Team 24

Magnetically Coupled Pump/Mixer System for Cryogenic Propellant Tank Destratification Final Presentation

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Sponsor: NASA Marshall Space Flight Center
Florida Space Grant
AME Center

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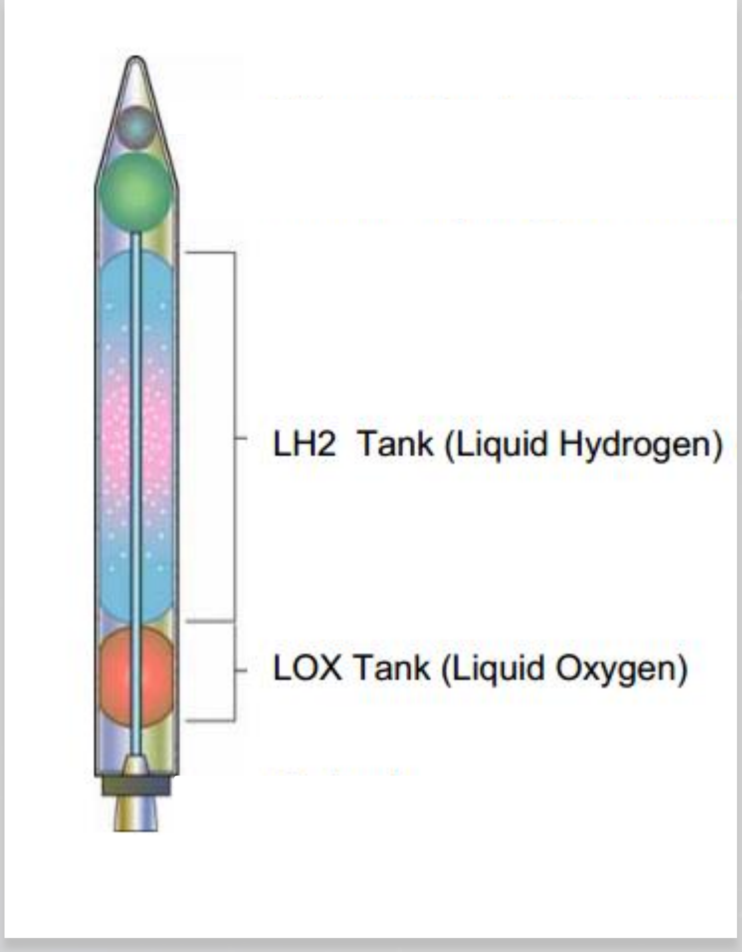
Instructors: Dr. Shih and Dr. Gupta

Agenda

- Background, Motivation, and Project Definition
- Prototype Design and Assembly
- Analyses
- Design of Experiment and Results
  - Water and LN Testing
- Project Management
- Future Improvements
- Conclusion

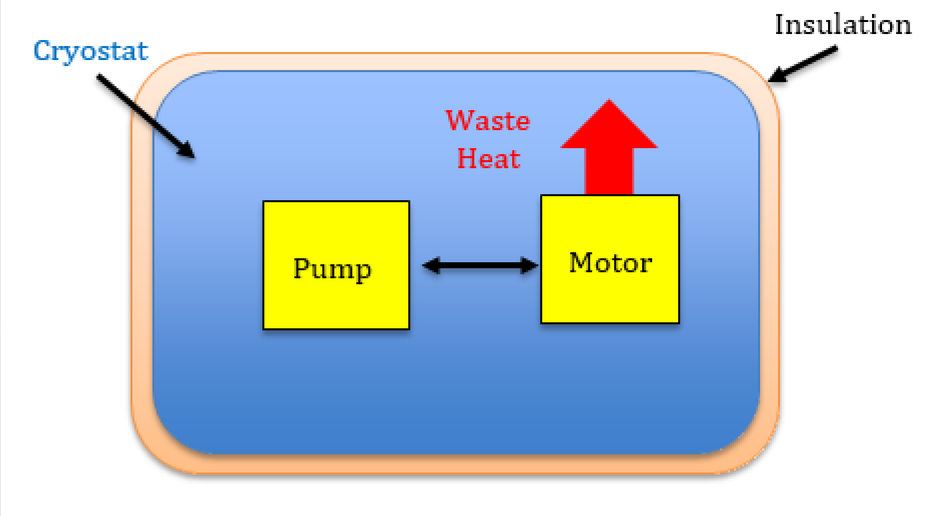
Background

- Cryogens used as rocket fuel
  - Excess cryogens must be stored
- Issues with long term storage of cryogens
  - Stratification
  - Pressure control
  - Venting
- Mixing the propellants
  - Destratification
  - More time before venting



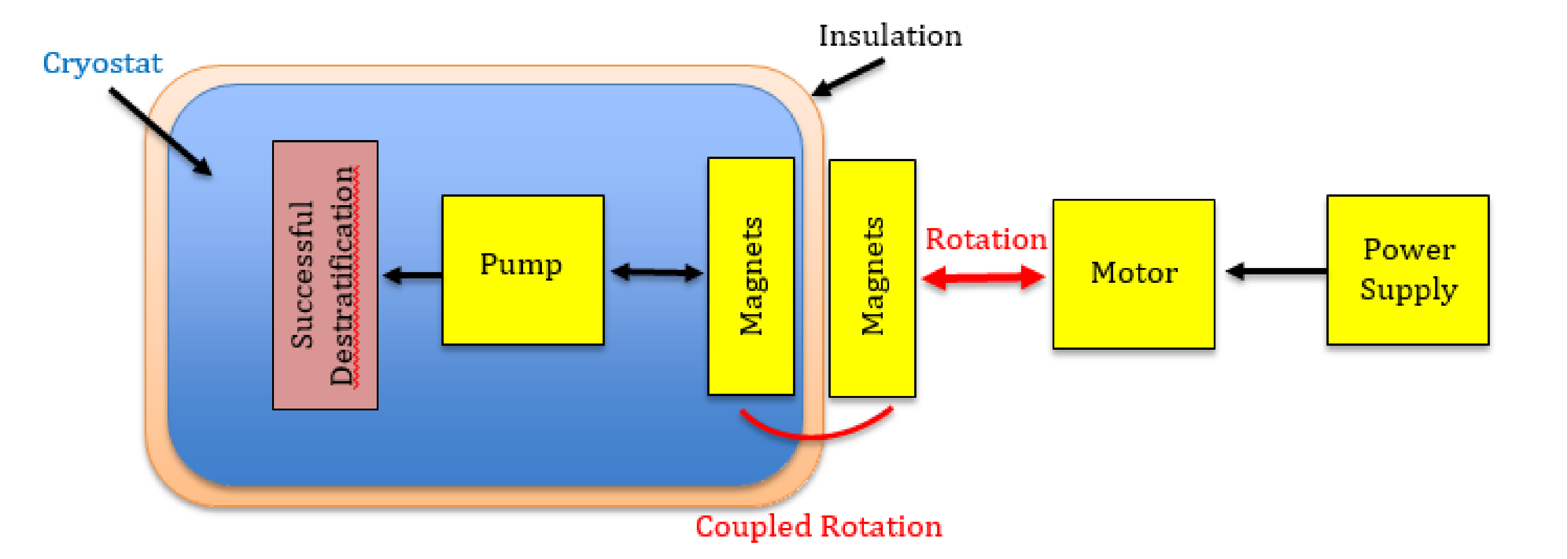
Motivation

- Current system
  - Various AC single and 3 phase motors
  - Waste heat added to cryogens
  - Motor couple to a pump operating in submerged conditions
- Designed system
  - Remove waste heat through magnetic coupling



Block diagram of current system

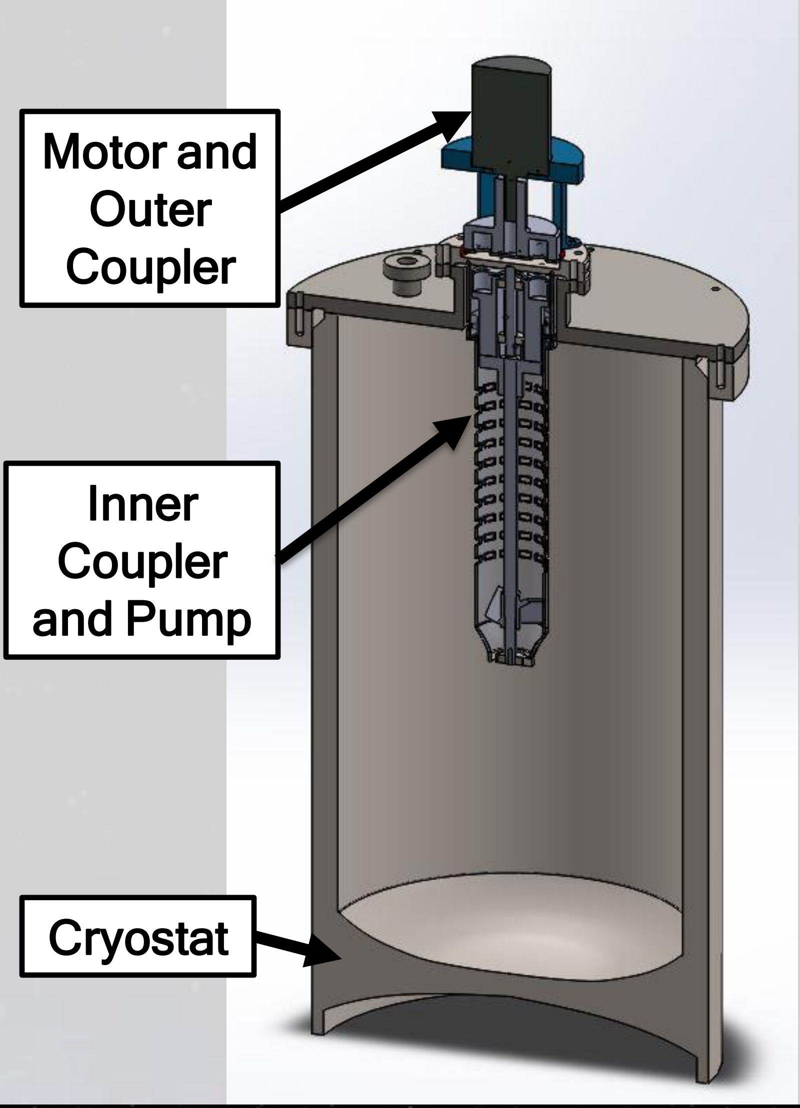
Project Description



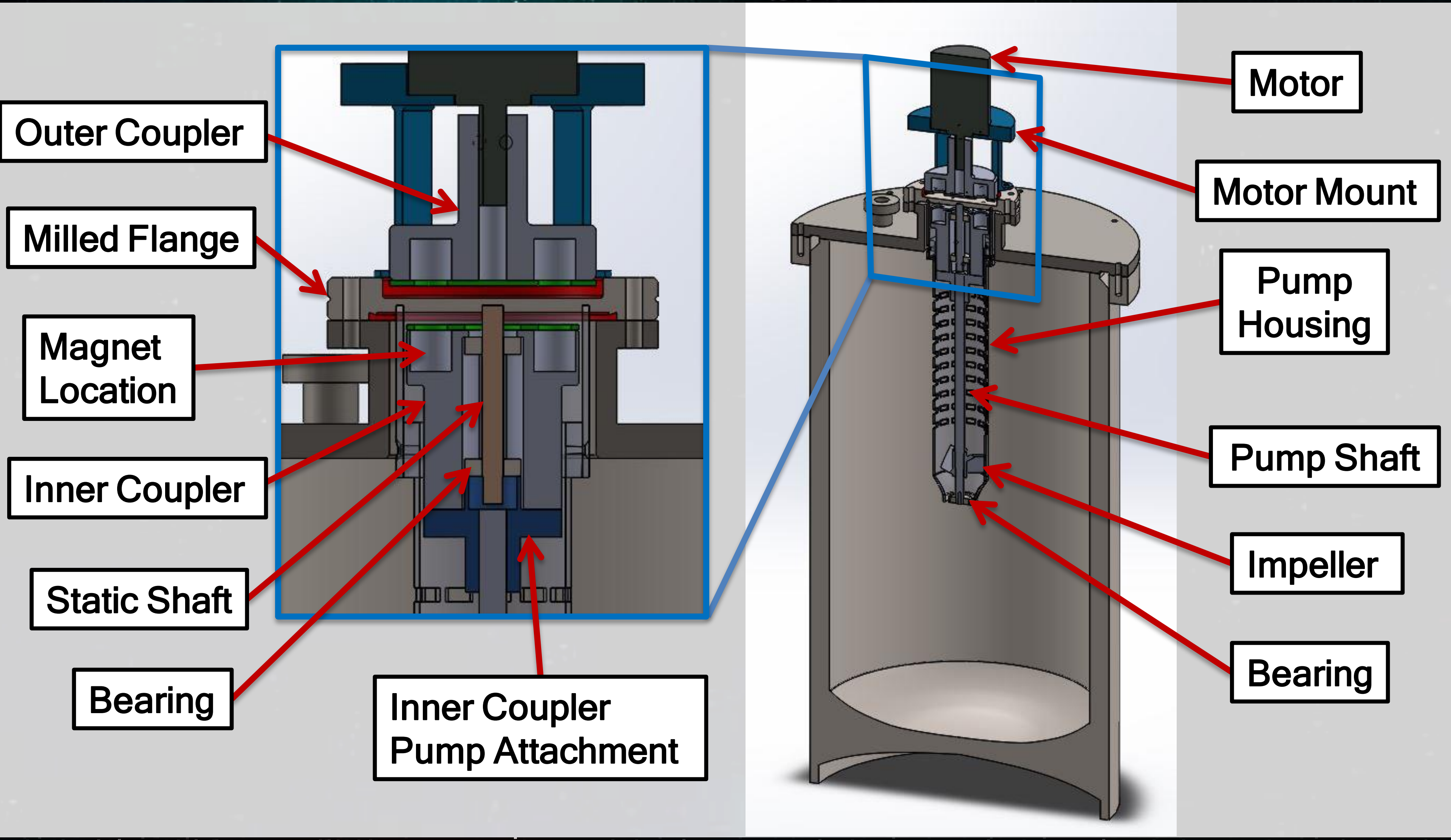
- Design an electric motor-pump/mixer unit that makes use of magnetic coupling technology.
  - The motor must be on the outside of the cryogenic tank
  - Meets volumetric flow rate of current system (5-15 gpm)
  - The entire pump system must fit through a 3.75 inch port on top of the tank

Prototype Design

- Suspension
  - Bearing System at static shaft and pump housing
- Magnetic Coupling
  - Four 0.75” diameter 1 T magnets coupled through milled flange to paired four
  - Distance between the couplers 0.75 in
- Motor
  - Provides sufficient power to mix 5-15 gpm
- Size Constraints
  - Coupler and Pump System fit through 3.75” port

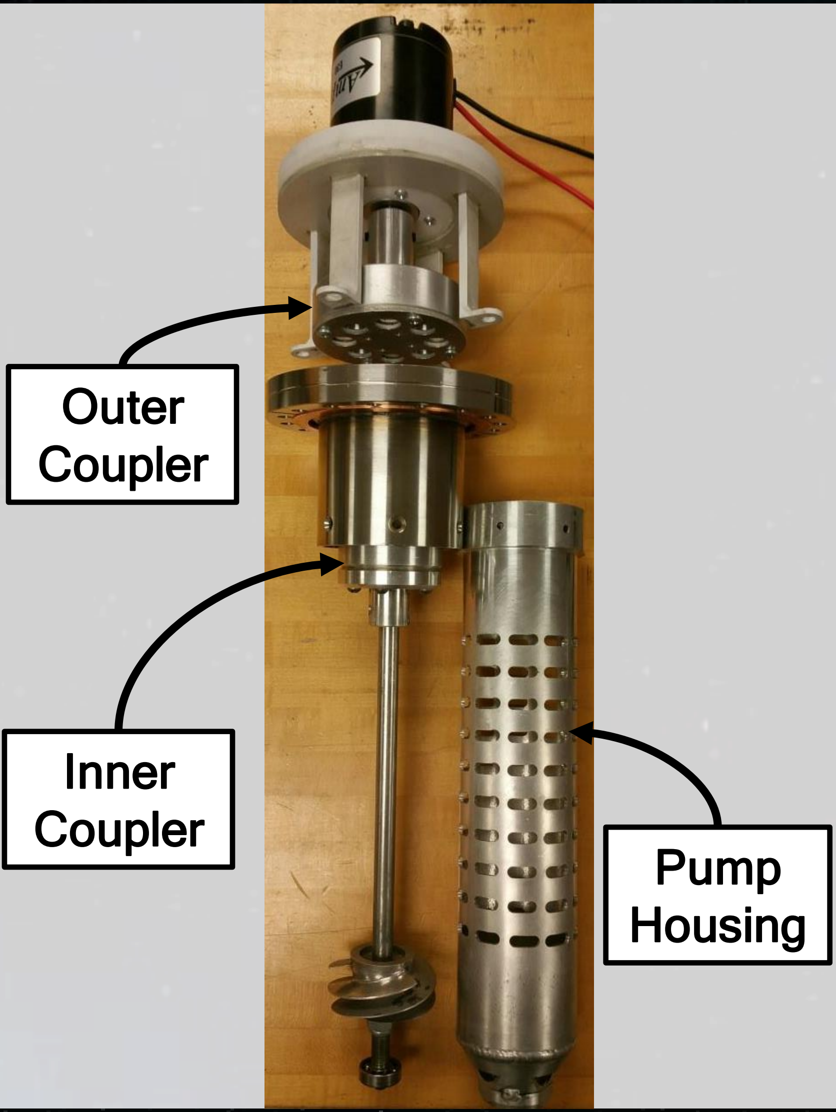


Prototype Design



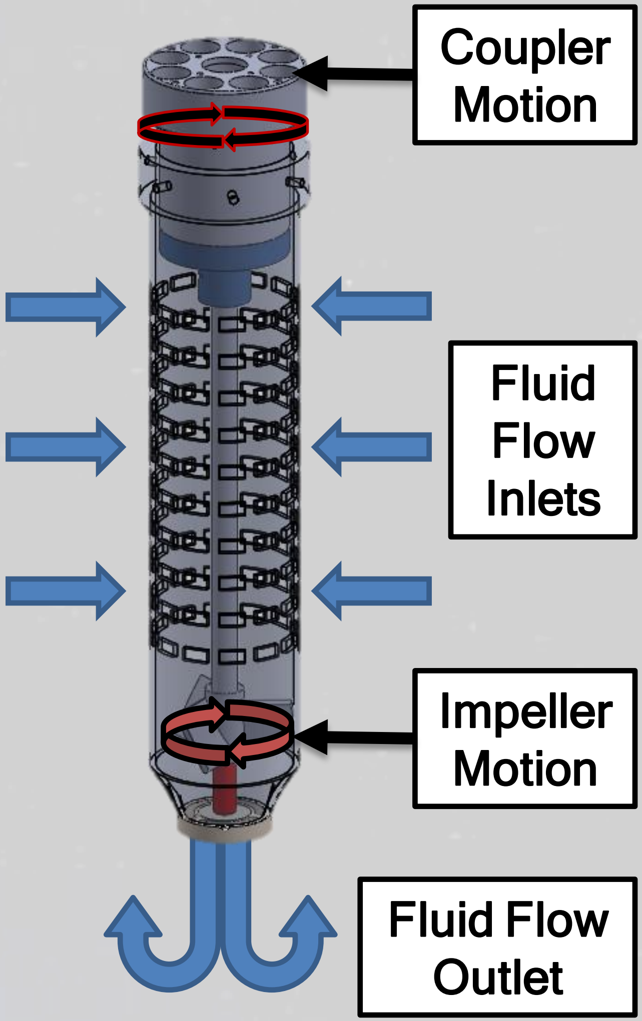
Design Assembly

- Outer coupler secured to motor right above flange
- Weld static shaft and pump anchor and bearing plate
- Attach fully assembled Inner Coupler
- Press fit bearings and bushing
- Connect Pump Attachment with attached Pump Shaft and Impeller
- Assemble Pump Housing over Pump Shaft (press fit end bearing)



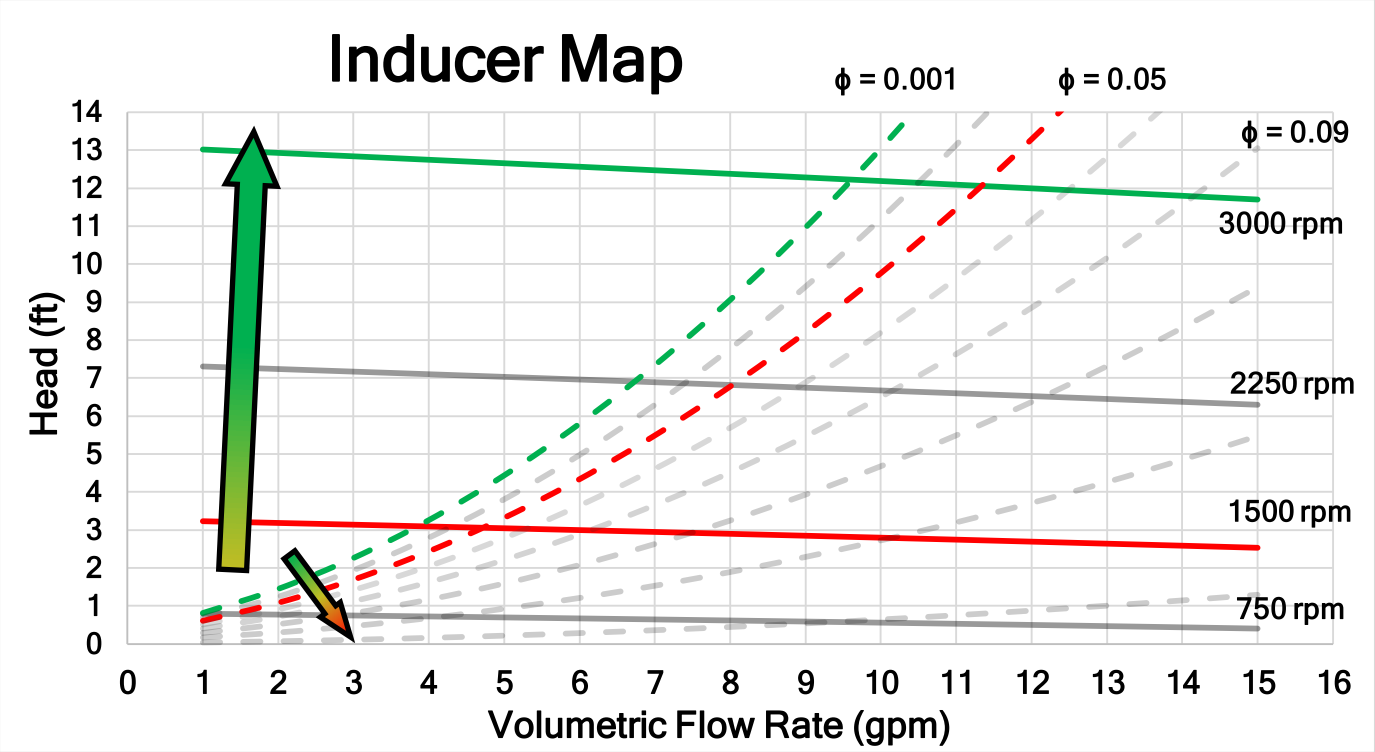
Pump Design

- Rotational motion from the inner coupler (black arrows) spins impeller (red arrows)
- Impeller motion sucks fluid from inlets through pump housing and through outlet
- Inlets begin 3” from top of tank to ensure suction
- Outlet located 13” inside tank as per sponsor specification



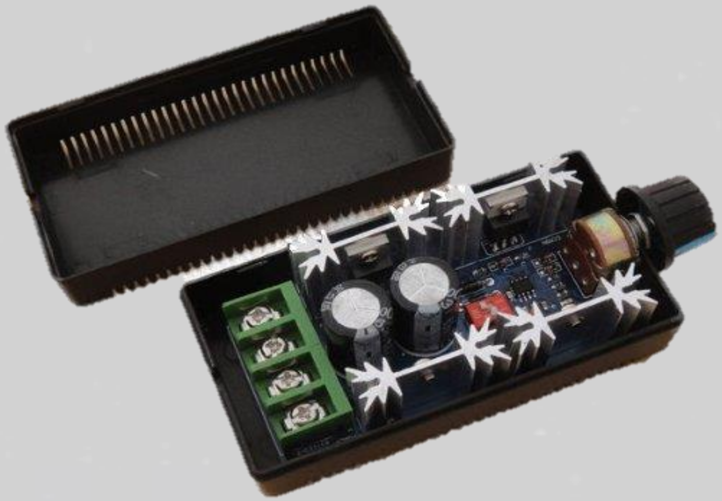
Pumping Capacity Analysis

- Head needed found to be 3 ft.
- Needed power of motor found to be >0.5 HP.
- Pumping calculations using non-dimensionalized flow coefficient (φ) and RPM.
- Lower flow coefficient, φ, wanted.
- Motor needs to output >2500 RPM.



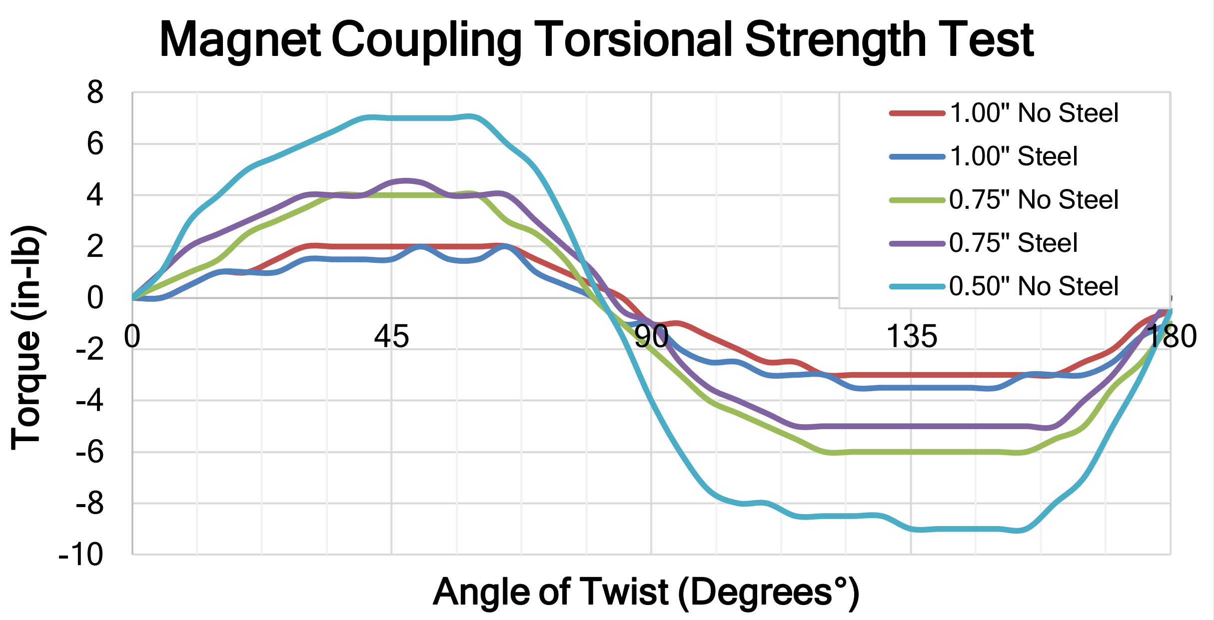
Motor Specification Analysis

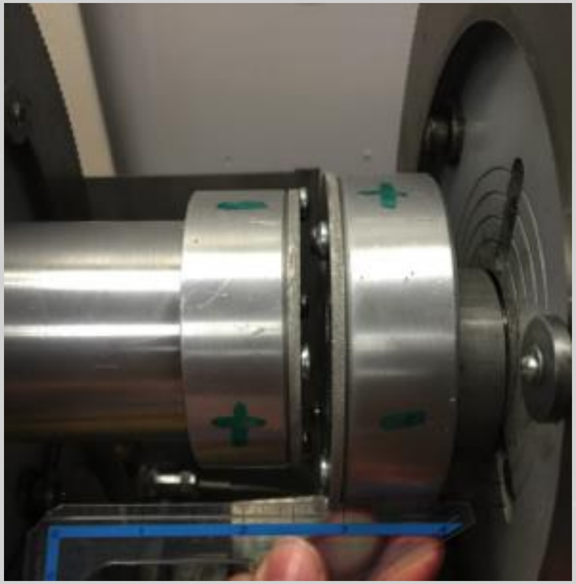
- Motor purchased 24 V DC motor that provides a Peak HP of 1.0 and an RPM @24V of 5600.
- Motor controller using a potentiometer used to control motor speed.
- Using one 24 V DC battery provided to the group by Dr. Gupta



Magnet Experimental Analysis

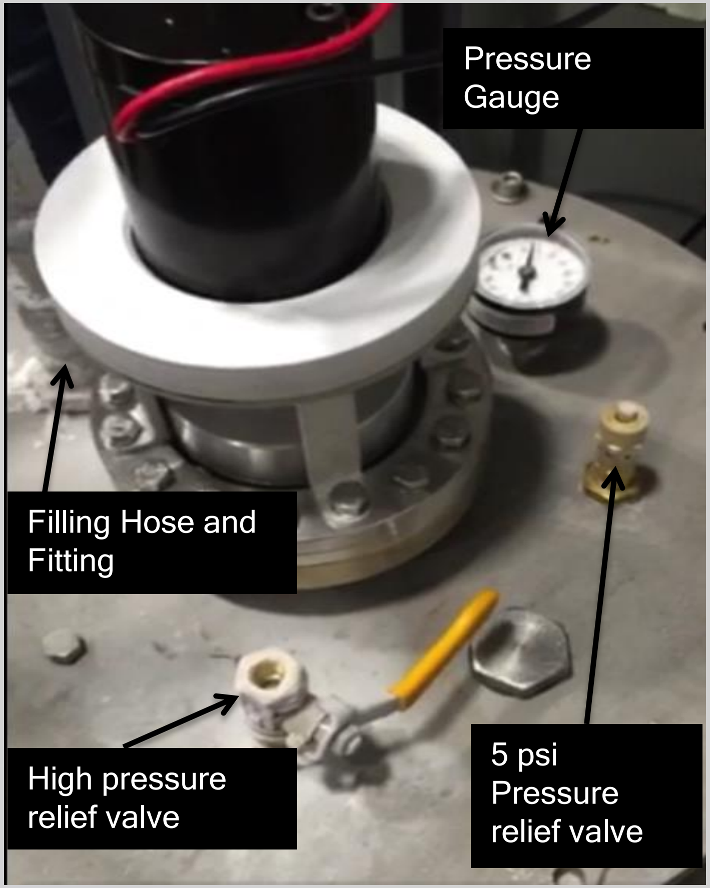
- Magnet number reduced from 8 to 4
- Reduction amplifies coupling strength
- Tested at 1.0”, 0.75”, and 0.5” with and without steel plate
- Rotates at 20°/min with recordings every 5°
- At the coupler distance, maximum torque found to be 4 in-lbs.





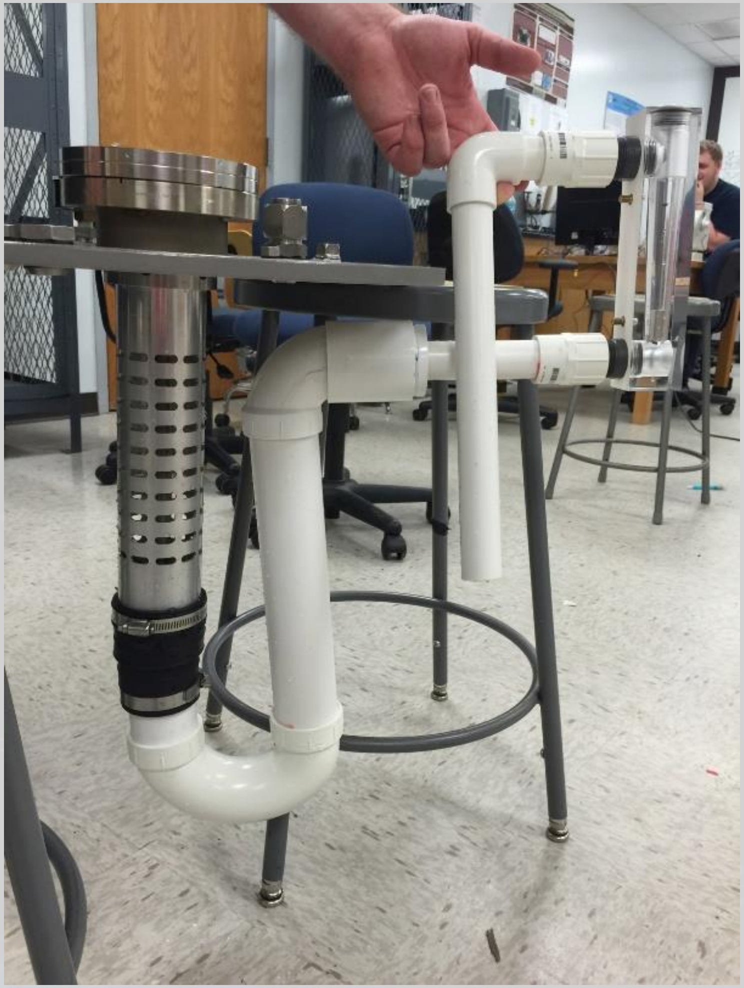
Safety

- Cryogens
  - LN temperature range: 63K – 77K
- Pressure build up
  - Pressure relief valve
  - Sealing
- High velocity components
- Electrical components
- Magnets



Experimental Testing

- Water Testing
  - Ensure design is operable in water
- Volumetric Flow Rate
  - Design piping system
  - Connect flow meter
  - Record maximum Flow Rate



Experimental Testing

- Liquid Nitrogen
  - Ensure design operable in liquid nitrogen
  - Recorded frequency of pressure relief
    - Without pump
    - With pump

Water Test Results

- Water Testing
  - Successful
- Volumetric Flow Rate
  - Reached an average maximum flow rate of 14gpm
  - Maximum flow rate of 16gpm

Cryogenic Test Results

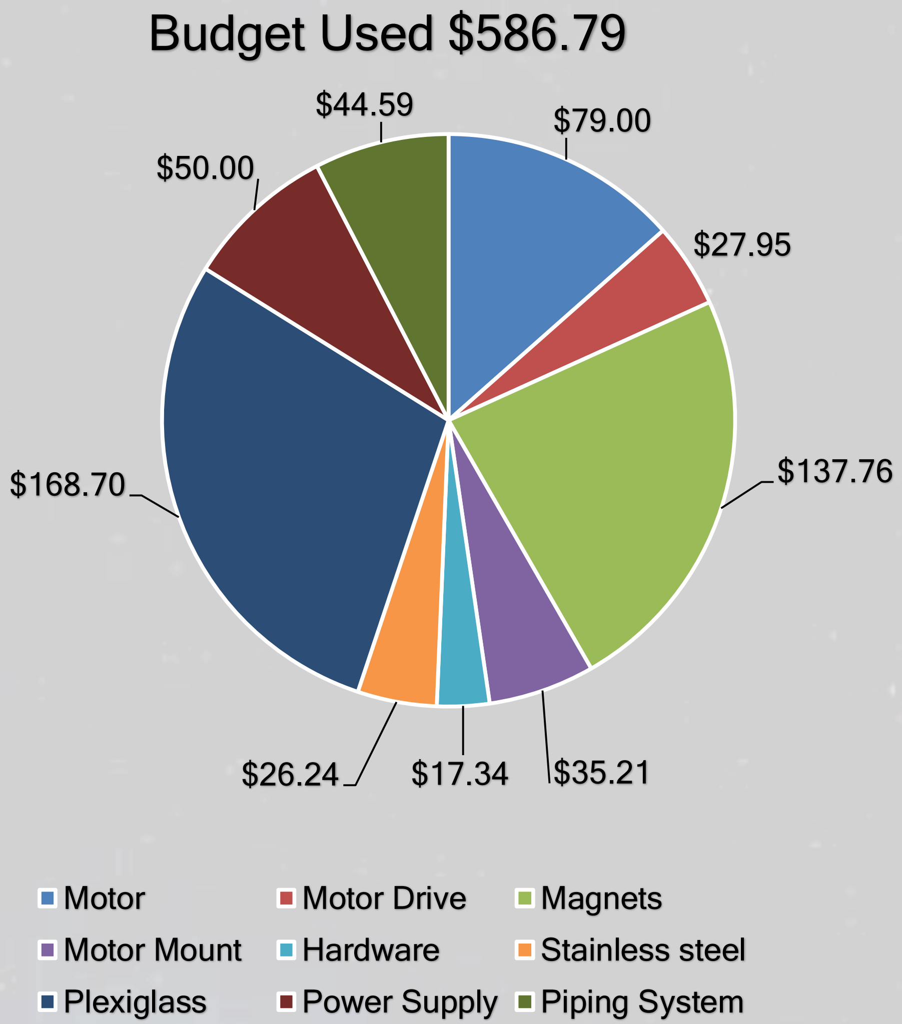
- Liquid Nitrogen Testing
  - Without pump frequency of 0.6Hz
  - With pump frequency of 0.3Hz

Reliability

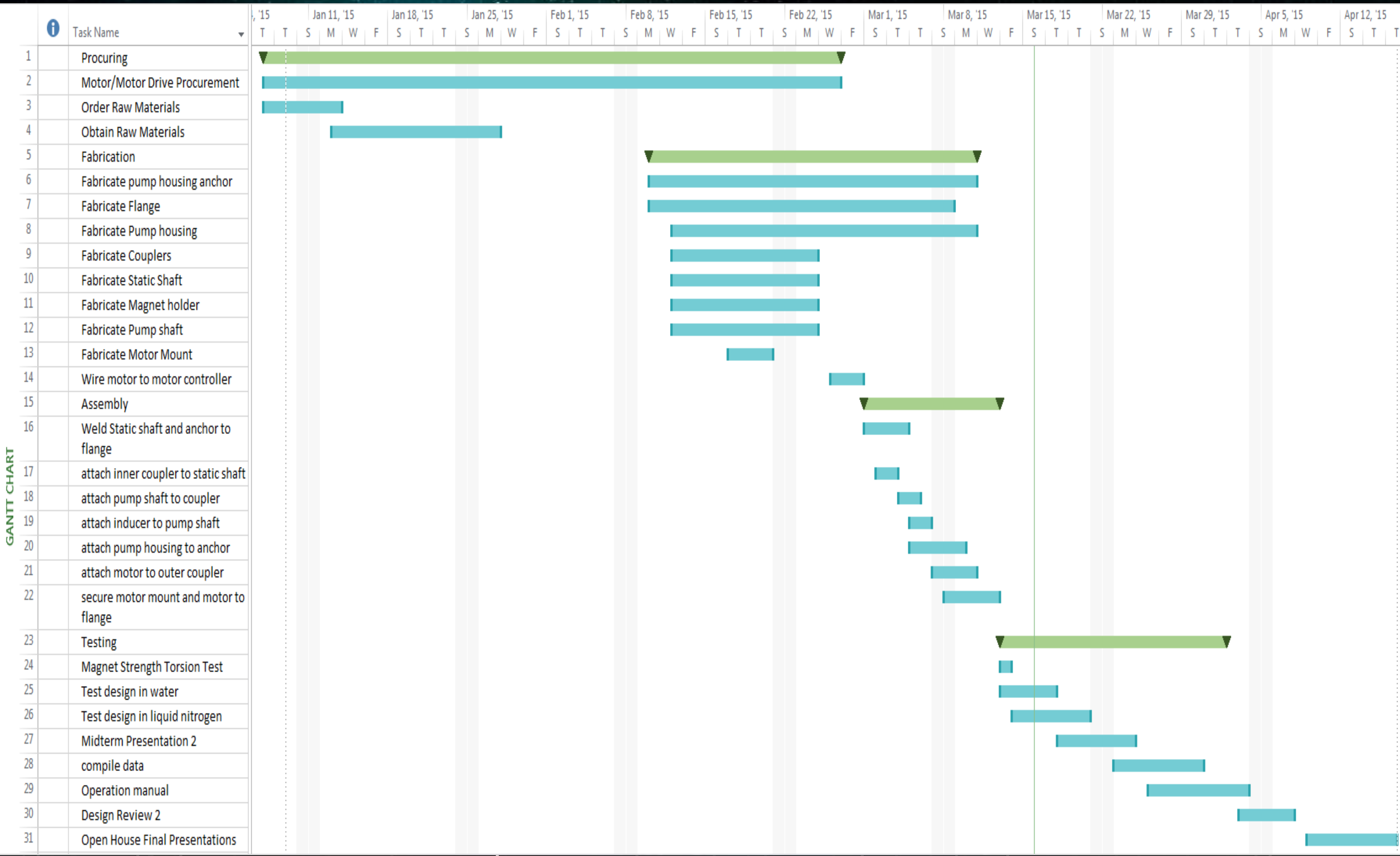
- Bearings
  - Life of 8000hrs
- Magnets
  - Minute decrease in strength over 10 years
  - High strength in cryogenic temperatures
- Materials
  - High strength
  - No ductile to brittle transition

Budget and Procurement

- Budget $600 Florida Space Grant
- Materials Purchased
  - Bearings
  - Magnets
  - Motor
  - Motor Driver
  - Plexiglass
  - Nuts & Bolts
- Materials Supplied
  - Fabrication Materials
    - Aluminum
    - Stainless Steel
  - Cryofab CF 1424-F
  - 6” ConFlat SS flange
  - Impeller



Scheduling


GANTT CHART
Task Name
Jan 11, '15
Jan 18, '15
Jan 25, '15
Feb 1, '15
Feb 8, '15
Feb 15, '15
Feb 22, '15
Mar 1, '15
Mar 8, '15
Mar 15, '15
Mar 22, '15
Mar 29, '15
Apr 5, '15
Apr 12, '15
1 Procuring
2 Motor/Motor Drive Procurement
3 Order Raw Materials
4 Obtain Raw Materials
5 Fabrication
6 Fabricate pump housing anchor
7 Fabricate Flange
8 Fabricate Pump housing
9 Fabricate Couplers
10 Fabricate Static Shaft
11 Fabricate Magnet holder
12 Fabricate Pump shaft
13 Fabricate Motor Mount
14 Wire motor to motor controller
15 Assembly
16 Weld Static shaft and anchor to flange
17 attach inner coupler to static shaft
18 attach pump shaft to coupler
19 attach inducer to pump shaft
20 attach pump housing to anchor
21 attach motor to outer coupler
22 secure motor mount and motor to flange
23 Testing
24 Magnet Strength Torsion Test
25 Test design in water
26 Test design in liquid nitrogen
27 Midterm Presentation 2
28 compile data
29 Operation manual
30 Design Review 2
31 Open House Final Presentations

Future Improvements

- Bearings
  - Incorporate dry lubricant
- Vibration Analysis
  - Motor mount
  - Pump shaft
- Nonmagnetic materials
- In depth prototype testing

Conclusion

- Design an electric motor-pump/mixer unit that makes use of magnetic coupling technology.
- Magnet number reduced from 8 to 4
  - Produced 4 in-lbs of torque
- Volumetric Flow Rate
  - Reached an average flow rate of 14gpm
  - Maximum flow rate of 16gpm
- Cryogenic Testing
  - Reduced venting by 50%

References

- [1] Senior Design Project Definition Group 24. N.p.: n.p., n.d. PDF.
- [2] W., Van Sciver Steven. Helium Cryogenics. New York: Plenum, 1986. Print.
- [3] "Magnetic Couplings | Technology | Magnomatics." Magnetic Couplings | Technology | Magnomatics. N.p., n.d. Web. 25 Sept. 2014.
- [4] "HowStuffWorks "Parts of the Tesla Turbine"" *HowStuffWorks*. N.p., n.d. Web. 09 Oct. 2014.
- [5] Pump, Nikkiso Cryogenic. *NIKKISO CRYOGENIC PUMP* (n.d.): n. pag. Web.

Questions?

Website: http://eng.fsu.edu/me/senior_design/2015/team24/

Project Specifications

Requirement	Specification
Tank Size	• Height: 29 in • Outer Diameter: 16 in • Inner Diameter: 14 in • Gross Capacity: 60 Liters
Insulation	• 0.5 in of foam • >20 layers of multi-layer insulation (MLI)
Mounting	• Mounted to 6 in flange • Flange has 4 in port into tank
Pump Motor	• Variable Flow Rate : 5 - 15 gpm • Generates 5 psid rise in pressure • Mixer/Pump must reach 12 inches into tank
Additional Requirements	• Tank must be adiabatic to surroundings • Pump shaft must be magnetically coupled to the motor shaft • Friction must be held to a minimum • System must be compact • Materials used for the magnetic housing and flange must be non magnetic • Materials must withstand extremely cold temperatures between 63K - 77.2K

Bill of Materials

Part	Vendor	Purpose	Quantity	Cost per Item	Total Cost
Magnets	K&J Magnets	Magnetic coupling	16	$8.61	$137.76
Motor	Amazon	Motor	1	$79.00	$79.00
Motor Drive	Amazon	Control Motor Speed	1	$27.95	$27.95
PVC 12"x12"x 1"	Amazon	Motor Mount	1	$35.21	$35.21
6-32 x 1/2"	Fastenal	Assembly	10	$0.20	$2.00
10-32x1/2"	Fastenal	Assembly	10	$0.20	$2.00
10-32x3/4"	Fastenal	Assembly	5	$0.40	$2.00
10-32 Nyloknut	Fastenal	Assembly	10	$0.30	$3.00
1/4-20x3/8"	Fastenal	Assembly	10	$0.30	$3.00
8-32X1.5"	Fastenal	Assembly	5	$0.40	$2.00
Keystock 1/8"x1/8"x1'	Fastenal	Assembly	1	$0.65	$0.65
3/16x1.25" clevis pin	Fastenal	Assembly	1	$0.23	$0.23
3/16x7/8" clevis pin	Fastenal	Assembly	1	$0.24	$0.24
3/16X3/4" clevis pin	Fastenal	Assembly	1	$0.20	$0.20
Cotter pin 1/16 x1	Fastenal	Assembly	20	$0.10	$2.00
12v Battery	FourAcre	Power supply	1	$50.00	$50.00
Stainless Steel	Online Metals	Pump Anchor	1	$26.24	$26.24
				Design Cost	$373.48
12"x24"x.5" Plexiglas	Professional Plastics	Testing Tank	4	$35.80	$143.20
12"x12"x.5" Plexiglas	Professional Plastics	Testing Tank	1	$25.50	$25.50
1'x1" PVC Pipe	Home Depot	Testing system	2	$2.23	$4.46
1'x2" PVC Pipe	Home Depot	Testing system	2	$3.36	$6.72
2" 180deg Bend PVC	Home Depot	Testing system	2	$3.23	$6.46
PVC glue	Home Depot	Testing system	1	$8.26	$8.26
Silicon sealant	Home Depot	Testing system	2	$6.75	$13.50
Rubber PVC Reducer	Home Depot	Testing system	1	$3.63	$3.63
2" to 1" PVC reducer	Home Depot	Testing system	1	$1.56	$1.56
				Testing Cost	$213.29
				Total Cost	$586.77

Bearing Calculations

$Fr := 6lbf$

$Fa := 10.5lbf$

$L_h := 8000hr$

$\omega := 1500rpm$

$$Fe := \left(Fr^2 + Fa^2\right)^{\frac{1}{2}} = 53.794\,N$$

$$C\_ := Fe \cdot L_{10}^{\frac{1}{3}} = 482.146\,N$$

From SKF bearing catalog

$C_0 := 193N = 43.388\,lbf$

From Table 11-24

$$\frac{Fa}{C_0} = 0.242$$

Linear Interpolation

$$e := .34 + (.38 - .34) \cdot \frac{.242 - .17}{.28 - .17} = 0.366$$

$V := 1.2$

$$\frac{Fa}{V \cdot Fr} = 1.458$$

$$Y := 1.15 + (1.31 - 1.15) \cdot \frac{.242 - .17}{.28 - .17} = 1.255$$

$X := .56$

$F_e := X \cdot V \cdot Fr + Y \cdot Fa = 76.539\,N$

$$C\_\_ := F_e \cdot L_{10}^{\frac{1}{3}} = 686.004\,N$$

Repeat process Until C does not change

Power Calculations

Pumping Requirement Calculations

Given - Volumetric Flow Rate $V := 15 \frac{gal}{min}$

$RPM := 1500 \frac{rev}{min}$

Inducer $d := 2.75\ in$

Convert vol flow rate to ft^3/sec

$V = 0.0334 \frac{ft^3}{sec}$

Find inducer inlet cross-sectional area

$A := \pi \cdot \left(\frac{d}{2}\right)^2$

$A = 0.0412\ ft^2$

The meridional flow velocity

$C := \frac{V}{A}$

$C = 0.8102 \frac{ft}{sec}$

The tip speed is then found

$U := \frac{RPM \cdot d}{2}$

$U = 17.9987 \frac{ft}{s}$

The flow coefficient is found

$\varphi := \frac{C}{U}$

$\varphi = 0.045$

From the given plot, the head coefficient is found

$\psi := \left(-4.0168 \cdot \varphi^2\right) - (1.4598 \cdot \varphi) + 0.3254$

$\psi = 0.2515$

The head of the pump is then found

$Head := \frac{\psi \cdot U^2}{\left(32.174 \frac{ft}{sec^2}\right)}$

$Head = 2.5328\ ft$

Convert the volumetric flow rate converted into mass flow rate

$m := V \cdot 62.3 \frac{lbf}{ft^3}$

$m = 2.0821 \frac{lbf}{s}$

Power requirement assuming 20% efficiency

$P := \frac{m \cdot Head}{0.2}$

$P = 0.0479\ hp$

With a factor of safety of x5 to x10

$Power := 10 \cdot P$

$Power = 0.4794\ hp$