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MEEN 402 Plan Summary
Bray: Embedded Valve and Actuator Sensors

DR3 Executive Summary:

The topic of this Design Report is the concept generation and selection for a method to determine key parameters within a Bray valve-actuator system. The senior design team working with Bray is: Zachary Walker, Cody Sims, Locke Lehmann, Avery Haynes, Michael Hager, and Travis Carlson. Bray assigned the team with developing a method to determine:

A) Valve position while in operation, independent of other parameters
B) Actuator output torque, independent of other parameters

Ball and butterfly valves play a pivotal role in a wide range of industrial applications and processes that encompass the conveyance of virtually any type of fluid medium. Failures or unanticipated performance degradation of these components can result in prolonged system shutdowns and may even pose a risk of worker exposure to hazardous gasses. Actuators, like valves, come in many different types. This project will mainly focus on rack-and-pinion style and scotch-yoke style actuators, both of which are manufactured by Bray. The torque supplied by the actuator may deteriorate over time, making it essential to obtain real-time data while the actuator is in operation. To mitigate these hazards and prevent productivity losses due to downtime, there is a need for a solution that can assess the valve or actuator condition over time.

Bray's current approach to torque measurement is the *IOT Torque Bracket*, which gauges the reaction torque exerted from the valve to the actuator. However, this method does not provide insight into the actuator's remaining operational capacity, making it unable to predict when the actuator might fail to control the valve. This issue is of great concern to Bray and their customers because an actuator malfunction can lead to valves becoming stuck in undesirable positions, potentially disrupting the functionality of the entire system to which the valves are integral.

Given the inherent non-digital nature of pneumatic actuators, like the two mentioned above, which lack built-in mechanisms for data recording and transmission, an external or integrated solution becomes imperative. Introducing an embedded sensor designed to measure actuator output torque independently of the reaction torque from the valve would empower Bray and their customers to continuously monitor actuator performance. This capability would allow them to determine precisely when an actuator requires replacement, thereby minimizing disruptions and maintaining the optimal functionality of their systems.

Through the first semester of the project, the design team has determined that indirect measurements are not desired due to their nature of being based on other parameters. The avoidance of indirect measurements will contribute to increased accuracy of data collection, although it adds difficulty to the project. Bray has placed a large focus on the accuracy of both methods they desire. Quantitatively, Bray would like the team to keep the error of the system under five percent. This requirement will drive the team to select the most accurate equipment and develop a process with the least amount of added error.

The design team has developed several possible solutions for each deliverable by utilizing different concept generation methods discussed in lecture. These methods include: brainstorming, mind-maps, TRIZ matrices, analogous designs, and bioinspired designs. A dozen concepts were created, and each were deeply analyzed using Pugh charts, IIAE matrices, and quantitatively driven team effort selection matrices.

For the valve position deliverable, the team is carrying out two separate solution concepts to be tested in the following semester. One is the potentiometer concept which is a way to determine position by connecting to the rotating ball in an electrical circuit. Potentiometers have relatively high accuracy and can be cheap to purchase. As the valve rotates, a potentiometer connected under the valve will vary in voltage depending on the position of the ball, so each voltage value will correspond with a degree of openness of the valve. This idea is very promising due to its strong performance in crucial aspects like accuracy and lack of influence on valve performance. The second solution includes magnetizing part of the ball and pointing a Hall Effect sensor to it. The sensor will be calibrated to recognize the open and closed position of the valve. As the ball rotates, the sensor will notice the change of the magnetic field and associate it with the valve's position.

Similar to the valve, the team is carrying out two separate solution concepts to be tested in the following semester. The first being a cylindrical strain gauge attached to the stop bolts in the actuator. The strain gauge will measure the deflection of the stop bolts as the spinning actuator comes into contact with them and the data acquisition unit will use material properties of the bolt to convert that strain into the applied torque, The second option for torque measurement is a motor-like device that will attach to the top of the actuator housing and slide a conducting belt around the indicator switch. This belt will pass through a magnetic field and generate a voltage in the motor whenever the valve opens or closes, and this generated energy can be correlated with the torque generated by the actuator.

These concepts were selected due to their accuracy, lack of interference with the system, and their simple embedded nature. After selecting these concepts, the team developed a risk analysis tree, a validation plan for MEEN 402, and performed some small-scale validation of the potentiometer for measuring position. Further details and products for each solution were also researched and decided upon. Moving into MEEN 402, the design team will continue to research parts for purchase and testing, refine the potentiometer designs in order to adhere to budget constraints and deliverable requirements, and compare results from each solution in order to determine the best one to present to Bray for implementation.

MEEN 402 Validation Plan:

The project is split up into two deliverables: finding the position of the valve and the torque of the actuator, and validation testing must be done for both deliverables. A validation plan was made to provide an overview of what information is needed to validate each design, which can be seen in **Table 1** for the position deliverables and **Table 2** for the torque deliverables. All requirements were made using Bray's input and the valve specifications.

Table 1: Top-level validation plan for the valve position deliverable.

Functional Requirement	Quantitative Requirement	Design feature	Validation Test
Measurement Accuracy Position	< 2%	Potentiometer	Measure the reading of the position slider of the rotary potentiometer and compare to actual rotation by hand (test how ambient temperatures affect accuracy)
Surrounding metals do not interfere with accuracy	<2 %	Hall effect sensor and magnet	Attach a magnetic point to the edge of the butterfly disc and measure change in magnetic field due to rotation
Ease of implementation	<2 hr	Prototype Apparatus	Time how long it takes to set up the sensors on the prototype valve system
Calibration Time	< 1 hr	Sensor	Time how long it takes the team to get accurate readings from the sensor system from start to finish
Measurement accuracy with extended use	< 5%	Potentiometer and Hall Effect Sensor	Measure the decay of accuracy as the potentiometer cycles till failure
Lifetime of sensor	> 2 million cycles	Potentiometer and Hall Effect Sensor	Rotating ball system that open and closes to test how many cycles until the sensor fails
Total power Consumption	<100 wh	Battery	Use prototype system and measure the amount of power consumed over an hour

Table 2: Top-level validation plan for the actuator torque deliverable.

Functional Requirement	Quantitative Requirement	Design feature	Validation Test
Measurement Accuracy Torque	< 5%	Cylindrical Strain Gauge and Motor	Measure and compare the reading of the torque reading to the actual set value (test how ambient temperatures affect accuracy)
Ease of implementation	<2 hr	Prototype Apparatus	Time how long it takes to set up the sensors on the prototype valve system
Calibration Time	< 1 hr	Sensor	Time how long it takes the team to start getting accurate readings from the sensor system from start to finish
Measurement accuracy with extended use (torque)	< 5%	Cylindrical Strain Gauge and Motor	Measure the decay of accuracy as the rotational torque bracket or potentiometer cycles till failure
Lifetime of sensors	> 2 million cycles	Cylindrical Strain Gauge and Motor	Rotating Actuator system that open and closes to test how many cycles until the sensor fails
Total power Consumption	<100 wh	Battery	Use prototype system and measure the amount of power consumed over an hour

Validation Plans

The first step in the validation testing for position is to ensure that the potentiometer set up can maintain a less than 2 percent error. The plan is to bore a hole through the bottom of the ball valve, attach the stem of the 10 kΩ potentiometer to the bottom of the ball valve, and put a multimeter in line to measure the resistance. Bray is providing a gear crankshaft that will turn the valve while displaying the degree of rotation the ball is at. Then, comparing the readings obtained from the potentiometer and the degrees on the rotation of the gearbox, the percent error can be found. This plan was selected to make sure that the connection between the potentiometer and the ball valve does not add any error to the potentiometer readings. It also validates that the potentiometer can be secured to the valve, or else there will be no readings taken and, therefore, no error value obtained.

The Hall effect sensor requires a different sort of validation test due to the ferromagnetic properties of the valve casing and parts. The plan for this test is to attach a magnetic strip to the disc of the butterfly valve. Then, the hall effect sensor will be placed around the valve, including the stem section, at the bottom of the valve, and the side portion. Using the same gear crankshaft apparatus as for the potentiometer, the actual rotation will be known then we can compare it to the voltage reading of the hall effect sensor to see if a below 2% error is possible. This plan was selected to test how the metal properties of the valve interfere with magnetic fields in different locations of the hall effect sensor to result in better accuracy readings and to see, in general, if the 2% error can be achieved or else it will not be able to be used in industry. The butterfly valve was selected because it is easy to access the disc to magnetize as it is completely exposed compared to the ball valve, where the ball is enclosed, so it would have to be taken apart to magnetize.

The plan for the cylindrical strain gauge will be tested for the accuracy of the torque measurements. A rack and pinion actuator will be used, and cylindrical strain gauges will be installed into the stop bolts by drilling small holes. The actual torque value will be known because the actuator was previously unused, and the expected value can be calculated by monitoring the pressure supplied to the actuator. Combining the strain data collected with the actuator torque a error value can be found. For the torque data to be valid, it must remain less than 5 percent. This plan was selected because if the collected data has more than 5 percent error, then it cannot be used in industry to predict the torque. Another important aspect of the test will be to see how far into the stop bolt the cylindrical strain gauge has to be placed to get accurate readings.

For the motor apparatus, the team and Bray do not know if this design will yield usable results, so the purpose of determining the accuracy is to see if it is a viable solution before it is embedded into the actuator. To start, the motor will be mounted to the top of the actuator with a band that is around the rotating shaft. A multimeter will be hooked up to monitor the voltage produced by spinning the motor. Then, the actual and experimental data can be compared using the conversion equation made by the team and knowing the actuator torque based on the pressure supplied. If the error is high, then the assumptions for time and rotation will be revisited to see if that is the issue. If troubleshooting does not yield usable results with an error below 5 percent, then the product will have failed and will not be moved forward. This test aims to see if this apparatus can obtain accurate data while not moving too far forward with the concept and embedding the solution into the actuator.

After all sensor systems have been tested and validated to see if they meet the respective error requirements, the team plans to optimize and finalize the designs that passed the initial validation testing. The first step for this is to optimize how long it takes to implement the sensor system, which is the ease of implementation. The plan is to time how long it takes to wire all of the sensors together to start transmitting data. The slots for the sensors will be manufactured but will not have the sensors implemented. The team will see how long it takes two people to set up the sensors, and it should be under 2 hours. If it is over, the longest part of the process will be identified, and the team will focus on reducing the time until it is under the 2-hour time limit. The reason for this validation is to ensure that the process of installation is not too complicated and time-consuming, wasting Bray’s manufacturing resources.

The next optimization stage is to bring the calibration time of the sensors down to under an hour. This test will be done by starting a new data collection log for all sensors, then collecting the data and correlating it to both torque and position. This process will be timed, and once again, if the sensors take too long to calibrate, the calibration process will be revisited to see what assumptions or techniques can be implemented to shorten the time. This test aims to reduce the valves' installation time because the companies will not want to install these smart valves if they shut off their facilities for too long. This plan was selected to be iterative and constantly shrink the longest process until the procedure is optimized.

After optimizing the installation and calibration techniques, the sensors that passed the initial validation test for error will be lifetime tested. The first stage of this process is to test how the accuracy of the sensors changes over millions of cycles of the valve. The plan to test this is to bring the valve and actuator apparatus with the sensors installed to Bray's facilities, where automated actuators repeatedly open and close the valves. They will be set up and monitored on the Bray computer system that will constantly record the number of cycles and the error of the sensors. Then, once a sensor starts getting an error over the allotted amount of 2% or 5%, the number of cycles will be noted. While this validation test is happening, the lifetime test will be happening simultaneously to see if any of the sensors stop providing data due to breaking. If the cycles are below the 2 million cutoff for either the error or the lifetime, then the sensor will be evaluated to see if alterations can be made or cut depending on Bray's advice. The plan was selected because the error of the sensors will change over time as repeated use causes degradation, and Bray's R&D department has the technology. The lifetime is also important to validate because if the sensor fails before the valve starts to fail, it will provide no useful data on how to prevent valve failure. This validation test should be done at Bray as they have all the proper equipment and tools to do this.

The final stage of validation planning will be determining each sensor's power draw to collect accurate data. The plan is to individually connect the battery to each sensor in the valve system. Then, the power consumption will be monitored using a multimeter to ensure that no sensor is drawing more power than what can be provided by a compact lithium-ion battery, which was determined to be 100 watt-hours. This validation plan will eliminate nonrealistic designs because if a sensor draws too much power, it will not be able to operate in a remote field for an extended time.

Project Plan Selection Validation

Overall, this plan was selected based on the feedback from Bray that the error of the measurements was the main concern while also trying to optimize the process of setting up the system. The initial accuracy test is to ensure that the valve is not interfacing with any of the sensors, causing the sensor's accuracy to be thrown off. This test will catch things like loose connections between mechanical parts or the valve and sensor system not acting together like the team anticipated. The next stage is to ensure the design is not overcomplicated by ensuring everything is easy to set up and can be easily calibrated, no matter the conditions. Lastly, the designed system has to be able to outlast the valve in terms of lifetime and maintain a level of accuracy, or else it will not be able to collect useful data because it will not be able to predict the failure of the valve. Power consumption will be used as a final test to see whether any concepts are not valid (needing more power than can be supplied by a portable battery).

To verify that this validation process is appropriate, our team will present the results to Bray every week to get input on whether it is okay to move forward to the next step or if a certain area needs to be looked at more. The most helpful thing is that the validation process is laid out in steps, so if something is not caught in the initial testing and optimizing phase, it will be caught when lifetime and power testing happens. Another useful process is that moving into the spring semester, our team plans to test multiple designs in validation testing so that if one fails, it can be dropped. The team can continue with the solution that works. Lastly, our team decided on measurable tests and set quantitative limits to what is accepted to avoid bias by just analyzing the raw data.

Approved Budget

Category		Component	Purchase Unit Cost	Number of Units	Total Unit Variable	Shipping Costs	Total Fixed Costs	Total Cost	Margin	Adjusted Cost
Tooling	FEDC Access									
		Voltmeter								
		3D Printing Access								
		Drill Press								
		Drill (Handheld)								
		Soldering Iron								
		Instant Weld								
Materials	Sensors									
		Potentiometer	$146.00	2	$292.00	$7.84	$7.84	$299.84	30%	$389.79
		Hall Effect Sensor	$53.12	2	$106.24			$106.24	30%	$138.11
		Rotary Torque Sensor	$1,000.78	0	$0.00			$0.00	30%	$0.00
		Rotary Potentiometer	$11.19	1	$11.19	$8.00		$11.19	30%	$14.55
		Bolt Strain Gauge (5)	$249.85	2	$499.70			$499.70	30%	$649.61
		Strain Gauge (6)	$29.99	2	$59.98			$59.98	30%	$77.97
		Neodymium Magnets	$15.00	1	$15.00			$15.00	30%	$19.50
	Power Transmission									
		Lead Wires	$0.56	20	$11.20			$11.20	30%	$14.56
		Solder	$7.48	2	$14.96			$14.96	30%	$19.45
		Battery Source	$187.80	1	$187.80	$15.00	$15.00	$202.80	30%	$263.64
	Product Casing									
		Pneumatic Rack & Pinion Actuator	$248.37	0	$0.00	$0.00	$0.00	$0.00	30%	$0.00
		Pneumatic Stotch-Yoke Actuator	$221.29	1	$221.29	$20.00	$20.00	$241.29	30%	$313.68
		Butterfly Valve	$380.89	0	$0.00	$0.00	$0.00	$0.00	25%	$0.00
		Ball Valve	$304.00	1	$304.00	$20.00	$20.00	$324.00	25%	$405.00
		Digital Analog Converter	$16.59	1	$16.59			$16.59	25%	$20.74
		Data Acquisition Unit	$79.00	1	$79.00	$5.00	$5.00	$84.00	25%	$105.00
Equipment										
		Metal 3D Printing Access								
		Valve Testing Equipment								
User Facilities										
		FEDC Shop Access								
		Bray Shop Access								
Software										
		Software Development								
Travel		College Station to Bray International	$104.66	5	$523.30			$523.30	0%	$523.30
				TOTAL	$2,342.25		$67.84	$2,410.09	27%	**$2,954.90**