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DETAILED WORKINGS REGARDING THE AERODYNAMIC RESEARCH CENTER ARC-JET'S CONTROL PANEL INSTRUMENTATION

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by

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ABSTRACT

DETAILED WORKINGS REGARDING THE AERODYNAMIC RESEARCH CENTER ARC-JET'S CONTROL PANEL INSTRUMENTATION

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The University of Texas at Arlington, 2019

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The updated gas control panel to be installed at the Aerodynamics Research Center (ARC) will better suit the needs for testing for the new national-level hypersonic research facility. An update was needed due to the previous system being a few decades old. However, the control panel was modeled similarly to that of the older system with different specifications and less parts. The panel contains the following parts: adapters, ball valves, pneumatic valves, bonnet valves, solenoid valves, spring actuators, pressure transducers, thermocouples, piping, pressure gauges, a dome regulator, an electronic pressure regulator, relief valves, and a sonic flow nozzle. The gas control panel was modeled to meet the following criteria: cost efficiency, flow rate regulation, and pressure regulation. The criterion for this gas control was to take in pressures of 2400 psi and reduce the pressure down to less than 75 psi.

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CHAPTER 1

INTRODUCTION

1.1 The Aerodynamic Research Center Facility

The Aerodynamic Research Center (ARC) conducts research focused in detonation, shock/boundary layer interaction, and experimental high-speed and high-temperature aerodynamics. It houses low-speed, transonic, supersonic, arc jet, and hypersonic tunnels. Having equipment of this caliber requires a process in order to conduct valid experiments, and ensure the safety of those conducting the experiments. Due to large amounts of pressure and high temperatures needed for experimentation, those who research at the ARC may also partake in the development of certain components of the facility.

1.1.1 Arc-Heated Hypersonic Wind Tunnel

The hypersonic wind tunnel at the University of Texas at Arlington (UTA) is one of a kind, as there is no other wind tunnel like it at any other university. Due to its uniqueness, grants from the Office of Naval Research and the Defense University Research Instrumentation Program, totaling more than $1.5 million, are in place for research on characterizing arc-jet plasma flow and purchase of a femtosecond laser, respectively. This is due to contributions that will be made for key technologies regarding hypersonic vehicles.

1.1.1.1 Contribution to Technology

When hypersonic vehicles cruise through the atmosphere, they travel at speeds of 3,500 miles per hour or more, and friction causes them to heat up to 15,000 degrees

Fahrenheit. Therefore, an effective heat shield is needed to due to the plasma that flows around the vehicle. The problem is current models are unable to predict the different situations that may happen. Therefore, the new facility will be used to develop techniques to characterize plasma flow. In addition, because the flow will be heated in the wind tunnel to temperatures that physical measurement devices cannot withstand, the femtosecond laser system will allow individuals to non-intrusively measure the temperature and composition of the plasma flow. Due to the amount of time it takes to develop heat shields for hypersonic vehicles, this will contribute significantly. [1]

1.2 Gas Control Panel Importance

The gas control panel to be installed at the Aerodynamics Research Center (ARC) is an upgrade that will better suit the needs for testing for the new national-level hypersonic research facility. The new facility was created for testing high-temperature materials, reproducing high-shear conditions, and viewing detailed flow and gas-surface interaction. An update was needed due to the previous system being a couple decades old and the newer system being different than the older one. However, the control panel was modeled similarly to that of the previous one [2] with different specifications and less parts.

CHAPTER 2

LITERATURE REVIEW

2.1 Current Gas Control Panel

The Gas Control Panel that is currently being used was initially sized with much higher pressures of nitrogen provided to the control panel. That pressure has been reduced significantly for the new configuration of the Arc-Jet, and therefore new parts have been order to better optimize the panels performance. Although the parts are newer, they have been studied and modeled to mimic those of the previous system as that configuration has been tested and has been proven to work.

2.1.1 Components of the Current Gas Control Panel

In regards to the Literature Review, the old system was studied for the new configuration. Figure 2.1 outlines the components that are currently used for the Gas Control Panel, and Appendix A portrays the identifiers for the parts outlined for this system. It was made by graduate student, Vijay Gopal, and modified as needed based on the research conducted from the literature review.

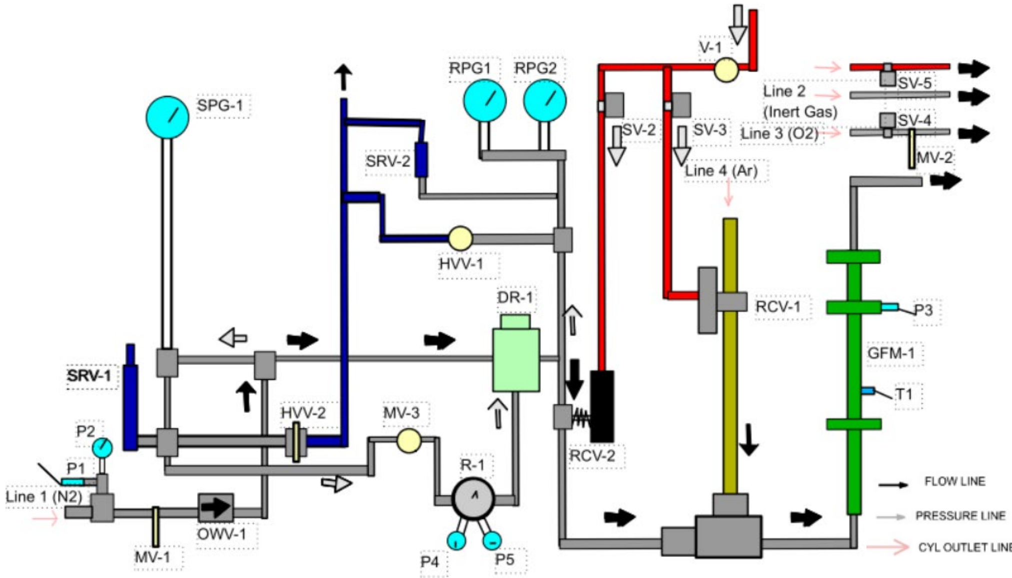

Figure 2.1: Current Gas Control Panel Schematic

The panel contains the following parts: adapters, ball valves, pneumatic valves, bonnet valves, solenoid valves, spring actuators, pressure transducers, thermocouples, piping, pressure gauges, a dome regulator, an electronic pressure regulator, relief valves, and a sonic flow nozzle. By reviewing the needs of the system for the new configuration, looking at the manuals for each of these individual components, reviewing the calculations for pressure and flowrate, and evaluating costs, one is able to reconfigure the current gas control panel. There are main components that one needs to analyze when accessing the previous panel. These same components will be analyzed in the future panel. The parts include valves, gauges, adapters/connectors, and critical components such as pressure regulators, relief valves, and the sonic flow nozzle. Therefore, the literature review of the previous system of each components its manuals are explained below, along with the explanation of what they are, and their integration to the overall system.

Table 2.1: Current Valve References

Identifier	Reference	Company	Valves				
			Ball	Bonnet	One Way	Manual	Solenoid
MV-1	High Performance Rotoball® Bi-Directional Valve - 7223D Series [3]	HOKE	X				
OWV-1	Ball Check Valves [4]	HiP	X		X		
HVV-2	30,000 PSI High Pressure Valves [5]	HiP				X	
HVV-1	3 Piece Process/Instrumentation, 60 Series [6]	WHITEY	X				
SV-2	Dayton 6X542 Solenoid Valve [7]	Dayton		X			
SV-3	Dayton 6X542 Solenoid Valve [7]	Dayton		X			
SV-4	Series A Solenoid Valve [8]	Granzow					X
V-1	Not Applicable because no longer made	WHITEY				X	

2.1.1.1 Valves

Looking at Table 2.1, one can see where the manuals were found for each part of the current configuration. MV-1 is a manual valve that is used for high cycle actuation application. It connects with an inlet and outlet of 3/8” NPT Female. It’s maximum operating pressure is 5000 psig, and it has a blowout-proof stem for added safety [3]. It is easily adjustable for quick usage. It is the valve used to let in the pressure of nitrogen from the nitrogen cylinders.

The one way ball check valve (OWV-1) from HiP is rated for pressures up to 20,000 psi [4]. It takes the pressure and feeds it into the regulator (R-1), while also carrying it up to be evaluated by the pressure gauge (SPG-1) to see how much pressure was rushed in at the inlet.

HVV-2 is another valve from the company HiP that is rated at 30,000 psi. It is a valve that stops flow to other parts of the system if excess pressure is released into the panel [5]. HVV-1 was originally created by the company WHITEY, but the company has now morphed into the company Swagelok. It will be used to purge the pressure if the dome regulator (DR-1) fails, and is rated for 2200 psi [6].

SV-2 and SV-3 are both solenoid valves that are standard by Dayton. They regulate pneumatic valves (RCV-1 & RCV-2). SV-4 is a gas rated solenoid valve due its large intake for a natural gas, and V-1 is a valve for the 175 psi inlet, which is used for a feed into the Pneumatic Valves.

2.1.1.2 Pressure Gauges

Table 2.2 shows the various pressure gauges that display the pressure at various points in the panel. Figure 2.1 shows that the first pressure gauge was P2, which read the pressure coming in from the nitrogen bottles, that read up to 6000 psi. The next gauge was SPG-1, which read the pressure after MV-1 or after the blow off valve, SRV-1, got rid of pressure. P4 and P5 read the inlet and outlet pressure of the dome regulator, which was key as DR-1 regulated the amount of pressure being fed further along the gas control panel by setting a certain pressure with a pilot regulator to the main regulator. P4 read the pressure before the pilot regulator set the needed pressure that was read by P5. RPG-1 and RPG-2 served as more accurate and visible checks as they were larger to read the pressure at the outlet of DR-1.

Table 2.2: Current Pressure Gauge References

Identifier	Reference	Company	Less than 6000	6000 psi	Over 6000 psi
P2	Not Applicable, no longer made	USG		X	
P4	Not Applicable, no longer made	USG		X	
P5	Not Applicable, no longer made	USG		X	
SPG-1	1259 Process Pressure Gauge [9]	ASHCROFT			X
RPG-1	1259 Process Pressure Gauge [9]	ASHCROFT	X		
RPG-2	1008A Pressure Gauge [10]	ASHCROFT	X		

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2.1.1.3 Critical Components

The main components that require the most analysis for this configuration are the dome regulator with its pilot regulator (R-1,DR-1), the blow off valves (SRV-1,SRV-2), and the critical flow nozzle (GFM-1). The dome regulator serves as a primary component for setting and regulating pressure, the relief valves are put into place to blow off any excess pressure in order to not further harm the system, and the sonic flow nozzle creates a shock that significantly reduces pressure in order to send the remaining flow rate and pressure to the Arc-Jet. R-1 and DR-1 were created by TESCOM and rated for 6000 psi. SRV-1 was a relief valve set in place if to much pressure came in Line 1, was set to blow off pressure at 5500 psi, and was made by HiP. SRV-2 was made by Circle Seal and was placed behind the dome regulator just in case the component failed and pressure needed to be expelled in order not to harm other components. This was rated at 1200 psi, If all goes well, a set amount of pressure will come to the sonic flow nozzle, GFM-1. Here the shock will decrease the remaining pressure to around 80 psi.

Table 2.3: Current Critical Components References

Identifier	Reference	Company	Pressure Regulator	Blow off Valve	Sonic Flow Nozzle
R-1	44-1100 Series Regulators Pressure Reducing [11]	TESCOM	X		
DR-1	26-1100 Series Regulator Pressure Reducing [12]	TESCOM	X		
SRV-1	Pressure Valves Fitting and Tubing [13]	HiP		X	
SRV-2	5100 Series Inline Relief Valves [14]	Circle Seal		X	
GFM-1	Critical Flow Nozzle [15]	Flow Dyne			X

2.1.2 Breakdown of the Current Control Panel

A basic understanding of how the system can be seen in is the following: nitrogen comes from the nitrogen bottles. For the old system, these pumps contained pressures up to 6000 psi. It is then read by the pressure transducer (P1), and pressure gauge (P2). A manual valve (MV-1) is placed just in order to close off the pressure if needed. The pressure then goes through the one-way check valve (OWV-1), and if the pressure is higher than 5500 psi, the pressure is then expelled with a blow off valve (SRV-1), and another manual valve (HVV-2) is closed in order for the pressure to exit through the blow off valve. However, if too much pressure is coming through, and the valve is not sufficient to close the pressure off, another blow off valve is put in place rated at 1210 psi (SRV-2). If all works according to plan, pressure between 600-750 psi goes through a dome regulator (DR-1). It can handle pressures up to 6000 psi; however, to protect other components further down the assembly, the blow off valves are set in place due to the fact the other components are not rated as high. The range is given because the specified outlet is set by the regulator (R-1). It takes in an inlet pressure of up to 6000 psi, which is read by the inlet pressure gauge (P4), and it is set to a specific pressure between 600-750 psi, which is read by the outlet pressure gauge (P5). The dome regulator outlet can take pressures between 15-2000 psi, but for the purposes of the experiments conducted at the ARC the pressures are set between 600-750 psi. Additionally, if the dome regulator fails, the blow off valve rated at 1210 psi will still be implemented to go off, and the manual valve (HVV-1) will be utilized to purge the pressure. Both pressure gauges (RPG-1 & RPG-2) are used to visually see the pressure that comes out of the dome regulator outlet. The pressure then needs to be transported to the sonic flow nozzle. It goes through a pneumatic valve (RCV-

2), which needs a pressure of 175 psi to operate. This is turned on and operated by the manual valve (V-1). In order for RCV-2 to operate it is driven by the solenoid valve (SV-2). The system additionally regulates argon. Like the one that regulates nitrogen, the pneumatic valve (RCV-1) is regulated by V-1 and driven by the solenoid valve (SV-3). After being regulated by the pneumatic valves, the pressure is then taken to the sonic flow nozzle. At this point, pressure is normally around 400 psi, this does vary though based on the experiment. However, enters in the Sonic Flow Nozzle (GFM-1), and a generates a shock in chocked flow that decreases a considerable amount of pressure before going to the Arc-Jet. This pressure based off of former experiments is around 80 psi or 5.5 atm. This pressure is what is expected before entering the Arc-Jet for further experimentation. Calculations regarding how this pressure decreases from 2400 psi to 80 psi are outlined in the methodology.

CHAPTER 3

METHODOLOGY

3.1 Understanding the Decrease in Pressure

For the control panel to operate, there are nitrogen bottles containing 1200 psi of nitrogen that are provided to the control panel. As outlined in the schematic, the pilot gas of nitrogen is flown into the control panel at the inlet. Piping allows for some decrease in pressure. The pressure is read off by the pressure gauges and continues to flow through the pipes. A set pressure is given to the regulator; therefore, the excess is blown off after the pressure is set. This set pressure ranges from 600-750 psi. The pressure is then decreased even more to reach around 70-80 psi (5-5.5 atm) due to the shock seen in the sonic flow nozzle. The decrease in this pressure is explained further in the following paragraphs.

3.1.1 Critical Components

The critical components that were analyzed extensively for this project were the dome regulator, relief valves, and sonic flow nozzle. The dome regulator regulates pressure, and if excess amounts of pressure somehow get into the system, relief valves are set into place to release that pressure. The sonic flow nozzle generates a shock in chocked flow that decreases a considerable amount of pressure before going to the Arc-Jet. These critical components are outlined in Figure 3.1.

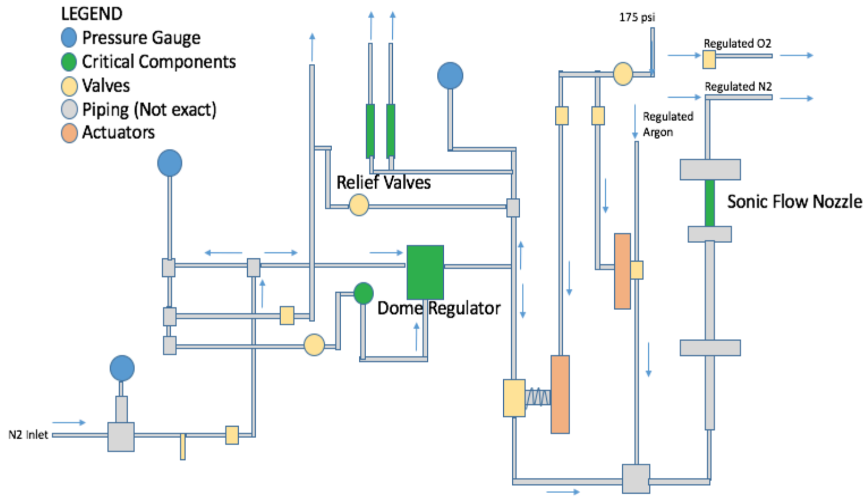


Figure 3.1: Critical Component Outline

For the new control panel, the following manuals were analyzed in order to achieve optimal efficiency for the new specifications of the panel. Table 3.1 shows the references of all the information needed to create graphs and perform calculations.

Table 3.1: Future Panel References for Critical Components

Identifier	Reference	Company	Critical Components		
			Pressure Regulator	Relief Valves	Sonic Flow Nozzle
DR-1	Pressure Regulators RHPS Series [16]	Swagelok	X		
ER-1	High Pressure Ratio Regulator [17]	Proportion Air	X		
SRV-2	SERIES HPRV-750 Flow Datasheet [18]	Generant Valves		X	
GFM-1	Critical Flow Nozzle [15]	Flow Dyne			X

3.1.1.1 Dome Regulator

The dome regulator is key to the success of the control panel. If the dome regulator does not work, excess amounts of pressure will have to be released by the relief valves and the experiment for the Arc-Jet can no longer be conducted. Therefore, choosing the correct dome regulator for this control panel is critical. One looks at the performance curves [19] of different dome regulators can be observed to find the one where the curves do not intersect with the expected lines of the experimental ones. The lines that are not curved are based off the parameter set by the sonic flow nozzle that will be discussed further. The current Dome Regulator being used worked for the old configuration for 6000 psi, but it will not work for the new configuration as the curves do cross lines of the expected nitrogen flow to outlet pressure as seen in Figure 3.2.

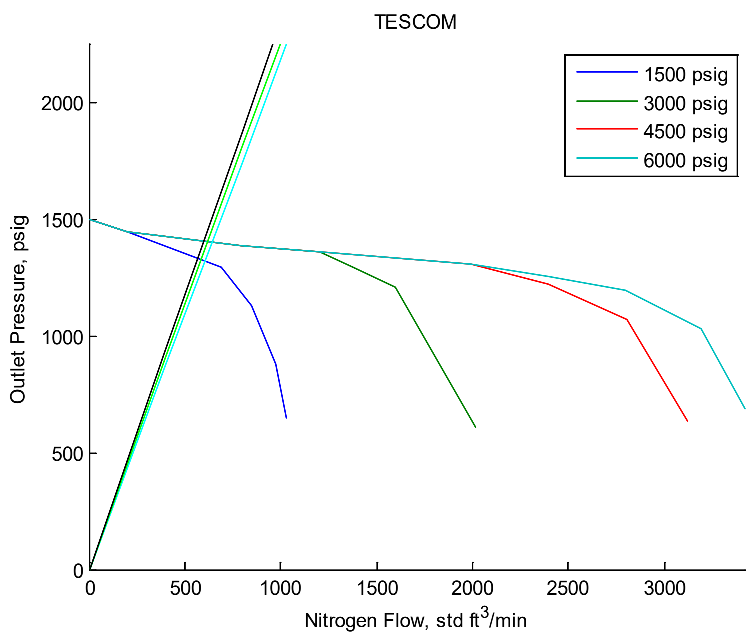


Figure 3.2: Old Dome Regulator Performance Curves

Figure 3.3 shows a considered Dome Regulator. However, due to it being close to some of the ranges needed, the group decided to be absolutely sure of the safety of machinery, and therefore, another dome regulator was chosen.

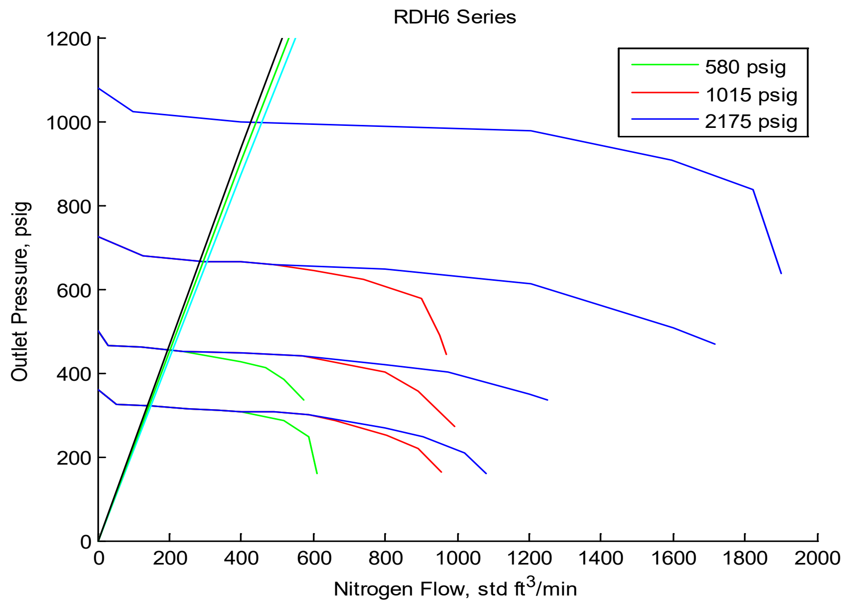


Figure 3.3: Considered Dome Regulator Performance Curves

Therefore, Figure 3.4 shows the that the best dome regulator was selected due to the fact the drops of the curves do not intersect with the experimental lines. The curves of interest were particularly that of 580 psig and 1015 psig as those were below and above 600-750 psi.

The regulator contains a large dome for stability and a pilot regulator, which is integral with dynamic regulations. It has a balanced poppet design that is diaphragm sensing. Additionally, it has external feedback due to the main regulator being limited by the standard outlet pressure range. This is why the pilot regulator is set in place with a dome-to-outlet pressure ratio of approximately 1:1.

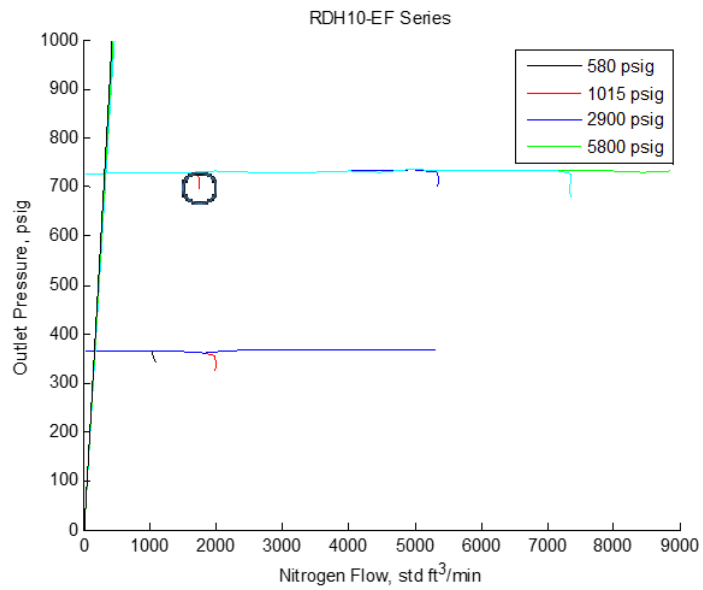


Figure 3.4: Chosen Dome Regulator Performance Curves

Another consideration that will be utilized with the Swagelok Pressure Regulator is an electronic pressure regulator by Proportion Air. As seen in the Figure below, the assembly for the electronic pressure regulator includes a QBX that pilots the RG1262, and the QBX would receive pressure feedback from one of the DST pressure transducers.

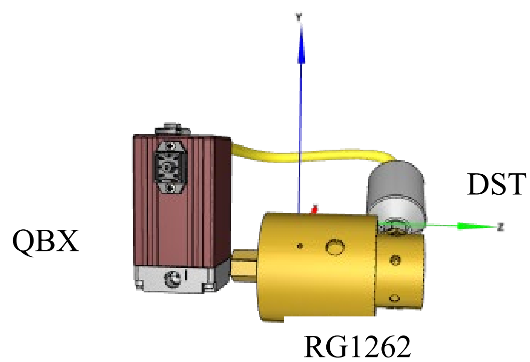


Figure 3.5: Electronic Pressure Regulator Assembly

In order to use this assembly, one would need to be able to supply the QBX a pressure of around 70 psig for a 3000 psig unit. The RG1262 is a ratio regulator that works off a ratio of 45:1. Meaning it can use a smaller pressure to control a larger pressure.

The QBX would be commanded to the pressure that you need to the pressure you require downstream. Once the QBX receives the signal the solenoid valve will open and pressurize the dome of the RG1262 causing media to pass through. The DST will provide feedback to the QBX as to what pressure is on the outlet and the QBX will compare this feedback with the command and modulate in order to bring the pressure in line with the command. As for how to command the unit, one will utilize LabView and take the cable attached to the unit and wire it into the computer. As indicated by the curves below, the electronic pressure regulator meets the requirements seen by the dome regulator.

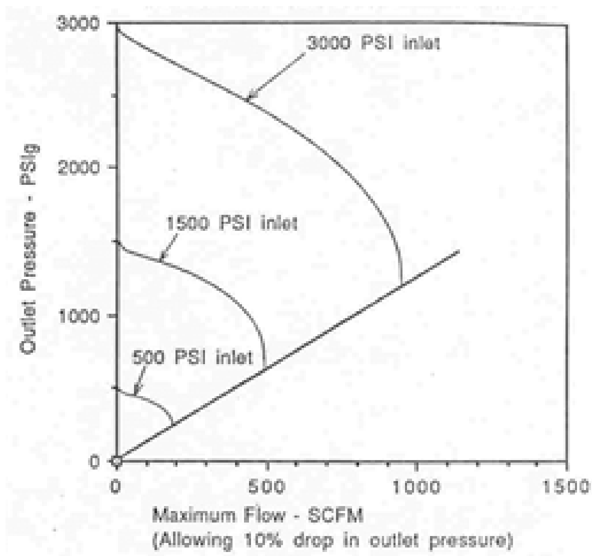


Figure 3.6: Electronic Pressure Regulator Curves [17]

3.1.1.2 Relief Valves

Other critical elements of the control panel are the relief valves. If the relief valves cannot handle the mass flow rates of the dome regulator, the excess pressure will not be blown off entirely. Having that pressure go down further into control panel and to Arc-Jet, would be quite detrimental. Looking at Figure 3.6 below, at about 1200 psi, the dome regulator can handle a volumetric flow rate of about 2000 ft^3/min. Then using standard density of nitrogen, one would get 1.35 kg/s for the mass flow rate. Using choked flow relations, one could calculate the orifice size needed for the relief valves, which was needed to be over 0.6 inches. The relief valves selected can handle volumetric flow rates of 84,750 ft^3/hr and the orifice size is 0.75 inches. Therefore, with two relief valves, the mass flow rate can be handled. Based on the calculations done of the orifice size of the relief valve and the mass flow rate found based off the dome regulator performance curves, one is able to see that the relief valves were selected correctly. The explained calculations can be seen below.

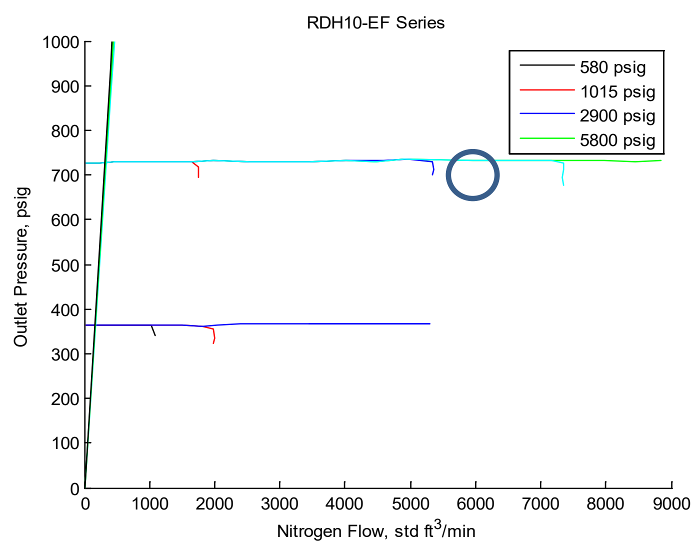


Figure 3.7: Maximum Flowrate Due to Pressure Regulator

From the graph one can see that the maximum volumetric flow rate at 2900 psi is around 5500 ft^3/min. Due to the two nitrogen bottles containing 1200 psi, one evaluated whether the relief valves can expel 2400 psi. The calculations can be seen below. $P_o =$ 800 psi was stated due to it being the decided cracking pressure if things went wrong.

$$\dot{V} \approx 4550 \frac{ft^3}{min} = 2.15 \frac{m^3}{s} \rightarrow \text{Volumetric Flow Rate therefore around 2400 psi}$$

$$\rho = 1.25 \frac{kg}{m^3} \rightarrow \text{Standard Density of Nitrogen}$$

$$\dot{m} = 2.6875\frac{kg}{s} \rightarrow \text{Maximum Mass Flow Rate}$$

$$T_o = 285\ K$$

$$P_o = 800\ psi = 5516000\ Pa$$

$$R = \frac{8.314}{.028} = 296.92\frac{J}{K * kg}$$

Using the calculations, one could determine the diameter needed for the orifice of the relief valve.

$$\dot{m} = P_o A_t \sqrt{\frac{\gamma}{RT_o}}\left(1+\frac{\gamma-1}{2}\right)^{\frac{\gamma+1}{-2(\gamma-1)}}$$

$$A_t = \frac{\dot{m}}{P_o\sqrt{\frac{\gamma}{RT_o}}\left(1+\frac{\gamma-1}{2}\right)^{\frac{\gamma+1}{-2(\gamma-1)}}}$$

$$A_t = \frac{2.6875}{5516000\sqrt{\frac{1.4}{296.92 * 285}}\left(1+\frac{1.4-1}{2}\right)^{\frac{1.4+1}{-2(1.4-1)}}}$$

$$A_t = (2.07 * 10^{-4})\ m^2$$

$$A_t = \frac{\pi}{4}(d)^2$$

$$d_t = \sqrt{\frac{4}{\pi}(1.656 * 10^{-4})}$$

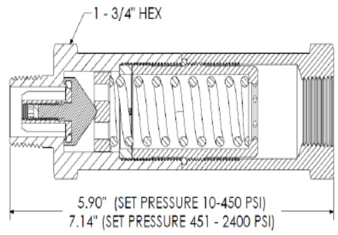
$d_t =$ .0162 m = .6378 in; orifice diamter of around 0.7 inches needed

Several different configurations, in order to solve the issue of releasing excess pressure were considered. This included considering rupture discs. However, the relief valves were the most cost efficient in the long run, and were the one that met closest to the requirements.

SERIES HPRV-750 Flow Datasheet

Description

Flow information stated in this addendum is for HPRV Series Inline Valves in the 3/4" NPT port configuration. For all 3/4" valve types other than Inline (HPRVM and HPRVA), consult factory.



Nominal Set Pressure	Range (PSI)	Orifice (in)	Kd	Flow* (SCFH N2)	Minimum Reset**
-	Less than 75	Consult Factory			
140	72-175	0.750	0.285	23,580	85%
200	176-240	0.750	0.280	32,230	
300	241-310	0.750	0.265	44,805	
400	311-450	0.750	0.256	57,095	
500	451-575	0.750	0.164	45,425	90%
700	576-810	0.750	0.159	61,200	
1000	811-1250	0.750	0.155	8[illegible],750	
-	1251-2400	Consult Factory			

*flow rates listed are at 110% pressure accumulation above nominal spring set pressure.
**published reseat values are on decreasing pressure after the valve has achieved 110% flow condition.

Figure 3.8: Generant Valves Datasheet [18]

It has a ¾" orifice diameter with a cracking pressure of 1000 psi, which works for both the dome regulator and will not harm the experiments being conducted up to this point. The Generant Valves chosen, as shown in Figure 3.7, shows that the valves meets all the needed requirements, and the calculations below indicate that chosen relief valves meet the requirements if multiple were bought.

$$T_o = 285 \text{ K}$$

$$P_o = 1000 \text{ psi} = 6894800 \text{ Pa}$$

$$R = \frac{8.314}{.028} = 296.92 \frac{J}{K * kg}$$

$$d_t = .75 \text{ in} \approx .01905 \text{ m}$$

$$A_t = \frac{\pi}{4}(.01905)^2 = (2.8502 * 10^{-4}) \text{ m}^2$$

$$\dot{m} = P_o A_t \sqrt{\frac{\gamma}{RT_o}} \left(1 + \frac{\gamma - 1}{2}\right)^{\frac{\gamma+1}{-2(\gamma-1)}}$$

`

$$\dot{m} = (6894800)(2.8502 * 10^{-4})\sqrt{\frac{1.4}{(297)(285)}\left(1 + \frac{1.4 - 1}{2}\right)^{\frac{1.4+1}{-2(1.4-1)}}}$$

$$\dot{m} = 4.6256\frac{kg}{s}$$

The mass flow rate is indicated in Figure 3.4 as 84,750 ft^3/hr, which is 0.667 m^3/s. Therefore, mass flow rate is 0.83375 kg/s. This number is very different from the one calculated. Using the 0.83375 kg/s, four of them can be purchased and put in parallel. However, this is not necessary as it is getting rid of pressure; therefore, two can be purchased to suffice the requirements needed by the relief valves.

3.1.1.3 Sonic Flow Nozzle

Although the dome regulator and relief valves are critical components, the one part that is even more crucial is the sonic flow nozzle. The sonic flow nozzle generates a shock in chocked flow that decreases a considerable amount of pressure before going to the Arc-Jet. Based on experimental data and the current construction of the current sonic nozzle, mass flow rate was within the ranges of 0.6 to 0.11 kg/s, pressure was around 400 psi, the diameter of the throat was 0.177 inches, and the diameter of the exit is 0.68 inches as shown in Figure 3.9.

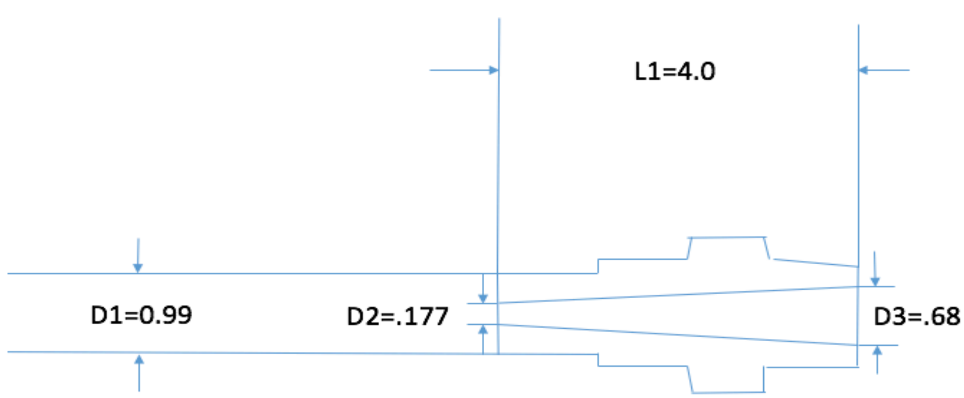


Figure 3.9: Sonic Flow Nozzle Basic Schematic

Using Isentropic Relations, one could verify the mass flow rate at the throat, and using normal shock relations, one could figure out the pressure after the shock from the sonic flow nozzle. This pressure should be around, or under, 5.5 atm based of previous experiments done at the ARC. In order for one to analyze the part previously made for the Gas Control Panel, one had to look at graphs generated by the company who made the Sonic Flow Nozzle, which was Flow Dyne Engineering, Inc. The graph for their Sonic Flow Nozzle is shown in Figure 3.6.

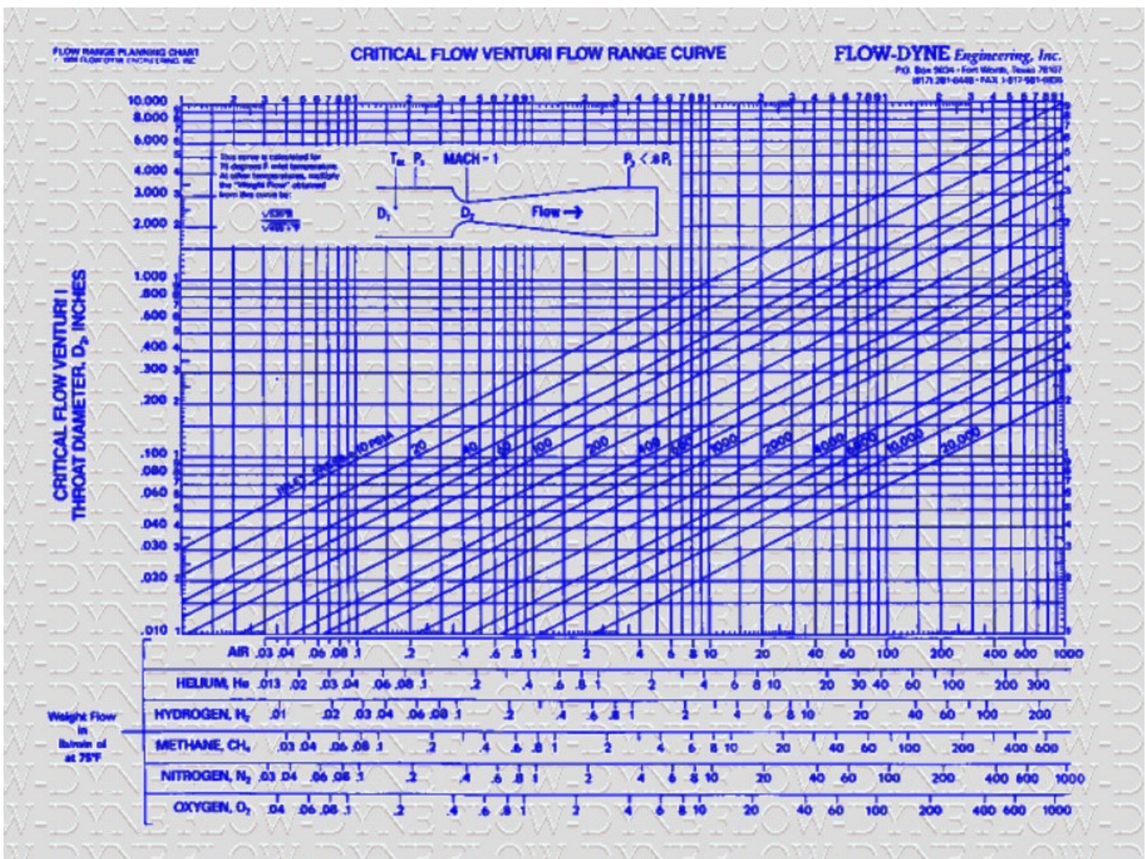


Figure 3.10: Flow Dyne Curves [15]

In order to use the above graph, and use the relations stated on their website, one had to verify if there process would work for the new system. In order for the final component to work, the mass flow rate must be analyzed, and the exit pressure must be around 5.5 atm. Below is the given information that was used for the analysis.

$$T_o = 297\ K = 534.6775\ R \rightarrow due\ to\ Flow\ Dyne\ Graph\ given\ for\ 75°\mathrm{F}$$

$$P_o = 400\ psi = (2.758 * 10^6)\ Pa \rightarrow from\ experimental\ data\ at\ the\ ARC$$

$$R = \frac{8.314}{.028} = 296.92 \frac{J}{K * kg} \rightarrow Gas\ Constant\ for\ Nitrogen$$

$$d_t = .177\ in\ \approx\ 0.0044958\ m \rightarrow Current\ throat\ diameter$$

$$A_t = \frac{\pi}{4}(0.0044958)^2 = (1.5875 * 10^{-5})m^2$$

$$\gamma = 1.4 \rightarrow Specific\ Heat\ of\ Nitrogen$$

The following relationship was used to verify the pressure of 400 psi as it was utilized by former ARC experiments, and will additionally be used for the new configuration.

$$\dot{m} = P_o A_t \sqrt{\frac{\gamma}{RT_o}} \left(1 + \frac{\gamma - 1}{2}\right)^{\frac{\gamma+1}{-2(\gamma-1)}}$$

$$\dot{m} = (2.758 * 10^6)\ (1.5875 * 10^{-5}) \sqrt{\frac{1.4}{(297)(297)}} \left(1 + \frac{1.4 - 1}{2}\right)^{\frac{1.4+1}{-2(1.4-1)}}$$

$$\dot{m} = 0.1013\ \frac{kg}{s} = 13.4\ \frac{lb}{min}$$

From the Chart for Nitrogen when $T_o = 297\ K, d_t = .177\ , \dot{m} = 13.4\ \frac{lb}{min}, P_o = 400\ psi.$

Therefore, using Flow Dyne's graph has been verified, and the following relationship can be utilized from their website:

$$\dot{m} = K \frac{P_o}{\sqrt{T_o}}$$

Where pressure is in psi, Temperature is in degrees Rankine, and mass flow rate is given in lb/min. For further verification, the constant K has been determined, and can be manipulated as needed for future use.

$$K = \dot{m}\frac{\sqrt{T_o}}{P_o}$$

$$K = 13.4\frac{\sqrt{534.67}}{400}$$

$$K = .775$$

This constant is close to the experimental constant seen in LabView by graduate students. The input constant into LabView was 0.7905; thus, further verifying the use of the Sonic Flow Nozzle from this company and their relationships. However, one needs to verify the exit pressure as well. One needs to utilize the pressure curves of the dome regulator, and intersect it with the above K equation for the sonic flow nozzle. Setting a certain pressure will allow one to be able to determine the mass flow rate needed to then be equated to the mass flow rate of the plenum. This is how one verifies the exit pressure, and it is outlined below.

First one had to set a pressure. The pressures that were typically used for experiments ranged from 400-650 psi. Thus, curves were interpolated to find a mass flow rate at this range. The mass flow rate found though yielded to be to high from those outlet pressure of the previous dome regulator. Therefore, the interpolation was not utilized, and the bottom curve was used for the intersection as seen in Figure 3.11.

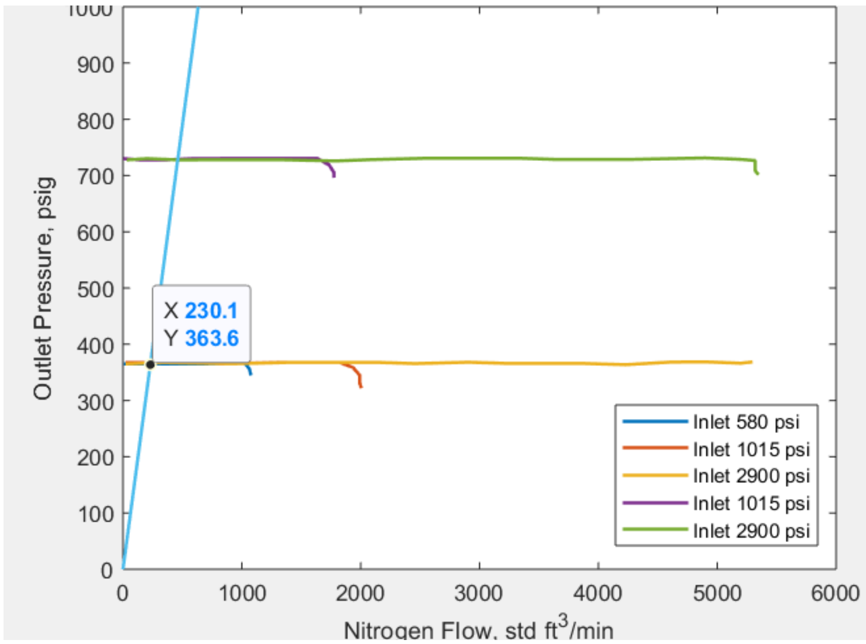


Figure 3.11: Operating Point for Exit Pressure Calculation

Due to the graph being in terms of volumetric flow rate instead of mass flow rate as the sonic flow nozzle equation is stated, the sonic flow nozzle equation is manipulated, and shown below.

$$\dot{V} = \frac{K\frac{P_o}{\sqrt{T_o}}}{\rho}$$

Where $\rho = 0.0725\frac{lb}{ft^3}$ for Nitrogen, $K = 0.7905$, and $T = 534.6$ R. The light blue line is sonic flow nozzle line that intersects the dome regulator curves. According to Figure 3.11, $\dot{V} = 230.1\frac{ft^3}{min}$. Density is a function of mass and volumetric flow rate as seen in the equation below.

$$\rho = \frac{\dot{m}}{\dot{V}}$$

This equation can be manipulated to solve for mass flow rate for the sonic flow nozzle.

$$\dot{m} = \rho\dot{V}$$

$$\dot{m} = 0.0725\frac{lb}{ft^3} * 230.1\frac{ft^3}{min} = 16.68\frac{lb}{min} = 0.126\frac{kg}{s}$$

Knowing $\dot{m} = 0.126\frac{kg}{s}$ for the sonic nozzle and dome regulator operating point, one can solve for pressure at the arc heater. Below are the listed inputs needed to further solve for the plenum pressure.

$$\dot{m}_{SonicNozzle} = 0.126\ \frac{kg}{s}$$
$$h = 5\frac{MJ}{kg}$$
$$cp_{N2} = 1300\frac{J}{kgK}$$
$$\gamma_{,ArcHeater} = 1.28$$
$$R = 296.92\frac{J}{K * kg}$$

$$d_{ArcHeater,throat} = 2.032\ cm$$

$$A_t = \frac{\pi}{4}(0.02032)^2 = 3.24 * 10^{-4}$$

With these givens one can calculate the exit pressure.

$$\dot{m}_{SonicNozzle} = \dot{m}_{ArcHeater}$$

$$\dot{m}_{SonicNozzle} = 0.133\ \frac{kg}{s}$$

$$\dot{m}_{ArcHeater} = MFP(P_{o,ArcHeater}, T_{o,ArcHeater}, \gamma_{,ArcHeater})$$

$$\dot{m}_{ArcHeater} = P_{o,ArcHeater}A_{ArcHeater}\sqrt{\frac{\gamma_{,ArcHeater}}{RT_{o,ArcHeater}}}M_{ArcHeater}\left(1 + \frac{\gamma_{,ArcHeater} - 1}{2}M_{ArcHeater}{}^2\right)^{\frac{\gamma_{,ArcHeater}+1}{-2(\gamma_{,ArcHeater}-1)}}$$

$$T_{o,ArcHeater} = \frac{h}{cp_{N2}} = \frac{5\frac{MJ}{kg}}{1300\frac{J}{kgK}} = 3846\ K$$

$$P_{o,ArcHeater} = \frac{\dot{m}_{ArcHeater}}{A_{ArcHeater}\sqrt{\frac{\gamma_{,ArcHeater}}{RT_{o,ArcHeater}}}M_{ArcHeater}\left(1 + \frac{\gamma_{,ArcHeater} - 1}{2}M_{ArcHeater}{}^2\right)^{\frac{\gamma_{,ArcHeater}+1}{-2(\gamma_{,ArcHeater}-1)}}}$$

$$P_{o,ArcHeater} = \frac{0.126}{(3.24 * 10^{-4})\sqrt{\frac{1.28}{296.92(3846)}}1\left(1 + \frac{1.28 - 1}{2}1^2\right)^{\frac{1.28+1}{-2(1.28-1)}}}$$

$$P_{o,ArcHeater} = 625727\ Pa = 6.175\ atm$$

Although not exactly 5.5 atm, this pressure makes sense due to the fact piping will attribute to loss in pressure, and the dome regulator purchased is different from the ones used from experiments conducted at the ARC. Due to the pressure meeting the expectations of the old configuration, the new configuration has been verified and can be used for future experiments to be conducted at the ARC. In order to easily verify that the sonic flow nozzle is working as it should, calibration curves were requested to be made from the company CEESI. A sample of the calibration can be seen below for Nitrogen.

Table based on a curve fit from data file number(s) 18UNOT-0002_1
Temp: 70°F Press: 123-1321 PSIA Fluid: Nitrogen

Curve fit form:
Cd = a + b * Red^(-.5)

a: 9.9079 E-01 b: 3.1400 E+00

psia	mdot lbm/hr	psia	mdot lbm/hr	psia	mdot lbm/hr	psia	mdot lbm/hr	psia	mdot lbm/hr
123.00	247.16	364.0	734.64	605.0	1227.74	846.1	1726.34	1087.1	2230.16
130.09	261.42	371.1	749.06	612.1	1242.33	853.1	1741.09	1094.2	2245.04
137.18	275.68	378.2	763.49	619.2	1256.91	860.2	1755.85	1101.2	2259.96
144.27	289.95	385.3	777.92	626.3	1271.51	867.3	1770.61	1108.3	2274.86
151.36	304.23	392.4	792.36	633.4	1286.11	874.4	1785.37	1115.4	2289.75
158.44	318.50	399.5	806.80	640.5	1300.73	881.5	1800.12	1122.5	2304.66
165.53	332.79	406.6	821.24	647.6	1315.34	888.6	1814.89	1129.6	2319.60
172.62	347.07	413.6	835.70	654.7	1329.95	895.7	1829.67	1136.7	2334.51
179.71	361.36	420.7	850.15	661.7	1344.57	902.8	1844.43	1143.8	2349.42
186.80	375.66	427.8	864.62	668.8	1359.20	909.9	1859.22	1150.9	2364.34
193.89	389.96	434.9	879.08	675.9	1373.83	916.9	1874.02	1158.0	2379.27
200.98	404.27	442.0	893.55	683.0	1388.46	924.0	1888.79	1165.0	2394.20
208.07	418.58	449.1	908.03	690.1	1403.10	931.1	1903.60	1172.1	2409.13
215.15	432.89	456.2	922.51	697.2	1417.74	938.2	1918.41	1179.2	2424.07
222.24	447.22	463.3	937.00	704.3	1432.39	945.3	1933.19	1186.3	2439.04
229.33	461.54	470.3	951.49	711.4	1447.04	952.4	1948.01	1193.4	2453.99
236.42	475.87	477.4	965.98	718.5	1461.70	959.5	1962.81	1200.5	2468.94
243.51	490.20	484.5	980.49	725.5	1476.37	966.6	1977.64	1207.6	2483.90
250.60	504.54	491.6	994.99	732.6	1491.03	973.7	1992.44	1214.7	2498.86

Figure 3.12: Sample Calibration from CEESI

CHAPTER 4

DISCUSSION

4.1 Overview of Gas Control Panel

Now that the pressure has been analyzed, the specific components of how the entire new configuration will be put together can be discussed. Figure 4.1 shows the schematic of the new configuration that will be discussed.

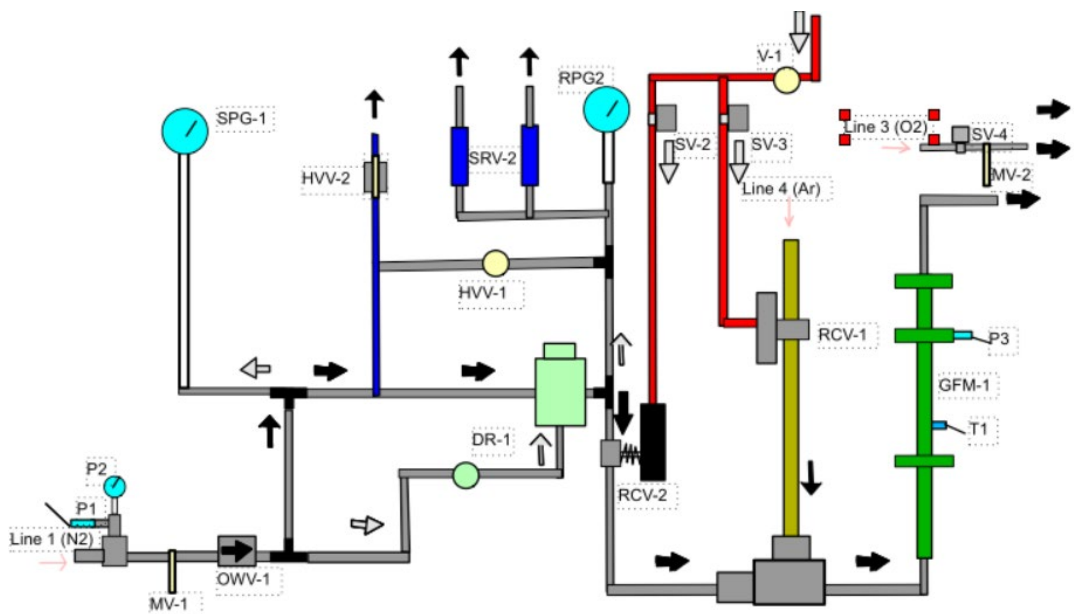


Figure 4.1: Future Control Panel Schematic

4.1.1 Components of the Future Gas Control Panel

There are a lot of parts being considered for the new control panel as it has been analyzed more in depth. However, a lot of the same parts are being reused from the previous configuration. Although many parts are being reused, components have been disregarded due to not seeing a need for the parts. This is outlined in Table 4.1.

Table 4.1: Comparison of Parts

Identifier	Same	Different	Disregarded
P1	✔		
P2		✔	
P3	✔		
P4			✔
P5			✔
SPG-1	✔		
RPG-1			✔
RPG-2	✔		
MV-1	✔		
MV-2		✔	
MV-3			✔
HVV-1	✔		
HVV-2		✔	
V-1		✔	
SV-2	✔		
SV-3	✔		
SV-4	✔		
SV-5			✔
RCV-1	✔		
RCV-2	✔		
R-1		✔	
DR-1		✔	
T1	✔		
SRV-1			✔
SRV-2		✔	
OWV-1		✔	
GFM-1	✔		

4.1.1.1 Future Valves

Regarding the valves, a lot of the chosen parts were kept the same. However, for one to visualize what was used regarding the new configuration, Table 4.2 has been provided below.

Table 4.2: Future Valve References

Identifier	Reference	Company	Valves				
			Ball	Bonnet	One Way	Manual	Solenoid
MV-1	High Performance Rotoball® [3]	HOKE	X				
OWV-1	Backflow-Prevention Valves [20]	McMaster			X		
HVV-2	On/Off Valves [21]	McMaster				X	
HVV-1	3 Piece Process/Instrumentation, 60 Series [6]	Swagelok	X				
CV-2	3 Piece Process/Instrumentation, 60 Series [6]	Swagelok	X				
SV-2	Dayton 6X542 Solenoid Valve [7]	Dayton		X			
SV-3	Dayton 6X542 Solenoid Valve [7]	Dayton		X			
SV-4	Series A Solenoid Valve [8]	Granzow					X
V-1	On/Off Valves [21]	McMaster				X	

Looking at Table 4.1, one can see where the manuals were found for each part of the future configuration. MV-1 was chosen to be the exact same part that was utilized in the older configuration, due to the fact that it is easily adjustable and can handle high pressures. The one way ball check valve (OWV-1) was swapped for one from McMaster Carr, due to the fact that it was significantly cheaper, and could handle pressures up to 3000 psi. It is also used for High-Pressure prevention valves, and mounts similarly to the one from HiP in the previous configuration. McMaster was also utilized in the selection of HVV-2, due to the fact that the one from HiP was rated for 30,000 psi, which was way above the range needed for this configuration. This also made the current panels part considerably more expensive in comparison to that from McMaster-Carr. The manual valve from McMaster-Carr takes in pressures up to 4500 psi for inert gases, which is more applicable compared to that from HiP. HVV-1 was kept to be the same part as a comparison of other similar parts did not seem to reap as many benefits as keeping the original part. Additionally, this part was purchased again (CV-2), as it was needed to drive the Pneumatic

Spring Actuator (RCV-2). Furthermore, the Dayton Solenoid valves and the Granzow Solenoid valve were kept the same (SV-2,SV-3,SV-4), as they served their purpose for the old system. V-1 was changed due to finding a cheaper part at McMaster-Carr with similar specifications outlined from the old part.

4.1.1.2 Future Pressure Gauges

Only two pressure gauges were deemed as fit for purchase for the new configuration. Those being SPG-1 and RPG-2, as referenced in Table 2.2. The reason for not purchasing gauges was due to the fact that there is no technical need for them. They were small gauges that calculated pressures at the inlet of the control panel, and the P4 and P5 calculated pressures at inlet and outlet of R-1 and DR-1. However, because R-1 and DR-1 are now a combined system, instead of separate, there is no need for them. Additionally, RPG-1 was removed due to not having a need for two pressure gauges read the same pressure after the outlet of the dome regulator.

Table 4.3: Future Pressure Gauge References

Identifier	Reference	Company	1000 psi	3000 psi
SPG-1	1259 Process Pressure Gauge [9]	ASHCROFT		X
RPG-2	1008A Pressure Gauge [10]	ASHCROFT	X	

Regarding the critical components, these were outlined in the methodology in Table 3.1. However, now that all the parts of the old configuration and new system have been analyzed, one can see how the parts come together. Table 4.3 gives a description of all of the inlet and outlet fittings.

Table 4.4: Inlet and Outlet for Parts

Identifier	Description	Manufacturer	Inlet	Outlet
MV-1	Manual valve (N2 Inlet)	HOKE	3/8" NPT Female	3/8" NPT Female
OWV-1	Check Valve (one-way high pressure)	McMaster	1/4" NPT Female	1/4" NPT Female
SPG-1	Pressure gauge (Line-1)	ASHCROFT	1/2" NPT	N/A
HVV-2	Manual valve (Line-1 after MV-1 purge)	McMaster	1/4" NPT Female	1/4" NPT Female
A4	Before DR-1 ; Stainless Steel Swagelok Tube Fitting, Male Connector	Swagelok	1/2 in. Tube OD	1" NPT
A5	Before DR-1; Stainless Steel Swagelok Tube Fitting, Male Connector	Swagelok	1/2 in. Tube OD	1/2" NPT
DR-1	Manual Pressure Regulator	Swagelok	1" NPT Female	1" NPT Female
A6	After DR-1; Stainless Steel Swagelok Tube Fitting, Male Connector	Swagelok	1" NPT	3/4 in. Tube OD
A7	After DR-1; Stainless Steel Swagelok	Swagelok	3/4" Ferrules & Nut	N/A
HVV-1	Manual valve (DR-1 outlet purge)	Swagelok	1/4" NPT Female	1/4" NPT Female
SRV-2	Relief Valves	Generant	3/4" NPT	3/4" NPT
RPG-2	Pressure gauge (DR-1 out pressure, more accurate)	ASHCROFT	1/4" NPT	N/A
CV-2	Valve for Spring Actuator	Swagelok	3/4" NPT Female	3/4" NPT Female
RCV-2	Pneumatic Spring Actuator	Swagelok	N/A	N/A
SV-2	Solenoid valve (drives pneumatic RCV-1)	Dayton	N/A	N/A
SV-3	Solenoid valve (drives pneumatic RCV-1)	Dayton	N/A	N/A
V-1	Manual valve (175 psi inlet)	McMaster	3/4" NPT Female	3/4"NPT Female
RCV-1	Pneumatic valve, spring, (Argon flow) & Valve	HOKE	1/8" NPT Female	1/8" NPT Female
SV-4	Solenoid valve (Oxygen from line 3); with oxygen cleaning service	Granzow	1/4" NPT Female	1/4" NPT Female
GFM-1	Gas Flow Meter: Critical Flow Venturi & Approach Tube	FlowMaxx	SCH 80 Male Pipe	N/A

4.1.2 Costs for Future Gas Control Panel

The running total cost of this panel, due to the fact a few piping and the stainless steel panel need to still be purchased, is outlined below. Many of these parts prices are not outlined on their websites, and are only provided when inquired. Not only did all the new parts match the requirements needed for the new control panel, but it was also cost effective as well as seen in Table 5.1.

Table 4.5: Running Total of Future Gas Control Panel

Regulator/Dome Regulator	Swagelok	$3,275.61
Ball Valve	Swagelok	$170.10
1/2" to 1" Connector	Swagelok	$16.90
1/2" to 1/2" Connector	Swagelok	$39.80
3/4" to 1" Connector	Swagelok	$39.80
Spring Actuator	Swagelok	$294.50
3/4" Ferrules	Swagelok	$13.31
Valve for Spring Actuator	Swagelok	$504.46
Ultra High Pressure Valve (2)	McMaster	$153.34
Brass Valve for 175 psi	McMaster	$13.36
High Pressure Valve	McMaster	$59.96
Pressure Gauge-1000	ASHCROFT	$100.80
Pressure Gauge-3000	ASHCROFT	$62.80
Solenoid Valves (2)	Dayton	$80.10
Pressure Transducer	OMEGA	$780.00
Temperature Transducer	OMEGA	$38.50
Pneumatic Valve	HOKE	$232.54
Manual Valve	HOKE	$604.75
Gas Flow Meter	Flow Maxx Engineering	$1,580.00
Electronic Pressure Regulator	Propotion Air	$2,309.50
Bolted Bonnet Valves (2)	Grainger	$160.00
Relief Valve	Generant	$296.32
Solenoid Valve (O2)	Granzow	$206.67
TOTALS		$11,033.12

CHAPTER 5

CONCLUSION

Because one has done the required Literature Review by studying all the components from both the old and new configurations, one can modify the control panel to obtain optimal efficiency. As stated previously, the panel contains the following parts: adapters, ball valves, pneumatic valves, bonnet valves, solenoid valves, spring actuators, pressure transducers, thermocouples, piping, pressure gauges, a dome regulator, an electronic pressure regulator, relief valves, and a sonic flow nozzle. All of these parts were studied in order for the system to work as a cohesive whole and were considered based of functionality, efficiency, and cost.

Due to the fact that the gas control panel met all the flow rate and pressure requirements and was cost effective, the new control panel is set for the new experimentation for the new facility. This project showed one to be able to apply the knowledge learned in the classroom to a real life problem, and forced one to research each individual component in order to fully understand how it integrates into the grand scheme for the whole system. Future work includes buying the remaining necessary plumbing, putting together the panel, and running future experiments by utilizing it.

APPENDIX A

CURRENT CONTROL PANEL DETAILS

Identifier	Description	Manufacturer	Model/Details
P1	Pressure transducer (N2 Inlet)	OMEGA	PX-3093KG5V
P2	Pressure gauge (N2 Inlet)	USG	Range: 0-6000 [psi]
P3	Pressure transducer (GFM-1 Flow meter)	OMEGA	PX-3091KGV (Shielded cables)
P4	Pressure gauge (R-1 Regulator in)	USG	Range: 0-6000 [psi]
P5	Pressure gauge (R-1 Regulator out)	USG	Range: 0-6000 [psi]
SPG-1	Pressure gauge (Line-1)	ASHCROFT	Range: 0-10000[psi]
RPG-1	Pressure gauge (DR-1 out pressure)	USG	Range: 0-3500[psi]
RPG-2	Pressure gauge (DR-1 out pressure, more accurate)	ASHCROFT	Range: 0-1000[psi]
MV-1	Manual valve (N2 Inlet)	HOKE	316 SS High pressure
MV-2	Manual valve (O2 Inlet)	-	Ball valve
MV-3	Manual valve (R-1 inlet supply valve)	-	-
HVV-1	Manual valve (DR-1 outlet purge)	WHITEY	SS 316 2200 [psi]
HVV-2	Manual valve (Line-1 after MV-1 purge)	HiP	30k [psi] max
V-1	Manual valve (175 psi inlet)	WHITEY	-
SV-2	Solenoid valve (drives pneumatic RCV-2)	Generic	-
SV-3	Solenoid valve (drives pneumatic RCV-1)	Generic	-
SV-4	Solenoid valve (Oxygen from line 3)	Granzow	High pressure
SV-5	Solenoid valve (traverse cooling)	Generic	-
RCV-1	Pneumatic valve, spring, (Argon flow)	HOKE	0722A4
RCV-2	Pneumatic valve (Nitrogen), spring,	WHITEY	133-SR and CF3M 200 [psi] max for control
R-1	Regulator Valve (Control air for Control Valve DR-1)	TESCOM	44-1100/ inlet 6000 [psi], outlet 15-2000 [psi]
DR-1	Control valve	TESCOM	26-1111-282 inlet and outlet rated for 6000 [psi]
T1	Thermocouple (GFM-1 Flow meter)	OMEGA	Type T
SRV-1	Blow off valve 5500[psi]	HiP	60 22HF0 316 SS
SRV-2	Blow off valve (pressure rating 1210[psi])	Circle Seal	5159B-2MP-1210
OWV-1	Check Valve (one-way high pressure)	HiP	316 SS 20 382
GFM-1	Gas flow meter (ARC-HEATER SUPPLY),	Flow Dyne Eng. Corp	Approach tube: ATP-P010250-SMPT, Coupling CP010001-SFPT, NOZZLE NP010177, D^2 0.177

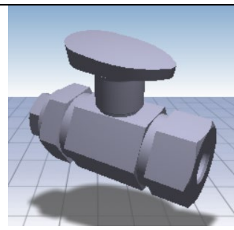
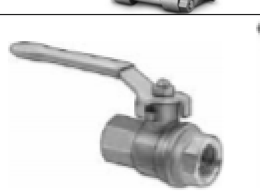
APPENDIX B

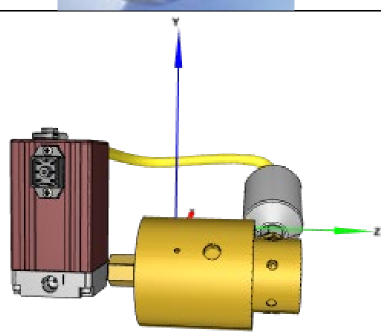
FUTURE CONTROL PANEL DETAILS

Identifier	Description	Manufacturer	P/N
SPG-1	Pressure gauge (Line-1)	ASHCROFT	45 1259SD 04L 3000#
RPG-2	Pressure gauge (DR-1 out pressure, more accurate)	ASHCROFT	63 1008S 02L 1000#
MV-1	Manual valve (N2 Inlet)	HOKE	7223F6YD20
MV-2	Manual valve (O2 Inlet)	McMaster	9786K21
HVV-1	Manual valve (DR-1 outlet purge)	Swagelok	SS-62TF4
HVV-2	Manual valve (Line-1 after MV-1 purge)	McMaster	9786K21
V-1	Manual valve (175 psi inlet)	McMaster	47865K24
SV-2	Solenoid valve (drives pneumatic RCV-2)	Dayton	6X542
SV-3	Solenoid valve (drives pneumatic RCV-1)	Dayton	6X542
SV-4	Solenoid valve (Oxygen from line 3); with oxygen cleaning service	Granzow	A2U30-00V-K
RCV-1	Pneumatic valve, spring	HOKE	0722A5
RCV-2	Pneumatic Spring Actuator	Swagelok	MS-133-SR
SRV-2	Blow off valve 1000[psi]	HOKE	M5159B-8M-1000
OWV-1	Check Valve (one-way high pressure)	McMaster	7838K54
A5	Before DR-1 ; Stainless Steel Swagelok Tube Fitting, Male Connector, 1/2 in. Tube OD x 1 in. Male NPT	Swagelok	SS-810-1-16
A6	Before DR-1; Stainless Steel Swagelok Tube Fitting, Male Connector, 1/2 in. Tube OD x 1/2 in. Male NPT	Swagelok	SS-810-1-8
A7	After DR-1; Stainless Steel Swagelok Tube Fitting, Male Connector, 3/4 in. Tube OD x 1 in. Male NPT	Swagelok	SS-1210-1-16
A8	After DR-1; Stainless Steel Swagelok Ferrules & Nut, 3/4 in.	Swagelok	SS-1212/3/4-1
GFM-1	Gas Flow Meter: Critical Flow Venturi & Approach Tube	Flow Dyne Eng. Corp.	NP01-0177-SMPT; ATP-0100179-SMPT;
DR-1/R-1	Manual Pressure Regulator	Swagelok	RDHN10-02-8-NNK-EF
(E)DR-1/R-1	Electronic Pressure Regulator: QBX, Dome Regulator, DST, Valve Assembly, 6 foot Chord	Proportion Air	QB2XANEEZP133.33PSG3DRR; RG1262; DSTEY00ZP6000PSGA; KITASSM; QBT-C-6;

APPENDIX C

TABLE OF COMPONENTS OTHER THAN PIPING AND ADAPTERS

Part	Description	Identifier/Manufacturer	Significance
	Manual Valve for N2 Inlet	HOKE/MV-1	Chosen due to ease in turning the valve for high pressurized systems
	One Way Check Valve	McMaster Carr/OWV-1	High Pressure Backflow Prevention Valve
	Pressure Gauge	ASHCROFT/SPG-1	Visual display pressure before dome regulator
	Pressure Gauge	ASHCROFT/RPG-2	Visual display after Dome Regulator
	Manual Valve after purge of MV-1	McMaster Carr/HVV-2	Chosen due to it being more cost efficient than original part
	Adapter Before/After DR-1	Swagelok/A5,A6,A7,A8	Needed to fit into the 1" inlet for DR-1
	Manual Pressure Regulator	Swagelok/DR-1	Pilot Regulator sets pressure, and the main regulator blows off that output
	Manual Valve for DR-1 outlet purge	Swagelok/HVV-1	Same as previous configuration
	Manual Valve for 175 psi inlet	McMaster/V-1	Valve cheaper than the one previously used

	Solenoid Valves that drives Pneumatic Valves	Dayton/SV-2 & SV-3	Same as previous configuration
	Solenoid Valve cleaned for gas	Granzow/SV-4	Same as previous configuration
	Pneumatic Valve	HOKE/RCV-1	Same as previous configuration
	Pneumatic Valve	Swagelok/RCV-2	Same as previous configuration
	Sonic Flow Nozzle	FlowMaxx Engineering/GFM-1	Same part as previous configuration
	Electronic Pressure Regulator	Proportion Air/(E)DR-1/R-1	Chosen to experiment with due to manual pressure regulators causing errors in previous experiments

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BIOGRAPHICAL INFORMATION

Prior to coming to the University of Texas at Arlington, Rachel had earned both her high school diploma and Associates of Science in General Science in 2016. During her time at the University of Texas at Arlington, she earned an Honors Bachelor of Science in Aerospace Engineering with a minor in Mechanical Engineering. She was a member of the Leadership Honors Program, Maverick Mentors, and the Honors College. She was the Public Relations director for Maverick Mentors her sophomore year, and mentored two freshman as well. She partook in the Undergraduate Research Opportunity Program during the Summer of 2018. Her future endeavors include taking a job as a Systems Engineer at Lockheed Martin, and continuing to pursue her graduate studies at the University of Texas at Arlington in order to receive her Master of Science in Aerospace Engineering.