PEAPOD

Pneumatically Energized Auto-throttled Pump Operated for a Developmental Upperstage

Test Readiness Review

Customer: Special Aerospace Services

Chris Webber and Tim Bulk

Overview

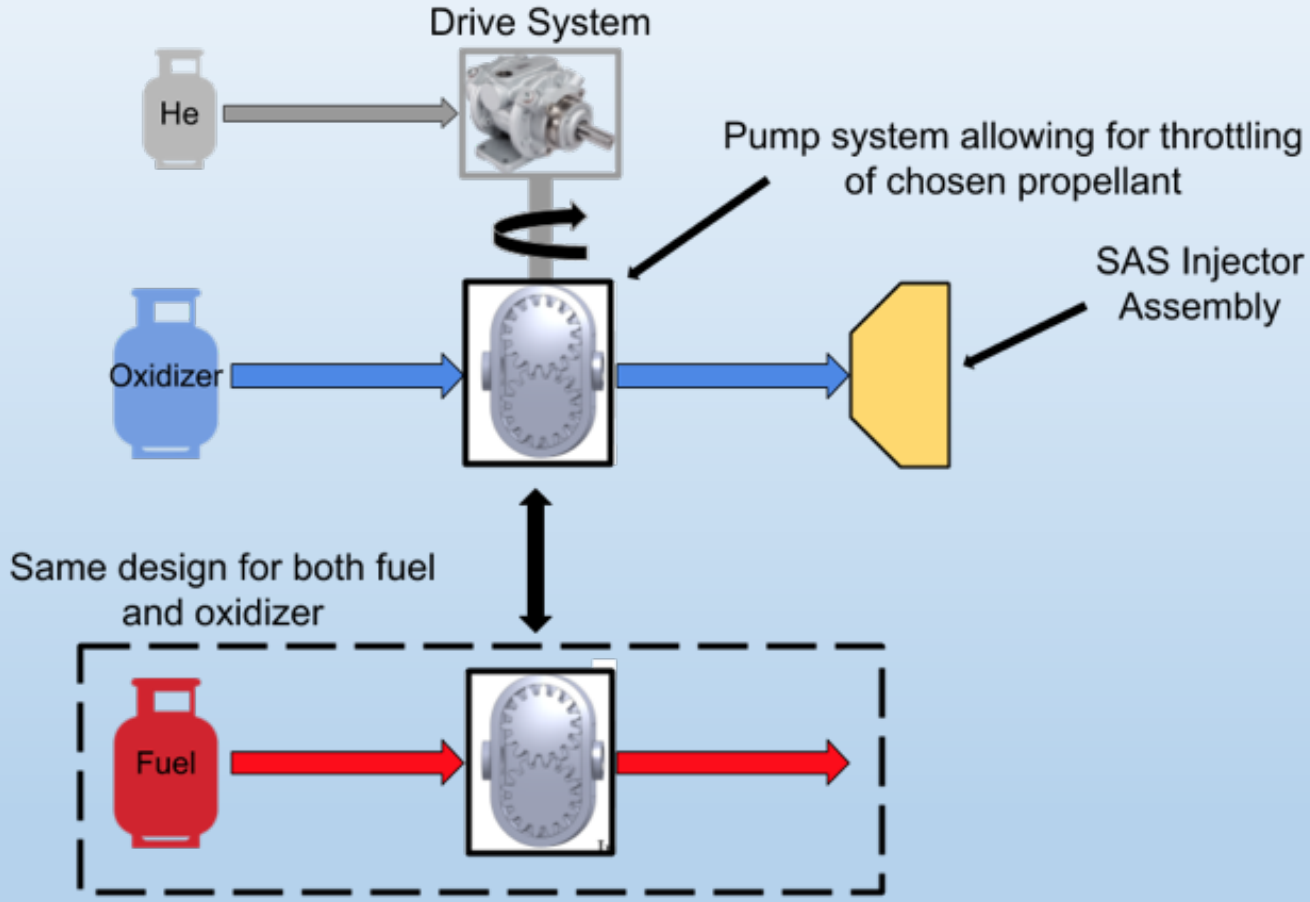
- Project Overview
- Schedule
- Test Readiness
- Budget

Project Overview

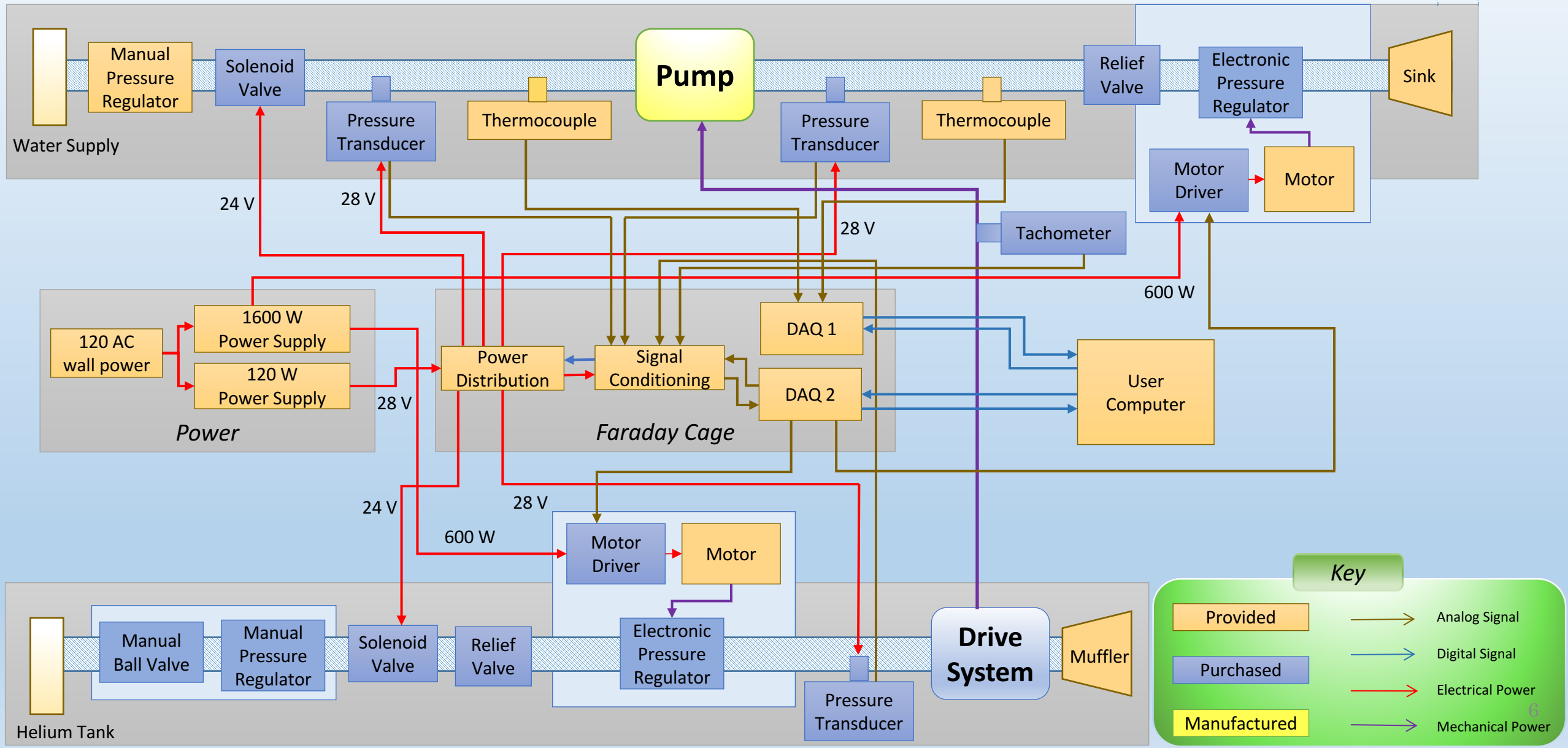
Project Motivation

- Design, manufacture, and test a pneumatically powered pump system for use on an upper stage rocket engine or lander.
  - Proof of concept pump system for hypergolic propellants
  - 10%-100% throttleability
  - Pneumatically powered

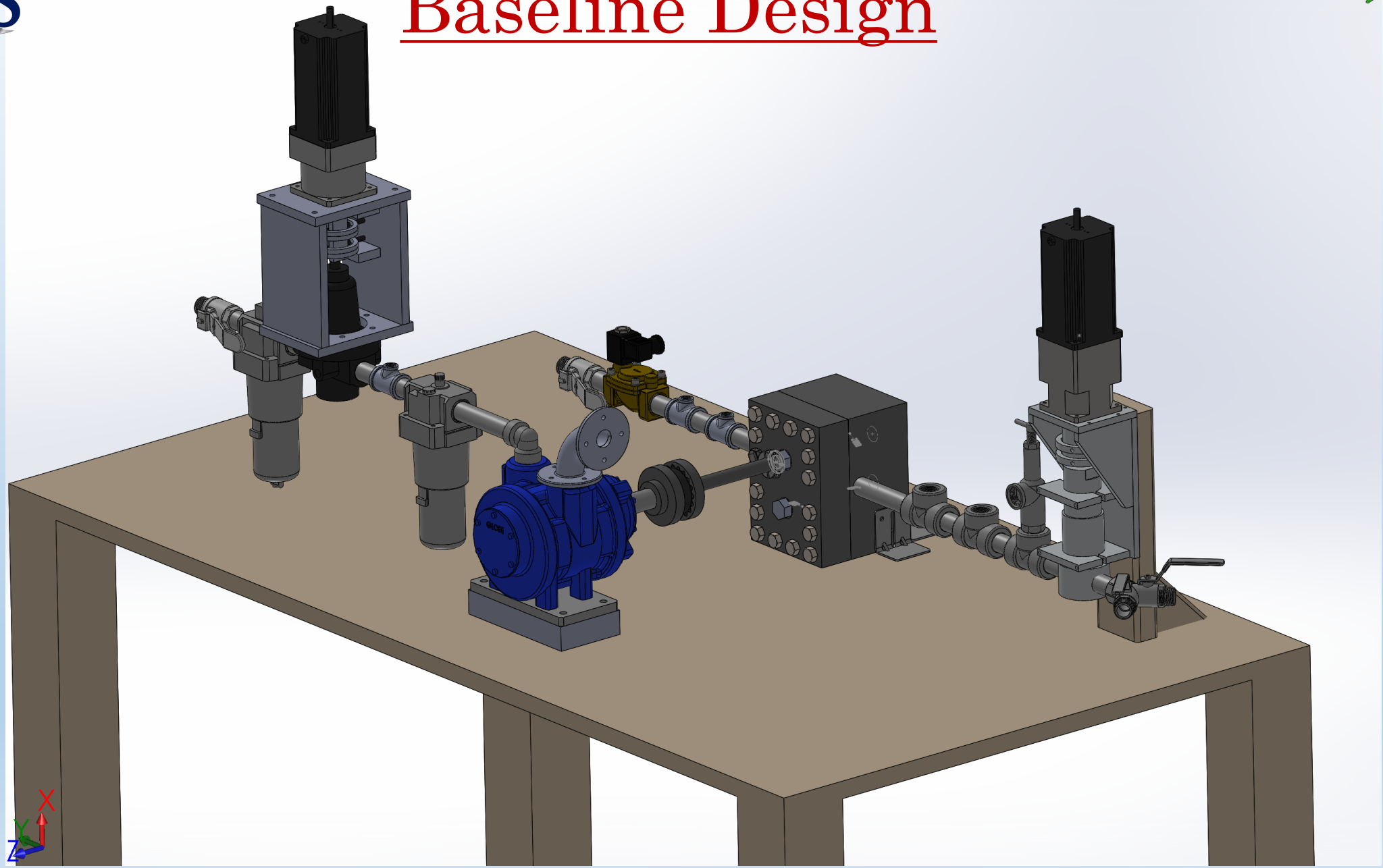
CONOPS


Drive System
He
Pump system allowing for throttling of chosen propellant
SAS Injector Assembly
Oxidizer
Same design for both fuel and oxidizer
Fuel

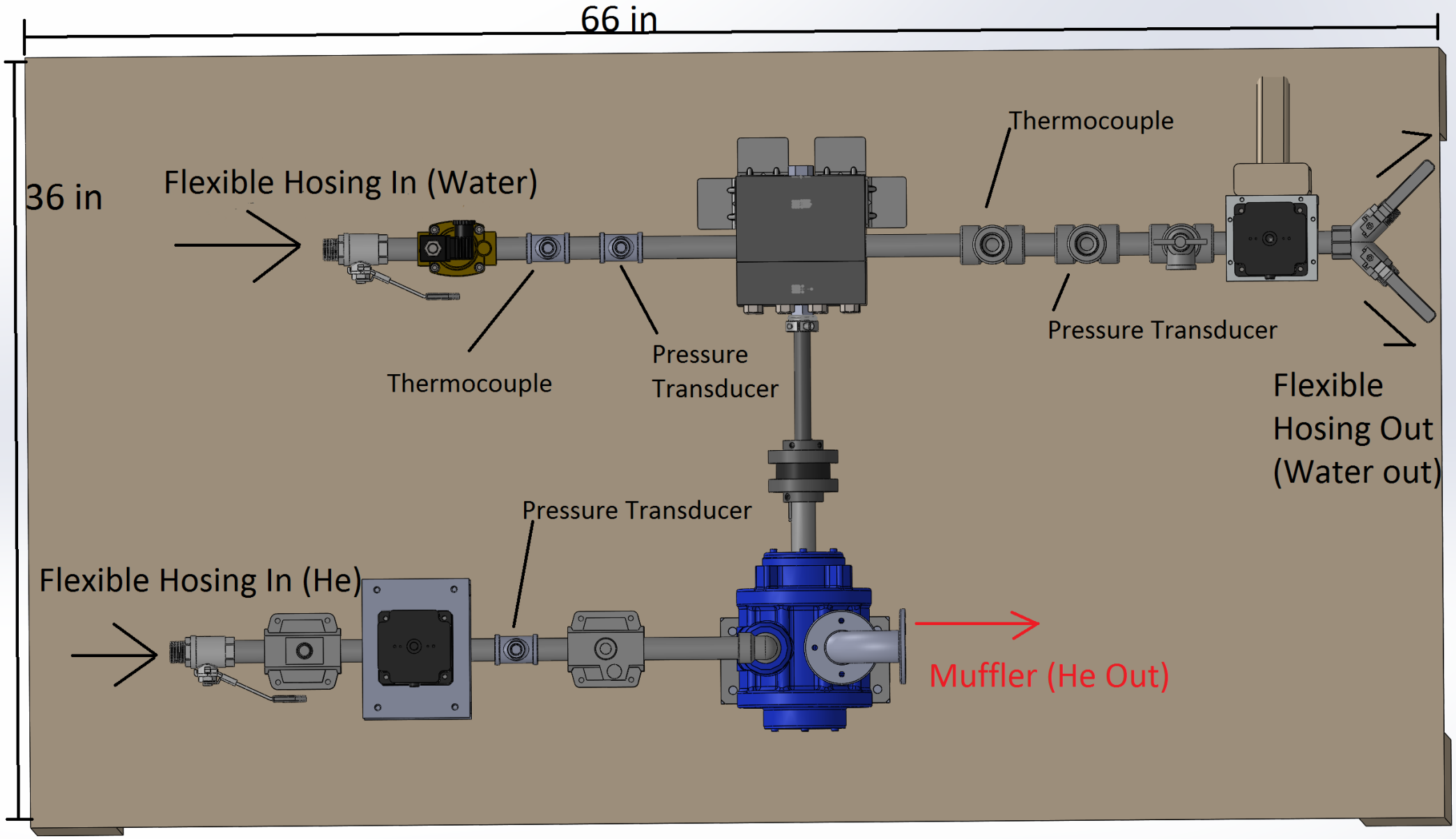
Functional Block Diagram



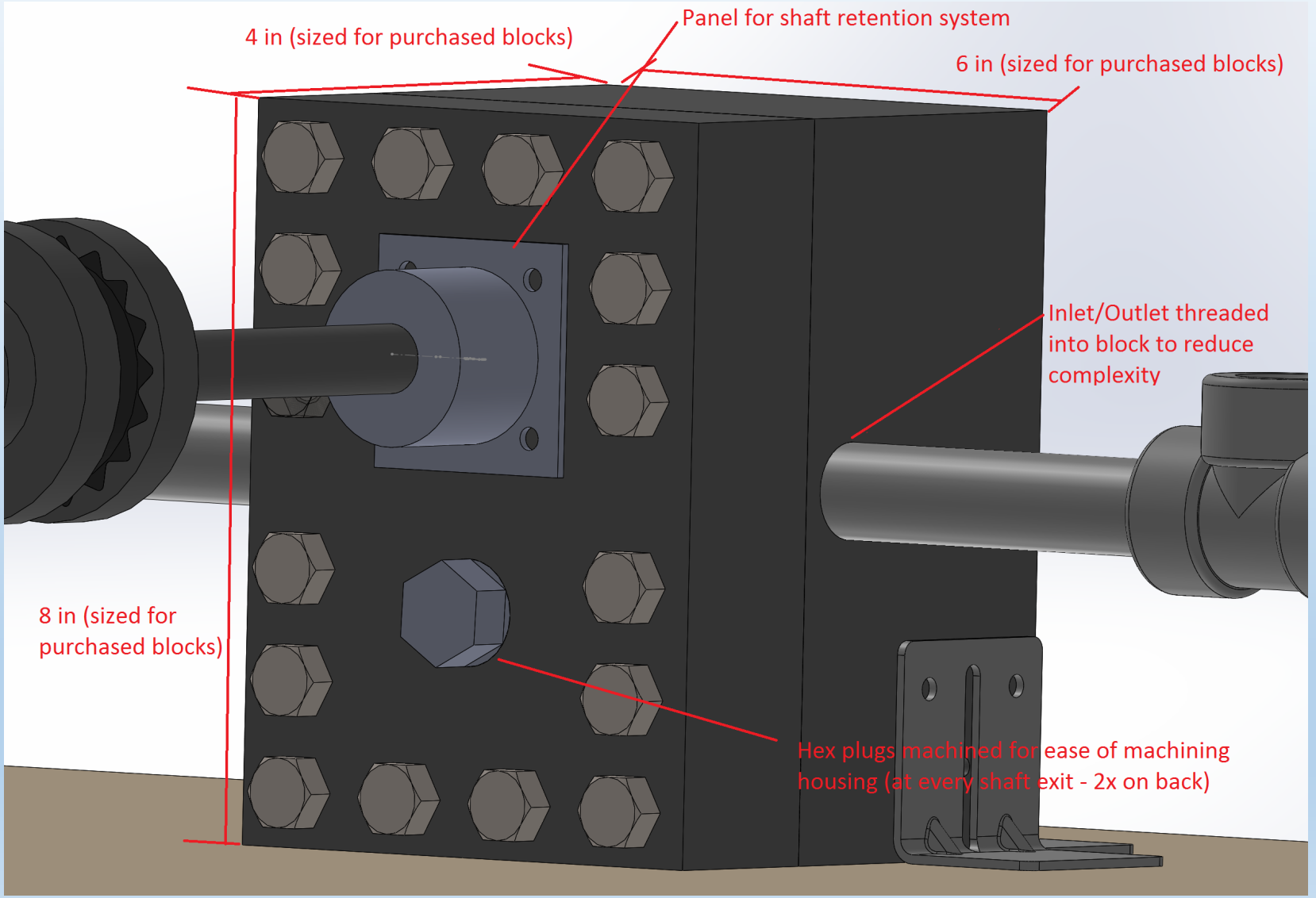
Baseline Design



Baseline Design



Design Changes



Design Changes – Air Motor Pressure Regulator

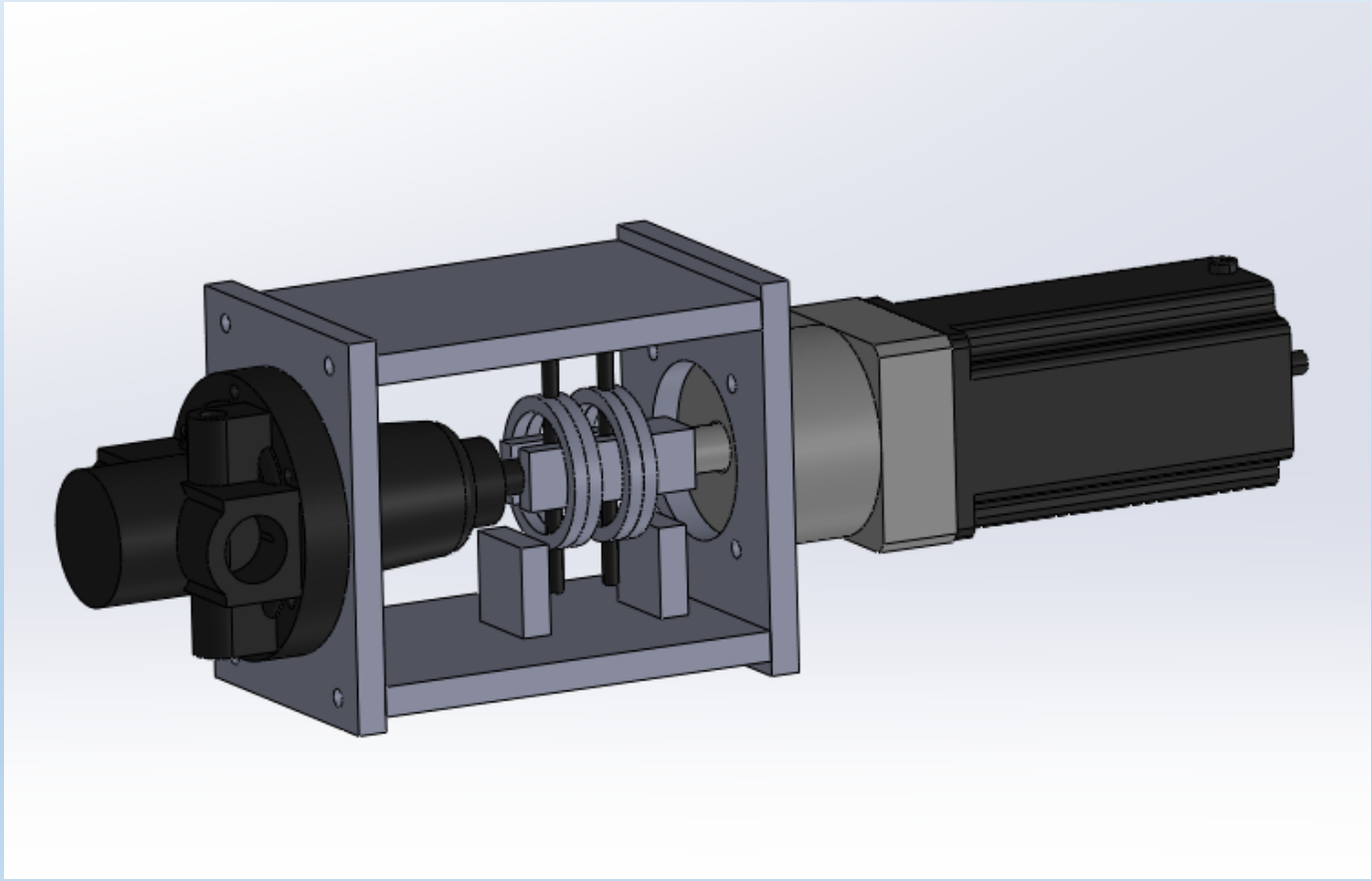
Constructed from a manual regulator and stepper motor:

Manual Regulator:

- 400 scfm flowrate (360 required)
- 0 psi to 120 psi (105 psi required)
- 12 turns for 0 psi to 105 psi
- 8 N-m max. adjustment torque

Stepper Motor (HT34-487) w/Gearbox

- 2.2rev/s max. rotation rate (0.6 rev/s required)
- 25 N-m min. torque (8 N-m required)



Design Changes – Back-Pressure Regulator

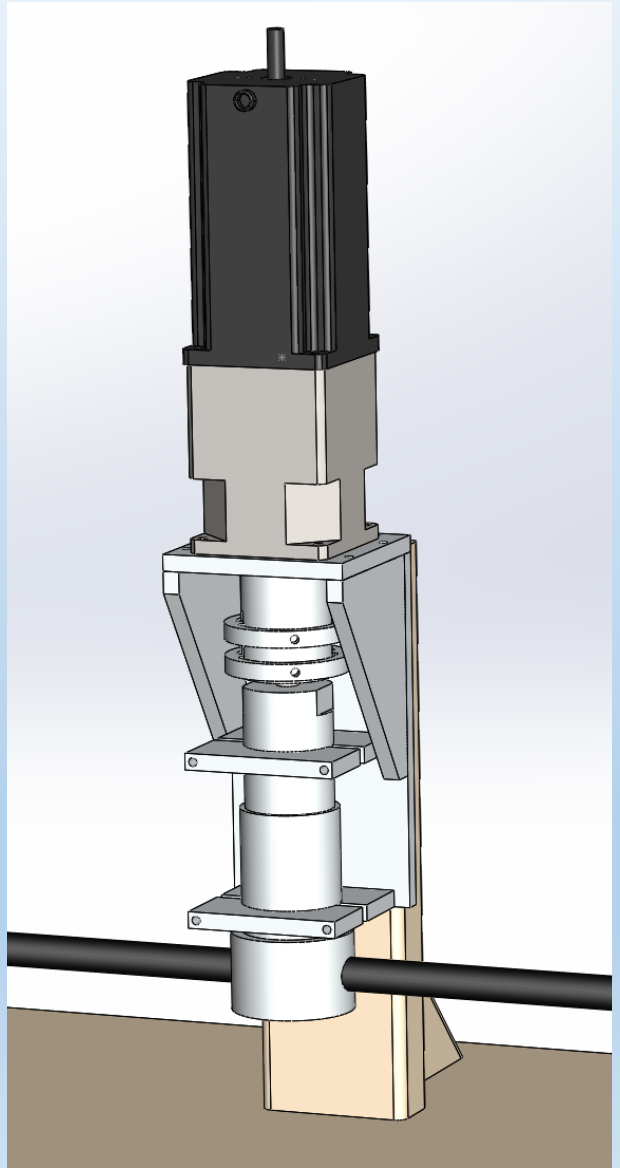
Constructed from a manual back-pressure regulator and stepper motor:

Manual Back-Pressure Regulator:

- 200 lpm flowrate (84 required)
- 75 psi to 750 psi (full range req.)
- 11 turns for 75 psi to 750 psi
- 15N-m max. adjustment torque

Stepper Motor (HT34-487) w/Gearbox

- 4 rev/s max. rotation rate (2.2 rev/s required)
- 25 N-m min. torque @ 2.2 rev/s (15 N-m required)



Critical Project Elements

CPEs from CDR	Rationale
Develop a functioning pump	Manufacturing of the pump is in progress, but assembly and operation of the pump could pose a time risk.
Meet efficiency requirement of 75%	Control and design of the pump could cause the pump to achieve a lower efficiency.
Correct acquisition of pressure, RPM, and mass flow rate	Have yet to acquire a measurement on flow rate, which is needed for Level 1 Success.
Developing throttling capabilities (10-100%)	Throttling the air motor using a stepper motor attached to a regulator creates unforeseen mechanical and control loop challenges.
Safe operation of pump and drive system	Operating a pump with high pressures using digital control can present a multitude of problems towards safety.
Budgetary restrictions	A multitude of parts to purchase

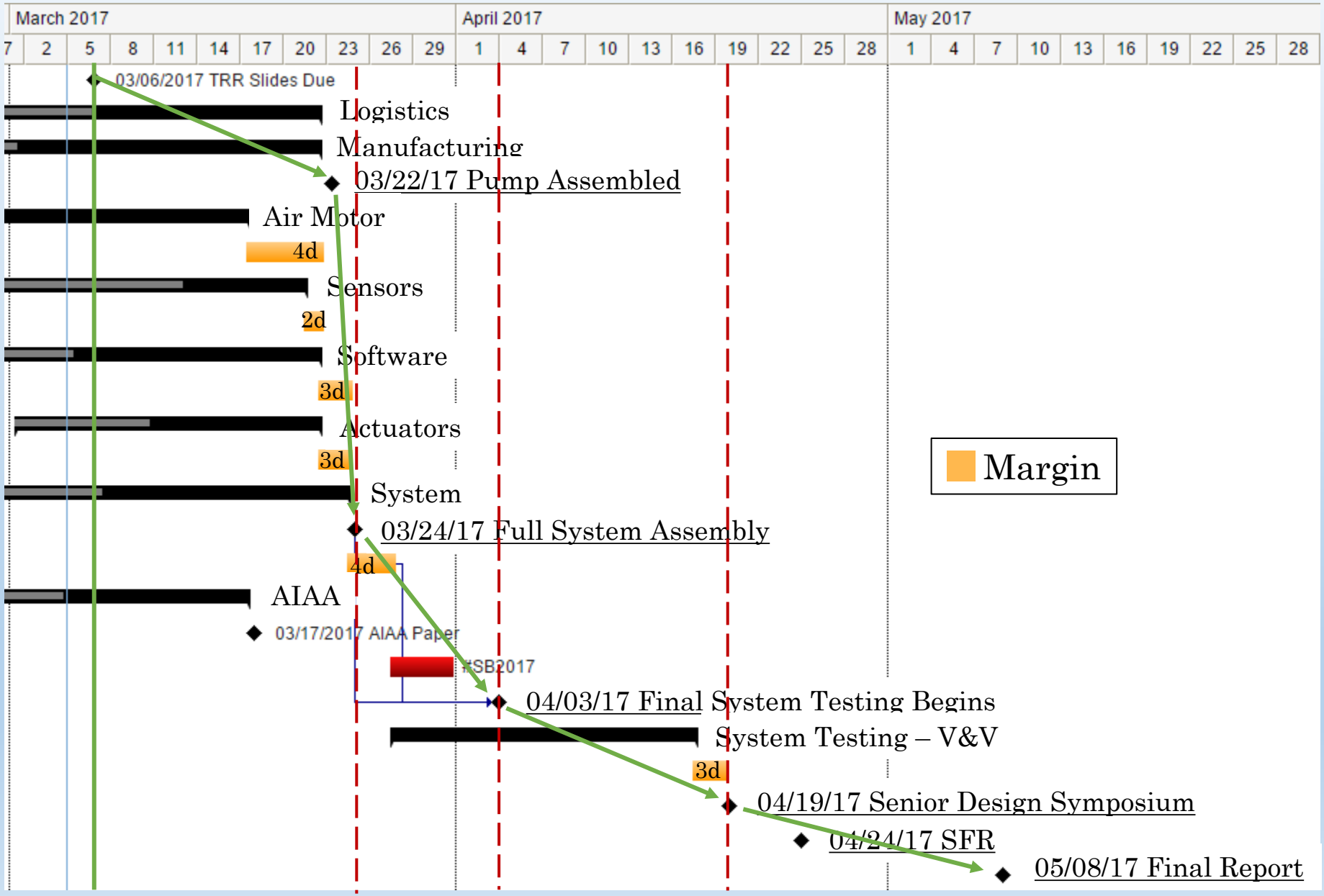
Levels of Success

Level	Performance Success
1	• 750 ± 15 psi outlet pressure • Structural FOS 2.5 • 120 seconds of operation • 75% efficiency of pump at full throttle
2	• 10-100% throttleability • 0-100% throttle in 2 seconds • All level 1 requirements
3	• 0-100% throttle in 1 second • All level 1 and 2 requirements • ~~Hypergolic Compatible~~

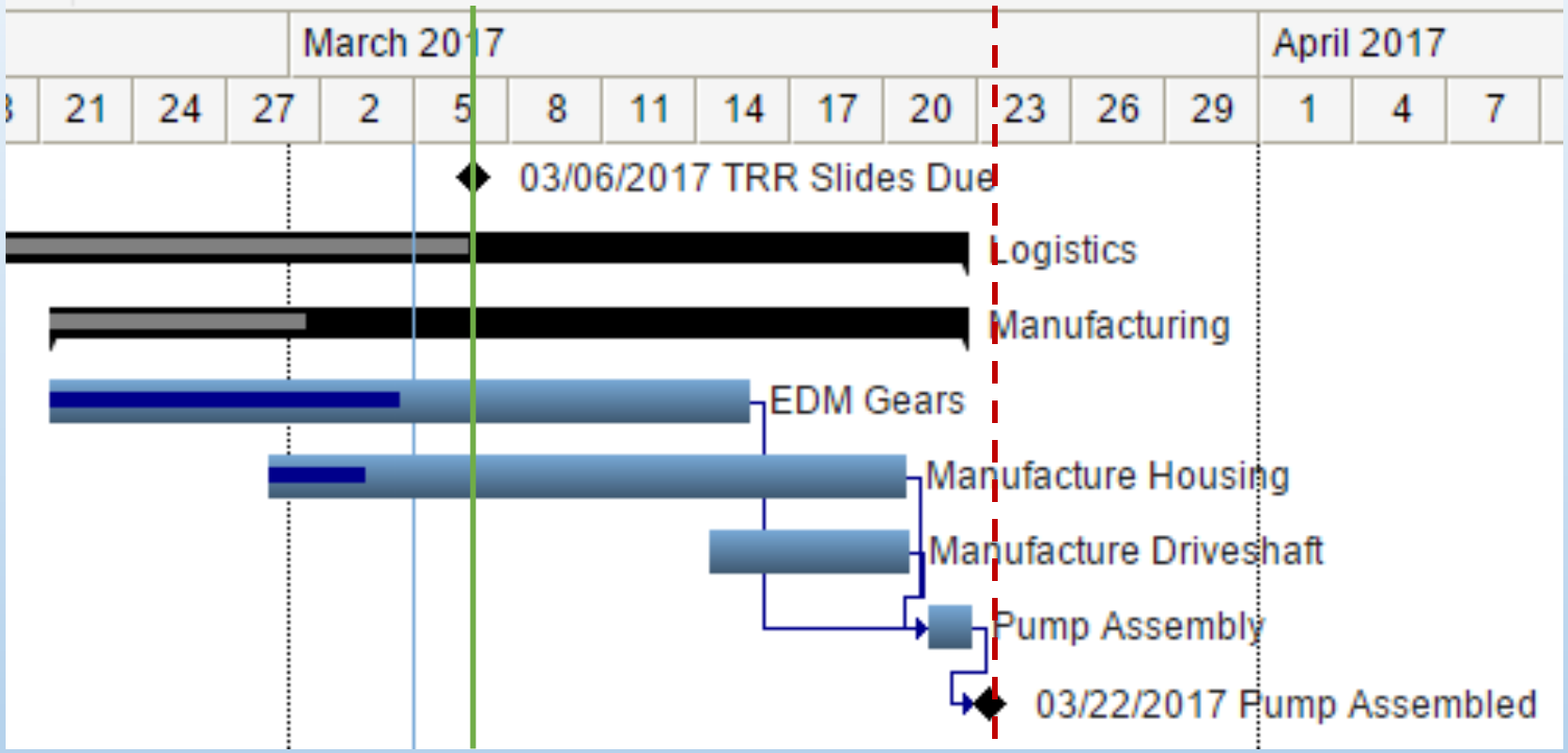
Key
On Track
Completed
Concerned
~~**Will Not Meet**~~

Schedule

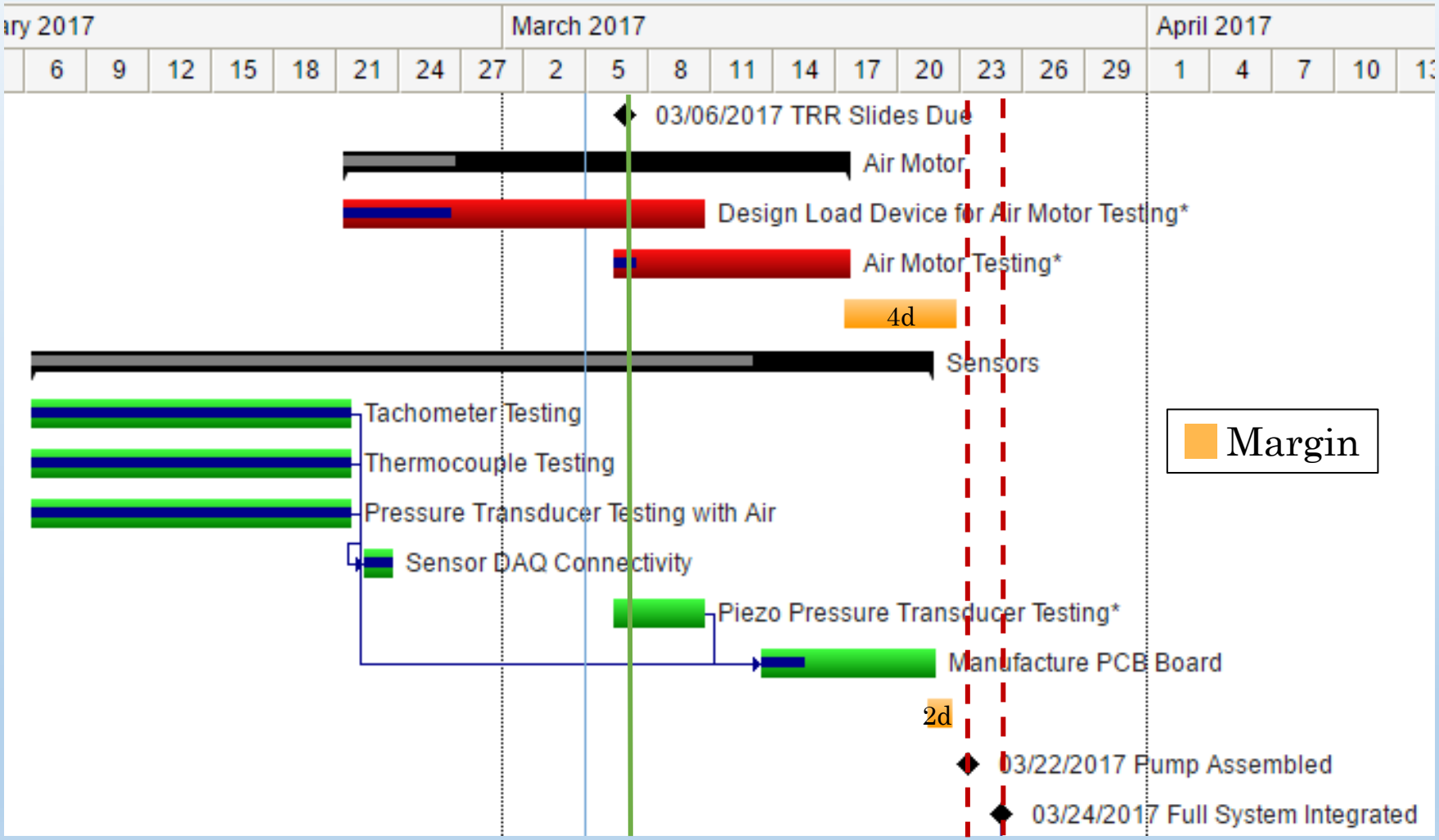
Overview


March 2017
April 2017
May 2017
7 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13 16 19 22 25 28 1 4 7 10 13 16 19 22 25 28
03/06/2017 TRR Slides Due
Logistics
Manufacturing
03/22/17 Pump Assembled
Air Motor
4d
Sensors
2d
Software
3d
Actuators
3d
System
03/24/17 Full System Assembly
4d
AIAA
03/17/2017 AIAA Paper
ASB2017
04/03/17 Final System Testing Begins
System Testing – V&V
3d
04/19/17 Senior Design Symposium
04/24/17 SFR
05/08/17 Final Report
Margin

Manufacturing



Testing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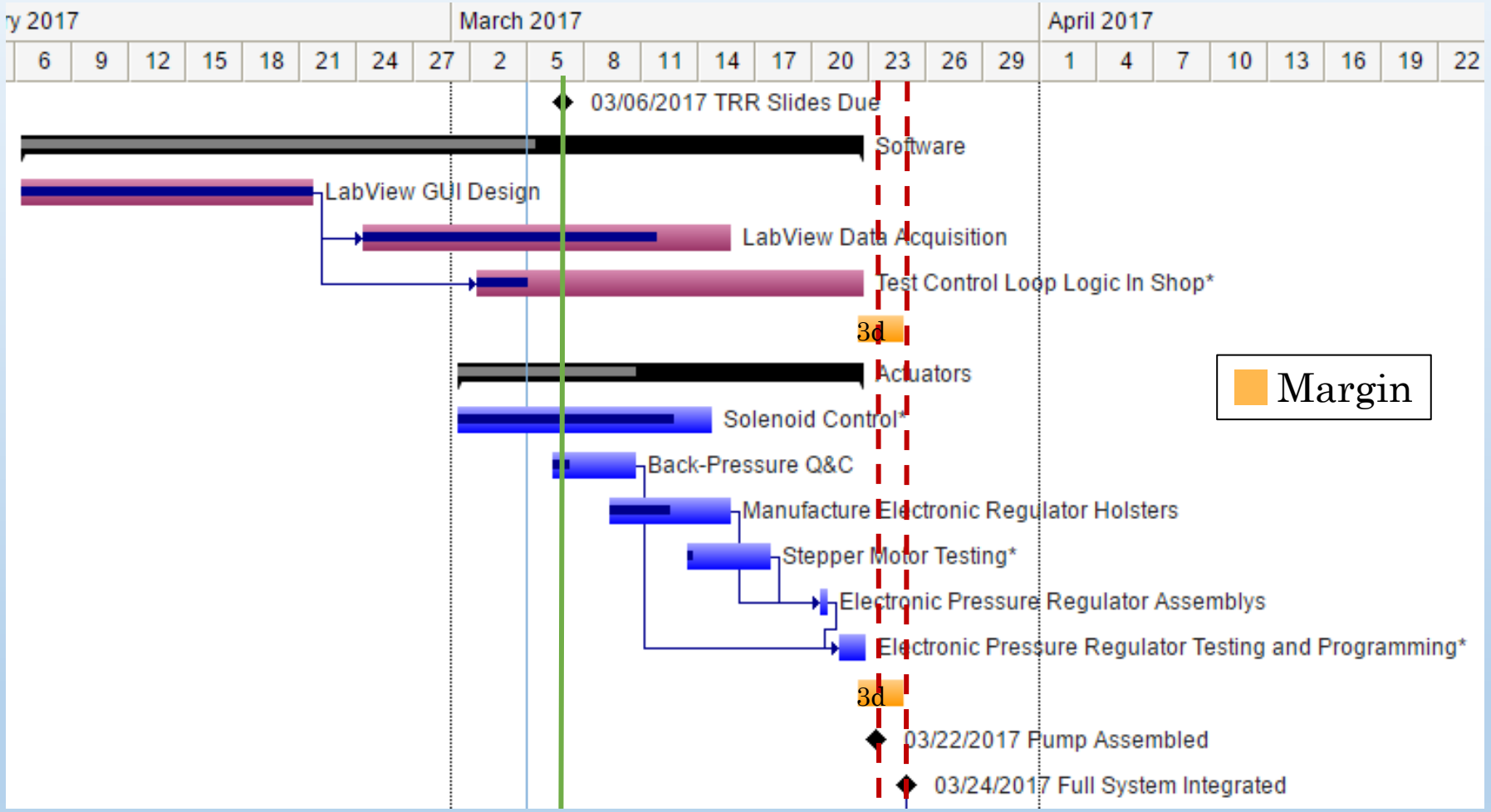
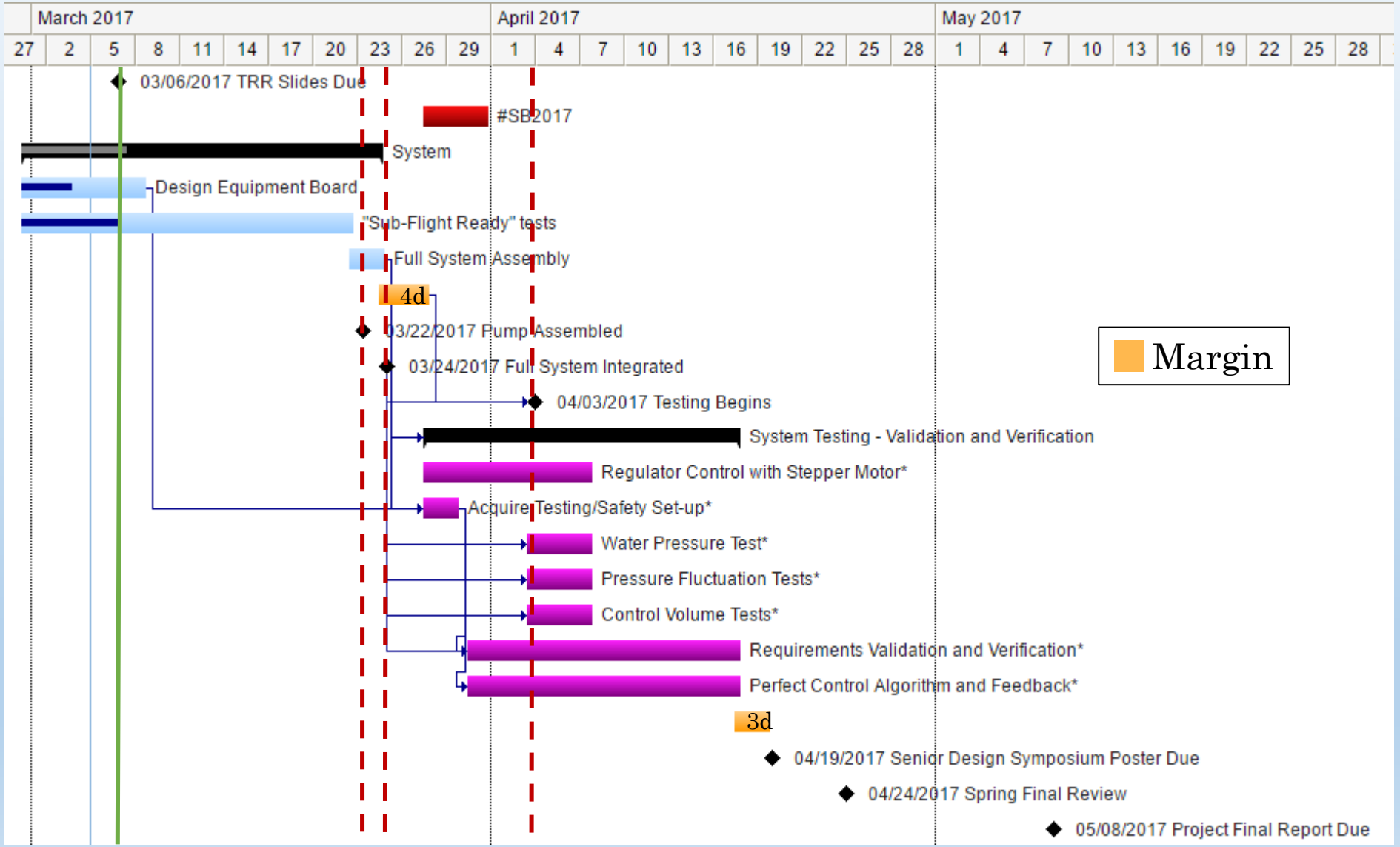
March 2017
April 2017
6 9 12 15 18 21 24 27 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13
03/06/2017 TRR Slides Due
Air Motor
Design Load Device for Air Motor Testing*
Air Motor Testing*
4d
Sensors
Tachometer Testing
Thermocouple Testing
Pressure Transducer Testing with Air
Sensor DAQ Connectivity
Piezo Pressure Transducer Testing*
Manufacture PCB Board
2d
03/22/2017 Pump Assembled
03/24/2017 Full System Integrated
Margin

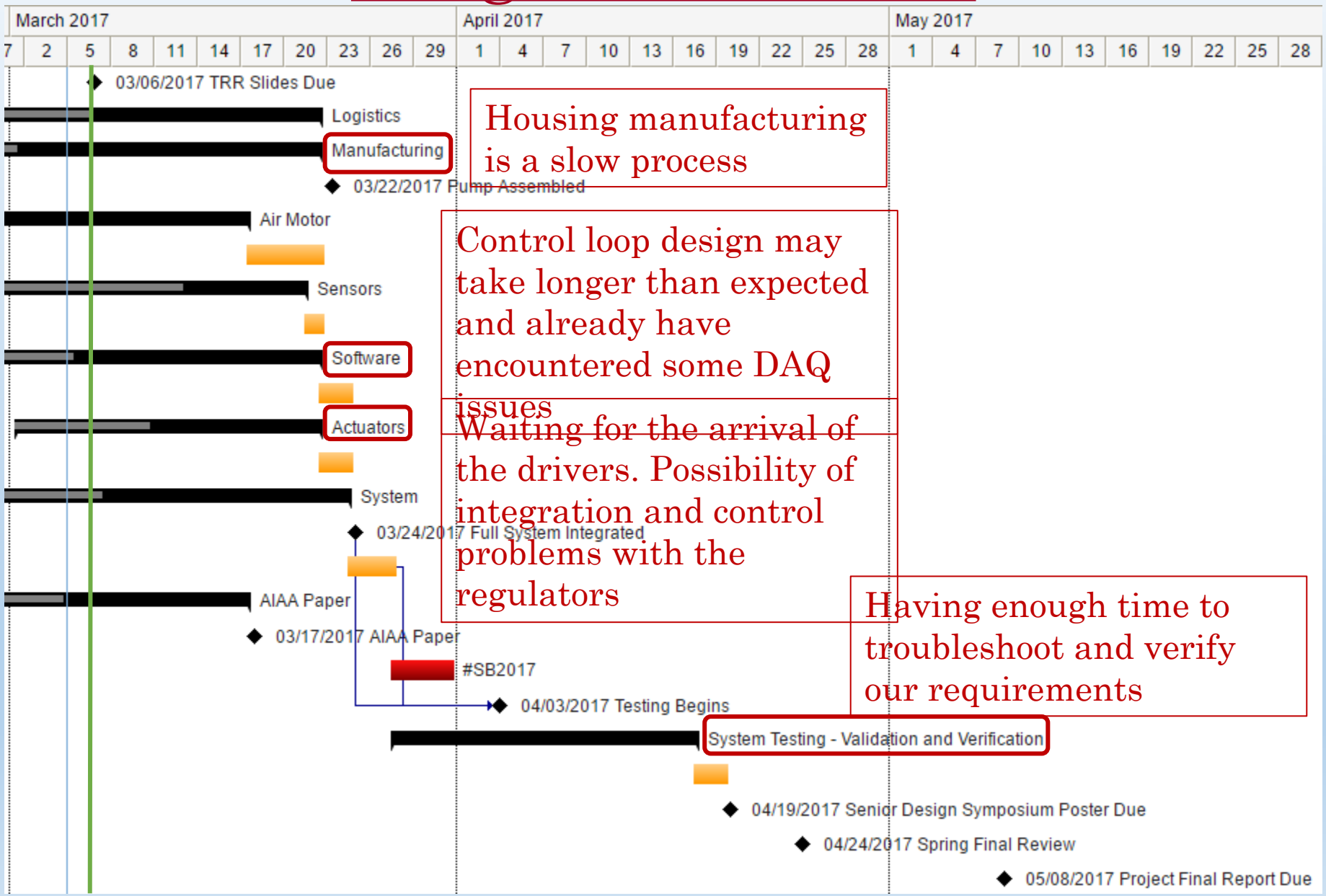
Testing


y 2017
March 2017
April 2017
6 9 12 15 18 21 24 27 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13 16 19 22
03/06/2017 TRR Slides Due
Software
LabView GUI Design
LabView Data Acquisition
Test Control Loop Logic In Shop*
3d
Actuators
Solenoid Control*
Back-Pressure Q&C
Manufacture Electronic Regulator Holsters
Stepper Motor Testing*
Electronic Pressure Regulator Assemblys
Electronic Pressure Regulator Testing and Programming*
3d
03/22/2017 Pump Assembled
03/24/2017 Full System Integrated
Margin

Testing


March 2017
April 2017
May 2017
27 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13 16 19 22 25 28 1 4 7 10 13 16 19 22 25 28
03/06/2017 TRR Slides Due
#SB2017
System
Design Equipment Board
"Sub-Flight Ready" tests
Full System Assembly
4d
03/22/2017 Pump Assembled
03/24/2017 Full System Integrated
04/03/2017 Testing Begins
System Testing - Validation and Verification
Regulator Control with Stepper Motor*
Acquire Testing/Safety Set-up*
Water Pressure Test*
Pressure Fluctuation Tests*
Control Volume Tests*
Requirements Validation and Verification*
Perfect Control Algorithm and Feedback*
3d
04/19/2017 Senior Design Symposium Poster Due
04/24/2017 Spring Final Review
05/08/2017 Project Final Report Due
Margin

Largest Concerns



Housing manufacturing is a slow process

Control loop design may take longer than expected and already have encountered some DAQ issues

~~Waiting for the arrival of~~ the drivers. Possibility of integration and control problems with the regulators

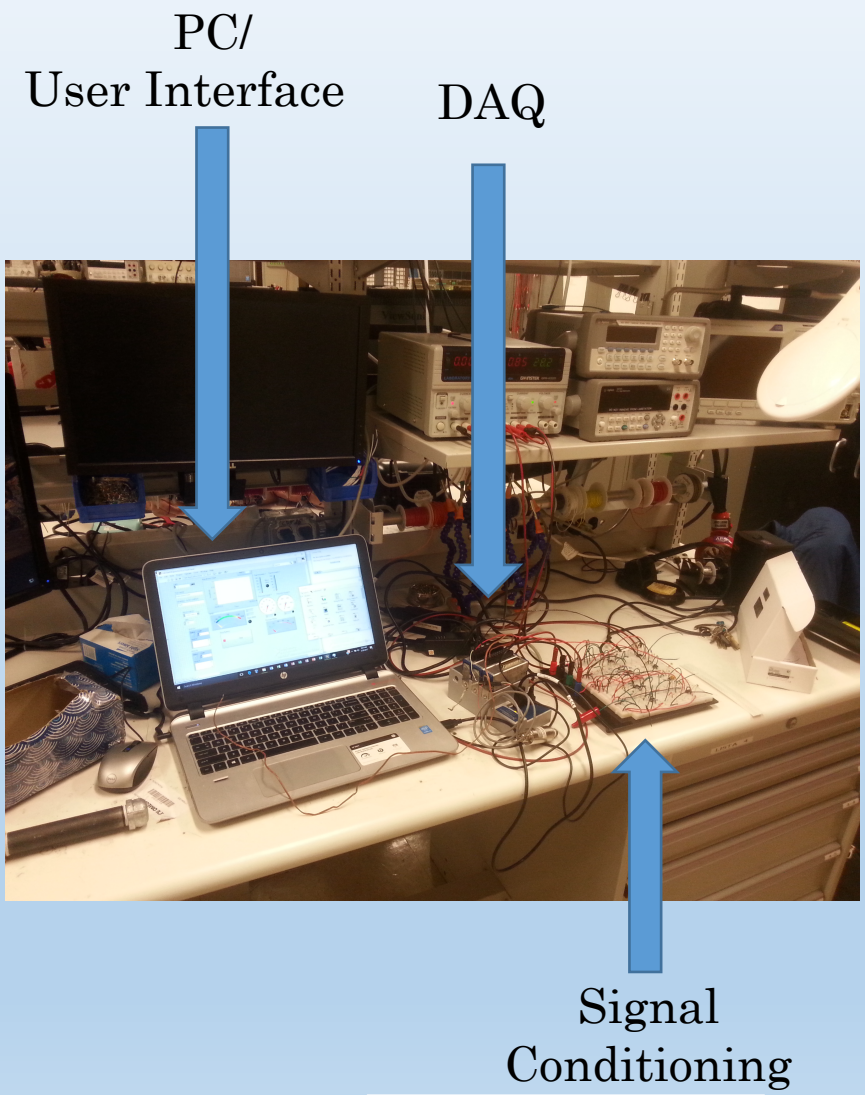
Having enough time to troubleshoot and verify our requirements

Test Readiness

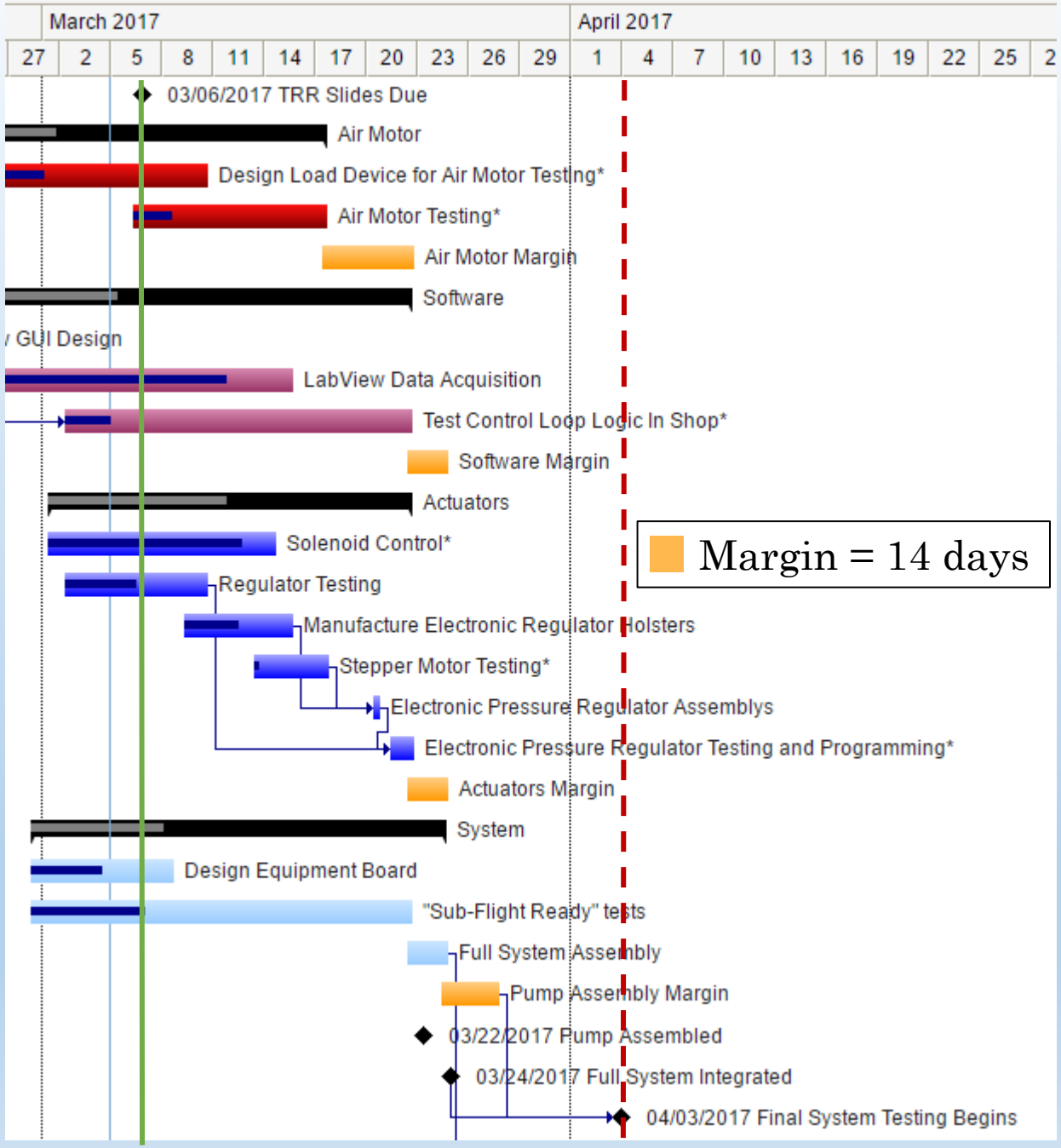
Testing Status

- Completed Tasks
  - DAQ Data Collection
  - Sensor Calibration
  - Sensor Signal Conditioning
  - Leak Testing

Requirement(s) met:
- FR.7



Subsystem Test Plan Overview



Subsystem Test Plan Overview

Feb. 6-28

- Sensor Q&C and breadboard design
- DAQ GUI
- Solenoid Testing

Feb. 28 – Mar. 6

- DAQ Sensor Integration
- Regulator Testing

Mar. 6-12

- Air Motor Testing
- Control Logic Development

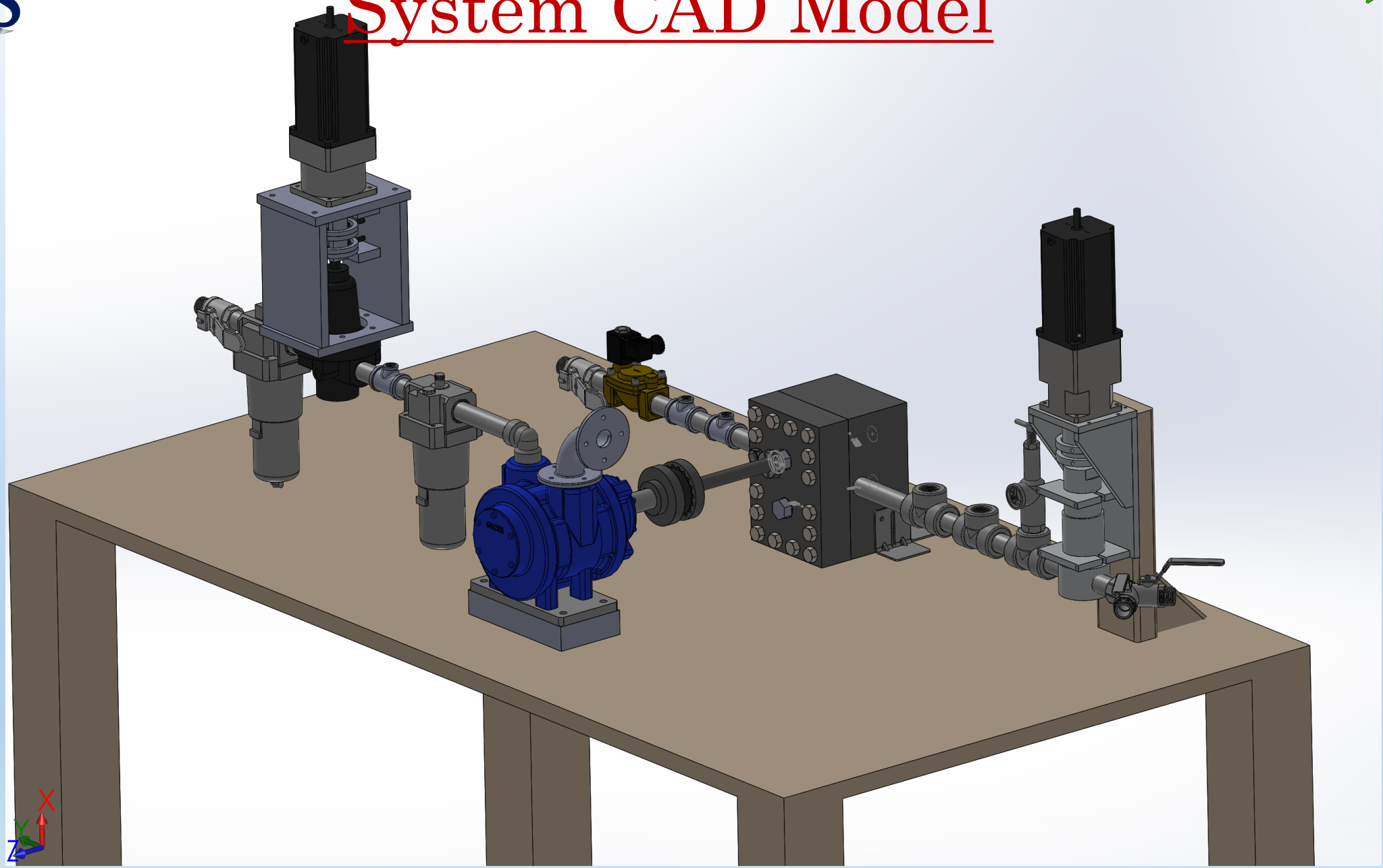
Mar. 12-20

- Stepper Motor Test
- Air Motor Throttling
- Iteration of control algorithm

Mar. 20-22

- Pump Assembly

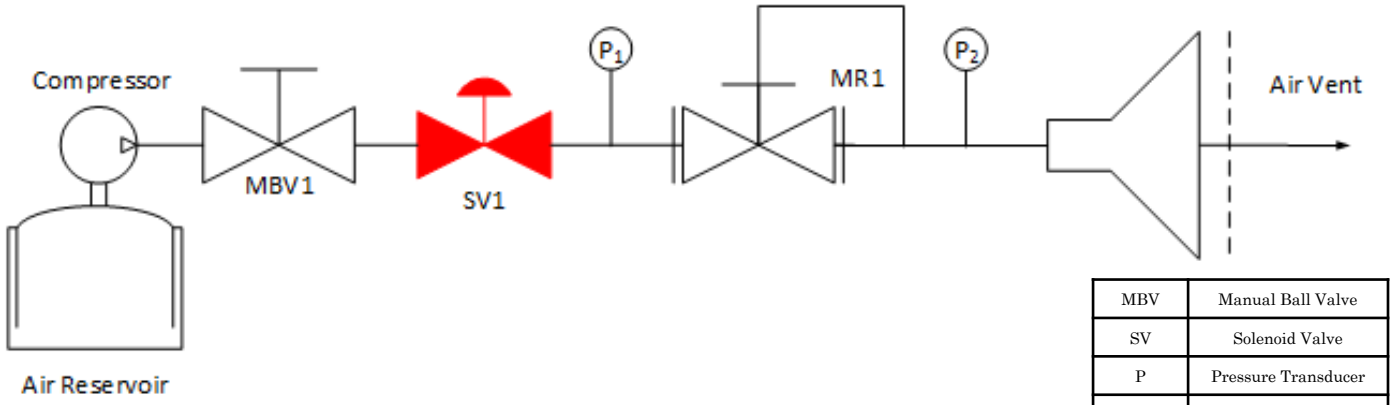
System CAD Model



Pressure Regulator Testing

Test Rationale: Relate regulator opening to downstream pressure through data collection. Use results to calibrate downstream pressure to regulator thread engagement.

Test Setup:



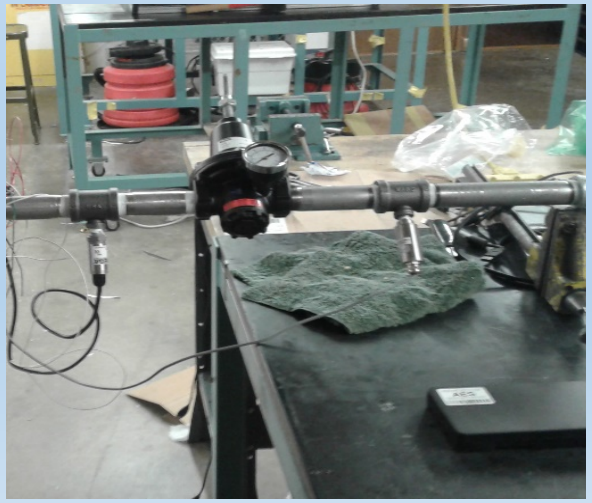
MBV	Manual Ball Valve
SV	Solenoid Valve
P	Pressure Transducer
MR	Manual Regulator

Equipment required:

- 1” Manual Ball Valve
- 1” Electric Solenoid Valve
- 2x Pressure Transducer (1/4”NPT fitted in Tee)
- 1” Manual Pressure Regulator
- 1” Venting Cap
- 1” Piping

Facilities required:

- Air compressor providing 100PSI provided in Projects Room



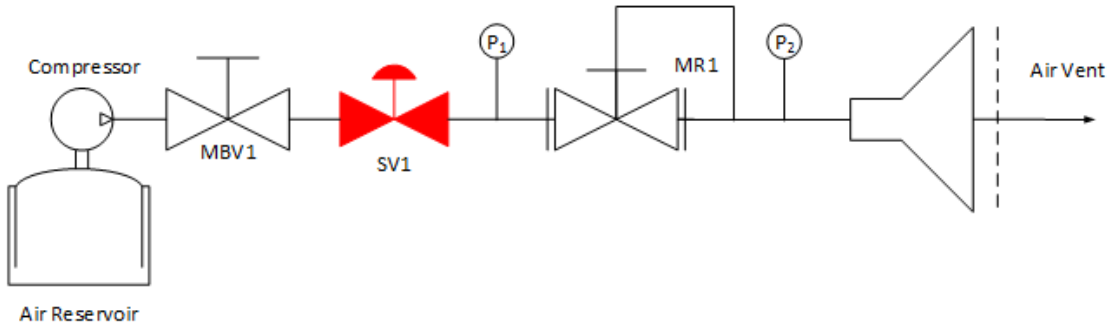
Pressure Regulator Testing

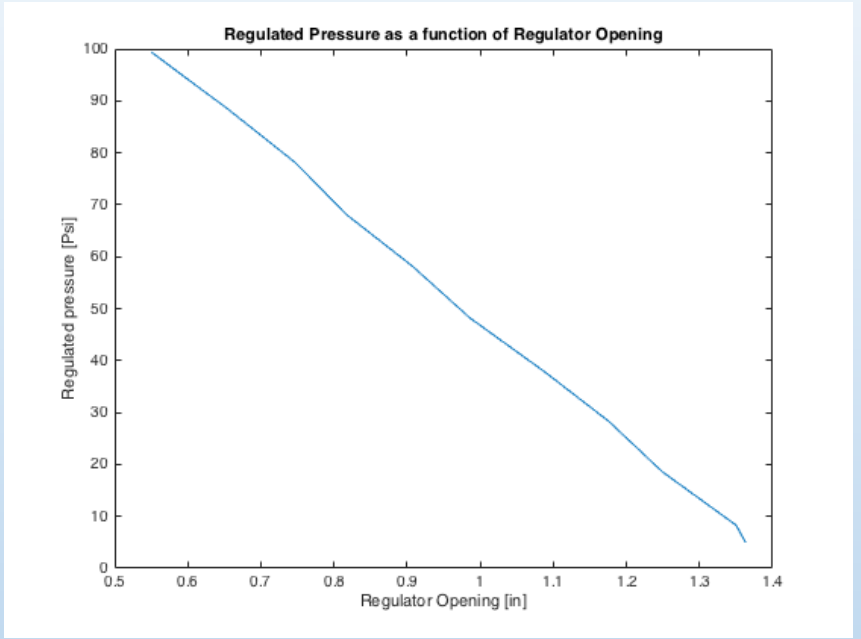
Test Procedure: Set regulator to certain thread engagement, record the subsequent downstream pressure. Repeat as needed for a sufficient amount of points over the full pressure range.

Risk Mitigation: The results of this test will help to operate the regulator electronically, getting the project closer to fulfilling its requirement of electronically regulating the pump.

Time Requirement: 7 man hours

Test Setup:





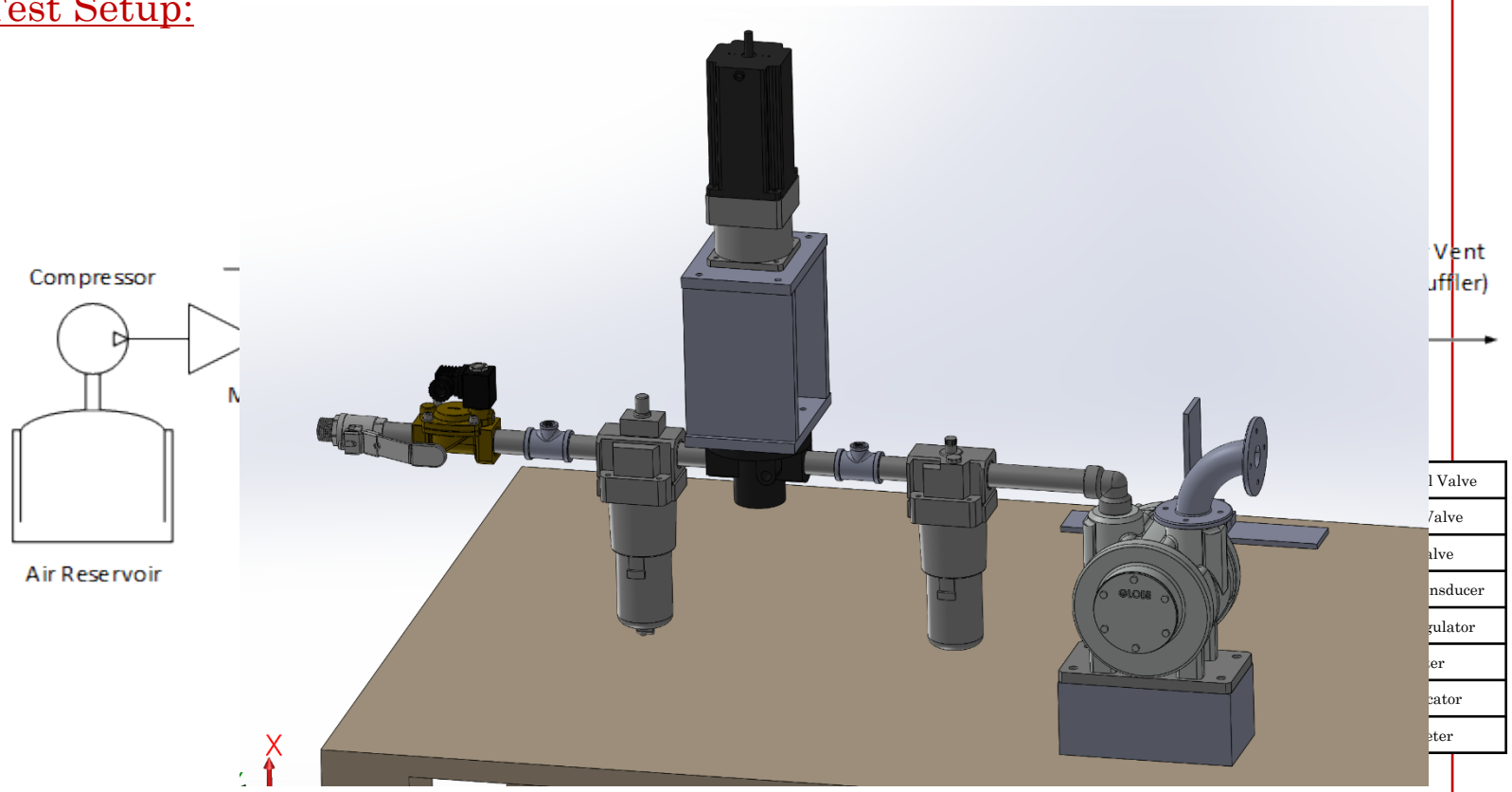
Notable Results:
The relationship between the regulator thread engagement and the downstream pressure is **roughly linear**, allowing for an initial simple controller to be designed.

Requirements met at test completion: None

Air Motor Testing

Test Rationale: Determine the operational throttle range of the motor. Quantification of motor vibrations.

Test Setup:



Equipment required:

- 1” Manual Ball Valve
- 1” Electric Solenoid Valve
- 125PSI Relief Valve (1/4”NPT fitted in Tee)
- 1” Air Filter
- Pressure Transducer (1/4”NPT fitted in Tee)
- 1” Manual Pressure Regulator
- 1” Air Lubricator
- Air Motor with muffler mounted on exhaust
- Tachometer
- Shaft Torque Device
- 1” Piping

Facilities required:

- Air compressor providing 100PSI Air @45CFM, provided on East Campus

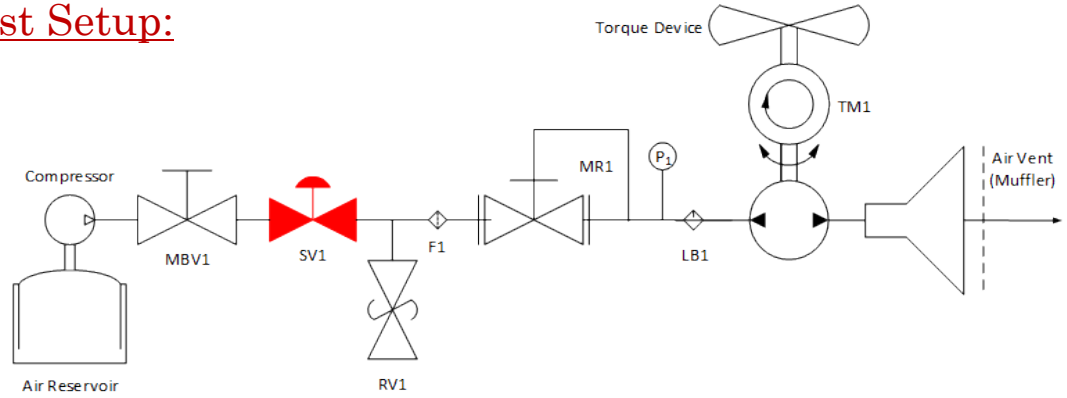
Air Motor Testing

Test Procedure:
Regulator is set to a known pressure (starting at 10PSI), the system is activated. The resulting RPM of the drive shaft is recorded. The test is run for a the full range of pressures 0-100PSI.

Risk Mitigation: The results of this test will verify that the motor can attain the full throttle range of 10-100% throttle-ability. This test will also quantify expected vibrations the motor will induce on the test assembly

Time Requirement: 20 man hours

Test Setup:

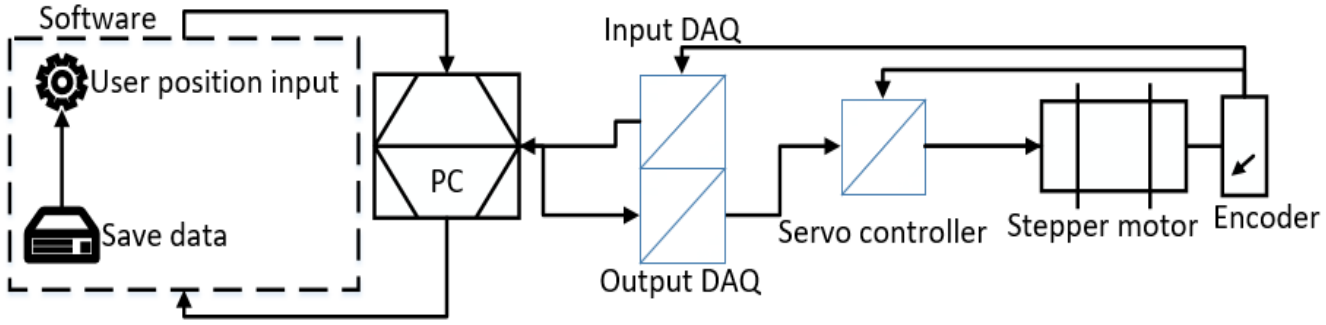


Requirements met at test completion:
- FR2 – Pump is throttleable

Stepper Motor Testing – Phase 1

Test Rationale:
Determined motor can be controlled through LabVIEW. Quantify accuracy of control system and slew rates

Test Setup:



Equipment required:
- Computer
- Data Acquisition (DAQ)
- Stepper Motor
- Motor Driver
- 1600W power supply

Facilities required:
- Projects room

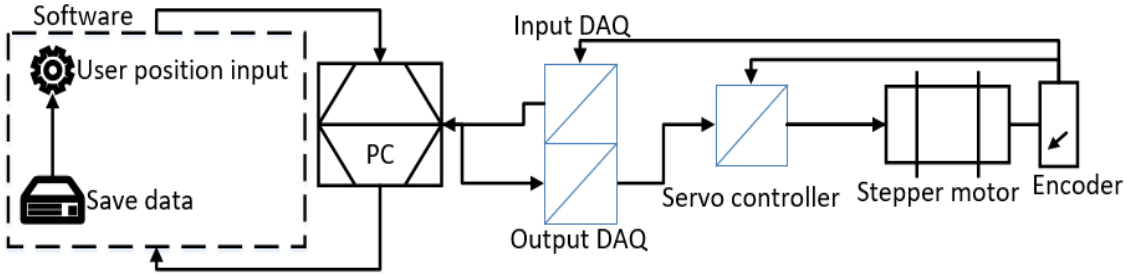
Stepper Motor Testing – Phase 1

Test Procedure:
Motor will be connected to the DAQ, while LabVIEW commands the motor to step to specific angles.

Risk Mitigation: The results of this test will verify that the stepper motor can be controlled through LabVIEW allowing pressure to be regulated to the angles specified.

Time Requirement: 10 man hours

Test Setup:



Requirements met at test completion: None

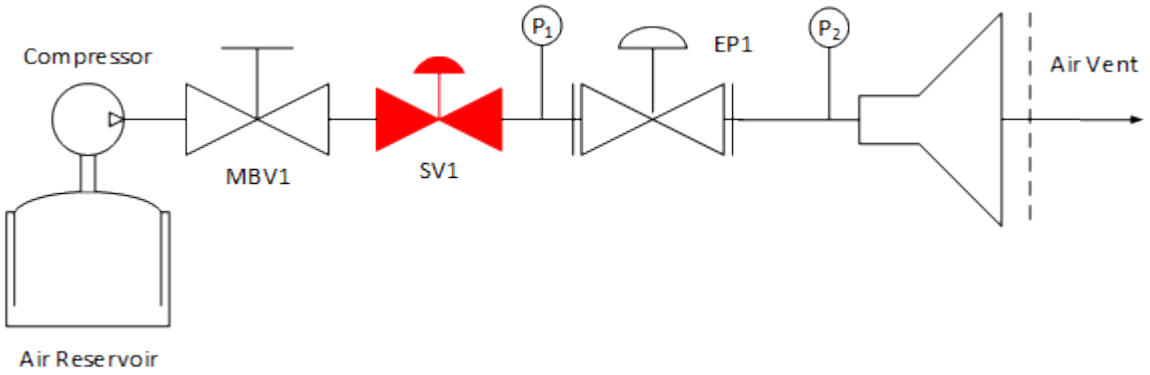
Stepper Motor Testing – Phase 2

Test Procedure:
Motor will be connected to the DAQ, while in LabVIEW the command the motor to step at specific angles. The corresponding downstream pressure is recorded. The test is then iterated through a series of pressure settings

Risk Mitigation: The results of this test will verify that the stepper motor can be controlled through LabVIEW allowing pressure to be regulated electronically. This allows for the development of the feedback control with the downstream pressure transducer.

Time Requirement: 10 man hours

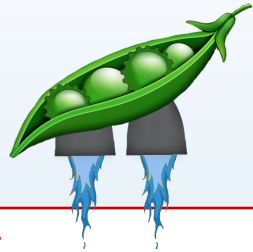
Test Setup:



MBV	**Manual Ball Valve**
SV	Solenoid Valve
P	Pressure Transducer
EP	Electronic Pressure Regulator

Requirements met at test completion: None

Air Motor Throttling



Test Rationale: Verify that acquired stepper motor operates as expected. Verify that control algorithms and driver correctly actuate motor to desired positions. Quantify accuracy of control system and slew rates

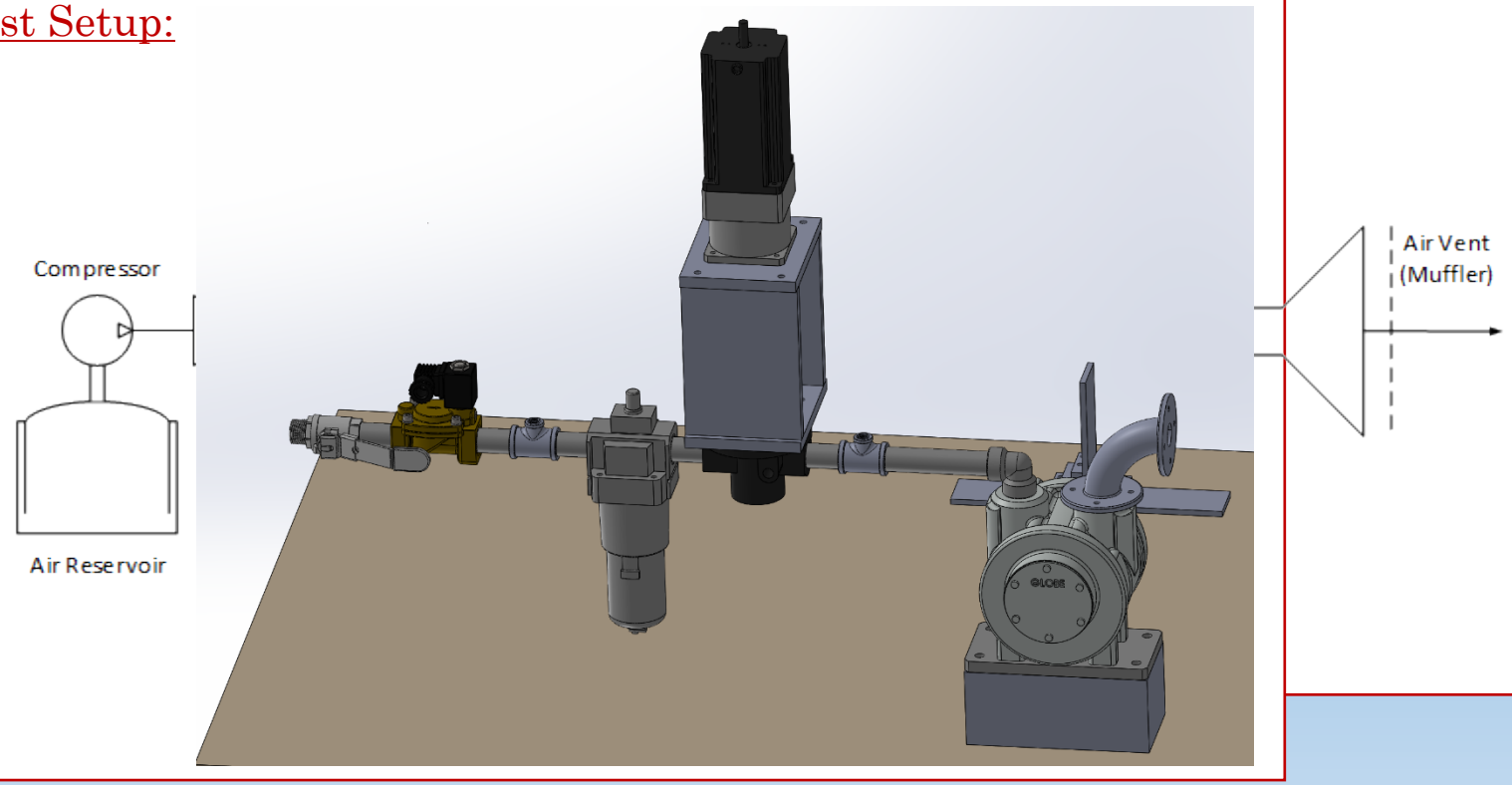
Facilities required:

- Air compressor providing 100PSI Air @45CFM, provided on East Campus

Equipment required:

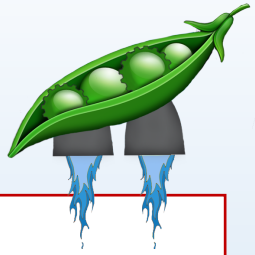
- 1” Manual Ball Valve
- 1” Electric Solenoid Valve
- 125PSI Relief Valve (1/4”NPT fitted in Tee)
- 1” Air Filter
- Pressure Transducer (1/4”NPT fitted in Tee)
- 1” Manual Pressure Regulator mounted with stepper motor
- 1” Air Lubricator
- Air Motor with muffler mounted on exhaust
- Tachometer
- Shaft Torque Device
- 1” Piping

Test Setup:



MBV	Manual Ball Valve
SV	Solenoid Valve
RV	Relief Valve
P	Pressure Transducer
BPR	Back Pressure Regulator
EP	Electronic Pressure Regulator
F	Air Filter
LB	Air Lubricator
TM	Tachometer

Air Motor Throttling



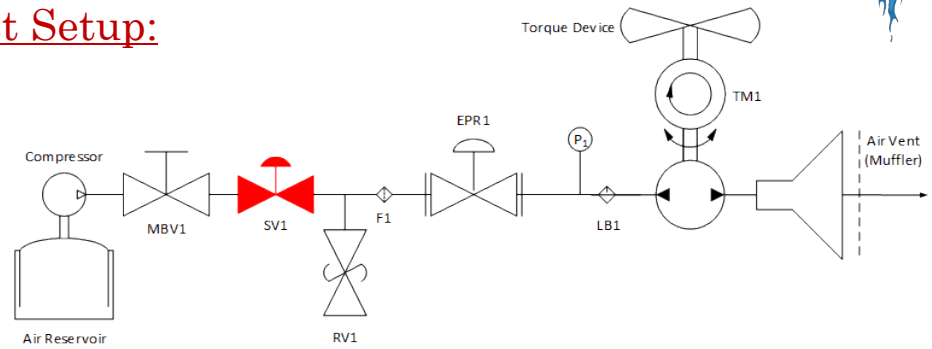
Test Procedure:

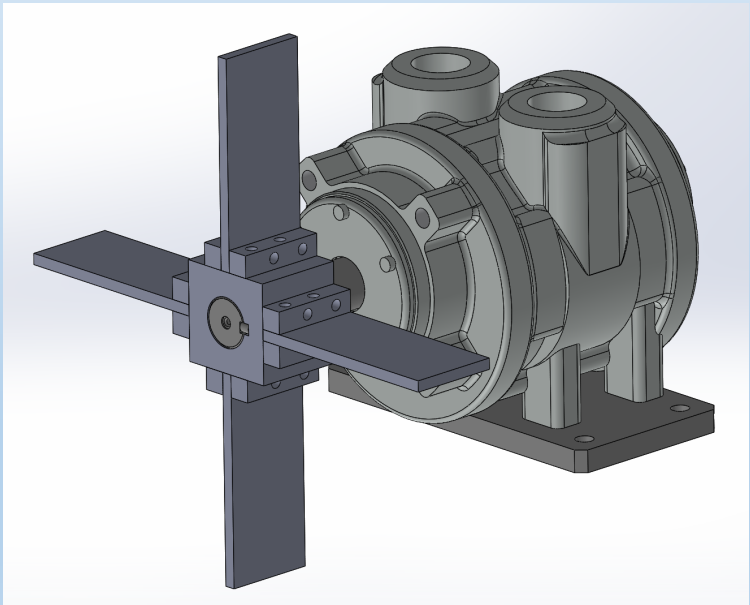
The DAQ system is loaded with a desired throttle profile. The DAQ now starts up the test by setting the motor to 10% throttle. The motor is then ran through a throttle profile.

Risk Mitigation: The results of this test will verify that the stepper motor can actuate the regulator through the full range of 10-100% to guarantee electronic throttle-ability. This test will also quantify the slew rate of this control system.

Time Requirement: 15 man hours

Test Setup:

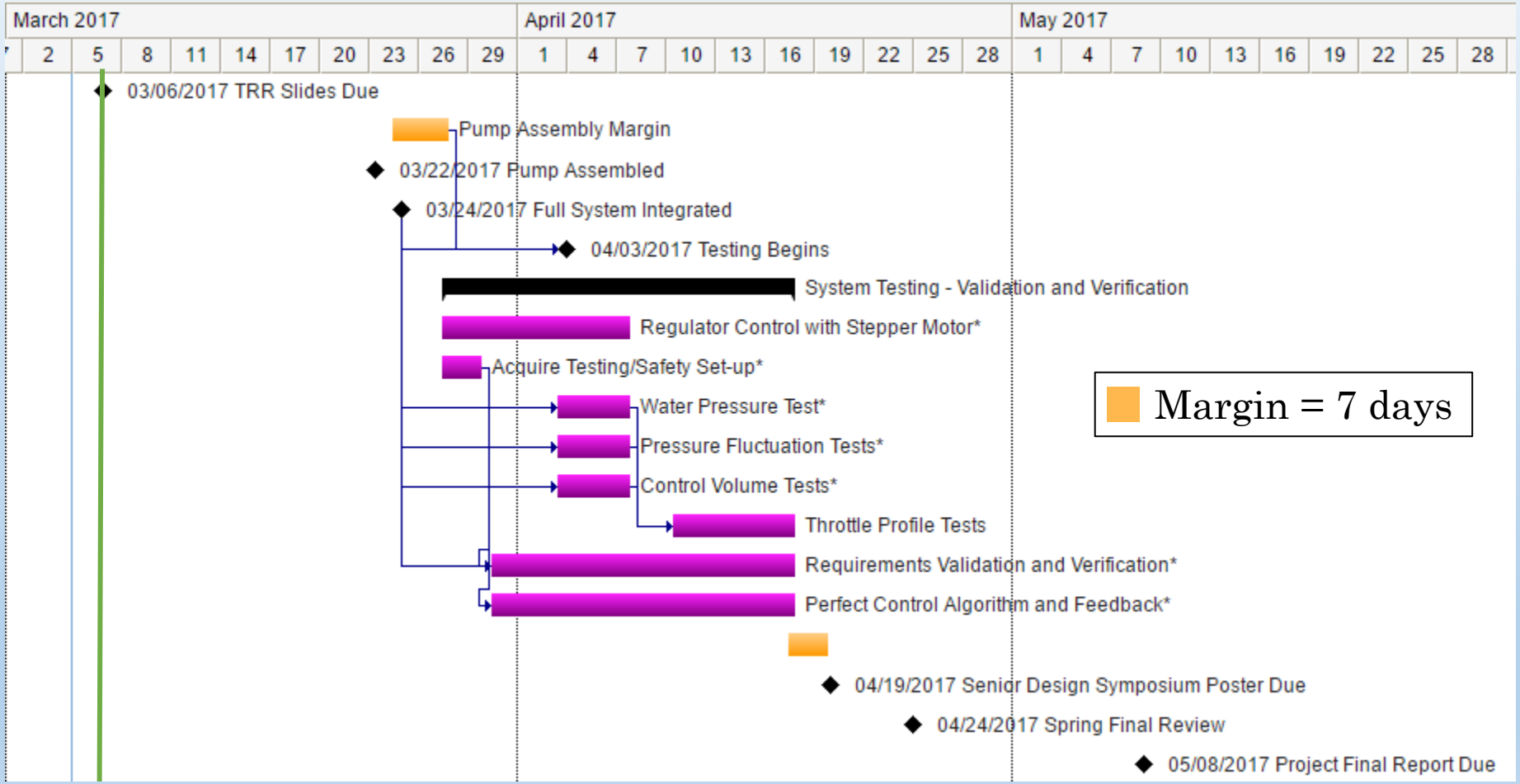




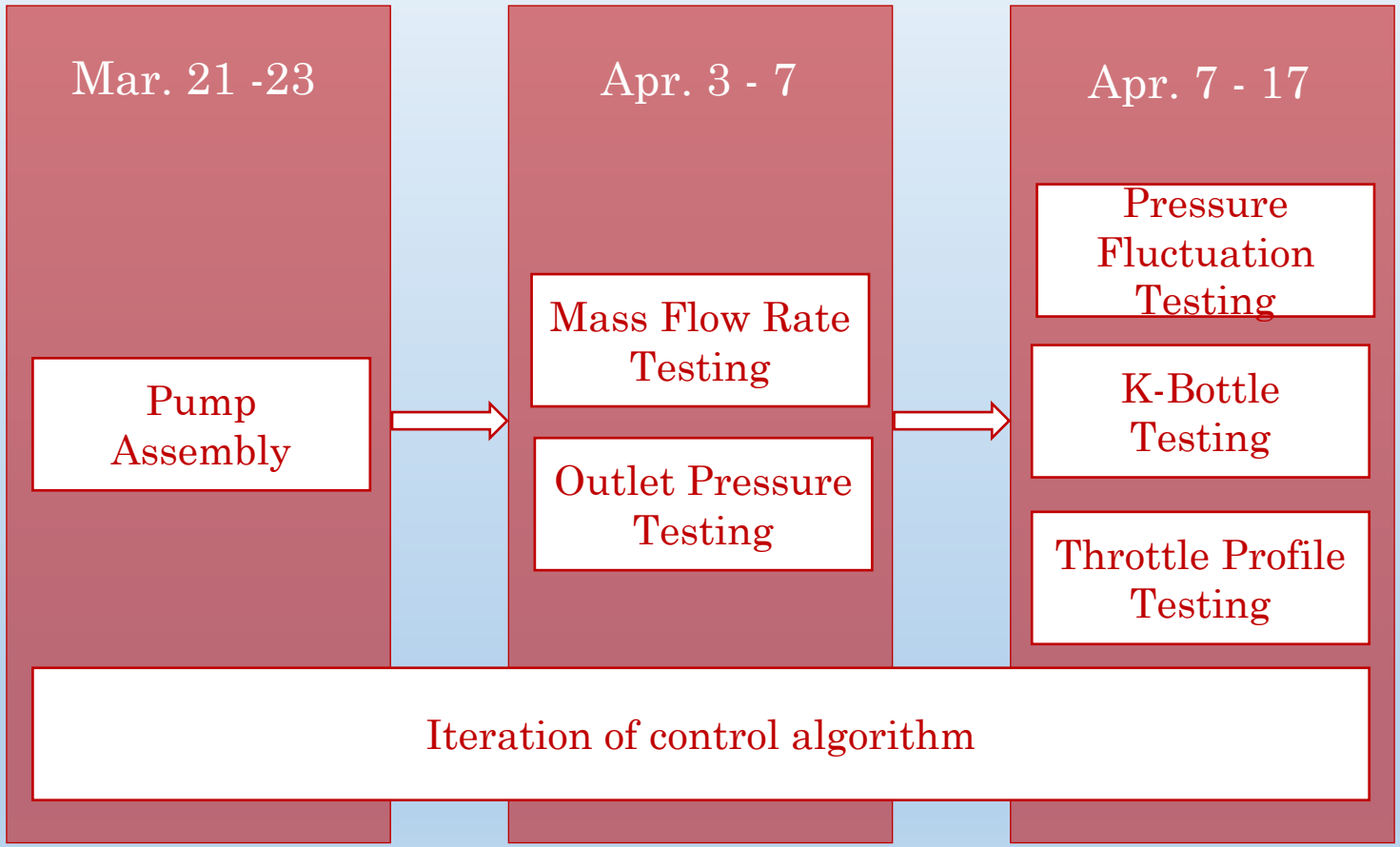
Requirements met at test completion:

- FR2 - Pump is electronically throttleable
- FR4 - Pump system can run throttle profile

Final Test Plan Overview



Final Test Plan Overview



Mass Flow Rate Testing

Test Rationale: Verify that after full assembly the pump outputs the expected amount of water for a certain throttle setting.

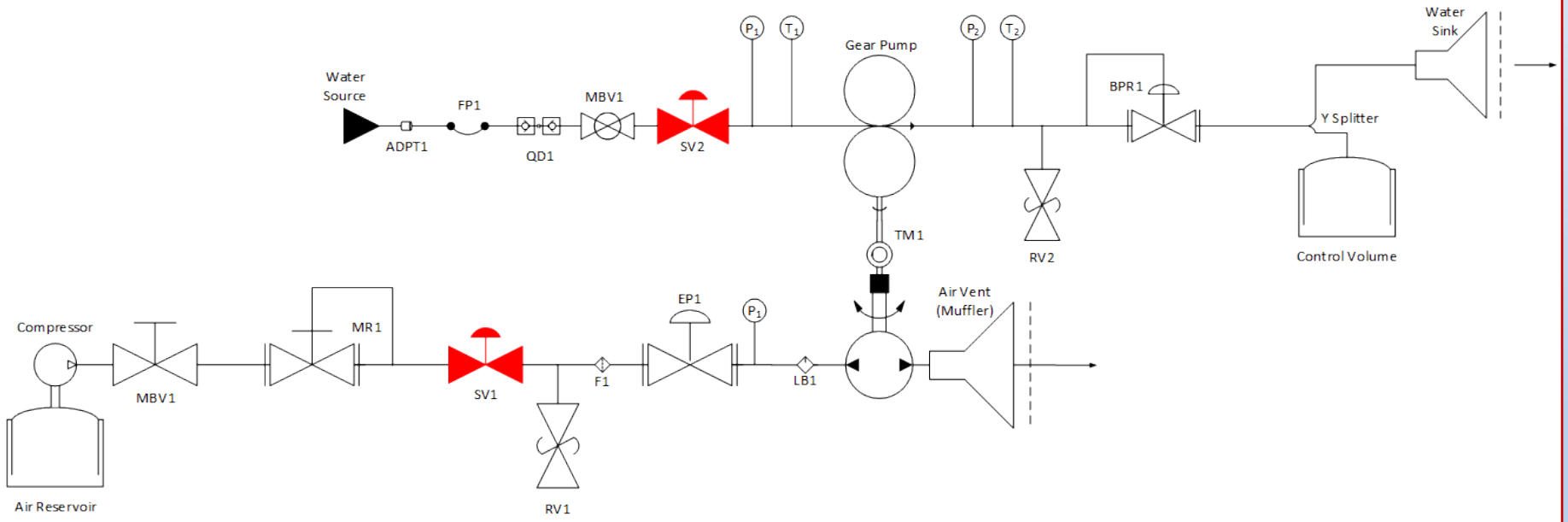
Equipment required:

- Complete Assembly of all systems, operational DAQ and control components

Facilities required:

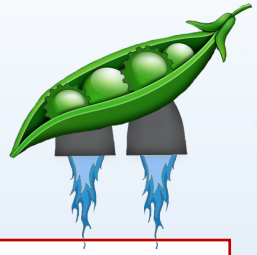
- Air compressor providing 100PSI Air @45CFM, provided on East Campus

Test Setup:



MBV	Manual Ball Valve
SV	Solenoid Valve
RV	Relief Valve
P	Pressure Transducer
T	Thermocouple
MR	Manual Regulator
BPR	Back Pressure Regulator
EP	Electronic Pressure Regulator
F	Air Filter
LB	Air Lubricator
TM	Tachometer

Mass Flow Rate Testing



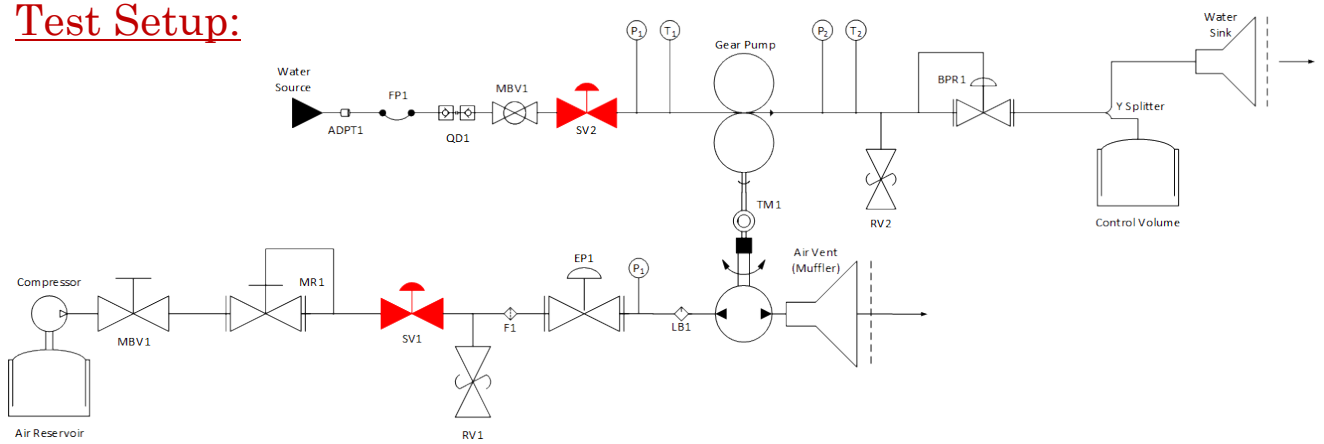
Test Procedure:
The DAQ system is loaded with a desired throttle setting (constant). The pump is set to run, the flow is switched to the control volume for a certain amount of time and then switched back to the regular sink.

Risk Mitigation: The results of this test will verify that the system meets design expectations, that is meeting an output flow rate of 1.4L/s

Time Requirement: 20 man hours

Requirements met at test completion:
- DR2.1 - Pump operates at 1.4L/s at full throttle

Test Setup:



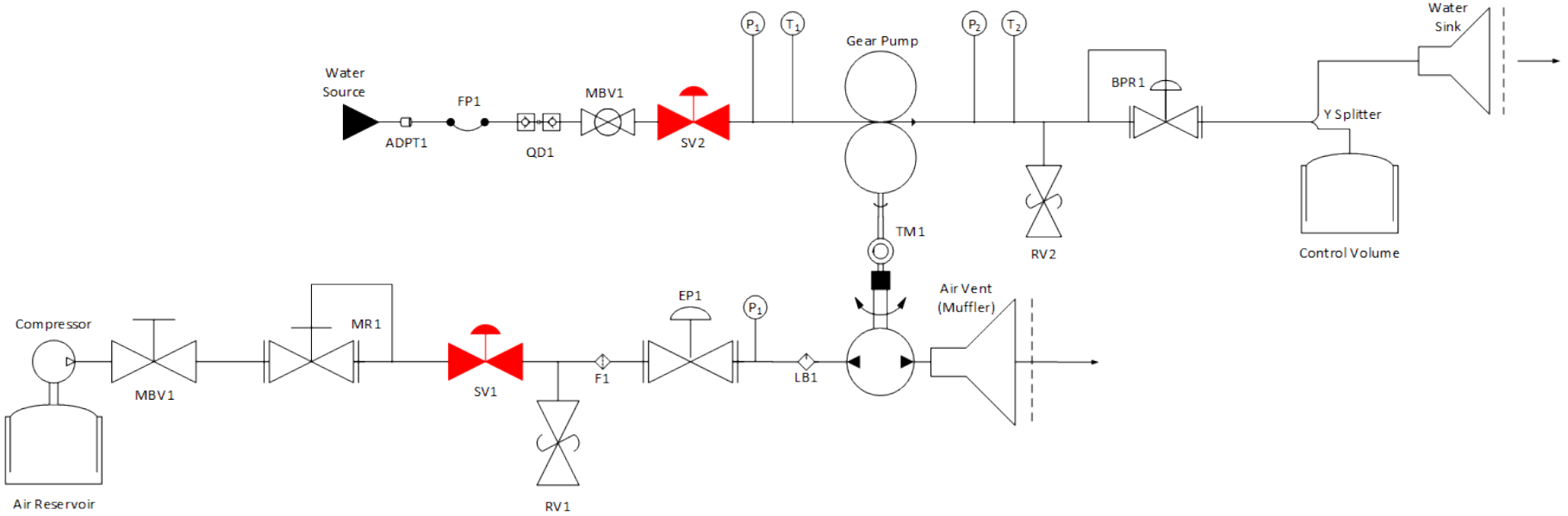
Pressure Fluctuation Testing

Test Rationale: Verify that after full assembly the pump output flow has minimal pressure fluctuation.

Equipment required:
- Complete Assembly of all systems, operational DAQ and control components

Facilities required:
- Air compressor providing 100PSI Air @45CFM, provided on East Campus

Test Setup:



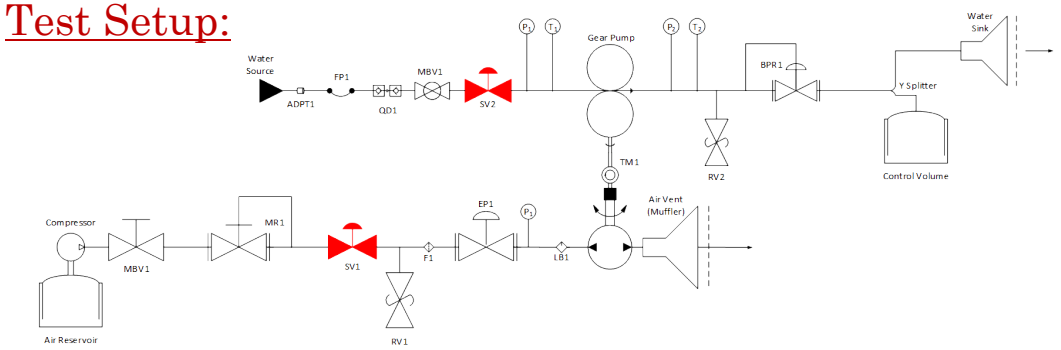
MBV	Manual Ball Valve
SV	Solenoid Valve
RV	Relief Valve
P	Pressure Transducer
T	Thermocouple
MR	Manual Regulator
BPR	Back Pressure Regulator
EP	Electronic Pressure Regulator
F	Air Filter
LB	Air Lubricator
TM	Tachometer

Pressure Fluctuation Testing

Test Procedure:
The DAQ system is loaded with a desired throttle setting (constant). The pump is set to run, the output flow pressure is measured and recorded.

Risk Mitigation: The results of this test will verify that the pump meets design expectations, that is of having pressure fluctuations no greater than 15PSI.
Time Requirement: 5 man hours

Test Setup:



Requirements met at test completion:

- DR2.3 - Pump operates with pressure fluctuations less than 15PSI

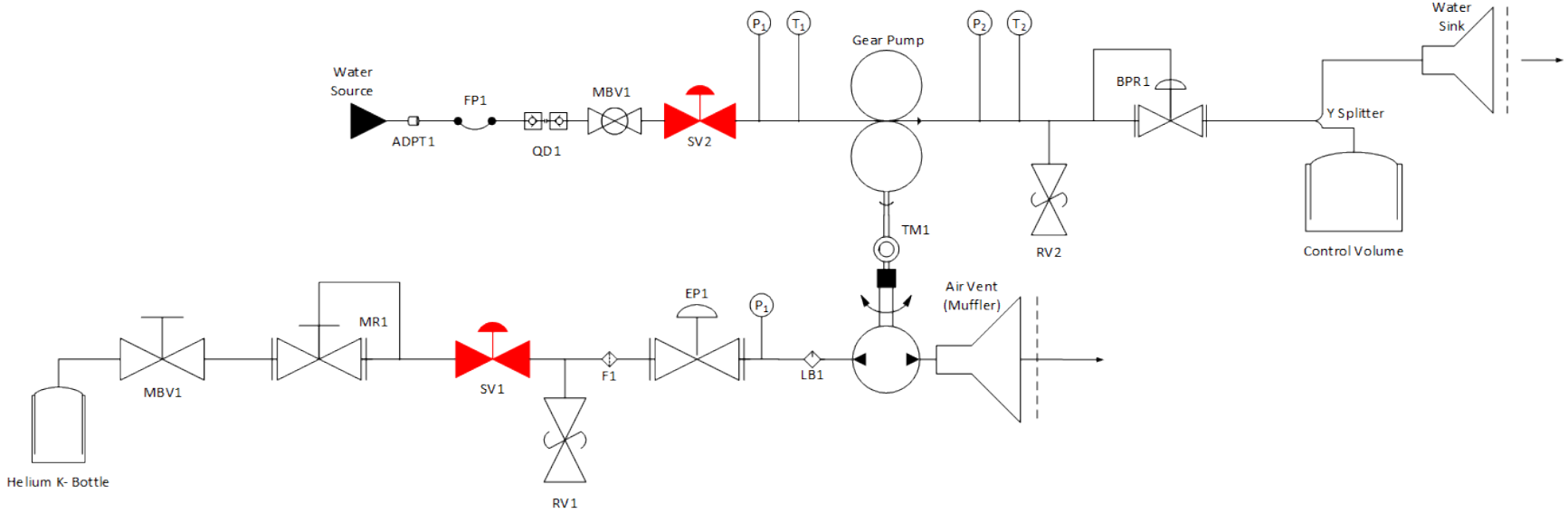
K-Bottle Testing

Test Rationale: Verify that after full assembly the pump system can operate using a Helium K-Bottle to run the motor.

Equipment required:
- Complete Assembly of all systems, operational DAQ and control components

Facilities required:
- Water Source
- Helium K-Bottle

Test Setup:



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SV	Solenoid Valve
RV	Relief Valve
P	Pressure Transducer
T	Thermocouple
MR	Manual Regulator
BPR	Back Pressure Regulator
EP	Electronic Pressure Regulator
F	Air Filter
LB	Air Lubricator
TM	Tachometer

K-Bottle Testing

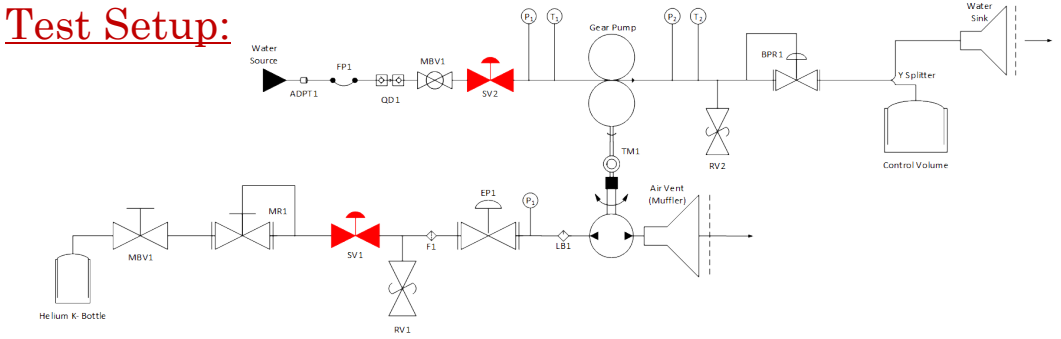
Test Procedure:

The pump system is setup as it normally would except that instead of using compressed air, the motor system uses a helium k-bottle.

Risk Mitigation: The results of this test will verify that the pump meets design expectations, that is of being able to run off of a helium k-bottle

Time Requirement: 10 man hours

Test Setup:



Requirements met at test completion:

- DR1.1 - Pump operates with a Helium K-Bottle

Throttle Profile Testing

Test Rationale: Verify that control algorithms drive the system through a desired throttle profile. Quantify accuracy of control system and slew rates

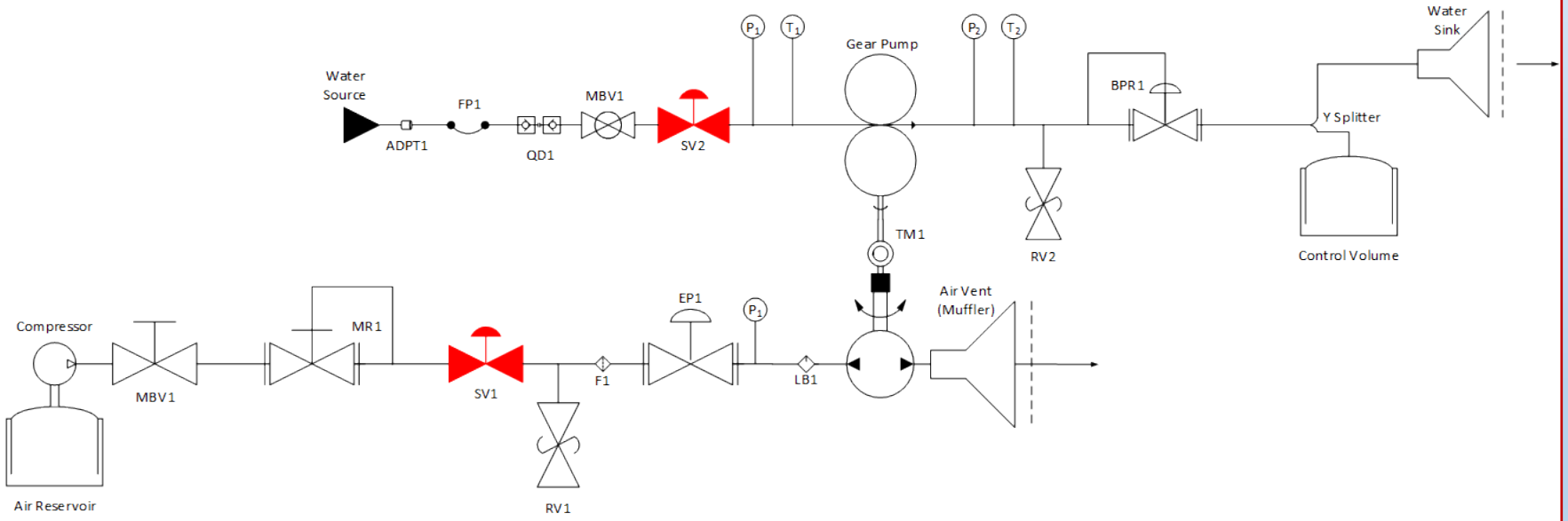
Equipment required:

- Complete Assembly of all systems, operational DAQ and control components

Facilities required:

- Air compressor providing 100PSI Air @45CFM, provided on East Campus

Test Setup:



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MR	Manual Regulator
BPR	Back Pressure Regulator
EP	Electronic Pressure Regulator
F	Air Filter
LB	Air Lubricator
TM	Tachometer

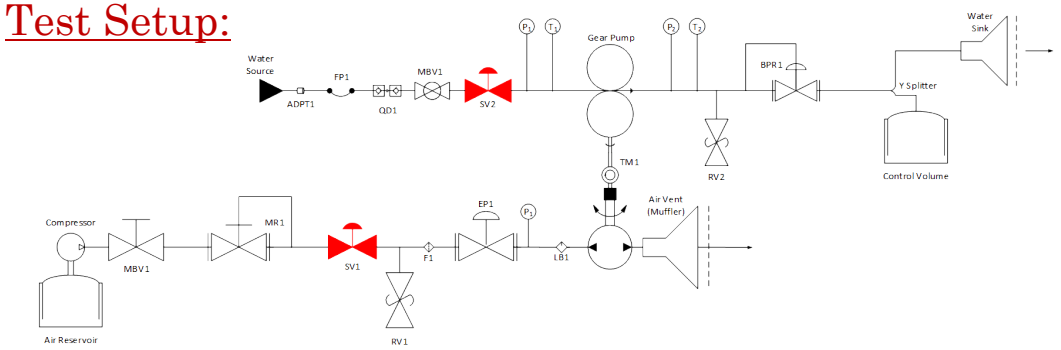
Throttle Profile Testing

Test Procedure:
The DAQ system is loaded with a desired throttle setting (constant). The pump is set to run, the full system operation is monitored and recorded.

Risk Mitigation: The results of this test will verify that the pump system can correctly run a throttle profile. Successfully doing this would demonstrate the completeness of the project.

Time Requirement: 15 man hours

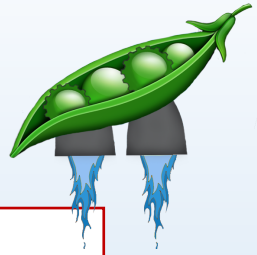
Test Setup:



Requirements met at test completion:

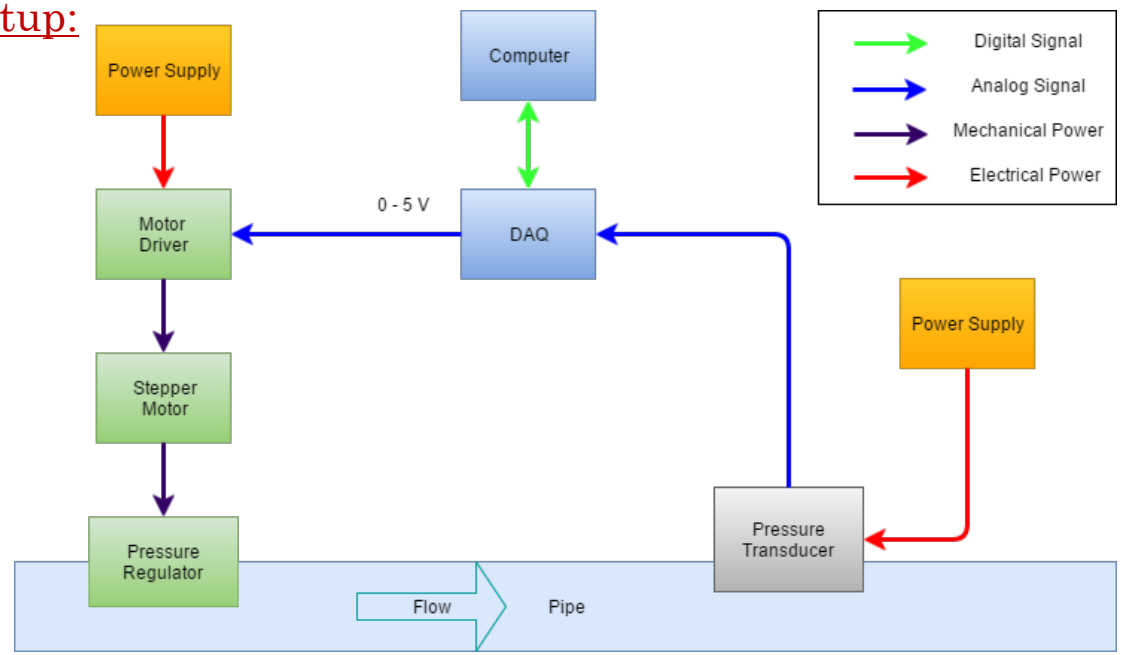
- All requirements are met at this point

Control Algorithm Iteration



Test Rationale: Verify that acquired stepper motor operates as expected. Verify that control algorithms and driver correctly actuate motor to desired positions. Quantify accuracy of control system, slew rates and torque.

Test Setup:



Equipment required:

- Pressure Transducer (1/4"NPT fitted in Tee)
- 1" Manual Pressure Regulator mounted with stepper motor
- Computer
- Data Acquisition DAQ
- Motor Driver
- Stepper Motor
- Power Supply
- 1" Piping

Facilities required:

- Projects room

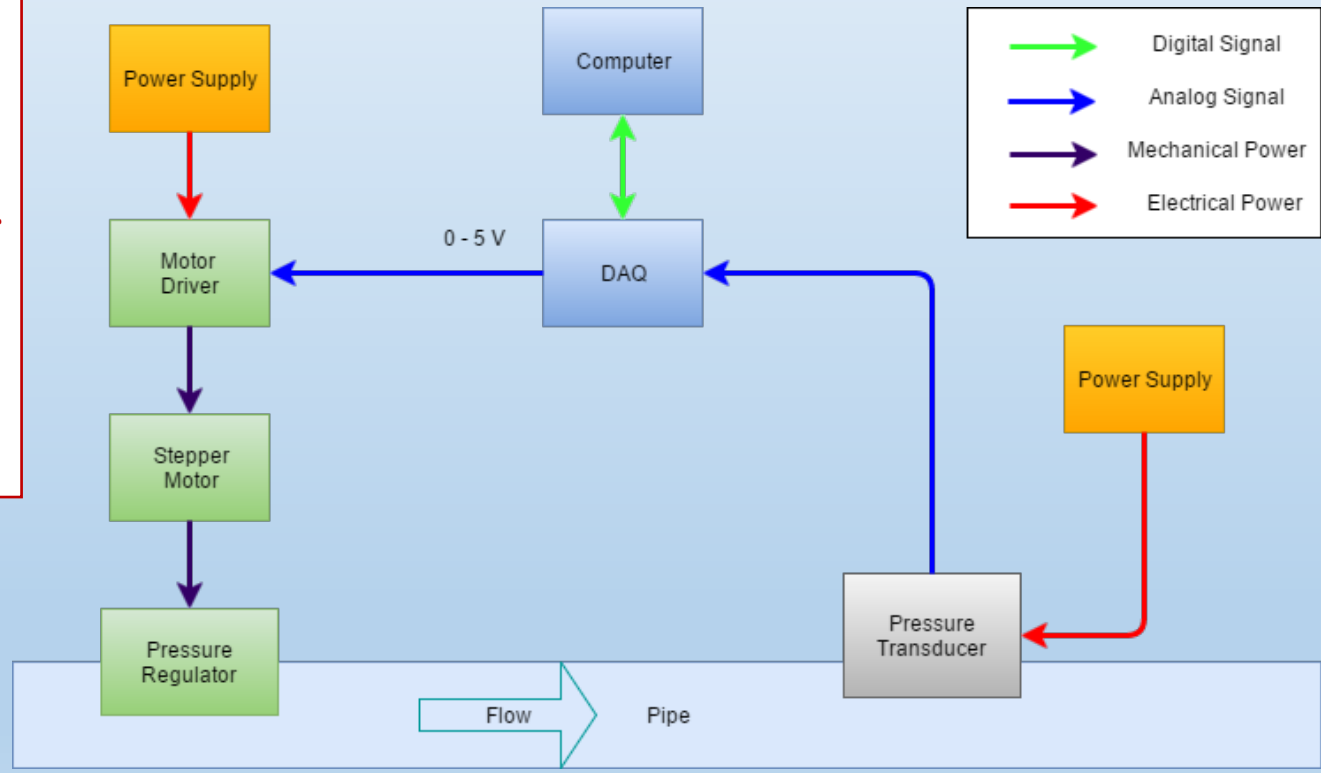
Control Algorithm Iteration

Test Procedure:
LabVIEW will be set to a specific pressure where the computer will control stepper motor to regulated the pressure through the pressure regulator. Different pressures will be tested to understand the slew rate for the system.

Risk Mitigation: The results of this test will verify that the stepper motor can actuate the regulator to the desire pressure, in order to guarantee electronic throttle-ability. This test will also quantify the slew rate of this control system.

Time Requirement: 20 man hours

Requirements met at test completion:
- FR2 - Pump is electronically throttleable



Budget

Budget Statistics and Progress

Catagory	Ordered	Unordered	Total	
Manufacturing	1998.58	0	1998.58	
Hardware	3356.22	750.30	4106.52	
Management	0	100.00	100.00	
Shipping	509.25	112.55	621.8	
		Total	$6,826.90	
		Funds	$8,000.00	
		Margin	17.18%	$1,173.10

- 85.89% of Parts purchased (by dollar value)
- $1173.10 of Margin!

*See backup slides for full itemized budget

Budget: Parts left to buy

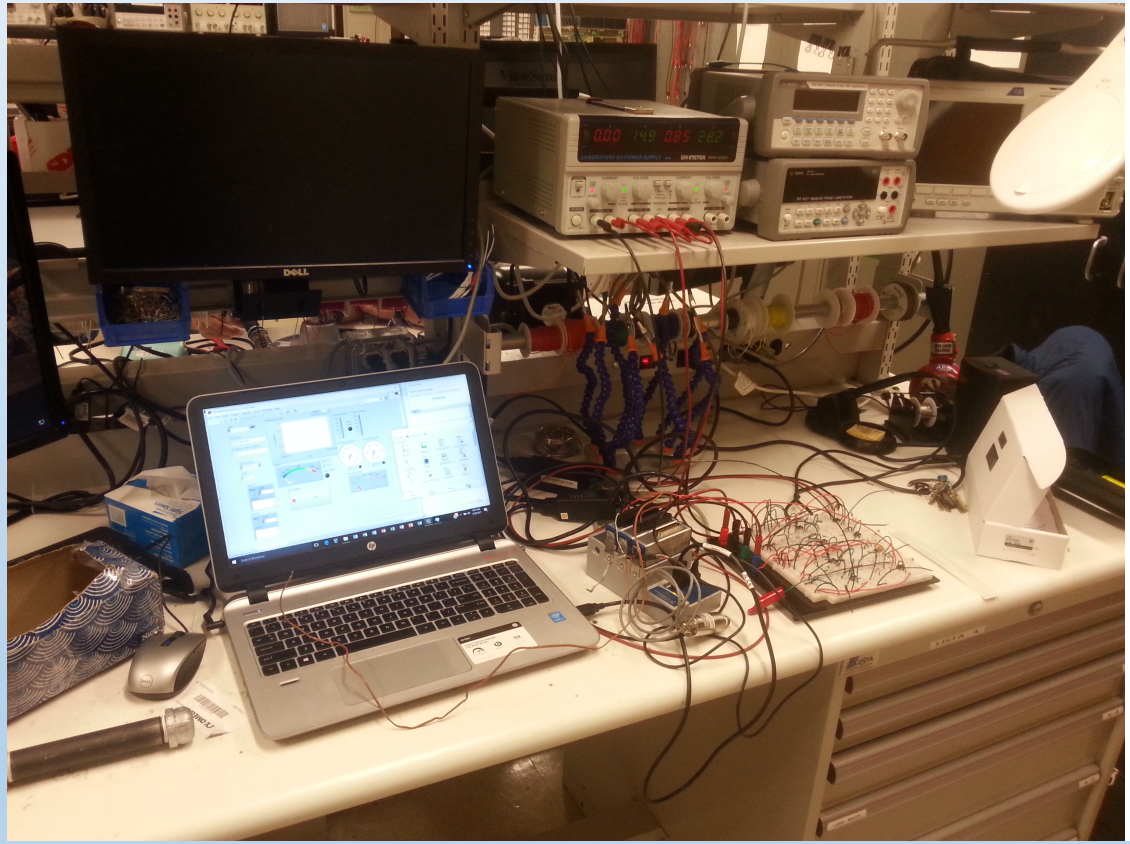
Part	Price	Quantitity	Subtotal	Shipping	Total
Drivers	300	2.00	600	90.00	690.00
Report Printing/ Binding	100	1.00	100	0.00	100.00
Brackets	100	1.00	100	15.00	115.00
Coupler	25.15	2.00	50.3	7.55	57.85

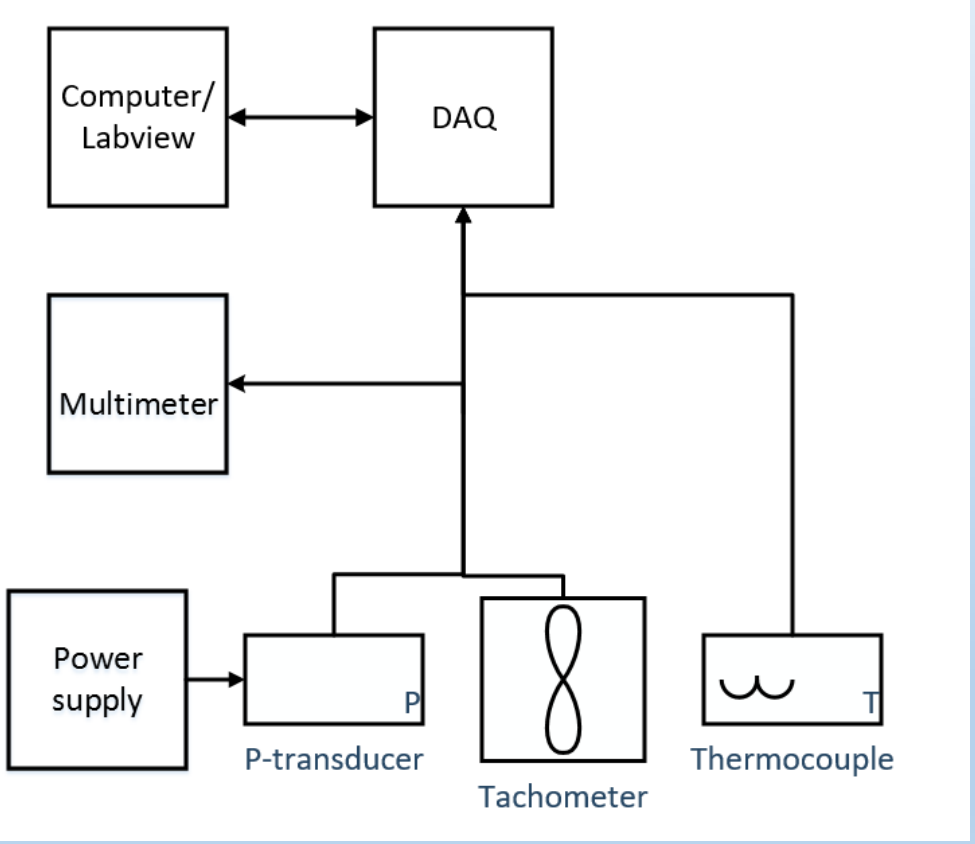
Left to buy: $962.85

Questions?

Backup

DAQ Input Testing



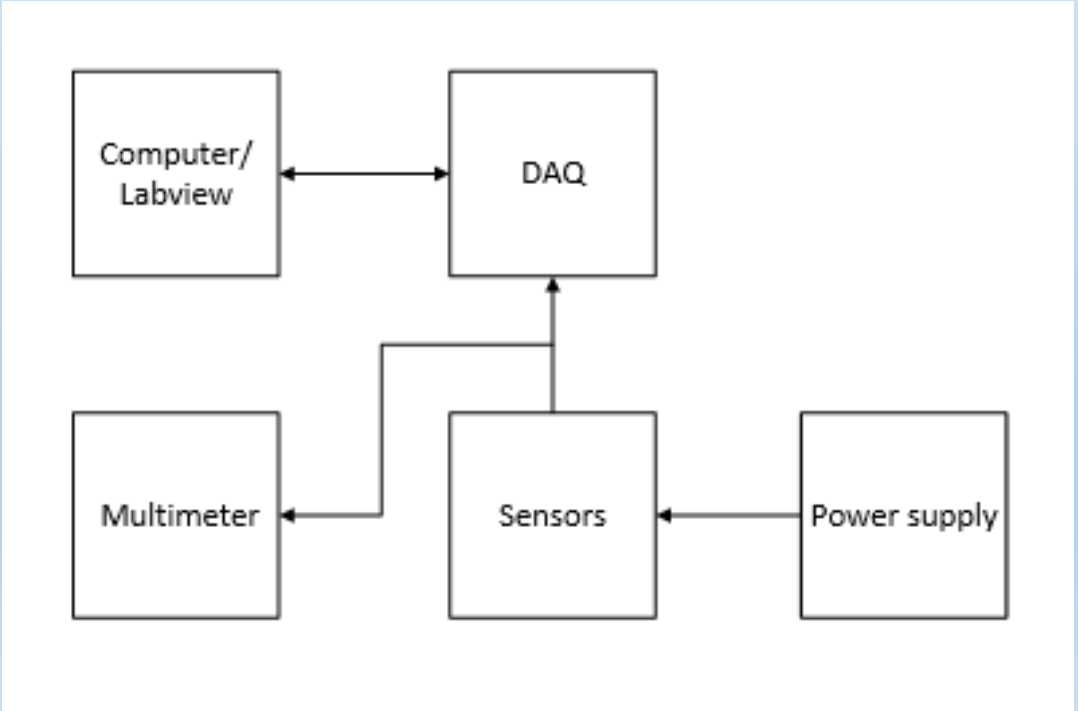


System Tests

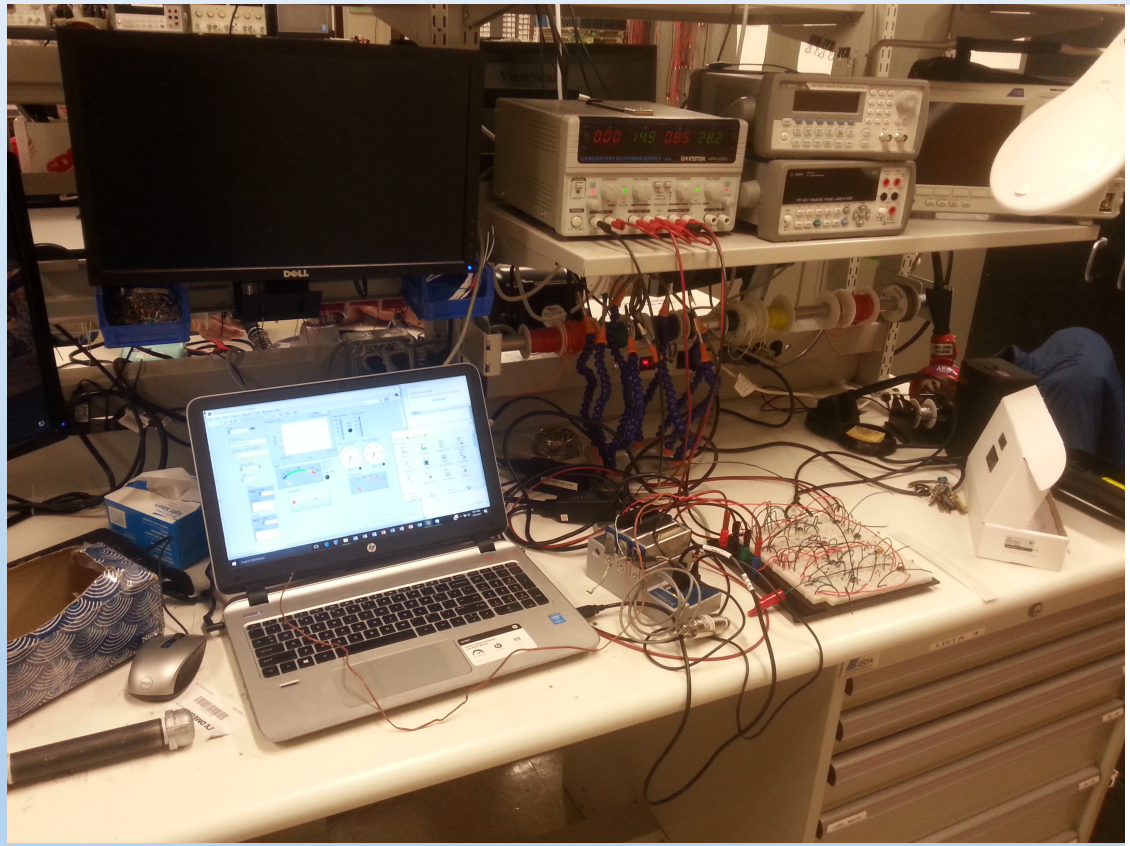
- Goals
  - Determine data variance and system (non-sensor) error
  - Qualitatively verify all datalinks work
- Equipment
  - DAQ
  - PC (with LabVIEW)
  - Thermocouples
  - Pressure transducers
  - Tachometer
  - Solenoid valves
  - DC power supply

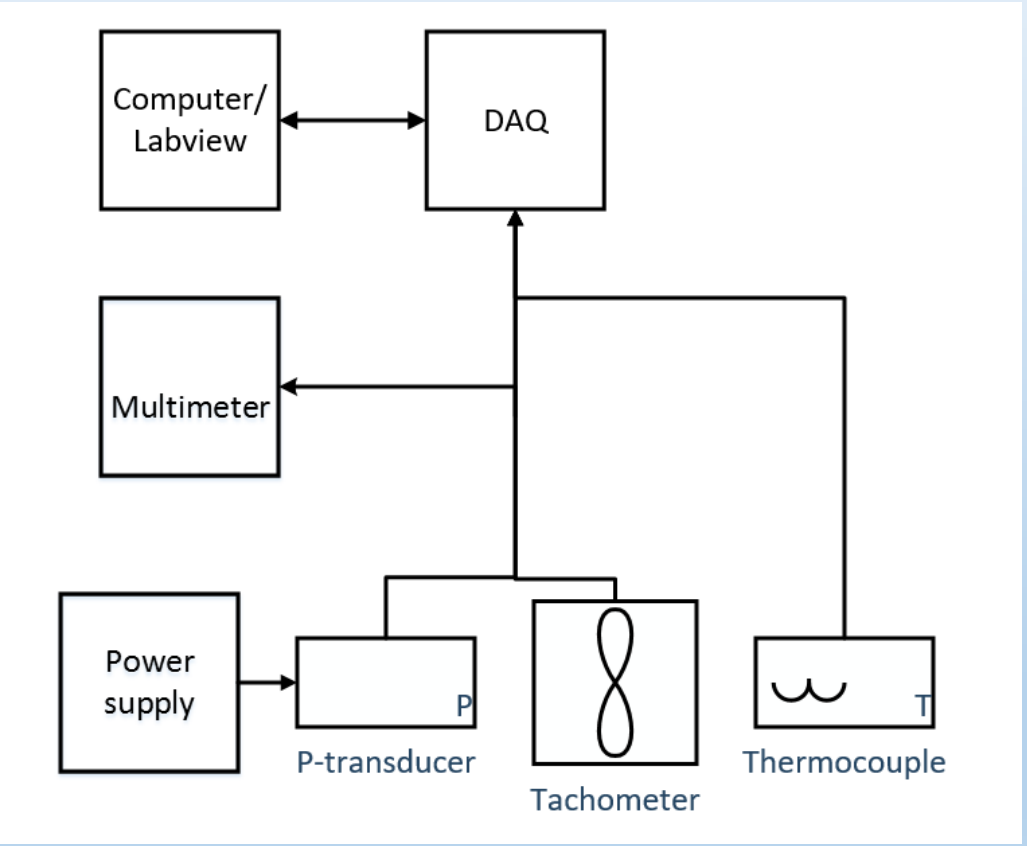
System Tests

- Procedure
  - Connect all devices appropriately
  - Run LabVIEW code (LabVIEWDAQpractice10) - collect pressure, temperature, tachometer data
  - Stop code, save data
  - Analyze data on MATLAB



IO testing




Computer/
Labview
DAQ
Multimeter
Power
supply
P
P-transducer
Tachometer
T
Thermocouple

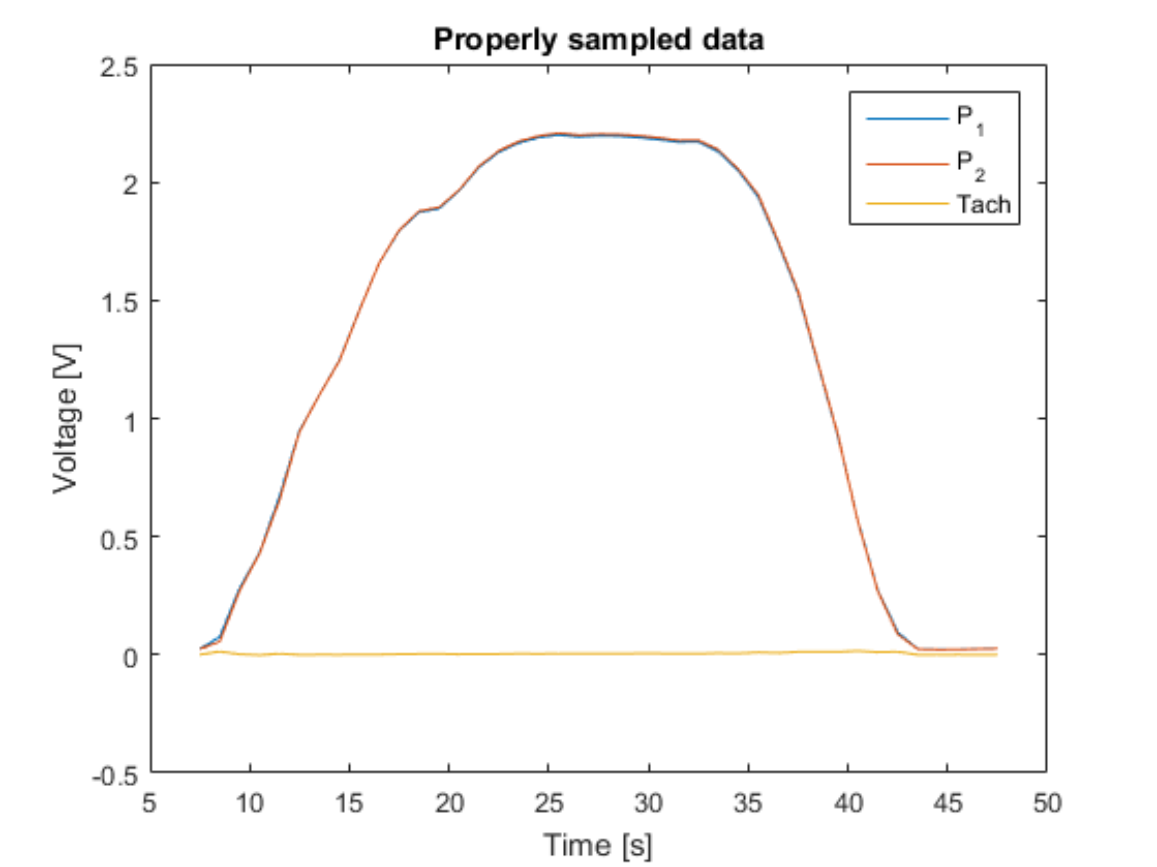
Input test

Results:

- Nominal sample rate limited to 1 kHz
- Max error 4 mV (vs multimeter)
- Data spiking (right) – corrected by using lower sample rate (rate shown: 1 kHz)

Verified

- Accuracy of thermocouple, pressure, and tachometer readings
- Maximum control loop rate
- Control possible, gain limits to be determined



DAQ Input Testing

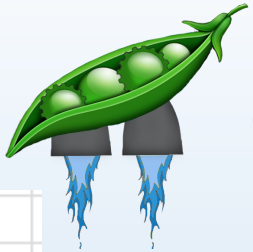
Goals: Verify correct real-time acquisition of data from pressure transducer, thermocouple, and tachometer

- Procedure highlights
  - Connect equipment
  - Run control and data VI
  - Measure pressure/tachometer data
  - Vary pressure and test device rotation speed
  - Run emergency shutoff
  - Stop VI
  - Process Data

Equipment required:

- 1 Pressure Regulator Test setup
- 1 thermocouple
- 1 tachometer
- 1 power drill (modified)
- 1 DAQ and PC system
- 1 DC power supply
- 1 multimeter

Risk Mitigation: The results of this test will ensure the certainty of data being measured from the pump, and validate the safety and control systems



Received	Ordered	Part	Part #	Price	Quantity	subtotal	Shipping	Total
x	x	Globe Motor	VA10J	1238.00	1	1238.00	125	1363.00
x	x	Tachometer		349.00	1	349.00	0	349.00
x	x	Reflective Tape		5.00	1	5.00	0	5.00
x	x	Reflective tab		5.00	1	5.00	0	5.00
x	x	Water Pipe		29.44	1	29.44	21.9	51.34
x	x	Hose2Pipe Adptr		4.81	4	19.24	10	29.24
x	x	Air Regulator		228.00	1	228.00	33.21	261.21
x	x	Pipe tee		14.27	2	28.54	15.3	43.84
x	x	Air filter		78.10	1	78.10	0	78.10
x	x	lubricator		82.58	1	82.58	0	82.58
x	x	lube		24.47	1	24.47	0	24.47
x	x	steel pipe		14.72	1	14.72	27.21	41.93
x	x	pipe nipple		3.93	1	3.93	0	3.93
x	x	brass valve		18.53	1	18.53	0	18.53
x	x	steel pipe		7.78	1	7.78	0	7.78
x	x	3 port ball valve		35.83	1	35.83	0	35.83
x	x	bushing adapter		8.56	1	8.56	0	8.56
x	x	hose 1		12.00	1	12.00	0	12.00
x	x	hose 2		12.33	1	12.33	0	12.33
x	x	pipe		79.72	1	79.72	0	79.72
x	x	bushing adapter		13.76	1	13.76	0	13.76
x	x	inline tee		8.68	2	17.36	0	17.36

x	x	stepper motor	0.00	1	0.00	0	0.00
x	x	3/4 solenoid	64.95	1	64.95	0	64.95
x	x	1" solenoid	87.95	1	87.95	0	87.95
x	x	Flexible Steel Hose	57.37	1	57.37	11.25	68.62
	x	EDM	1150.00	1	1150.00	0	1150.00
	x	BPRegulator	652.00	1	652.00	25.22	677.22
x	x	Housing block	495.00	1	495.00	113.87	608.87
x	x	304 Bushing	7.70	1	7.70	6.6	14.30
x	x	304 Straight Connector	11.30	1	11.30	0	11.30
x	x	Inline Tee Reducer	8.68	2	17.36	0	17.36
x	x	304 Stainless Bushing Female	7.70	1	7.70	0	7.70
x	x	Back Plate	125.00	1	125.00	0	125.00
	x	Pressure Relief Valve	69.00	2	138.00	9.99	147.99
		brackets	100.00	1	100.00	15	115.00
		coupler	25.15	2	50.30	7.55	57.85
x	x	Aluminum plate	43.58	1	43.58	8.63	52.21
x	x	Aluminum rod	26.00	1	26.00	6.21	32.21
		Drivers	300.00	2	600.00	90	690.00
	x	tooling	159.00	1	159.00	6.21	165.21
x	x	teflon seal	0.00	1	0.00	0	0.00
		report binding	100.00	1	100.00	0	100.00
x	x	microsoft office	0.00	1	0.00	0	0.00
x	x	labview	0.00	1	0.00	0	0.00
x	x	Matlab	0.00	1	0.00	0	0.00
x	x	solidworks	0.00	1	0.00	0	0.00
x	x	Gantter	0.00	1	0.00	0	0.00