Bray Embedded Valves and Actuators

Design Report 3 Presentation

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Introduction

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- Bray is a premier manufacturer of flow control and automation products and accessories.
- Assigned to work with Bray to:
  - Develop a method to internally measure valve position independent of an actuator
  - Measure actuator output torque to increase the valve's service life
  - Detect fluid leakage in the system
- Current solution: *IOT Torque Bracket*
  - Indirect measurement of actuator torque

Problem

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- Develop a method to internally measure valve position independent of an actuator, measure actuator output torque, and detect fluid leakage to increase the service life of the valve.
  - Leakage issue was dropped in favor of the other two
- Opportunity to incorporate 3D metal printing?

Value Proposition

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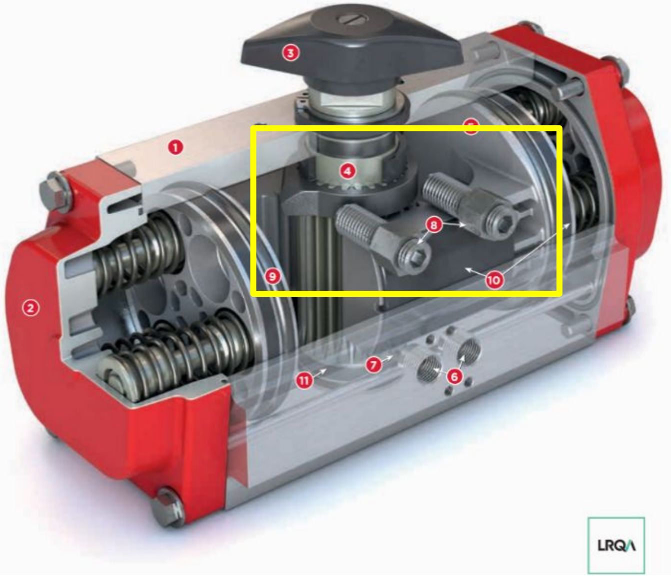
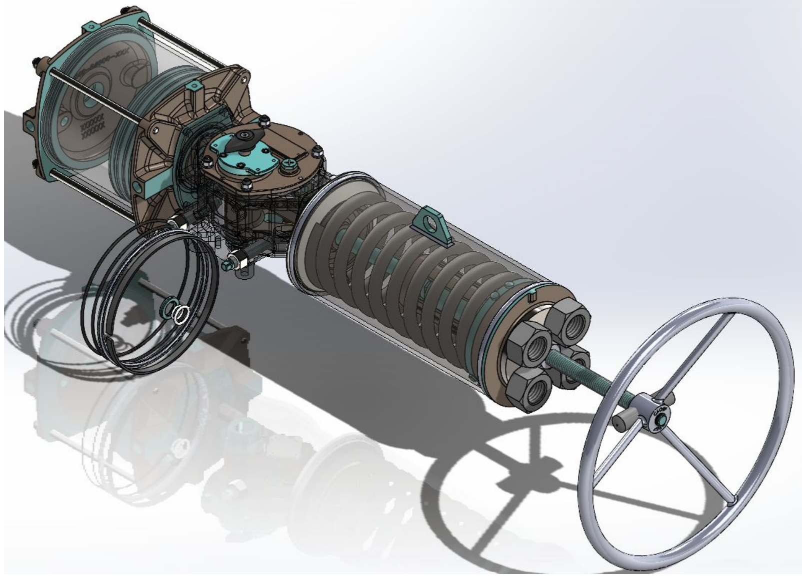
- More accurate valve and actuator monitoring
  - Planned preventative maintenance and live adjustments
  - Proactive rather than reactive maintenance
- Catching problems before they occur
  - Less part damage > longer life
  - Less downtime > more working time

Relevant Products



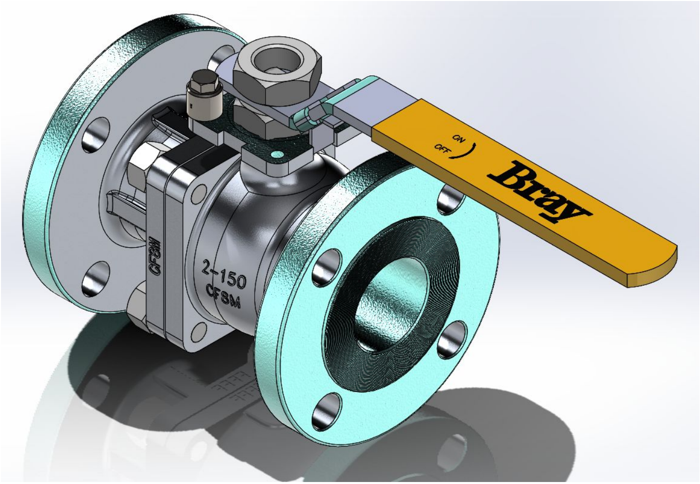
S92 rack-and-pinion actuator



S98 scotch-yoke actuator

Both are not yet “smart”

Relevant Products



- Butterfly and ball valves
  - Focusing on ball valve due to higher engineering complexity.
  - Project solution should be agnostic to valve type.

Customer Needs

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#	Need	Importance
1	Final product is embedded into the actuator casing	1
2	Product is scalable for different-sized valves	2
3	Product records and transmits sensor data	1
4	Works in a wide temperature range (-40℉-300℉)	4
5	Works under various pressures (100 psi - 740 psi)	3
6	Works for various fluid mediums	4
7	Measures actuator torque to < 5% error	1
8	Relatively short lead times for parts (3-4 weeks)	2
9	Determines true valve position independent of actuator	1
10	Works for both pneumatic and hydraulic actuators	3
11	Short time for calibrating the sensor	3

Functional Modeling

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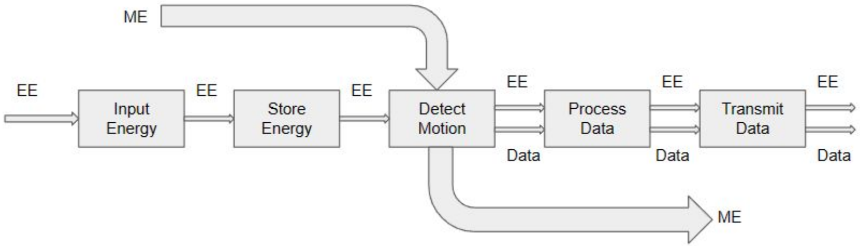
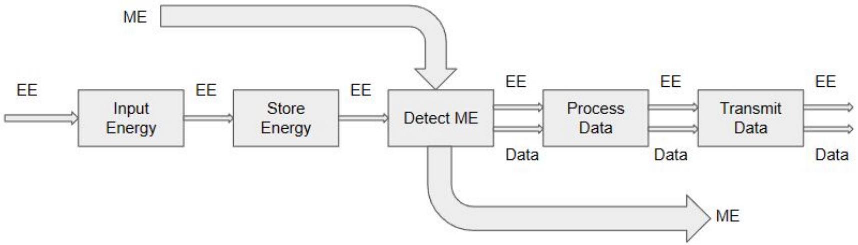
- Breaks down the problem into simple steps and “flows” of energy
- Integration of electrical and mechanical energy is key consideration



Position Measurement Function Chain



Torque Measurement Function Chain

Concept Generation

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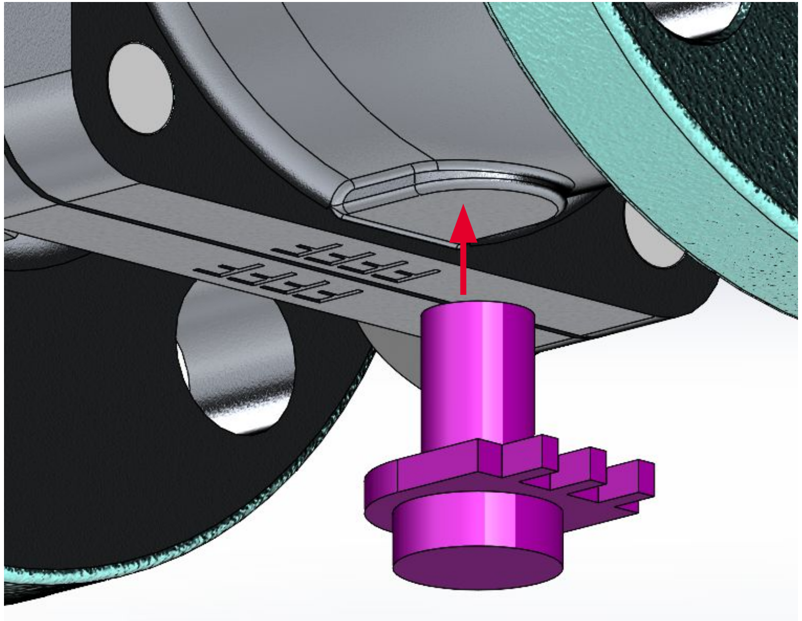
Position	- Rotary Potentiometer (voltage -> angular position) - Hall effect sensor to identify rotation of a magnetized point - Flow meters before and after valve - Fluid turbulence measurement
Torque	- Potentiometer (angular acceleration * I = torque) - Strain gauges on shaft - Strain gauges on stop bolts - Spring scale - Convert electric power generation to torque using time and rotation

Concept Refinement

- Only direct measurements preferred for better accuracy
  - Should not apply calculations to measured data
  - Ruled out any flow measurements
- Most important solution characteristics
  - <5% accuracy
  - No interference with system performance
  - Embedded nature

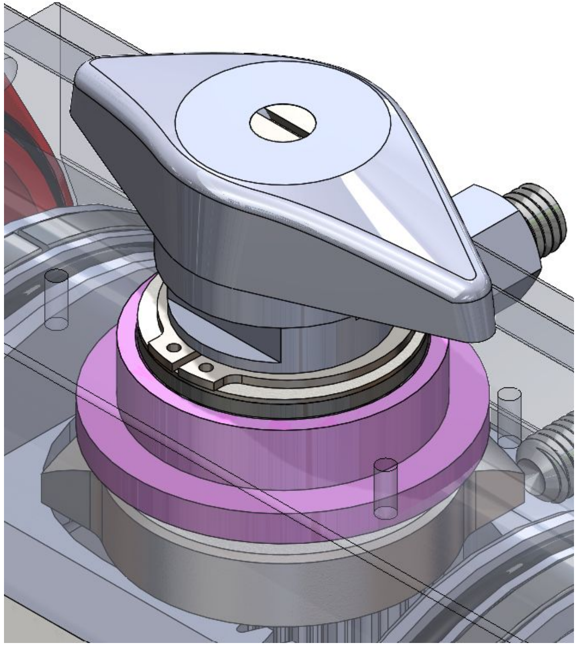
Original Concepts

- Position: Rotary Potentiometer
  - Resistance corresponds to angular position
  - Detects change from the expected open (0°) and closed (90°) position
  - Open and closed position could be tracked through time to identify trends
  - Independent of actuator - hole drilled and re-sealed



Original Concepts

- Torque: Rotary Potentiometer
  - Measure angular acceleration of the actuator stem
  - Experimentally find the moment of inertia for the actuator system
  - Combining angular acceleration and moment of inertia provides torque.



Review of Original Concepts

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- Position: Rotary Potentiometer
  - Valid idea
  - Important to seal sensor connection inside valve in order to ship to customers
- Torque: Potentiometer
  - Time-consuming - too difficult to find moment of inertia of every actuator/valve combination
  - Not independent of the valve
  - Two new ideas chosen instead

New Experimental Method

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- Test 2 concepts for each deliverable
  - Potentiometer and strain gauges are most promising, but others merit at least initial testing
- Valve position concepts
  - Rotary Potentiometer (same as original)
  - Hall Effect sensor
- Actuator torque concepts
  - Cylindrical Strain Gauge
  - Electrical Energy Generation

Hall Effect Sensor

- Position: Hall Effect sensor
  - Valve rotation produces magnetic field shift
  - Power source required
  - Independent of actuator

Cylindrical Strain Gauge

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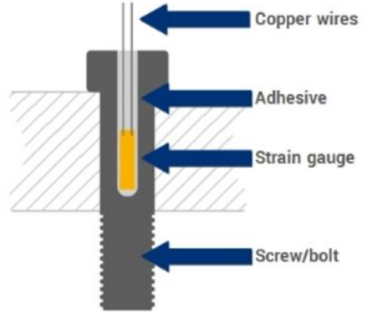
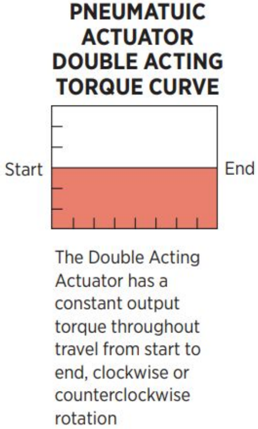
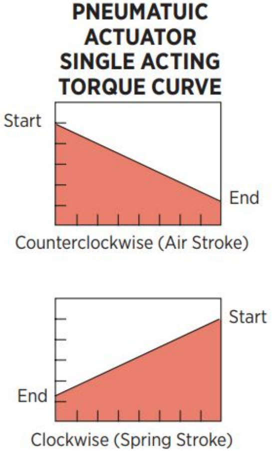
- Torque: Stop bolt strain gauge
  - Independent of valve
  - Records ending strain (max value)
  - E (modulus), A (area), R (radius) known
  - Use known parameters to make force-time graph from strain-time and obtain torque
  - Can plot over time to see trends
  - Predict future torque for opening and closing strokes



LB11 Installation Scheme





Torque Generator

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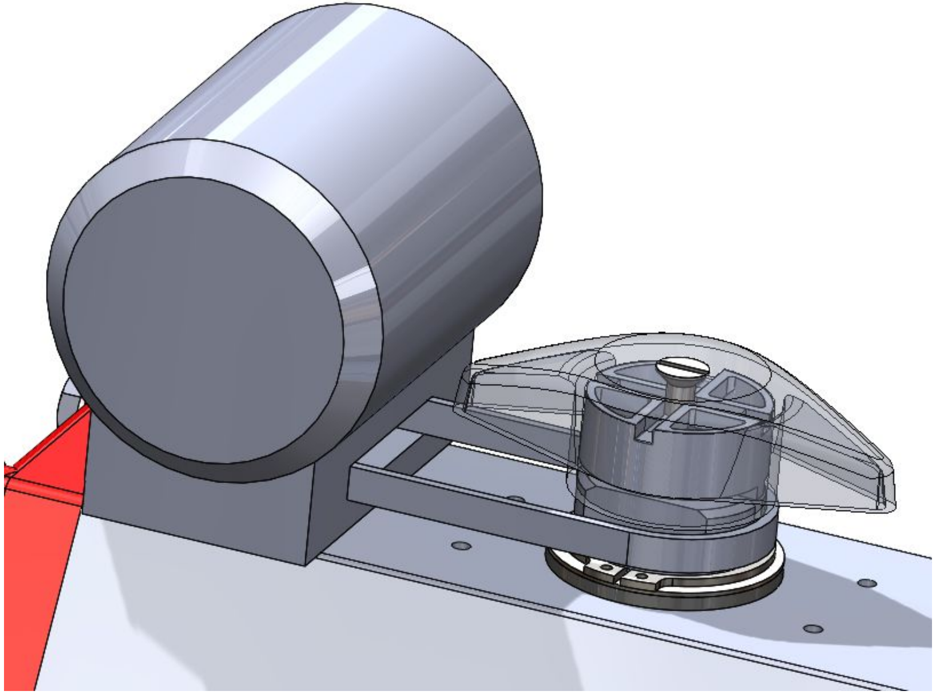
- Torque: Generator-like Device
  - Movement of switch generates voltage
  - Energy generated corresponds to energy input to valve
  - Work = Torque*Ө



Design Details

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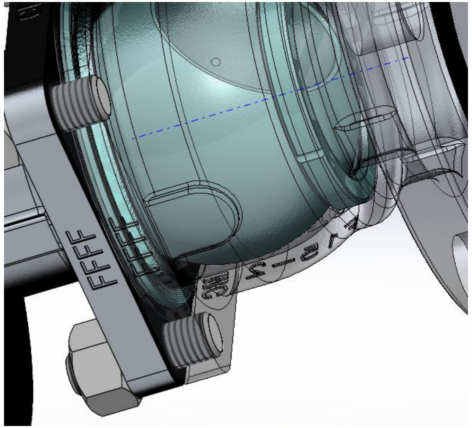
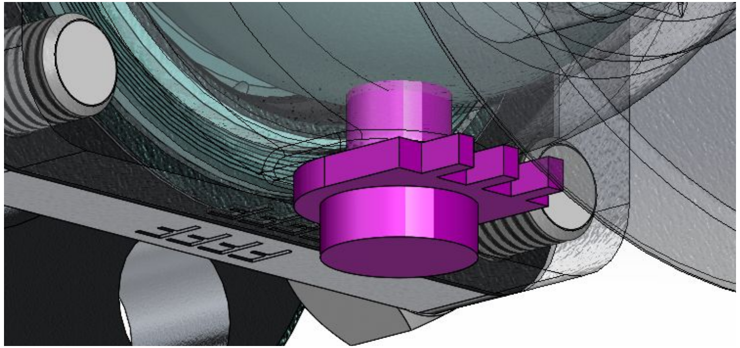
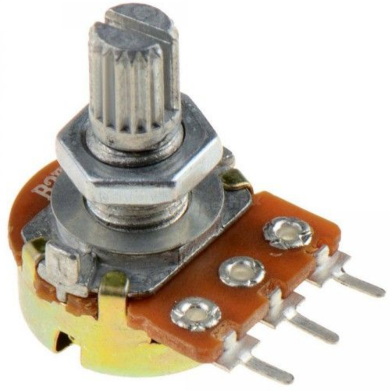
- Position: Rotary Potentiometer
    - Rotating part attached to ball or butterfly
    - Base fixed to valve casing
    - Hole through valve casing - must re-seal…3D metal printing? Metal seal?

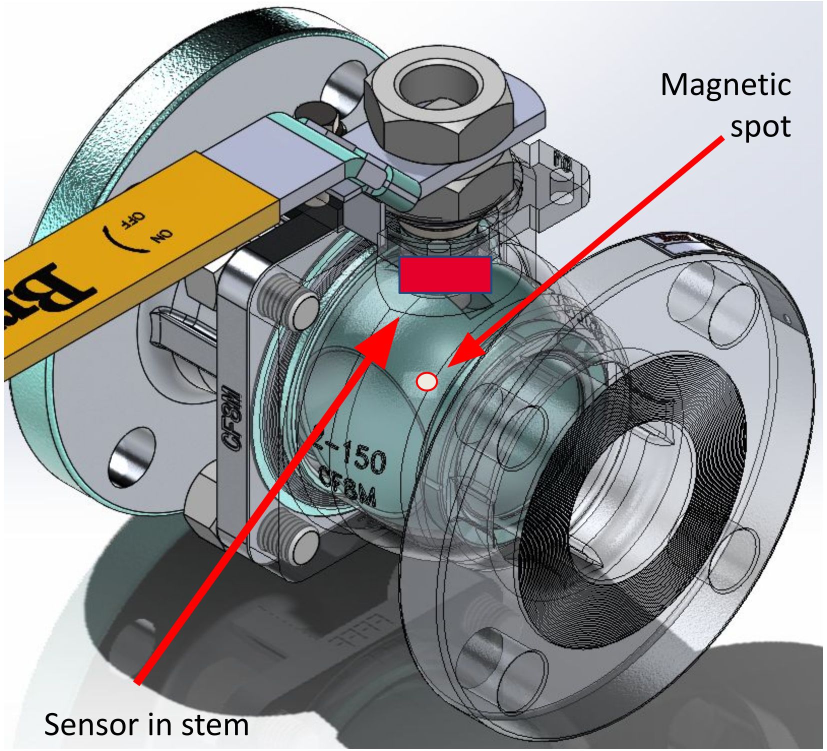






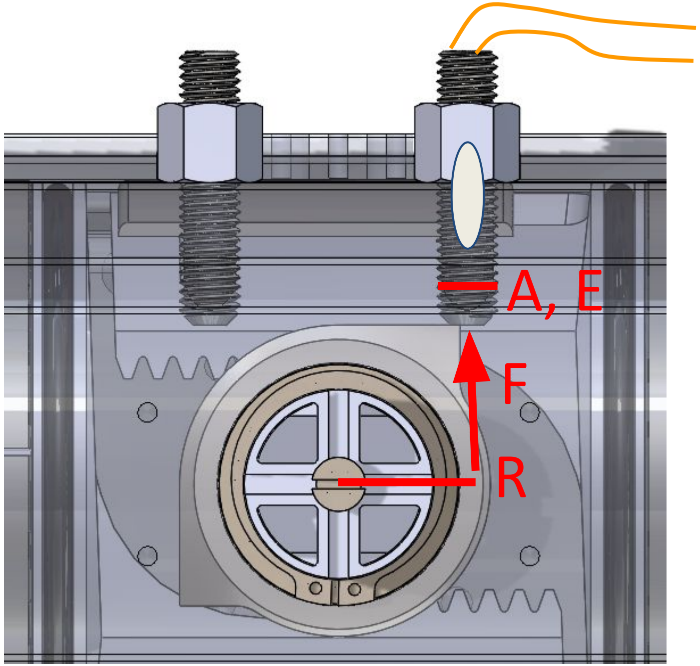
Design Details

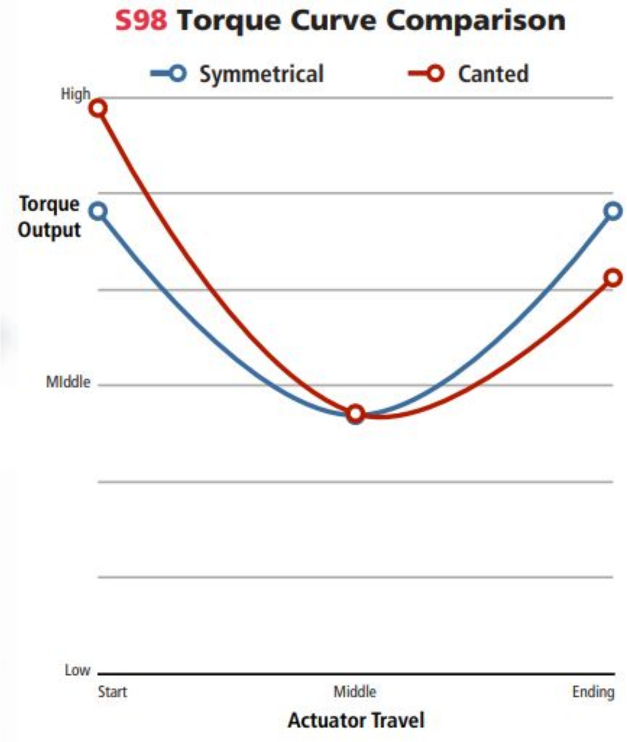
- Position: Hall Effect Sensor
  - Sensor tracks field from magnetized point on ball
  - Must determine "standard" magnetic fields at open/close
  - Must determine relationship between field readings and position
  - Embedded in casing or stem



Design Details

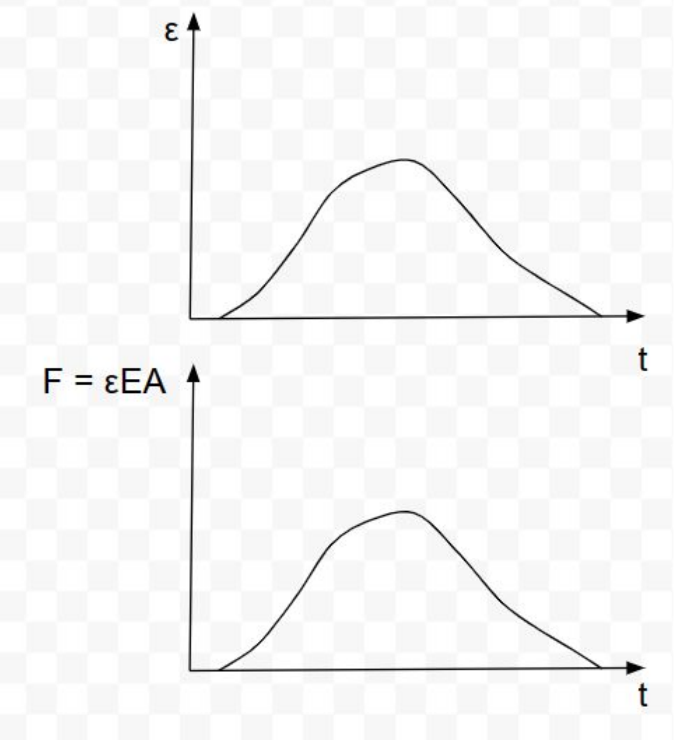
- Torque: Strain gauge in stop bolts





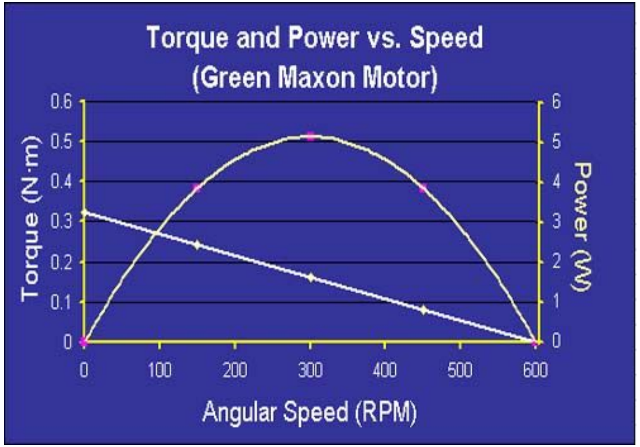
Design Details

- Torque: strain gauge in stop bolts
  - Gauge records: strain (ε) vs. time (t)
  - $$Average\ Force = \frac{\int F\,dt}{t}$$
  - $$\tau = F \times r$$
  - Can record torque for every open/close motion and identify performance

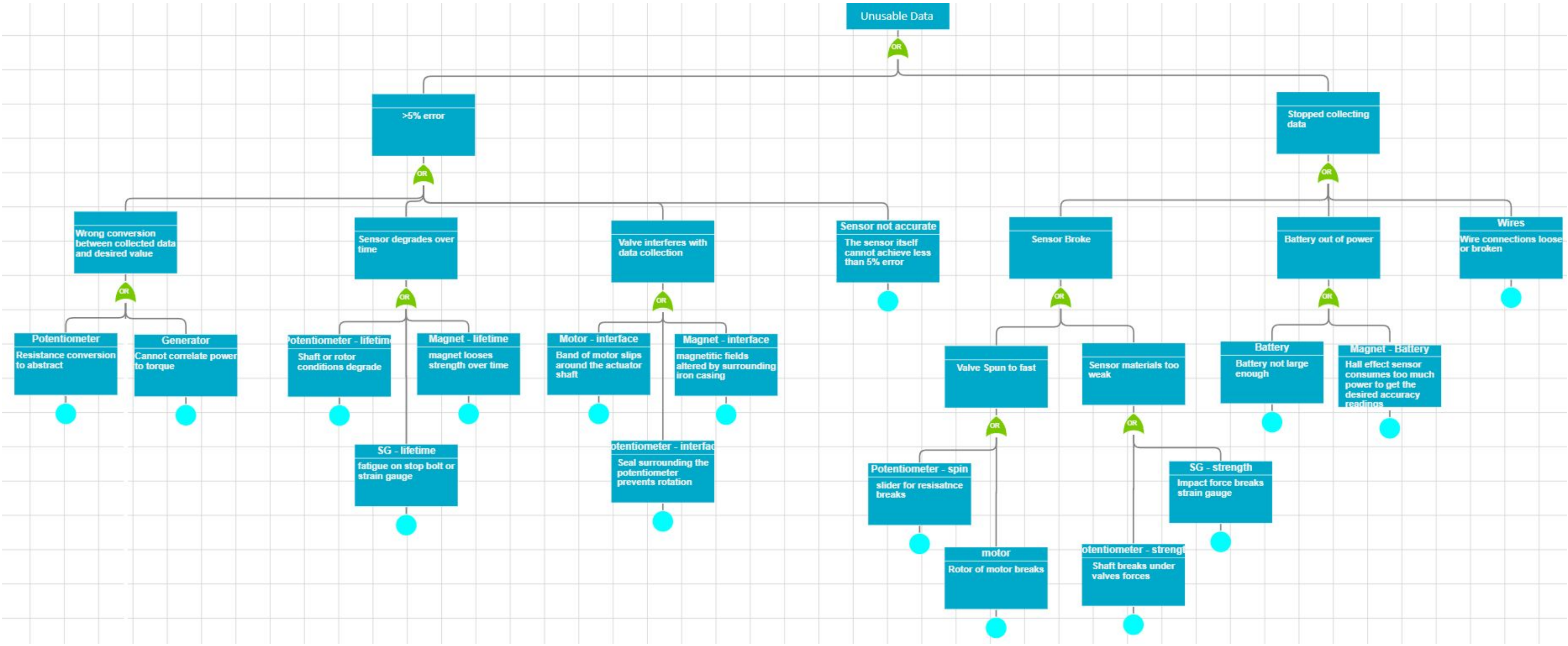


Design Details

- Torque: Electric Motor
  - Torque units: Nm ← distance
  - Energy Units: J = Nm ← displacement
  - Conversion: E = T*rad
  - Radians known as π/2
  - Record Volts generated from motor rotation
  - Motor in line with a known resistance a total power can be found
  - $$T = \frac{P \cdot \Delta t}{\frac{\pi}{2}}$$



Risk Assessment



Validation Testing - Position

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Functional Requirement	Quantitative Requirement	Design feature	Validation Test	Actual Value	Satisfied
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	<5 %	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 start getting accurate readings from the sensor system from start to finish		
Measurement accuracy with extended use (position)	< 5%	Potentiometer and Hall Effect Sensor	Measure the decay of accuracy as the potentiometer cycles till failure		
Lifetime of sensor	> 20 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		

Validation Testing - Torque

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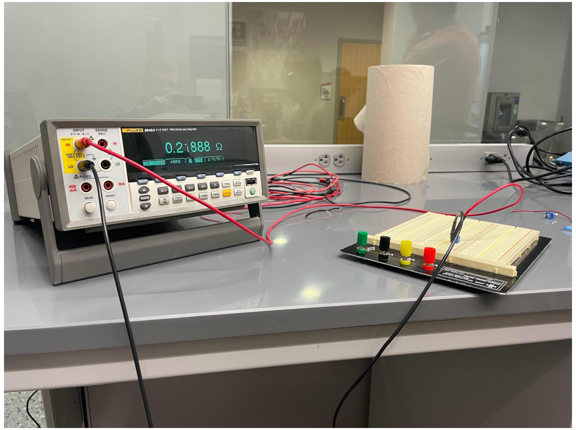
Functional Requirement	Quantitative Requirement	Design feature	Validation Test	Actual Value	Satisfied
Measurement Accuracy Torque	< 5%	Cylindrical Strain Gauge and Motor	Measure and compare the reading of the torque reading to the actual set value (test how ambient temperatures affect accuracy)		
Ease 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	> 20 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		

Initial Validation Testing

- Position: Potentiometer
  - Tested to see correlation between resistance and position
  - Linear 10 KΩ pot met the <5% accuracy reqt.



Position (degrees)	Resistance (ohms)	Predicted Position (degrees)	error %
0	0.24	-0.000024	0.24
270	94732	270.1	0.029
0	0.24	-0.000024	0.24
270	94748	270.1	0.046
0	0.22	-0.000081	0.81
270	94736	270.1	0.034
0	0.25	0.0000048	0.048
270	94806	270.3	0.11
0	0.25	0.0000048	0.048
270	94616	269.7	0.093
0	0.29	0.00012	1.2
270	94587	269.7	0.12

Budget Planning

Category	Component	Purchase Unit Cost	Assembly (Labor)	Number of Units	Total Unit Variable Cost	Shipping Costs	Other Fixed 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

Project Budget

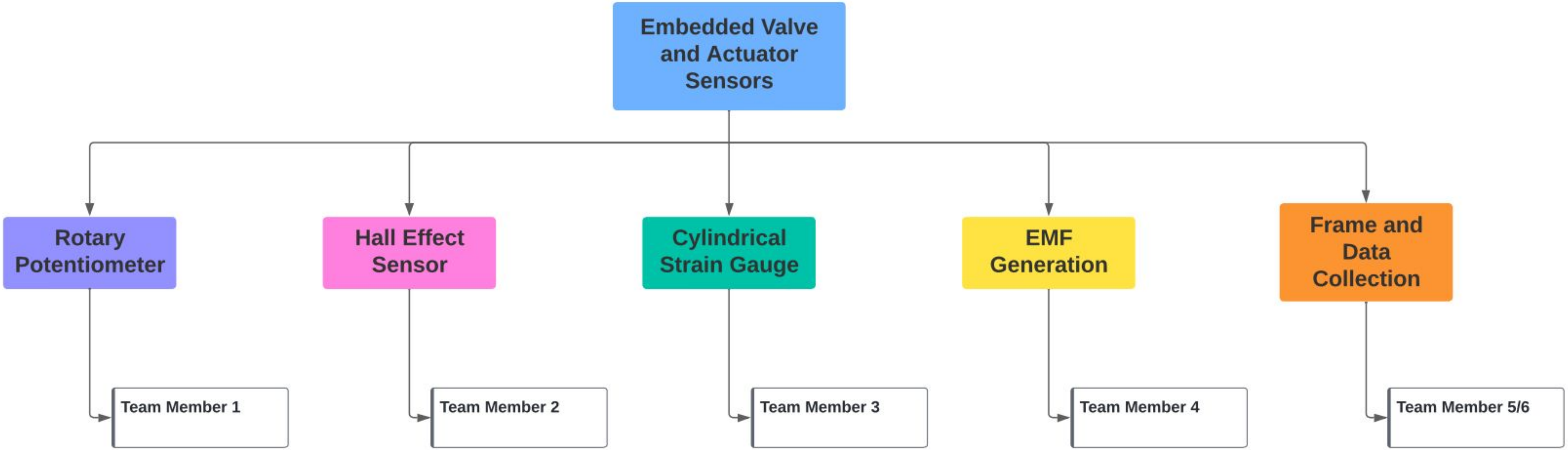
Texas A&M University

- Added 30% Margin
- Largest Expenses:
  - Bolt Strain Gauge ($500)
  - External Battery ($187)
  - Valve & Actuator Equipment ($844)
  - Travel ($105 per trip)

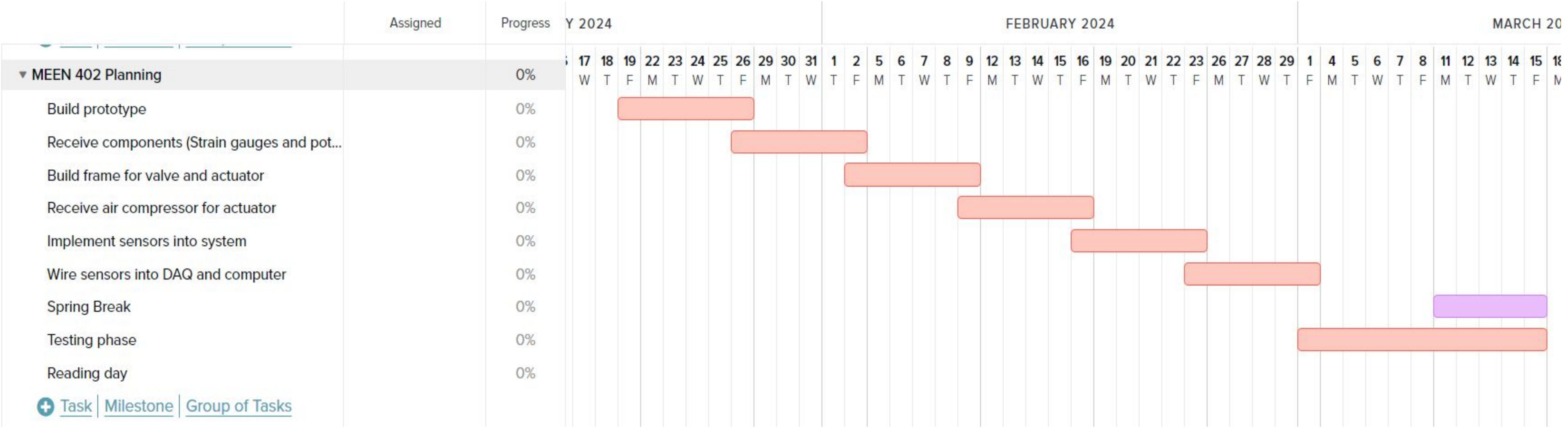
CATEGORY	COST
Tooling	$0
Sensors	$1,290
Power & Data	$298
Product Casing	$844
Facilities	$0
Travel	$523
TOTAL	**$2,955**

No expensed tooling or facility access

Work Breakdown Structure 402



Gantt Chart


Assigned
Progress
Y 2024
FEBRUARY 2024
MARCH 20
17 18 19 22 23 24 25 26 29 30 31 1 2 5 6 7 8 9 12 13 14 15 16 19 20 21 22 23 26 27 28 29 1 4 5 6 7 8 11 12 13 14 15
W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F
MEEN 402 Planning 0%
Build prototype 0%
Receive components (Strain gauges and pot... 0%
Build frame for valve and actuator 0%
Receive air compressor for actuator 0%
Implement sensors into system 0%
Wire sensors into DAQ and computer 0%
Spring Break 0%
Testing phase 0%
Reading day 0%
Task
Milestone
Group of Tasks

Process Risk Assessment

Process Risk	Probability	Severity	Actions to Minimise Risk
Missing deadlines	Unlikely	Major	Have an updated calendar with due dates relayed to team members regularly.
Safety concerns with handling equipment	Moderate	Major	Refer to FEDC staff if any questions arise when handling equipment.
Equipment scheduling conflicts at FEDC	Unlikely	Moderate	Reserve equipment as soon as possible, plan ahead for testing.
Student schedule conflicts	Moderate	Minor	Share schedules in Google Drive so common meeting times can be established early.
Solution time allocation	Unlikely	Major	Give our team time for prototyping and testing for each solution, and avoid becoming hyperfocused on a specific solution.

Final Deliverables

- Provide a comprehensive solution for detecting valve positions and internal actuator torque
- Scalable to varying actuator and valve sizes
- Solution is cost-effective and safe for the user
- Focus on the potentiometer and strain gauge as our solution, as well as the hall effect sensor and EMF generation
- Collaborate with Bray to 3D-print prototypes of solutions, which will undergo testing with their valves and actuators
- Adhere to milestones and deadlines, allowing us to provide effective material for our upcoming reports

Conclusions

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- Concepts to measure valve position
  - Rotary Potentiometer, Hall Effect Sensor
- Concepts to measure actuator torque
  - Cylindrical Strain Gauge, EMF Generation
- Spring Semester Goal
  - Develop, test, and validate design concepts and determine which best meets project deliverables.
- Needed Facility Access: FEDC (Texas A&M),
- Estimated Budget: **$2,955**
  - Approved and supplied by Texas A&M

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Questions?