/4"	7/16"-20 UNF	9	80
1 1/4"	1"	7/16"-20 UNF	9	80
1 1/2"	1 1/4"	9/16"-18 UNF	13	115
2"	1 1/2"	9/16"-18 UNF	13	115
2 1/2"	2"	9/16"-18 UNF	13	115
3"	2 1/2"	1" - 14 UNS	60	530
4"	3"	1" - 14 UNS	60	530
	4"	1" - 14 UNS	60	530

These torque figures are applicable on other stem packing materials such as carbon filled PTFE, UHMWPE and TFM.

IMPORTANT:

An excessively tightened stem nut can cause excessive packing wear and increase stem torque.

TABLE 2

Body Bolt Tightening Torque

Reduced Ball	Full Bore	Nut Thread	Tightening Torque	
			Nm	in.lb
1/2"	-	M8	18	160
3/4"	1/2"	M8	18	160
1"	3/4"	M10	39	345
1 1/4"	1"	M10	39	345
1 1/2"	1 1/4"	M12	65	575
2"	1 1/2"	M12	65	575
2 1/2"	2"	M12	65	575
3"	2 1/2"	1/2" -13 UNC	65	575
4"	3"	M16	160	1420
	4"	M16	160	1420

FIGURE 1

Body Bolt Tightening Pattern

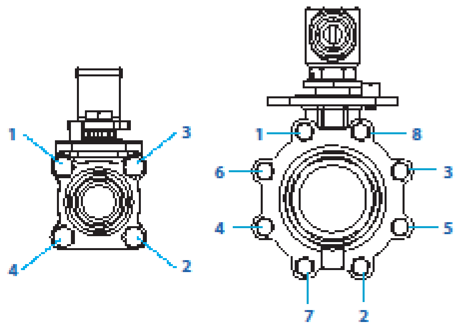
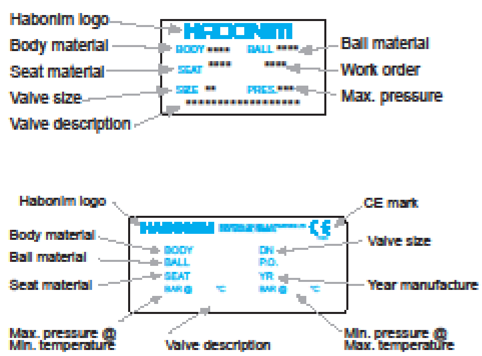


FIGURE 2

Valve Marking and Labeling

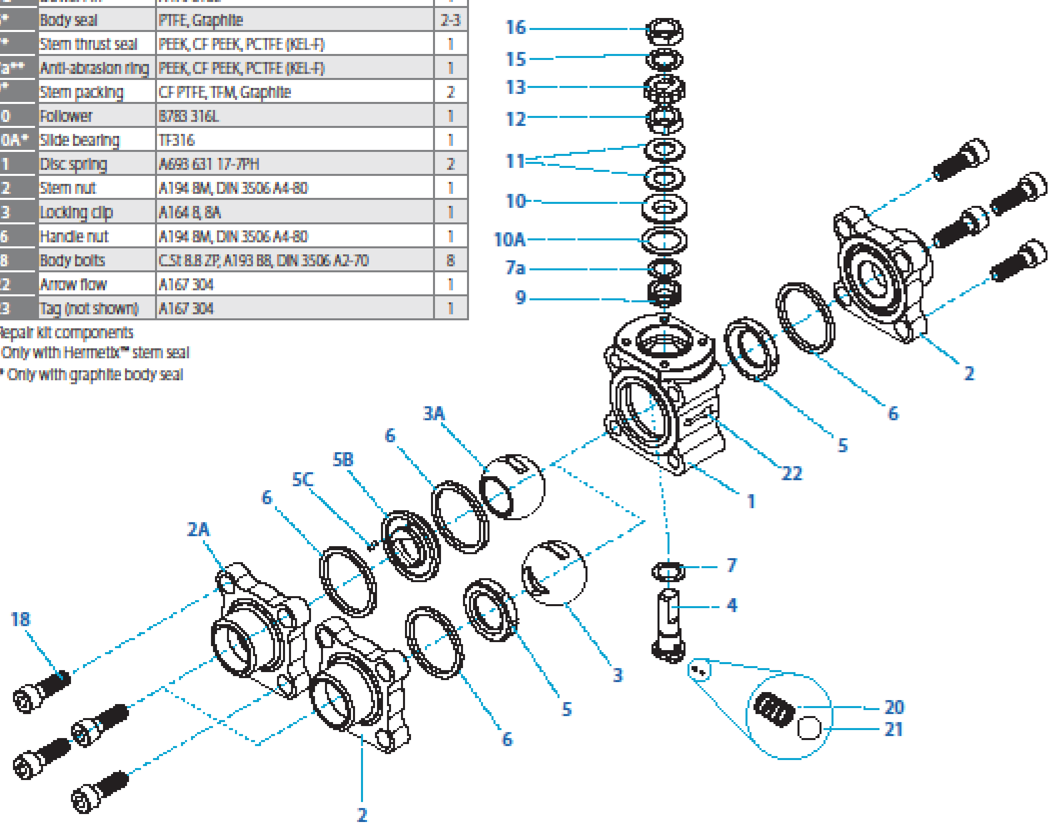
All valves marking is on a nameplate which is spot welded to the valve body. Valves for the European market and above 1" carry the CE mark with the information required by the PED.



½" to 2 ½" (DN15 to DN65)

Item	Description	Material specification	Qty.
1	Body	A351 CF8M, A216 WCB, A105, A351 CN7M, A494 M35-1, A494 CW-12MW, A494 CX-2MW, A351 CK3MCuN,A995 CD3MN 4A, A995CE3MN 5A	1
2	End	A351 CF3M, A216 WCB, A105, A351 CN7M, A494 M35-1, A494 CW-12MW, A494 CX-2MW, A351 CK3MCuN,A995 CD3MN 4A, A995 CE3MN 5A	1-2
2A	V- Port End	A351 CF3M, A216 WCB, A105, A351 CN7M, A494 M35-1, A494 CW-12MW, A494 CX-2MW, A351 CK3MCuN,A995 CD3MN 4A, A995 CE3MN 5A	1
3	V ball	A351 CF8M, B473 N08020, B164 N04400, B574 N06022, B574 N10276, A479 S31254, A479 S31803, A479 S32750	1
3A	Ball	A351 CF8M	1
4	Stem	A564 Gr 630 H1150D 17-4PH, B473 N08020, B164 N04400, B574 N06022, B574 N10276, A479 S31254, A479 S31803, A479 S32750	1
5*	Seat	RPTFE, CF PTFE, PEEK, CF PEEK, DELRIN, PCTFE (KEL-F)	1-2
5B	V seat	A479 316L	1
5C	Dowel Pin	A479 316L	1
6*	Body seal	PTFE, Graphite	2-3
7*	Stem thrust seal	PEEK, CF PEEK, PCTFE (KEL-F)	1
7a**	Anti-abrasion ring	PEEK, CF PEEK, PCTFE (KEL-F)	1
9*	Stem packing	CF PTFE, TFM, Graphite	2
10	Follower	B783 316L	1
10A*	Slide bearing	TF316	1
11	Disc spring	A693 631 17-7PH	2
12	Stem nut	A194 8M, DIN 3506 A4-80	1
13	Locking clip	A164 8, 8A	1
16	Handle nut	A194 8M, DIN 3506 A4-80	1
18	Body bolts	C.St 8.8 ZP, A193 B8, DIN 3506 A2-70	8
22	Arrow flow	A167 304	1
23	Tag (not shown)	A167 304	1

* Repair kit components
** Only with Hermetix™ stem seal
*** Only with graphite body seal



Appendix E

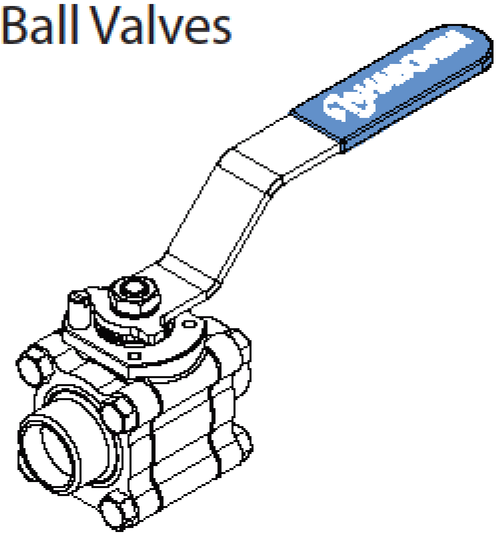
HABONIM
Industrial Valves & Actuators

Inspired By Challenge

47 Series Installation, Operating & Maintenance | 3-Piece Ball Valves

Series included:
47P, AF47P, 47X

Sizes included:
¼” - 8” (DN6 – DN200)



1. GENERAL
This Installation, Operating & Maintenance manual present the instructions required for safe use of Habonim 3-piece ball valves type 47 series. The manual relates to reduce bore and full bore. Before using any of these series valves, read the entire IOM carefully and make sure you understand everything. Where in doubt, please consult with Habonim.

WARNINGS & SAFETY INSTRUCTIONS

Habonim cannot anticipate all of the situations a user may encounter while installing and using Habonim valves. The user **MUST** know and follow all applicable industry specifications on the safe installation and use of these valves. Misapplication of the product may result in injuries or property damage. Refer to Habonim product catalogues, product brochures and installation, operating and maintenance manuals for additional product safety information or contact Habonim.

1. Keep hands and objects away from the valve ports at all times. Actuated valves could be accidentally operated, resulting in serious injury or valve damage.
2. Before removing a valve from the line, always make sure the line has been depressurized and drained. Cycle the valve a few times to relieve any pressure that could be trapped in the body cavity.
3. Utmost caution must be taken when handling a valve that has toxic, corrosive, flammable or a contaminant nature media flowing through its pipeline. The following safety precautions are recommended when dismantling valves with hazardous media:
   a. Wear eye shield, protective headgear, clothing, gloves and footwear.
   b. Have available running water.
   c. Have a suitable fire extinguisher when media is flammable.
4. Do not try to operate a valve that exhibits any sign of leakage. Isolate the valve and either repair or replace it.
5. Do not use or substitute non Habonim components or parts in Habonim valves and assemblies.

I47-10/15

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2. SIL

Under normal operating conditions the Habonim valve should be inspected for proper functioning and signs of deterioration every 50,000 cycles or 6 months (whichever comes first). Under severe operating conditions inspection should be more frequently; detected defects should be repaired promptly.

Severe operating conditions can be defined as:

- Application temperature less than -20 deg C
- Application temperature higher than +230 deg C
- Flow velocity higher than 5 m/sec for liquids, and 200 m/sec for gaseous
- Acidic media PH < 5 or alkaline media PH > 9
- Differential pressure over the valve above 70bar.

Habonim recommend a proof test interval of 12 months; in case of Fail to Open ESD system a partial stroke is acceptable to confirm that the installation is functioning properly.

For ESD systems with a Fail-To-Close demand, it is necessary to plan a system shut-down; de-energize the system and inspect the valve turning to its fully closed position.

It is essential to log-in the following parameters on site QA records as a proof for preserving SIL capabilities: date, hour, name and signature of the responsible engineer, air pressure on site, time to close the valve, time to open the valve.

Habonim recommend valve full maintenance operation every 500,000 cycles or 4 years, whichever comes first (refer to para. 7 in this IOM for maintenance instructions). The combined corrosion and erosion allowance for the valve body wall thickness is 1 mm. When this allowance has been eroded or corroded, mechanically removed or otherwise, the valve should no longer be used. Inspect the valve wall thickness every time the valve is maintained. Refer to Habonim Corrosion Data Chart T-614 to determine the corrosion rate for your application.

The estimated mean time to repair (MTTR) a valve, i.e. time net (line draining or cooling down time excluded from the valve MTTR) of replacing old valve with a new one is 60 minutes. Maintenance team must read and understand the Habonim product IOM before starting the operation. In case of a doubt please consult the Habonim engineering team.

When a valve has been repaired or any maintenance is performed, check the valve for proper function (proof testing). Any failures affecting functional safety should be reported to the Habonim factory. Client should consult the Habonim factory in order to obtain the product assessment, FMEDA report, and other associated statistical data to satisfy SIL level.

3. LIMITATIONS

The correct selection of materials of construction, seats and seals, internal valve components and pressure/temperature ratings determines the safe use of the valves and the particular performance requirements for the application. This information can be found on the nameplate welded to the valve body.

As the extent of applications that these valves can be used in, is large, it is not possible to cover all installation and maintenance instructions for service of the valves. It is the user's responsibility to use the valves as recommended and in accordance with the pressure and temperature limits as stated in this manual. Where in doubt, please consult with Habonim.

Any unstable fluid or gas should be identified by its manufacturer and must not be used with Habonim valves.

CAUTION:

The valves should be used in a well designed, adequately protected system **to ensure that external and internal pressure and temperature limits do not exceed the valve limits.**

The valve body rating can be higher than the seat rating.

Valve surface temperature may become extremely hot or cold due to ambient or operating conditions. Prevent any type of direct contact with the valve that may cause harm or injury .Avoid direct contact with the valve by wearing protective gloves.

The valves should be used in a well designed, adequately supported piping system such that it will not be subjected to undue forces, stresses or shock loads during service.

The valves are not designed to operate during or after earthquakes or under fatigue conditions. It is the responsibility of the owner to determine if fatigue conditions exist.

Do not allow dust layers to build up on the equipment.

The process fluid temperature shall not exceed the ignition temperature of the dust.

4. STORAGE

Prior to storage, inspect the valve for shipping damage. Keep all protective packaging, flange covers and end caps attached to the valves during storage. It is recommended to keep the valves in a clean and dry environment until ready for use.

Carbon Steel valves have a "black oxide" and oil dipped finish. This nontoxic process is performed to retard rusting during storage. It is not a substitute for paint or other means of protective coating to be applied to the valve once installed.

Stainless steel valves have their natural finish and do not require additional protection once installed.

5. OPERATING INSTRUCTIONS

Habonim Valves provide tight shut off when used under normal conditions and in accordance with Habonim's published pressure/temperature chart. If these valves are used in a partially open (throttled) position, seat life may be reduced. Consult with Habonim for the proper seat material selection.

Valve operation works by operating the valve handle 90° turn anti-clockwise to open, and 90° turn clockwise to close. On manually operated valves the valve is open when the handle or stem flats are parallel with the pipeline and closed when the handle or stem flats are perpendicular to the pipeline.

All standard valves are bidirectional and as such, can be installed for flow in either direction. Valves which are unidirectional will have a flow direction arrow welded to the body and separate assembly instructions.

A silicone-based lubricant is applied to assist valve break in. The lubricant, if unacceptable, may be removed by a solvent wash.

If a shut-off valve is installed for end of line service, it must be ensured that it is closed with a blind end connection and the valve is secured against being opened unintentionally.

WARNING: Never look into the valve bore while the valve is in a flowline. Pressure and fluids could escape from the valve causing bodily injury.

To prevent leakage, malfunctions resulting from internal wear or seal degradation, the user must establish a preventive maintenance and inspection program. This program must include:

a. Inspection of parts to detect loss of wall thickness which may result in decreased pressure capacity (see **para.** 2 for acceptable reduction of wall thickness).

b. Routine replacement of seals and inspection for proper operation (See **para.** 7 for maintenance instructions).

Valve operating torques as published in the Habonim literature are the normal expected maximum break-away torques. These torques have been confirmed by laboratory testing of each valve under controlled conditions. Highly viscous or abrasive media, frequency of operation and temperature fluctuations could cause an increase in valve torque.

6. INSTALLATION

The installation procedure for ball valves is critical to ensuring both long life and satisfactory performance. Valves stored on site awaiting installation should be kept in their original packing, in dry conditions, where damage will not occur (see **para. 4**). Before carrying out the installation, it is important to follow the basic procedures described below:

6.1 General

6.1.1. Carefully unpack the valve and check valve nameplate for identification of materials (see **Figure 2**).

6.1.2. Remove any special packing materials, which were used for packing.

6.1.3. Check the valve for any flow direction indication marks. Appropriate care must be taken, to install the valve for proper flow orientation.

6.1.4. Inspect the valve interior through the end ports to determine it is clean and free from foreign matter.

6.1.5. Cycle the valve and inspect any functionally significant features.

6.1.6. Read all the literature and note any special warning tags or plates attached to the valve.

6.1.7. Before installation check to insure the ball is in the fully open position in order to prevent possible damage to the ball and seats. The valve performance depends on its original conditions. At any stage do not leave the valve in the partially open position.

6.2 Threaded End Valves

6.2.1. Valves with threaded ends should be treated as a single unit and should not be dismantled when installing to pipeline.

6.2.2. Before installing the valves, make sure that the threads on the mating pipe are free from excessive grit, dirt or burrs.

6.2.3. When tightening the valve, apply a pipe wrench or spanner to the end connector closest to the pipe being worked, using standard piping practices.

6.2.4. Use appropriate joining sealants material in correct quantities.

6.2.5. If "back-welding" is required on threaded end valves, refer to the instructions for Weld End valves or to the "Habonim Welding Instructions" bulletin.

6.3 Weld End Valves in-line

6.3.1. Welding of valves shall be performed by a qualified person according to the ASME Boiler Construction Code Section IX. For valves to be welded within the EEA, refer to the requirements of ESR 3.1.2 of the Pressure Equipment Directive 97/23/EC.

6.3.2. Valves with Delrin® or UHMWPE seats must be disassembled before welding in line. For more information on recommended welding procedures or seat materials, please consult with Habonim.

6.3.3. Valves that will be welded directly to the line must be in the fully open position to protect the ball and seats from excessive temperatures during the welding procedures (aside those mentioned in **Para. 6.3.2**).

6.3.4. It is recommended to remove the valve wrench during the welding procedure. Protect or remove actuators from weld splatter or arc strikes. Valves in the "Fail Close" position should be cycled to the open position.

6.3.5. Use a temperature stick and a wet cloth wrapped around the center section to prevent overheating. DO NOT heat the center section over 150°C (300°F).

6.3.6. Align valve to pipe line, ensuring proper fit to minimize pipe load. Tack weld only.

6.3.7. Complete welding in small segments. Allow enough time for cooling between each segment.

6.3.8. After completing the welds, wait for the valve to cool below 90°C (200°F). Tighten the body bolts to torque figures and tightening patterns according to **Figure 1**.

6.3.9. Replace the wrench or actuator. It is recommended not to rotate the valve to the closed position before flushing the line.

6.4 Weld End Valves not in-line

6.4.1. Welding of valves shall be performed by a qualified person according to the ASME Boiler Construction Code Section IX. For valves to be welded within the EEA, refer to the requirements of ESR 3.1.2 of the Pressure Equipment Directive 97/23/EC.

6.4.2. Valves that will be disassembled before welding carry a packet with replacement body seals. Follow steps 2 to 9 of the DISASSEMBLY section but to not discard of the seat rings.

6.4.3. Prior to welding the ends to the pipe, make sure their flats are aligned to the body flats (see **NOTE in page 6**).

6.4.4. Do not scratch or cut the seats and sealing surfaces of the valves as this will cause valve leakage.

6.4.5. Assemble the valve without the ball and seats and follow steps 1 to 7 for Weld End Valves.

6.4.6. After the valve cools down, follow again steps 2 to 9 of the DISASSEMBLY section and section 7 to 13 of the ASSEMBLY section.

7. MAINTENANCE

HABONIM valves have a long and trouble free life, and maintenance is seldom required. When maintenance is necessary, valves can be refurbished on site.

To extend valve performance and reduce possible plant problems, the following procedures should be followed:

7.1. If leakage at the stem is noted, tighten the gland nut about a ¼-turn as a routine maintenance procedure. This will compensate for any wear or settling of the gland packing.

7.2. **Caution**: Excessive tightening of the stem nut can result in accelerated seal wear and high valve operating torque.

7.3. If the valve is removed from the line and disassembled, replacement of all seats and seals is recommended using the appropriate Habonim Repair kit. Examine all metallic sealing surfaces such as ball, stem, and the surfaces on the end connectors that contact the seats for wear, corrosion or damage.

7.4. Only Habonim's authorized spare parts should be used. Repair kits from Habonim consist of the following:
2 x seat ring
1 x stem gland packing (comprises of 1 or more parts)
1 x stem thrust seal
2 x body seals

7.5. In addition to repair kits, other spare parts available from Habonim are: valve balls, stems, glands, bolts, screws and nuts. Should additional parts be required, it is recommended that the complete valve be replaced.

7.6. When ordering repair kits, please provide the valve size and full figure number code and series.

8. DISASSEMBLY

The following instructions are for in-line disassembly of valves sizes ¼" to 2 ½" (DN6-DN65)

8.1. Cycle the valve with the line pressure fully relieved before attempting to remove the valve from the pipeline, to insure pressure has also been discharged from the valve cavity.

8.2. Bring the valve handle to the open position. Warning: trying to remove the valve body from the line in the closed position will damage the ball.

8.3. With the valve in the open position, loosen all 4 body bolts.

8.4. Remove all but one body bolt, so the valve body can swing away from its installed position and be brought out of the pipe line (see **figure 3**).

8.5. If it is required to completely remove the body, remove the last bolt and bring out the body center section.

8.6. Swing out the body from between the end connectors.

8.7. Remove and discard the seat rings and body seals. Be careful not to damage the sealing surfaces.

8.8. Support the ball to prevent it from falling out of body and turn handle to the closed position for its removal. Set the ball aside in clean secure area for reuse.

8.9. Remove the handle nut, serrated washer, handle, locking clip, stem nut, disk springs and follower. Place all components removed, in clean secure area.

8.10. Push the stem down into the body and remove it. Discard the stem thrust seal, bearing and packing, care taken not to scratch or nick the stem bore area of the body. Clean the stem and stem bore area.

The following instructions are for in-line disassembly of valves sizes 3" to 8"(DN80-DN200).

8.11. Cycle the valve with the line pressure fully relieved before attempting to remove the valve from the pipeline, to insure pressure has also been discharged from the valve cavity.

8.12. Bring the valve handle to the open position. Warning: trying to remove the valve body from the line in the closed position will damage the ball.

8.13. With the valve in the open position, loosen all body bolts.

8.14. Remove all body bolts and bring out the body center section.

8.15. Locate the side of the body that has the seat retaining ring. Support the ball from that side to prevent it from falling out of body and turn handle to the closed position for its removal. Set the ball and seat retaining ring aside in clean secure area for reuse. Remove and discard the seat rings and body seals. Be careful not to damage the sealing surfaces.

8.16. Remove the wrench bolt, wrench head and handle, stem nut, stop plate and follower. Place all components removed, in clean secure area.

8.17. Push the stem down into the body and remove it. Discard the stem thrust seal, bearing and packing, care taken not to scratch or nick the stem bore area of the body. Clean the stem and stem bore area.

9. ASSEMBLY

The following instructions are for in-line assembly of valves sizes ¼" to 2 ½" (DN6-DN65)

9.1. Lubricate the new stem thrust seal, bearing and packing, with appropriate lubricant (Molykote 33 - thin smear). Place the stem thrust seal on the stem.

9.2. Insert the stem horizontally into the center body with the threaded side first and carefully guide it up through the stem bore.

9.3. Holding the stem up insert the new packing over the stem and into the stem bore. Place the bearing, follower and two disk springs onto the stem. The first spring convex side down and the second spring convex side up.

9.4. Thread the stem nut onto the stem. Tighten the stem nut to the torque figures (**table 1**).

9.5. Place the locking clip on the stem nut by adjusting the orientation of the nut (in the clockwise direction).

9.6. Place the handle, serrated washer and thread the handle nut on the stem. Holding the handle tighten the handle nut tight.

9.7. Bring the handle to the closed position to insert the ball.

9.8. Place the ball in the center body until the stem tongue is engaged and bring the valve to the open position to prevent the ball from falling out.

9.9. Place the new body seals and new seat rings in the body.

9.10. Ease back the body assembly between end connectors, taking care not to score faces or damage seals, and reinstall body bolts and nuts.

9.11. To prevent galling of threads of bolts or nuts, lubricate threads with an anti-galling compound.

9.12. Tighten the body bolts to the torque figures (**table 2**), and according to tightening pattern illustrated in **figure 1**.

9.13. Leave the valve in the open position for flushing the line.

The following instructions are for in-line assembly of valves sizes 3" to 8"(DN80 - DN200).

9.14. Lubricate the new stem thrust seal, bearing and packing, with appropriate lubricant (Molykote 33 - thin smear). Place the stem thrust seal on the stem.

9.15. Insert the stem horizontally into the center body with the threaded side first and carefully guide it up through the stem bore.

9.16. Holding the stem up insert the new packing over the stem and into the stem bore. Place the bearing, follower and stop plate onto the stem

9.17. Thread the slotted gland nut onto the stem. Tighten the gland nut to the torque figures (**table 1**).

9.18. Place the wrench head on the stem making sure it is parallel to the stem groove for ball valve position. Insert the handle through the wrench head and tighten with the wrench bolt,

9.19. Bring the handle to the closed position to insert the ball.

9.20. Place the ball in the center body until the stem tongue is engaged and bring the valve to the open position to prevent the ball from falling out.

9.21. Place the new body seat rings, seat retaining ring and new body seals in the body.

9.22. Ease back the body assembly between end connectors, taking care not to score faces or damage seals, and reinstall body bolts and nuts.

9.23. To prevent galling of threads of bolts or nuts, lubricate threads with an anti-galling compound.

9.24. Tighten the body bolts to the torque figures (**table 2 or 3**), and according to tightening sequence illustrated in figure 1.

9.25. Leave the valve in the open position for flushing the line.

TABLE 1

Stem Nut Tightening Torque

		47P , AF47P		47X	
Valve size	Stem thread	Nm	Lb-In	Nm	Lb-In
½"- ¾"	⅜" - 24 UNF	4	35	6	53
1"- 1¼"	7/16" - 20 UNF	9	80	11	97
1½"- 2"+2½"*	9/16" - 18 UNF	13	115	15	133
2½"	M20 x 2.5	30	265	30	265
3" - 4"	1" - 14 UNS	60	530	60	530
6" - 8"	1½" - 12 UNF	120	1060	120	1060

* For Valve size 2½" with stem 1½".

IMPORTANT:

An excessively tightened stem nut can cause excessive packing wear and increase stem torque.

TABLE 2

Body Bolt Tightening Torque

AF47P					47P , 47X				
Reduced bore	Full Bore	Bolt Thread	Tightening Torque		Reduced bore	Full Bore	Bolt Thread	Tightening Torque	
			Nm	In.lb				Nm	In.lb
½"	¼",⅜"	M8	20	180	½"	¼",⅜"	M6	10	90
¾"	½"	M8	20	180	¾"	½"	M6	10	90
1"	¾"	M10	40	350	1"	¾"	M8	20	180
1¼"	1"	M10	40	350	1¼"	1"	M8	20	180
1½"	1¼"	M12	65	575	1½"	1¼"	M10	40	350
2"	1½"	M12	65	575	2"	1½"	M10	40	350
2½"	2"	M12	65	575	2½"	2"	M10	40	350
3"	2½"	M12	65	575	3"	2½"	M10	40	350
4"	3"	M16	180	1590	4"	3"	M12	65	575
	4"	M20	350	3100		4"	M16	180	1590
6"		M20	350	3100	6"		M20	350	3100
8"		M20	350	3100	8"		M20	350	3100

FIGURE 1
Body Bolt Tightening Pattern

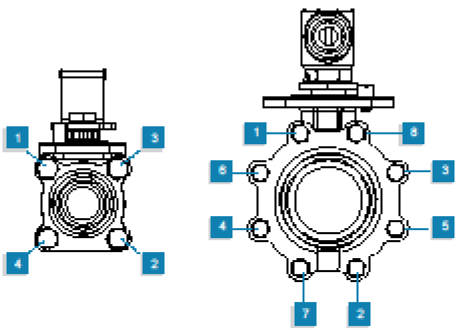


FIGURE 2
Valve Marking and Labeling

All valves marking is on a nameplate which is spot welded to the valve body. Valves for the European market and above 1" carry the CE mark with the information required by the PED.

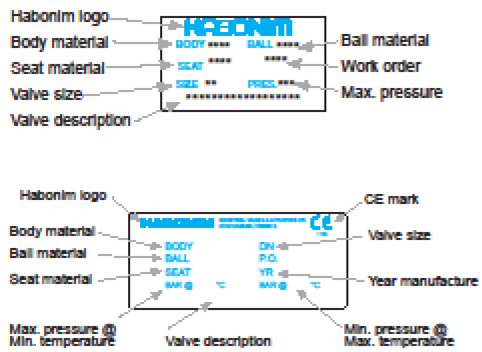
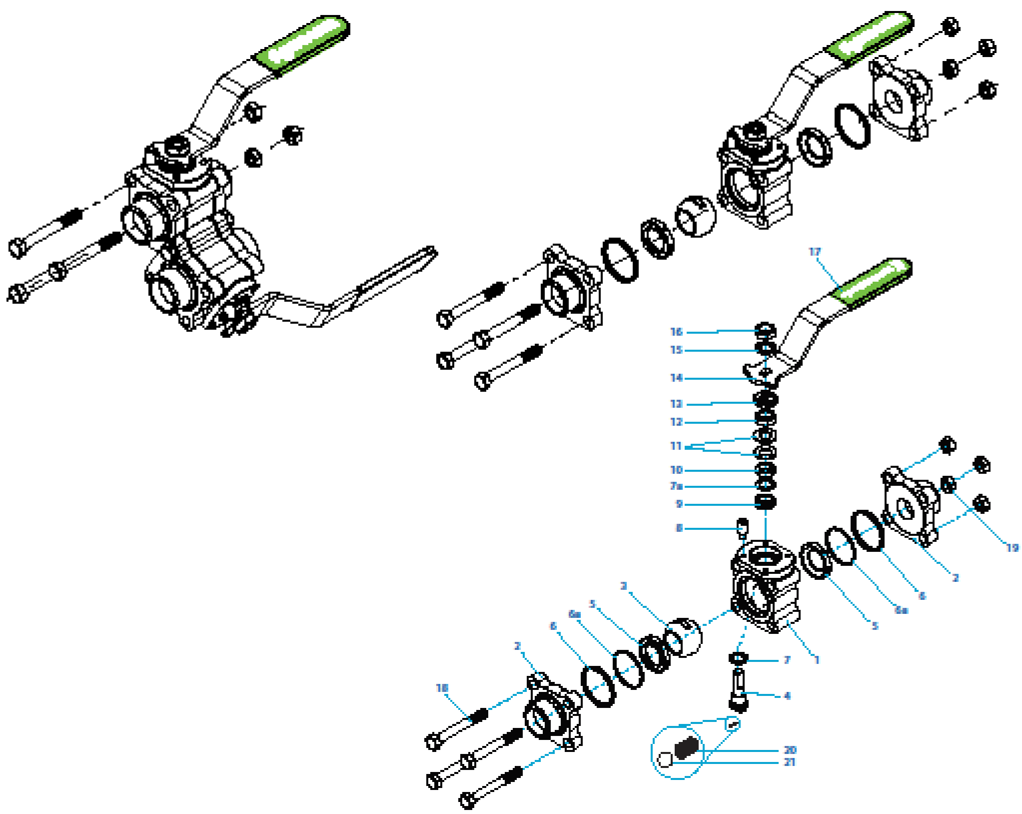
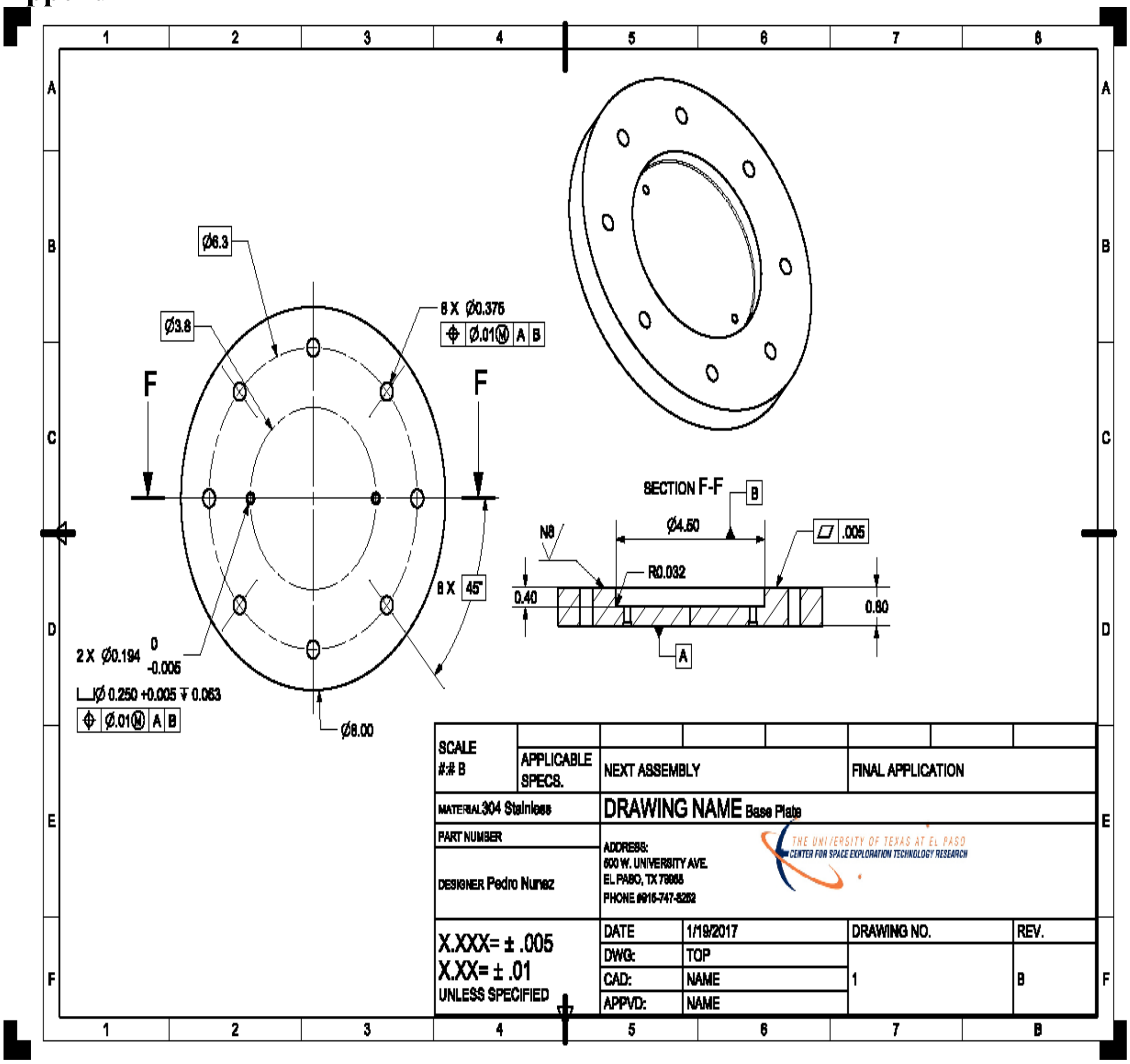


FIGURE 3
Valve swing out position

¼" to 2 ½" (DN6 - DN65)

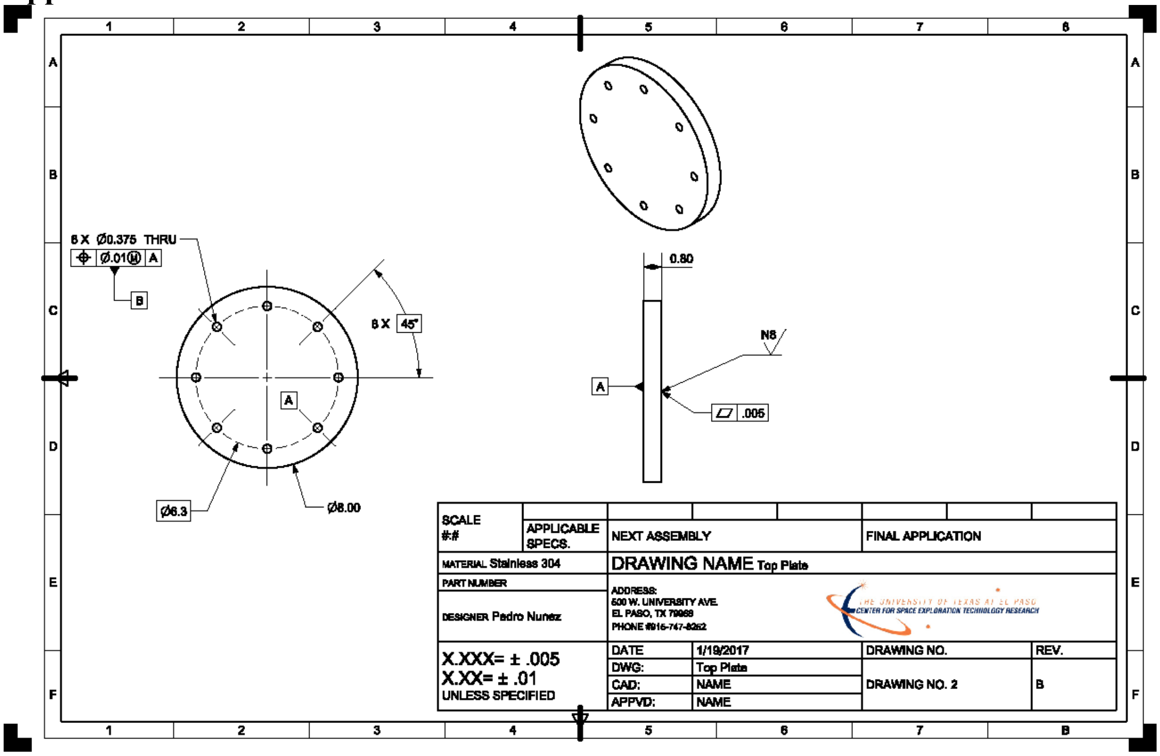


Appendix F



Ø6.3
Ø3.8
8 X Ø0.375
Ø.01Ⓜ A B
F
F
8 X 45°
2 X Ø0.194 0 -0.005
⌴Ø 0.250 +0.005 ↧ 0.063
Ø.01Ⓜ A B
Ø8.00
SECTION F-F
B
N8
Ø4.50
.005
R0.032
0.40
0.80
A
SCALE ##B
APPLICABLE SPECS.
NEXT ASSEMBLY
FINAL APPLICATION
MATERIAL 304 Stainless
DRAWING NAME Base Plate
PART NUMBER
ADDRESS: 500 W. UNIVERSITY AVE. EL PASO, TX 79968 PHONE #915-747-8252
THE UNIVERSITY OF TEXAS AT EL PASO
CENTER FOR SPACE EXPLORATION TECHNOLOGY RESEARCH
DESIGNER Pedro Nunez
X.XXX= ± .005
X.XX= ± .01
UNLESS SPECIFIED
DATE 1/19/2017
DWG: TOP
CAD: NAME
APPVD: NAME
DRAWING NO. 1
REV. B

Appendix G


6 X Ø0.375 THRU
Ø.01 Ⓜ A
B
6 X 45°
A
Ø6.3
Ø8.00
0.80
NS
A
.005
SCALE
#:#
APPLICABLE SPECS.
NEXT ASSEMBLY
FINAL APPLICATION
MATERIAL Stainless 304
DRAWING NAME Top Plate
PART NUMBER
DESIGNER Pedro Nunez
ADDRESS:
500 W. UNIVERSITY AVE.
EL PASO, TX 79968
PHONE #915-747-8262
CENTER FOR SPACE EXPLORATION TECHNOLOGY RESEARCH
X.XXX= ± .005
X.XX= ± .01
UNLESS SPECIFIED
DATE
1/19/2017
DWG:
Top Plate
CAD:
NAME
APPVD:
NAME
DRAWING NO.
DRAWING NO. 2
REV.
B

D-Cryo Series

- MOPD: 1000 PSI (69 Bar)
- C_V Range: 0.040 to 0.770 (K_V Range: 0.034 to 0.655)
- 15 Watts

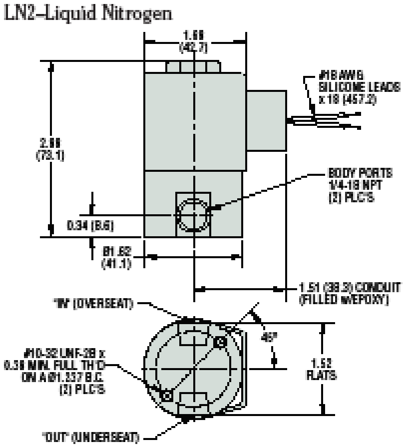
The D-Cryo Series is a 2-way, high flow, miniature Cryogenic valve designed and built for service down to –320°F (-196°C). Depending on your temperature requirements, the D-Cryo Series can be configured for liquid nitrogen (LN2), liquid carbon dioxide (LCO2), and other extreme temperature media. PTFE coated plungers, 316 Stainless Steel guide tubes and plunger springs, encapsulated coils, and PTFE or Rulon® seat seals produce a truly robust Cryogenic valve for applications requiring high cycle life and media temperature control.

Typical Applications

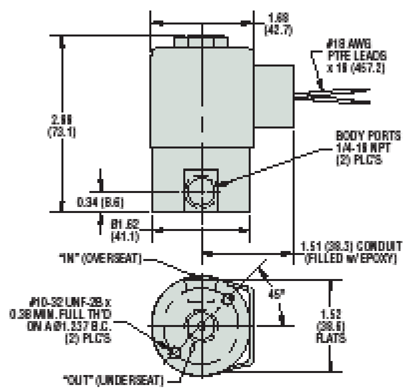
- Environmental Chambers
- Food Processing
- Laser Surgical Equipment
- Semiconductor Manufacturing

Dimensions

LN2–Liquid Nitrogen



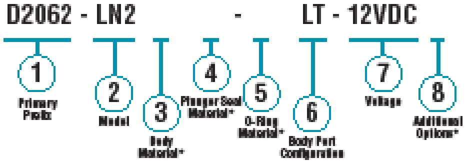
LCO2–Liquid Carbon Dioxide



How To Order

Use the **Bold** characters from the choices listed on the following page to construct a product code.

D2062 - LN2 - LT - 12VDC



* Blank entry indicates a "Standard" selection
(303 Stainless Steel, Rulon® and Variseal®, in this case).

Example:

D2062-LN2-LT-12VDC

2-Way N.C. Liquid Nitrogen Class-H Encapsulated Coil with lead-wires, conduit filled housing solenoid valve, with 303 stainless steel body, Rulon® plunger seal, Variseal® o-ring, 1/8-28 BSPT female thread, operating at 12 DC with rectified coil.

SOLENOID VALVES

Part Prefix Table ①

Orifice (Body) inches	Orifice (Body) mm	MOPD psig	MOPD bar	C_v (Body)	K_v (Body)	① Primary Prefix – Class 180°C (H), Encapsulated Coils – Lead Wires—Filled Conduit Housing	Lead Wires—Unfilled Conduit Housing	Lead Wires—Grommet Housing
3/64	1.19	1000	69	0.040	0.034	D2061	D2021	D2011
1/16	1.59	1000	69	0.070	0.060	D2062	D2022	D2012
3/32	2.38	640	44	0.165	0.140	D2063	D2023	D2013
1/8	3.18	375	26	0.305	0.259	D2064	D2024	D2014
5/32	3.97	185	13	0.365	0.310	D2065	D2025	D2015
3/16	4.76	130	9	0.470	0.400	D2066	D2026	D2016
1/4	6.35	40	3	0.770	0.655	D2067	D2027	D2017

② **Model**
- **-LN2** – Liquid Nitrogen model
- **-LCO2** – Liquid Carbon Dioxide model

③ **Body Material**

LN2 Only
- **(blank)** – 303 Stainless Steel*

LCO2 Only
- **(blank)** – 303 Stainless Steel*
- **BB** – Brass

④ **Plunger Seal Material**

LN2 Only
- **(blank)** – Rulon®*

LCO2 Only
- **(blank)** – PTFE*
- **MQ** – Silicone (consult factory)

⑤ **O-Ring Material**

LN2 Only
- **(blank)** – Variseal® (PTFE material with internal spring)*

LCO2 Only
- **(blank)** – Fluorosilicone*
- **TO** – PTFE

⑥ **Body Port Configuration**

LN2 Only
- **(blank)** – 1/4-18 NPT female thread*
- **LC** – 1/8-27 NPT female thread
- **LT** – 1/8-28 BSPT female thread
- **LU** – 1/4-19 BSPT female thread
- **BI** – Bottom over-seat port, female thread
- **BO** – Bottom under-seat port, female thread

LCO2 Only
- **(blank)** – 1/4-18 NPT, bottom under-seat port, female thread*
- **LC** – 1/8-27 NPT female thread
- **LT** – 1/8-28 BSPT female thread
- **LU** – 1/4-19 BSPT female thread
- **IL** – Inline porting, 180° apart

⑦ **Voltage**

LN2 Only
- ___**VDC** – DC (specify voltage)
- ___**VAC** – AC Rectified (specify voltage)

LCO2 Only
- ___**VDC** – DC (specify voltage)
- ___**VAC** – AC Rectified (specify voltage)

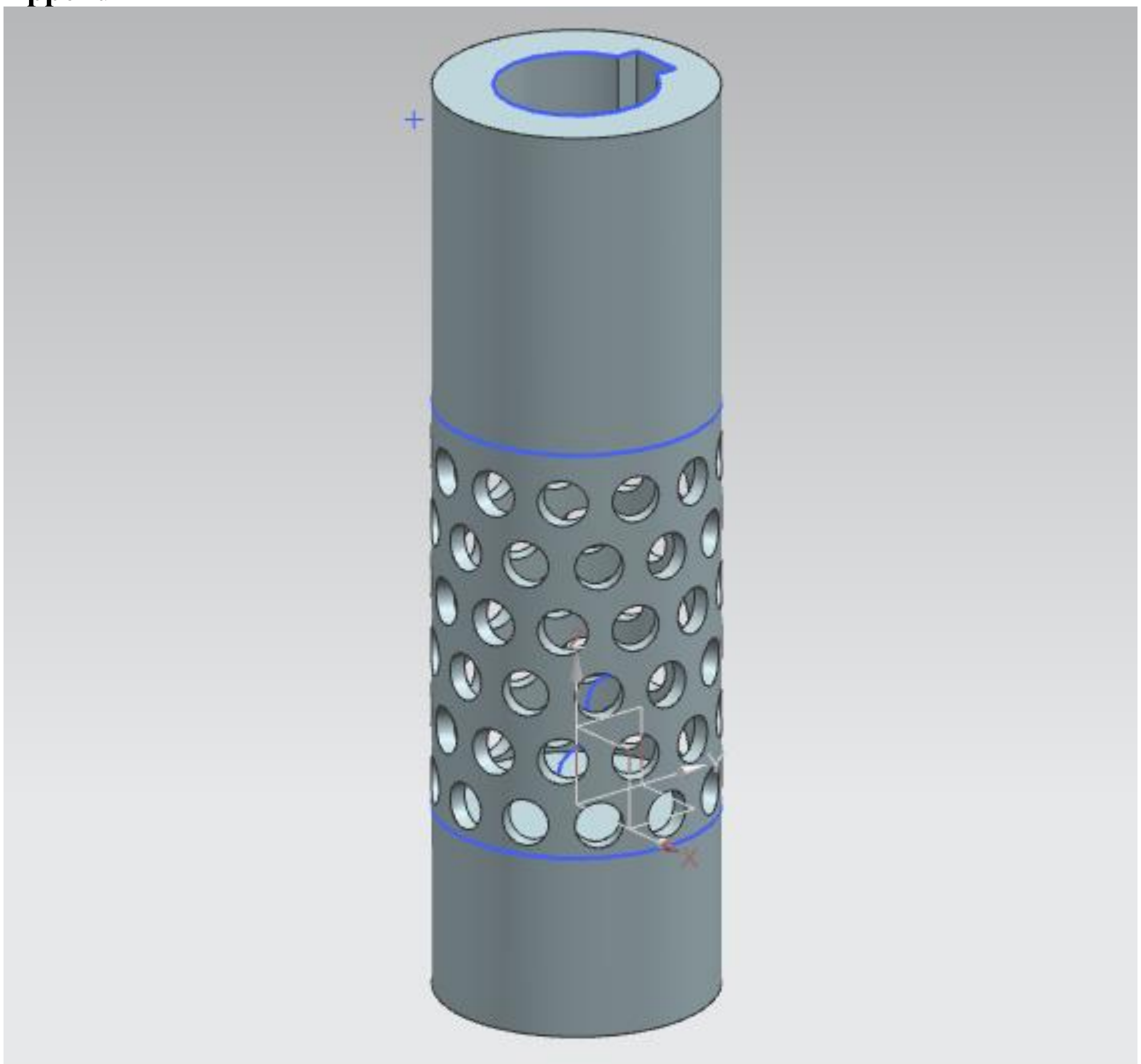
⑧ **Additional Options**

LN2 Only
- **(blank)** – Chamfered and PTFE coated plunger*
- **(blank)** – 316 Stainless Steel 1-piece guide assembly*
- **(blank)** – 316 Stainless Steel spring*

LCO2 Only
- **(blank)** – Chamfered and PTFE coated plunger*
- **(blank)** – 316 Stainless Steel 1-piece guide assembly*
- **(blank)** – 316 Stainless Steel spring*

* Standard selection; will be used unless otherwise specified. Standard selections are not referenced in final part number.

Appendix I



Vita

Pedro Nunez is a top 10% Jefferson High School Graduate from the class of 2011. He went on and attained his Bachelors of Science degree in Mechanical Engineering from the University of Texas at El Paso in the spring of 2015. In the fall of 2015, he was accepted into the graduate program from the University of Texas at El Paso. He started doing research under Dr. Ahsan Choudhuri at the Center for Space Exploration Technology Research. This research was comprised of LOX/LCH4 rocket propulsion systems. This experience in research granted him the chance to be an intern at Johnson Space Center and Marshall Space Flight Center. In the fall of 2017, he would be awarded a Master's of Science in Mechanical Engineering.

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This thesis/dissertation was typed by Pedro Nunez.