Group 24: Magnetically Coupled Pump System for Cryogenic Propellant Tank Destratification

FAMU/FSU College of Engineering
Department of Mechanical Engineering

Restated Project Definition and Scope

Group 24:

Matthew Boebinger	mgb11d
Kahasim Brown	krb10d
Anthony Ciciarelli	ajc07c
Janet Massengale	jlm12c

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Submitted to:
Dr. Nikhil Gupta

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1 Problem Statement

NASA Marshall Space Flight Center is in need of a way to mix cryogenics without adding any additional heat into a cryogenic system. Currently, a motor is placed inside a cryogenic tank in order to operate the mixing pump. The motor not only inserts heat to the system, but also causes a rapid pressure rise. Additionally, the motor used inside the system is costly. The purpose of this project is to reduce the heat added to the cryogenic system while effectively mixing the cryogen to sustain a uniform temperature.

2 Background Research

Pressure control and destratification, or the process achieving temperature equalization by mixing the internal air to eliminate stratified layers, presents issues with long term storage of cryogenic propellants. Heat leak from the surrounding environment causes these propellants to boil causing the pressure in the tanks to rise and there is an increase in the fluid saturation temperature if the tank is sealed off. In order to reduce the environmental; heat leak in conditions such as ground/atmosphere and space/vacuum, foam and insulation are used. In order to decrease rapid increase in pressure, the propellants can be mixed to create a more uniform temperature condition within the vapor and fluid portion of the tank.

Currently, the mixing process consists of using AC single or 3-phase motor systems, which are directly coupled to a pump and placed within the tank itself or mounted to a flange with the motor operating in a submerged condition. A simple block diagram of the current system can be seen in Figure 1. By using this method, waste heat from the motor is flowing into the tank and is generating a rapid pressure rise within the tank. Also, the feedthroughs or connectors may create leak paths for potential failure.

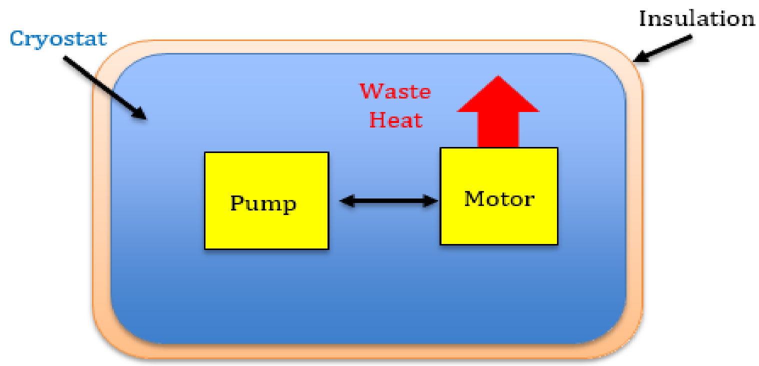


Figure 1: Block Diagram of current system in use at NASA

To decrease heat leak, high performance insulation systems are incorporated into the design of the tank, even with perfect vacuum, [2] thermal radiation can still contribute significantly to the total heat leak. The radiation from room temperature is also one of the main heat loads in cryogenic systems, and heat addition is what the team is trying to avoid throughout the entire project. Therefore the standard multi-layered insulation used at the NASA Marshall Space Flight Center will be used throughout the project.

Magnetic coupling was introduced that may allow the placement of the motor outside the cryogenic tank [3]. Magnetic couplings are generally used to transmit torque from one system to another where the magnetic transmission is required to maintain a hermetic seal to prevent leakage and contamination. The magnetic coupling is used in this project to transmit rotational motion from the motor across the tank wall to a mixer/pump located on the inside. The mixer/pump would be designed to operate in the cryogen receiving the magnetic rotational motion and imparting it to the fluid through impellers, etc. contained within a housing to produce flow up to 15gpm and pressure rise up to 5psid.

3 Objectives

For this project, the expected objective is to continuously be able to pump a cryogen inside a cryostat effectively making use of magnetic coupling technology. Additionally, all electrical components of this pumping system must remain on the outside of the cryostat and be mounted to a 6 inch conflate flange.

The goals for completion for the spring 2015 semester are as followed

- Procure all materials needed to build a prototype of the system
- Determine the attractive forces between the magnetic couplings to ensure no slipping
- Fabricate, assemble, and test the prototype in both water and liquid nitrogen

4 Constraints

There are several categories for our constraints and are as follows:

- Budget: The overall budget of the project consists of $500 from the Space Florida Grant for the purchasing of the motor, magnets, and fabrication costs. The materials will be provided by our sponsor as long as a complete prepared list is submitted.
- Ease of assembly: The design must be able to be fitted to the standard 6” ConFlat flange in order to be properly and easily installed onto the top of a Cryofab CF 1424-F cryostat.
- Size: The design must be compact and easily portable.
- Insulation and heat shielding: The design must not add heat to the system and therefore the motor must be insulated from the tank to prevent heat addition.
- Materials: The materials used in the design must be able to withstand such low temperatures without any structural damage. The materials of the tank must also be non-magnetic in order for the coupling to be successful.
- Magnets: There must be enough magnets used in the design to ensure that there is enough coupling strength to make any rotation motion one-to-one. The magnets

chosen must be able to penetrate through the tank material as well as the insulation used around the tank.

5 Design specifications

The design specifications of the system are broken down as the tank specifications that must meet the requirements of the sponsor. The pump/mixer system must meet the constraint of the tank and be portable to similar cryostats.

The cryogenic tank that will be used in the project is the Cryofab CF 1424-F cryostat. And the design must be attached to a 6 inch ConFlat flange in order to be easily assembled. The design must be compact and portable. The design also needs to be attached to the top of the cryostat. The motor-pump unit must make use of magnetic coupling technology and an electronic motor. The unit must be tested with water and liquid nitrogen. Table 1 shows all design specifications for the project.

Table 1: Design 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

6 Project Updates

Final Design

Since start of this project, there were a number of issues that had to be resolved. The first challenge consists of the size constraints of the inlet port of the currently used cryostats. The final compact design can be seen in Figure 2 with the components of the system labeled. The second of which consisted of difficulties with the computational analysis of the pump curve that led to more time being spent on this part of the project, however the calculations were completed and the required power from the motor was found to be 0.5hp and a required speed of 2500 RPM. The final change to the design that was made is related to the pump system. The design of this system has slightly changed; the inducer that was provided by NASA Marshall Space Flight Center will be used rather than constructing our own. Using this inducer and a self-constructed pump housing it is possible to achieve the pumping capabilities.

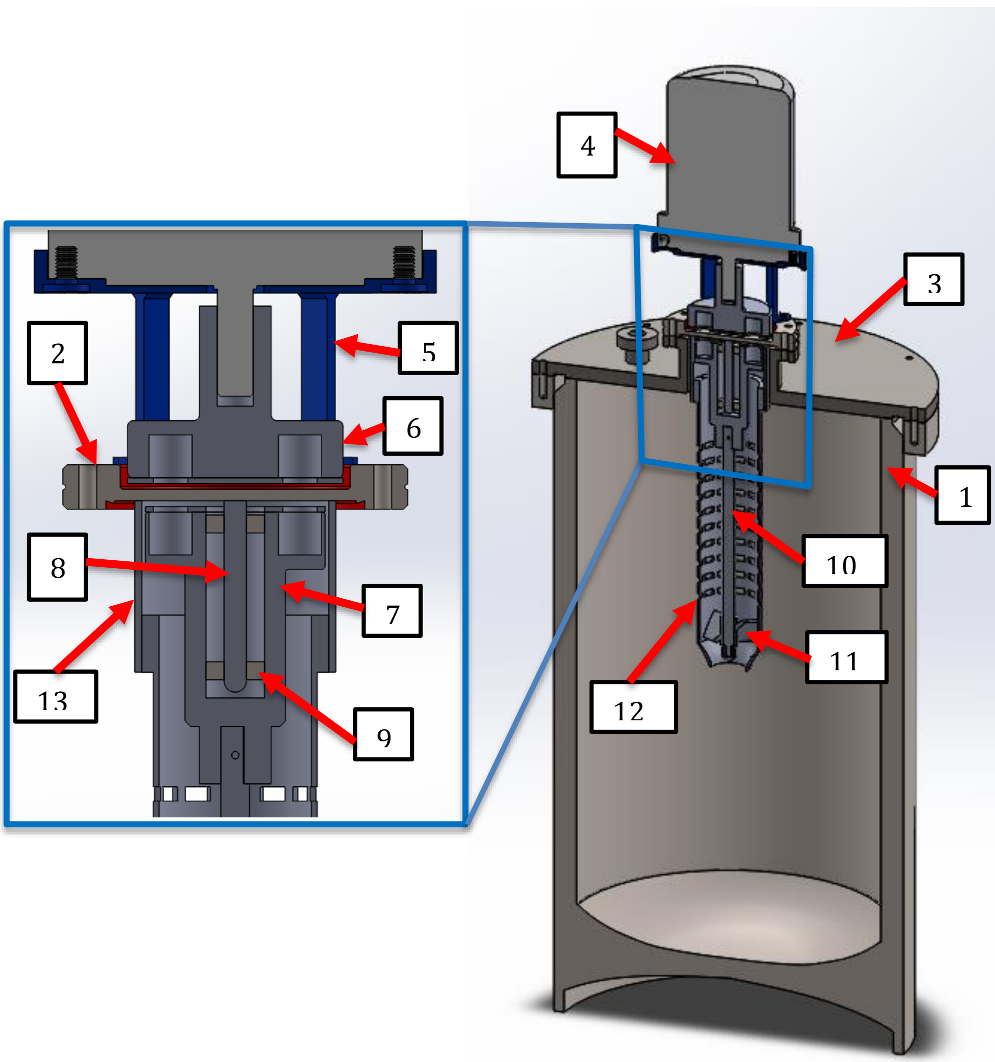


Figure 2: Design proposed by the group utilizing an axial pump. (1) Tank, (2) Flange, (3) Top of Cryostat, (4) Motor, (5) Motor Mount, (6) Outer Magnet Couple, (7) Inner Magnet Coupler, (8) Static Shaft, (9) Roller Bearings, (10) 10" Pump Shaft, (11) Pump Inducer, (12) Pump Housing, (13) Pump Housing Anchor

Procurement

All of the components of the system (magnets and motor) have been ordered and arrived over the winter break. The raw materials needed to fabricate the components of the design are being supplied by the NASA Marshall Space Flight Center. These materials are in the progress of being collected and sent from. Bill of material can be found in Appendix B.

Development

The fabrication and prototyping of this project will begin soon. We are currently in the process of setting up the electric components of the connecting the purchased driver to the selected motor. An experiment to test the coupling strength relative to the rotational displacement of the magnets using spring gauges is also being devised with the help of our faculty advisor. Upon the delivery of the raw materials, the design components will be sent to the machine shop to begin fabrication.

7 Budget

The original budget for this project was $500 provided by the Space Florida Grant. Due to some unforeseen expenses the budget was raised to $600 to accommodate these expenditures. The provided budget was used to pay for the items shown in Table 2. Additionally National Precision Bearings has provided the design team with two magnets free of charge to aid in the success of the project. Also NASA has agreed to supply the team with all the raw materials needed to fabricate the proposed design.

Table 2: Budgeted Items

Item	Price
Motor	$192.07
Motor Drive	$231.25
Power Supply Cord	$9.85
Magnets	$137.76
Total	$570.93

8 Schedule

Appendix A-1 shows the Gantt chart for this design project although it is important to stay on schedule the chart does provide some leniency. The leniency is to account for unexpected issues with the project plan and ensures we will not be delayed in the fabrication and testing of the design.

8.1 Assign resources

Table 3 shows a detailed breakdown of the tasks each group member is expected to complete in the time allotted for each task. Each group member is expected to complete the tasks assigned to him or her in a timely manner as to not delay the project.

Table 3: Resource Allocation

Tasks	Owner/Owners	Status
Research	All	Completed
Design Concept Generation	All	Completed
Choosing Final Design	All	Completed
CAD Drawings	Mathew Boebinger & Kahasim Brown	Completed
Computational Analysis	Matthew Boebinger, Anthony Ciciarelli & Janet Massengale	Completed
Initial Web Page Design	Janet Massengale	Completed
CAD Analysis/Working Model	Anthony Ciciarelli & Janet Massengale	Completed
Motor Selection	All	Completed
Material Selection	All	Completed
Pump Selection	All	Completed
Order Parts	Anthony Ciciarelli	Completed
Fabrication	All	20 days
Assembly	All	8 days
Final Web Page design	Janet Massengale	Completed
Testing	All	14 days
Compile Data	All	6 days

9 References

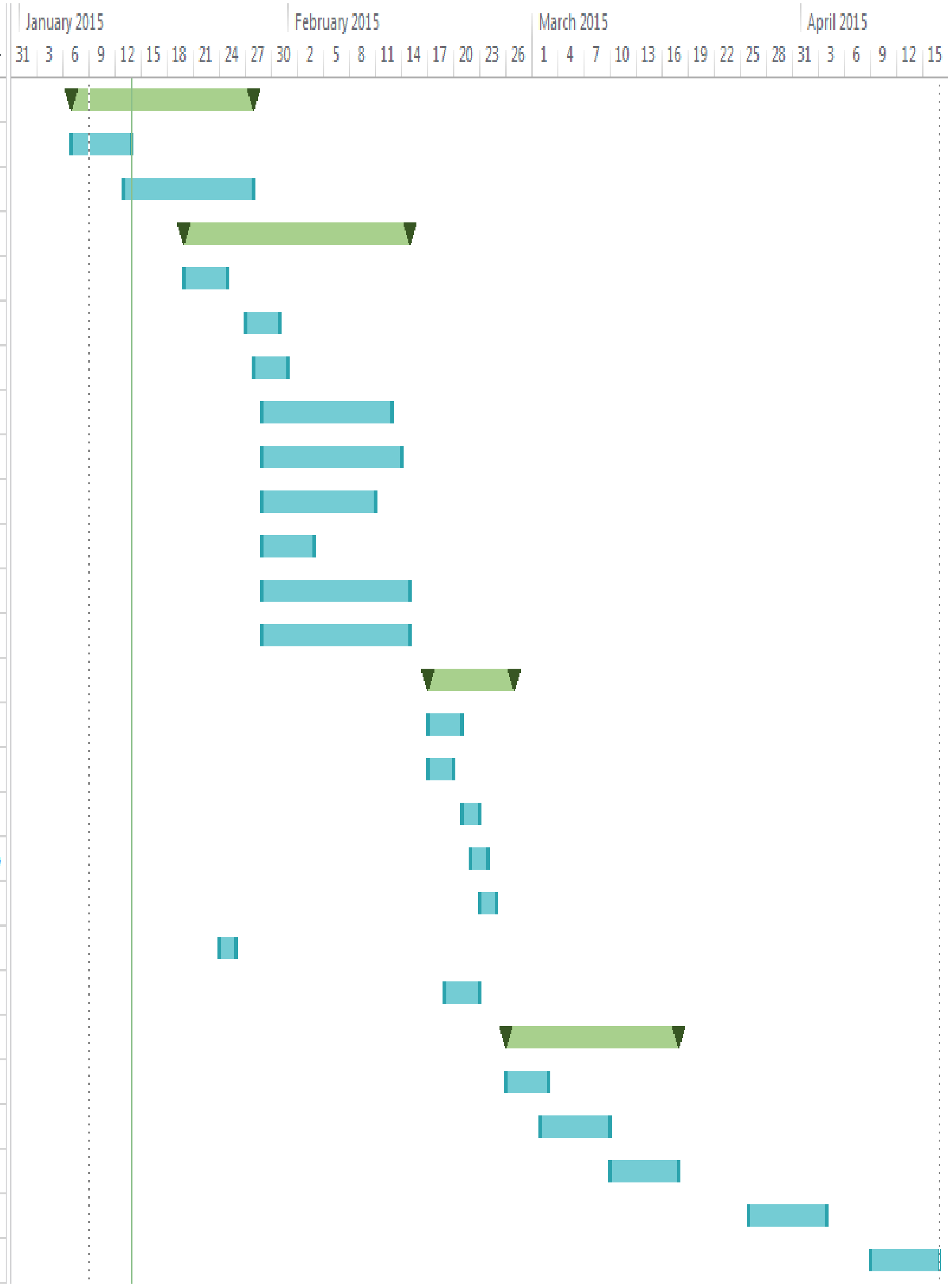
[1] Senior Design Project Definition Group 24. PDF.

[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.

Appendix A

	Task Name	Duration	Start	Finish
1	Procurement	15 days	Wed 1/7/15	Tue 1/27/15
2	Finish Procuremnt/Order Raw Materials	5 days	Wed 1/7/15	Tue 1/13/15
3	Obtain Raw Materials	11 days	Tue 1/13/15	Tue 1/27/15
4	Fabrication	20 days	Tue 1/20/15	Sat 2/14/15
5	Wire motor to motor controller	5 days	Tue 1/20/15	Sat 1/24/15
6	Fabricate Flange	4 days	Tue 1/27/15	Fri 1/30/15
7	Fabricate Motor Mount	4 days	Wed 1/28/15	Sat 1/31/15
8	Fabricate pump housing anchor	11 days	Thu 1/29/15	Thu 2/12/15
9	Fabricate Couplers	12 days	Thu 1/29/15	Fri 2/13/15
10	Fabricate Static Shaft	9 days	Thu 1/29/15	Tue 2/10/15
11	Fabricate Magnet holder	4 days	Thu 1/29/15	Tue 2/3/15
12	Fabricate Pump shaft	13 days	Thu 1/29/15	Sat 2/14/15
13	Fabricate Pump housing	13 days	Thu 1/29/15	Sat 2/14/15
14	Assembly	8 days	Tue 2/17/15	Thu 2/26/15
15	Weld Static shaft and anchor to flange	4 days	Tue 2/17/15	Fri 2/20/15
16	Secure motor mount and motor to flange	3 days	Tue 2/17/15	Thu 2/19/15
17	Attach inner coupler to static shaft	2 days	Sat 2/21/15	Sun 2/22/15
18	Attach pump shaft to coupoler	2 days	Sun 2/22/15	Mon 2/23/15
19	Attach inducer to pump shaft	2 days	Mon 2/23/15	Tue 2/24/15
20	Attach pump housing to anchor	2 days	Sat 1/24/15	Sun 1/25/15
21	Attach motor to outer coupler	3 days	Thu 2/19/15	Sun 2/22/15
22	Testing	14 days	Thu 2/26/15	Tue 3/17/15
23	Test design in water	3 days	Thu 2/26/15	Mon 3/2/15
24	Test design in Liquid Nitrogen	6 days	Mon 3/2/15	Mon 3/9/15
25	Compile Data	6 days	Tue 3/10/15	Tue 3/17/15
26	Operation Manual	7 days	Thu 3/26/15	Fri 4/3/15
27	Open House Final Presentations	6 days	Thu 4/9/15	Thu 4/16/15



Appendix B

Part #	Component	Product Description	Quantity	Vendor	List Price	Status
1	Motor Mount	12"x 12" x 3/4" Sheet of PVC	1	Amazon	$29.86	Not Purchased
2	Motor	Face Mount AC Motor	1	McMASTER-CARR	$233.68	Not Purchased
3	Bearings	Stainless Steel Roller Bearings	2	National Precision Bearings	$0.00	Ordered
4	Couplers	4" Diameter Stainless Steel Rod	1	Metals Depot	$267.06	Not Purchased
5	Coupler Face Plate	Coupler Face Plate/Bearing Holder	2	Metals Depot		
6	Static shaft	10 mm Stainless Steel Shaft	1	Metals Depot	$12.02	Not Purchased
7	Pump Shaft	.5" Aluminum Shaft	1	Metals Depot	$2.76	Not Purchased
8	Pump Housing Anchor	1'x1' x .12" Stainless Steel Sheet	1	Metals Depot	$30.24	Not Purchased
9	Pump Housing	Aluminum Sheet 1'x4'x.100"	1	Metals Depot	$52.20	Not Purchased
10	Magnets	Neodymium Cylinder Magnets	16	K&J Magnets	$8.61	Not Purchased
11	Power Cord	8' Power Supply Cord	1	Grainger	$9.85	Not Purchased
12	Power Switch	10 Amp on of Switch	1	Radio Shack	$3.99	Not Purchased
13	Electrical Enclosure	6"x3"x2" Project Box	1	Radio Shack	$4.99	Not Purchased
14	Cryostat	Cryofab CF-1424F	1	NASA	$0.00	Received
15	Flange	6" Conflat Flange	2	NASA	$0.00	Received
16	Gaskets	Copper Gaskets	4	NASA	$0.00	Received