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

FAMU/FSU College of Engineering
Department of Mechanical Engineering

<u>Project Plans and Product Specifications Report</u>

Group 24:

Matthew Boebinger mgb11d

Kahasim Brown krb10d

Anthony Ciciarelli ajc07c

Janet Massengale jlm12c

Due Date:

10/10/2014

Submitted to:

Dr. Scott Helzer and Dr. Nikhil Gupta

Table of Contents

Table of Figures

Table of Tables

Abstract

This Project Plan and Product Specification report lays out the design and performance specifications that the magnetically coupled pump system must meet according to want the sponsor desires. This is explained in the Constraints section of the report. In the Methodology section of this report, a schedule is planned out on what tasks must be taken in order to design and fabricate the pump system including resource and task allocation. Thus far in the project there has been a general background research conducted along with design generation and selection and a general budget outlined. A schedule has also been made and tasks have been allocated to individuals. Such tasks include computational analysis, CAD drawings, parts allocation, and fabrication. The next steps in the project will be design finalization, modeling, computational analysis, and material selection.

1 Introduction

The National Aeronautical and Space Administration proposed the research and development of an innovative cryogenic tank. Hosted by the NASA Marshall Space Flight Center the cryogenic tank project effectively mix cryogenic fluids to prevent heat addition and pressure rise with the use of magnetic coupling. This keeps the cryogen homogenous throughout the tank. The mixing process that is currently in use consists of electric motors directly couple to a pump inside the cryogenic tank submerged in the cryogen. This system is not applicable due to the heat addition caused by the electric motor, so the electric motor must be located on the outside of the cryostat.

The new apparatus for mixing the cryogen will have to fit inside a four inch opening that will be sealed with a six inch flange and must make use of magnetic coupling technology powered by an electric motor on the outside of the tank. The magnetic coupling technology transfers the rotation of the eclectic motor shaft to the opposite side of the sealed flange to produce cryogenic flow circulation within the pressurized space. The system will also have to be able to operate on either the top or bottom of the cryostat and must be compact.

With a budget of $500 and with donated materials, the group’s goal is utilize magnetic coupling technology and to develop a system that will produce variable flow preventing heat addition and pressure rise within the cryogenic tank.

2. Project Definition

2.1 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.

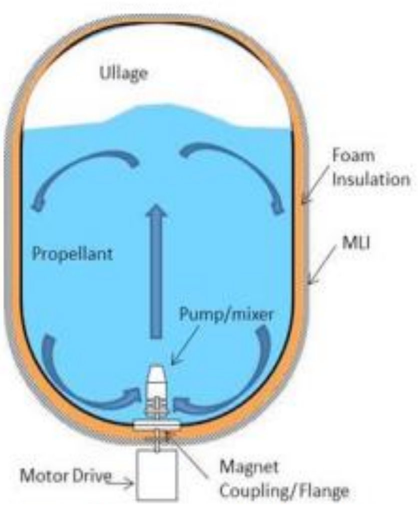


Figure 1: Current Tank Mixer System General Layout [1]

Currently and previously, the mixing process consists of using AC single and 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 (Figure 1). By using this method, heat will be generated within the tank causing the pressure to rise rapidly and, the feedthroughs or connectors will create leak paths for potential failure. Research and develop of motors suitable to handle low temperature conditions is highly expensive.

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 (Figure 2) 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. 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.[3] 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


Figure 2: Layers of insulation currently in place on cryogenic tank

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.

Even though there are different types of pumps that can be used for this application, the two that are being considered are a tesla pump and a tooth inducer. [4]Created by Nikola Tesla, the tesla pump uses a series of disks that can vary based on certain factors. Each disk is made with opening surrounding the shaft that acts as ports through which the fluid will exit and to make sure the fluid is passing freely, metal washers are used as dividers. The tesla pump is an ideal option for this type of application due to its simplicity and it can be built with readily available materials

[5]Inducers are used when low suction pressure is expected. Inducer blades are tapered, with a thicker blade width at the root to provide strength. It also provides a stable Net Positive Suction Head (NPSH) over a wide flow range.

NASA has given us the task to design, fabricate, and test an electric motor-pump unit that makes use of magnetic coupling technology to position the motor outside of the cryogenic tank, while still providing sufficient pumping pressure/flow and incorporating insulation between the coupling and tank wall so as not to introduce additional heat leak.

2.2 Need Statement

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

“Due to the motor used inside cryogenic tanks there is too much heat addition when mixing the fluids”

2.3 Goal Statement & Objectives

“Design a better way of mixing cryogenic fluids”

The objectives are as follows:

- Minimize heat addition to cryogenic system
- The pressure rise due to the pump must be 5psid
- Magnetically couple motor shaft to pump shaft
- Contain a minimum number of parts and be compact in arrangement

3 Constraints

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

- Budget: The overall budget of the project consists of $500 from Space Florida for the purchasing of the motor, magnets, and fabrication costs. The materials will be provided by our sponsor as long as a prepared list is submitted prior to November. Therefore, a complete list of materials will be needed prior to this date.
- 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 into the 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.

3.1 Design specifications

The design specification can be broken down to the tank specifications that must be met with the design and then the requirements that must be met by the motor-pump system.

The cryogenic tank that will be used in the project is the Cryofab CF 1424-F cryostat. The dimensions are as follows in Table 1 and referenced in Figure 3.

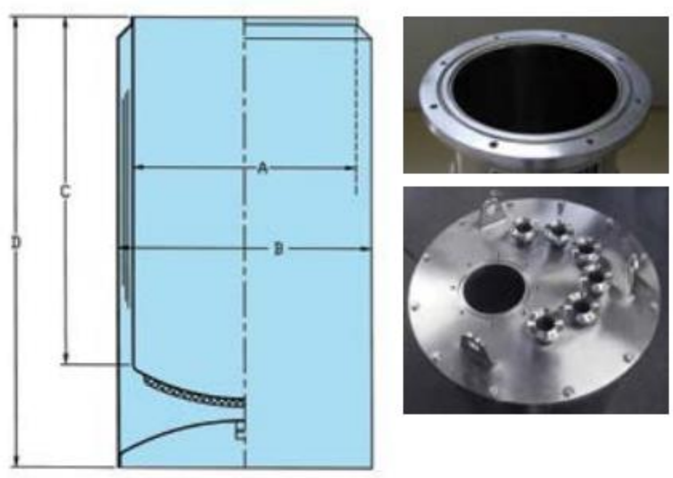


Figure 3: Cryostat Dimension Figure Guide provided by the sponsor

Table 1: Cryostat Dimensions

Model	“A” Inside Diameter (Inches)	“B” Outside Diameter (Inches)	“C” Inner Depth (Inches)	“D” Overall Height (Inches)	Gross Capacity (Liters)	Loss Rate (Liters/Hr)	Liters/Inch
CF 1424	13.93	16.0	24.0	29.0	59.9	0.340	2.49

The cryogenic propellants must be stored at the low pressure of 15 to 25 psia. In order to prevent the pressure from rising, the mixer will make the temperature homogenous to prevent the cryogen from boiling. The heat will also be limited through the use of 0.5 in of foam and 20-30 layers of MLI (Multi-Layer Insulation) where necessary.

The motor-pump system must be fitted to a 6” ConFlat flange made of stainless steel, which can be seen in Figure 4. This flange can be milled to 1/10 inch in thickness to guarantee that the magnets can sufficiently couple through the flange. The seal mechanism is a knife-edge that is machined below the flange’s flat surface. These knife edges make grooves in the opposite side of the gasket as the flange-pair is tightened thus yielding a leak-tight seal. The flange has a 4 inch port into the tank, therefore the entire apparatus inside the tank must not exceed 4 inches in diameter so it can be easily inserted into the tank.

Figure 4: Picture of Flanges used provided by the sponsor

The final design looks similar to that pictured in Figure 5. The pump pictured in the design concept is a Tesla pump. This design or one using an already fabricated 3 tooth inducer (Figure 6) will be selected.

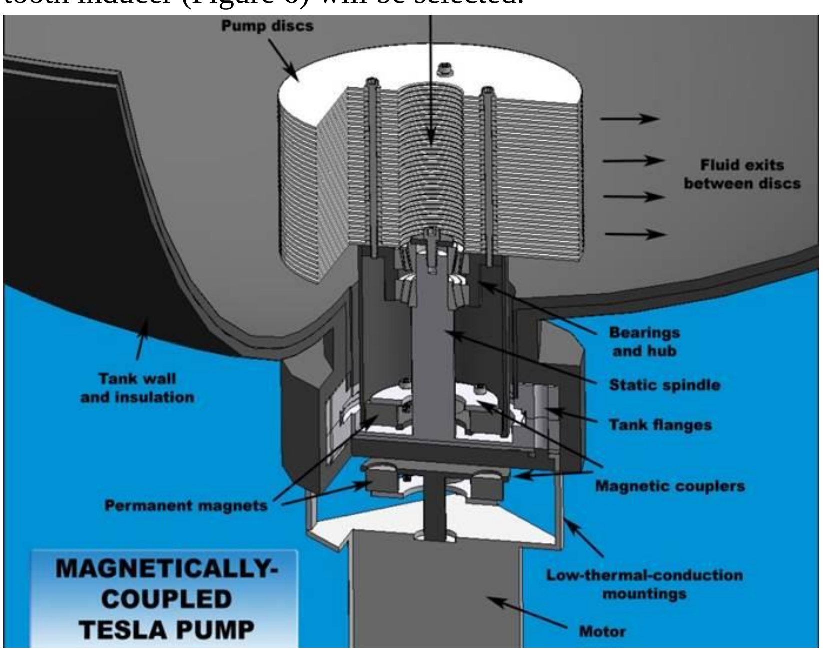


Figure 5: Design for magnetically couple Tesla pump provided by the sponsor

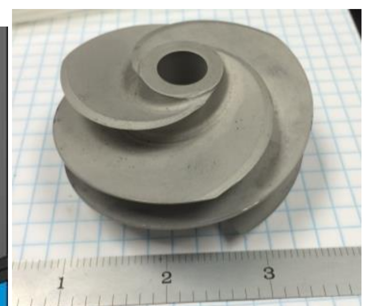


Figure 6: Three tooth inducer with diameter of 2.5in provided by the sponsor

In both designs however 6-8 magnets will be used for the coupling on the magnet plates. The pump/mixer must reach 12 inches into the tank to ensure that the fluid be thoroughly mixed. As previously stated the motor-pump system must have variable volumetric flow of 3-15 gpm and a pressure rise of up to 5 psid.

3.2 Performance specifications

The design should be compact and easily installed into an existing cryogenic tank. It should also not introduce any additional heat into the cryogenic system. The cryogenic tank will be vacuum-sealed and there must be minimal heat leak from the environment into the cryogenic system. The pump will have a variable volumetric flow rate of no less than 3gpm up to 15 gpm. The mixer should also facilitate a pressure rise of up to 5 psid in the mixed fluid. Additionally the device will be able to successfully perform destratification of the cryogenic fluids with ease. 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.

4 Overall plan/Methodology/Approach

The best methods to construct the magnetic coupled mixer/pump system require iterations, mathematical analysis, and much more for optimal design. These iterations consist of preparatory design methods to finalize the design selected. These preparatory design methods are taken from several fields of study in the engineering field. These actions emphasize the overall direction of constructing the magnetic couple mixer/pump system:

- Formulate a reasonable size of the system through theoretical estimation
- Determine the best cryogenic material and thermal fluid system design by researching the specific fields in engineering
- Choose a multi-layered insulation suitable for cryogenics
- Broaden research to obtain a suitable motor and impellor to create a appreciable fluid flow rate
- Establish a financial plan and spend based on the budget
- Utilize engineering computer software such as CAD Drawing
- Create Gantt charts, blueprints, virtual systems or theoretical calculations sheets. These theoretical calculations were derived from magnet lab testing.
- Search the market for useful materials/products with great quality and price.
- Present the details of the project to evaluators, sponsors, and the general public
- Finalize the decision and construct the project satisfying the objectives

Based on these actions, the system will be a successful sponsored project with the capabilities of being introduced to the market.

Budget

The Budget for this design project is $500 and is provided by the Space Florida Grant. The budget will be allocated in order to purchase magnets, a motor, and fabricating materials. Additionally, NASA will provide materials, a cryostat, conflat flanges, some fabrications, and possibly a motor. Although it is very early in the design process, a breakdown of estimated percentages each component will require from the budget is provided in Table 2.

Table 2: Approximate Budget percentages

Item	Percentage of Budget
Fabrication	50%
Magnets	10%
Motor	20%
Total	80%

These costs are based on some rough estimates found researching the Internet. Additionally these percentages are subject to change based on how much aid is provided from NASA. The group will do its best to keep the cost of the project as minimal as possible while still providing a quality product.

4.1 Schedule

Gantt Chart

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 design of the project.

4.2 - Assign resources

Background Research

The background research is an integral part of this and any design project. In order for all group members to have a good understanding of the scope of the design project everyone will participate in the research stage. Basic understanding of cryogens, thermal fluids, and magnetic coupling is required to make this design project successful. The background research stage will take no more than two weeks.

Design Concept Generation

Once all group members have done their part in researching the required fields a design concept will be generated. This stage of the project is sometimes called the brainstorming stage. All members of the group will input their knowledge to the design and help to come up with a viable concept. All group members will be present for this process, not only to make sure everyone is on the same page but also to generate the best possible concept using each group member’s expertise in the design. The design concept generation should roughly take one week

CAD Drawings

CAD drawings will begin after the design concept generation process. The CAD drawings require specific dimensions of the design concept and solidify the original design. It will introduce a 3D diagram of the concept and make it a more tangible design. This process will take a week and only require two team members to complete. Matthew Boebinger and Anthony Ciciarelli will be responsible for the CAD drawings.

Computational Analysis

At the same time the CAD drawings are being done, Janet Massengale and Kahasim Brown will be doing the majority of the computational analysis. Additionally Matthew Boebinger and Anthony Ciciarelli will be providing further assistance adding their expertise as needed. The computational analysis is important because it will allow for material, motor, and pump selection. Additionally it will provide limits on the geometry of the design making changes where needed. The computational analysis stage will run parallel with CAD drawings and take 2 weeks to complete.

CAD Analysis/Working Model

Once the CAD drawings and computational analysis have been completed the governing equations, materials, pump, and motor selection will be applied to the CAD drawings. CAD analysis will provide detailed breakdown of how the system operates as well as point out areas of concern. The CAD analysis will performed by Matthew Boebinger and Anthony Ciciarelli and should only take 3-4 days.

Parts Order Form

Parts will be ordered once the CAD analysis is completed and all issues are resolved. The order form will be turned in no later than November 23 2014 in order to be compliant with NASA regulations. The ordering process will take no longer than 3-4 days and will be carried out by Anthony Ciciarelli and Janet Massengale. The products may take 2-3 weeks to arrive and will put a hold on any future processes of the design.

Fabrication

Fabrication and assembly will begin as soon as the necessary parts arrive. This process will begin at the end of this semester and most likely take 3-4 weeks spilling over into the beginning of next semester. All group members will be involved in the fabrication process.

5 Conclusion

This project requires the design and assembly of a magnetically coupled cryogenic pump. There are many constraints when dealing with cryogens, which limits the type of design that can be used. Additionally our sponsor has added some constraints to the design, such as the design must be able to be installed on either the bottom or top flange, and the design must be able to fit inside a four inch diameter flange. In order to develop a functioning design basic knowledge of thermal fluids, cryogens, and thermal coupling are required. In addition to the basic knowledge required it is vital that various task be allocated to certain group members in order to make the group more efficient. In the future CAD drawings will be formulated, computational analysis will be performed, parts will be ordered and fabrication will begin.

6 References

[1] Senior Design Project Definition Group 24. N.p.: n.p., n.d. PDF.

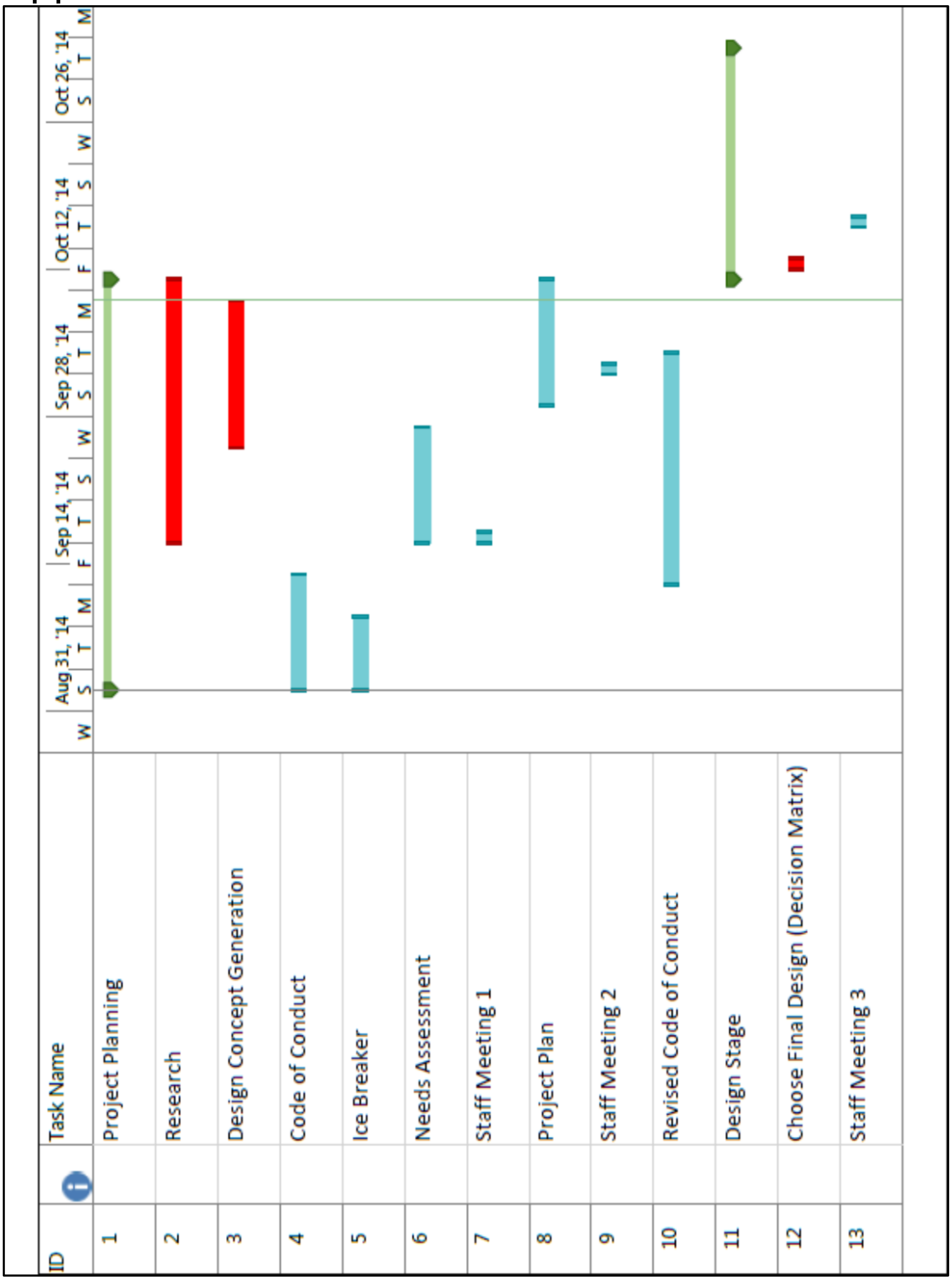
[2] W., Van Sciver Steven. Helium Cryogenics. New York: Plenum, 1986. Print.

[3] "Magnetic Couplings | Technology | Magnomatics." Magnetic Couplings | Technology | Magnomatics. N.p., n.d. Web. 25 Sept. 2014.

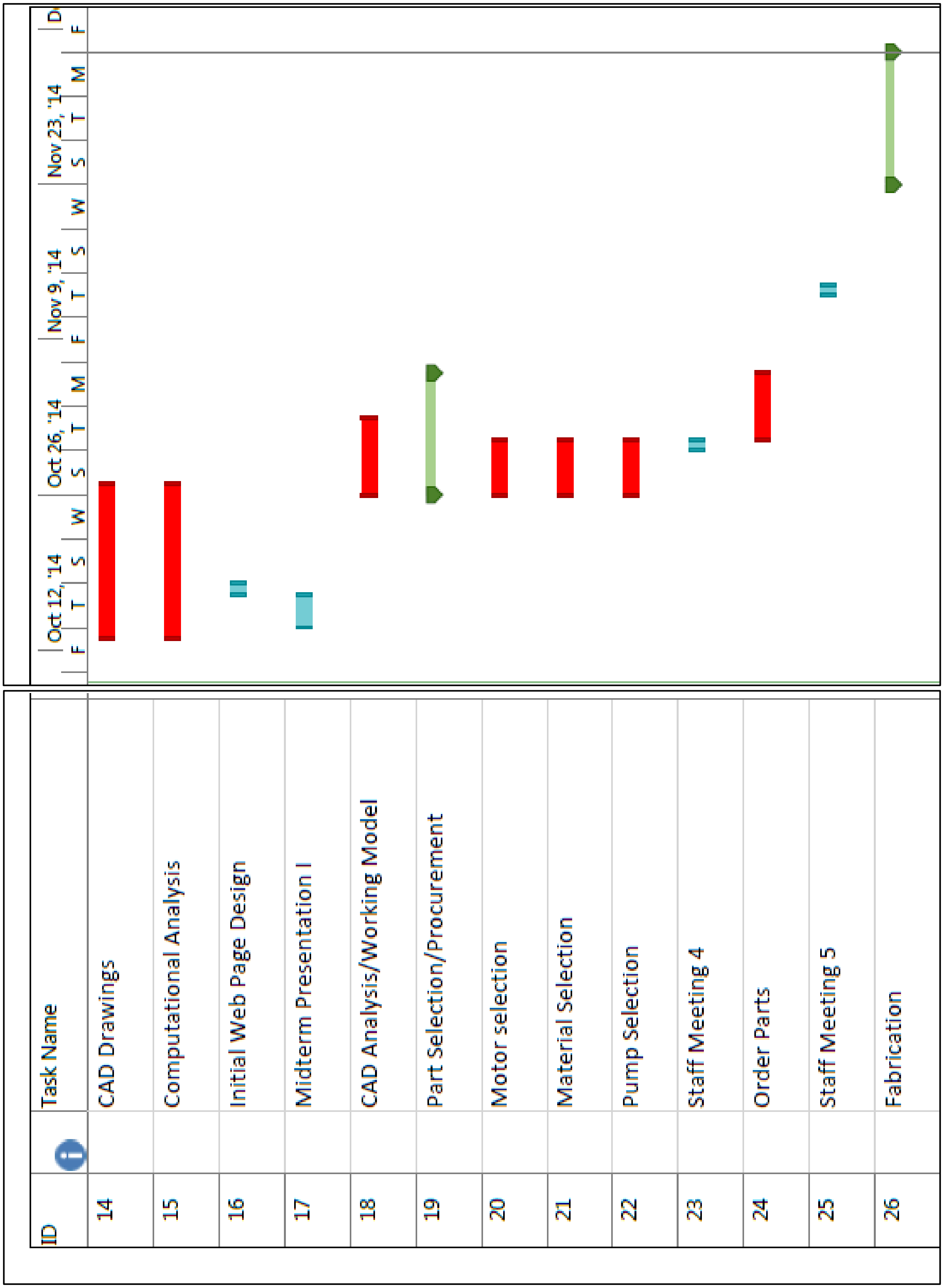
[4] "HowStuffWorks "Parts of the Tesla Turbine"" *HowStuffWorks*. N.p., n.d. Web. 09 Oct. 2014.

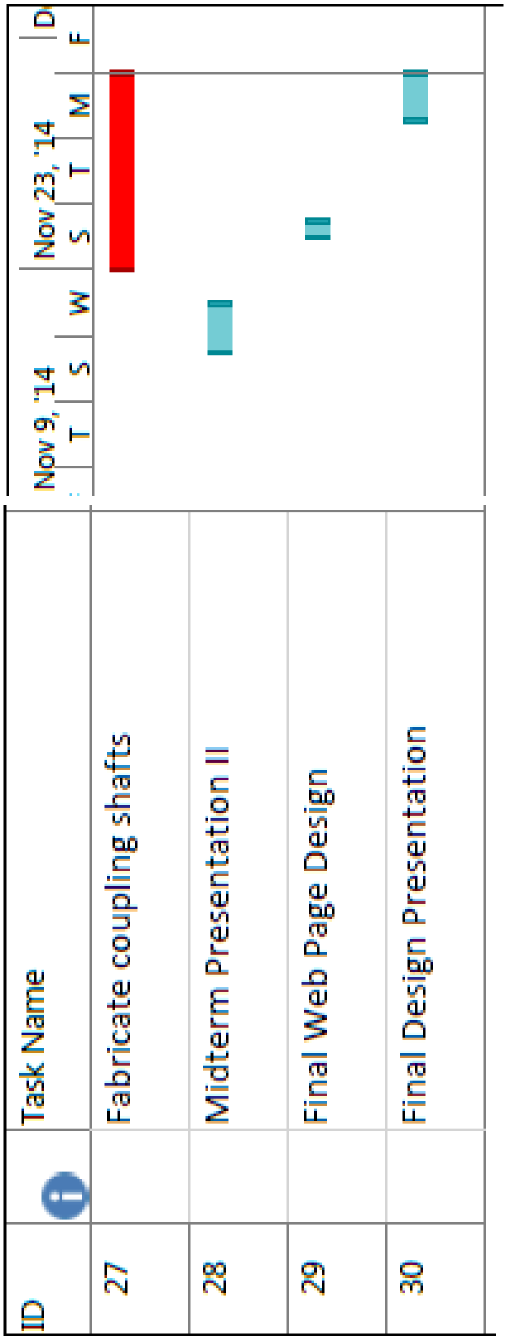
[5] Pump, Nikkiso Cryogenic. *NIKKISO CRYOGENIC PUMP* (n.d.): n. pag. Web.

Appendix-A



ID
Task Name
1 Project Planning
2 Research
3 Design Concept Generation
4 Code of Conduct
5 Ice Breaker
6 Needs Assessment
7 Staff Meeting 1
8 Project Plan
9 Staff Meeting 2
10 Revised Code of Conduct
11 Design Stage
12 Choose Final Design (Decision Matrix)
13 Staff Meeting 3
Aug 31, '14
Sep 14, '14
Sep 28, '14
Oct 12, '14
Oct 26, '14


ID
Task Name
14 CAD Drawings
15 Computational Analysis
16 Initial Web Page Design
17 Midterm Presentation I
18 CAD Analysis/Working Model
19 Part Selection/Procurement
20 Motor selection
21 Material Selection
22 Pump Selection
23 Staff Meeting 4
24 Order Parts
25 Staff Meeting 5
26 Fabrication
Oct 12, '14
Oct 26, '14
Nov 9, '14
Nov 23, '14
F T S W S T M F T S W S T M F


ID
Task Name
27
Fabricate coupling shafts
28
Midterm Presentation II
29
Final Web Page Design
30
Final Design Presentation
Nov 9, '14
Nov 23, '14
T
S
W
S
T
M
F