VTT Rotor Back EMF Test Fixture

Deliverable Name: Project Plan and Product Specification

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Abstract

The objective of this senior design project is to design a test fixture that will measure the back electromotive force generated when the rotor is rotated at a constant speed within the stator. The motivation for this is to allow Danfoss Turbocor to properly evaluate the quality of the rotors they is receiving from a third party manufacturer. The goal of this project is to have a fully designed, manufactured, and tested back EMF test fixture prior to the conclusion of the senior design class. This test fixture will be implemented into the preexisting production line at Danfoss Turbocor. The final submission package to Turbocor will include a 3D prototype of the final design, and a drawing package for each individual part sufficient for a re-creation of the test fixture, should that be desired by Turbocor. There are several design constraints imposed on the test fixture, all of which will be met or exceeded in the final design. The team has been divided into several roles to ensure that all facets of the project are accounted for. Additionally, within the individual roles additional resource allocation has been done to ensure each individual task is taken into account. A schedule, including a work breakdown sctructure, for the design portion of this project has been made and put into a Gantt chart to ensure that the design is completed prior to the final design review on November 20th, 2014. To ensure that the manufacturing portion of senior design goes without delay, all needed parts and materials will be ordered prior to the end of the fall semester.

1 Introduction

The Danfoss Group is a global leader with a wide range of products utilized in areas such as cooling food, air conditioning, heating buildings, and electric motors. Danfoss Turbocor is a wholly owned subsidiary of The Danfoss Group and is one of the pioneers of the oil-free centrifugal compressors. Turbocor began as a R&D startup in Australia in 1993, and in 2004, Danfoss and Turbocor formed a 50/50 joint venture called Danfoss Turbocor.[1] They offer the world's first completely oil-free compressors designed for the Heating, Ventilation, and Air-Conditioning (HVAC) industry. The use of magnetic bearings sets Danfoss Turbocor apart from the other compressor manufacturers. This allows for oil-free operation while significantly reducing sound generation[2] Danfoss Turbocor has their headquarters and manufacturing facility in Tallahassee, FL, and does business around the world.

Danfoss Turbocor plans to launch a new compressor model before the end of 2014. Current production plans call for the use of a rotor that will be manufactured by a third party company. There needs to be a way to quality check these rotors to ensure they are up to Turbocor standards prior to installing them in the compressor. To test these rotors, Danfoss Turbocor must measure the back electromagnetic force delivered by the electric motor when the rotor is being rotated inside of the stator. Electromotive force, or EMF, typically refers to voltage generated when a motor is spun. Measuring this voltage can be used as a method to determine the rotational speed of the motor, which is called back EMF. The reason it is referred to as a back EMF force is because the voltage pushes against the current that induces it.[3] By measuring this back EMF force, Danfoss Turbocor will be able to verify the quality of the rotors being supplied by a third party manufacturer. Eventually, Turbocor plans to manufacture these rotors in-house, but until they switch over to manufacturing these themselves, they require this method of quality assurance.

To successfully and efficiently implement this testing procedure, a test fixture must be created that can be integrated into the manufacturing line. The equipment will be used to perform the back EMF measurements on each rotor prior to its assembly into the compressor. A previous test fixture has been developed by Turbocor for use on one of their smaller compressor models. The test fixture for this application will be similar; however, there are additional constraints that make the implementation more difficult. One of the biggest challenges is to determine a method of centering the rotor within the stator. This is essential because if the rotor is slightly off center, it cannot be tested properly. Additionally, there is a large magnetic force induced when the rotor is pushed into the stator. This is not of concern in the smaller compressor models as the small force can easily be overcome by a human; however, in the new larger compressor model this force is significant and it is not safe to manually load the rotor. Due to the magnetic nature of the components used in the assembly of the compressors, magnetic material should not be used in areas within the magnetic field of the rotor.

2 Project Definition

2.1 Background research

Turbocor has already created a test fixture for their smaller compressor, which will serve as guide for the new design to test a larger rotor. However, the current fixture cannot be modified to test the new rotor due to an increase in size, electromagnetic force and a need for a more reliable unit as discussed previously. The overall setup of this previously developed test fixture does give this senior design group an opportunity to view the essential features of the test fixture. A picture of the previously utilized back EMF test fixture can be seen below in Figure 1.

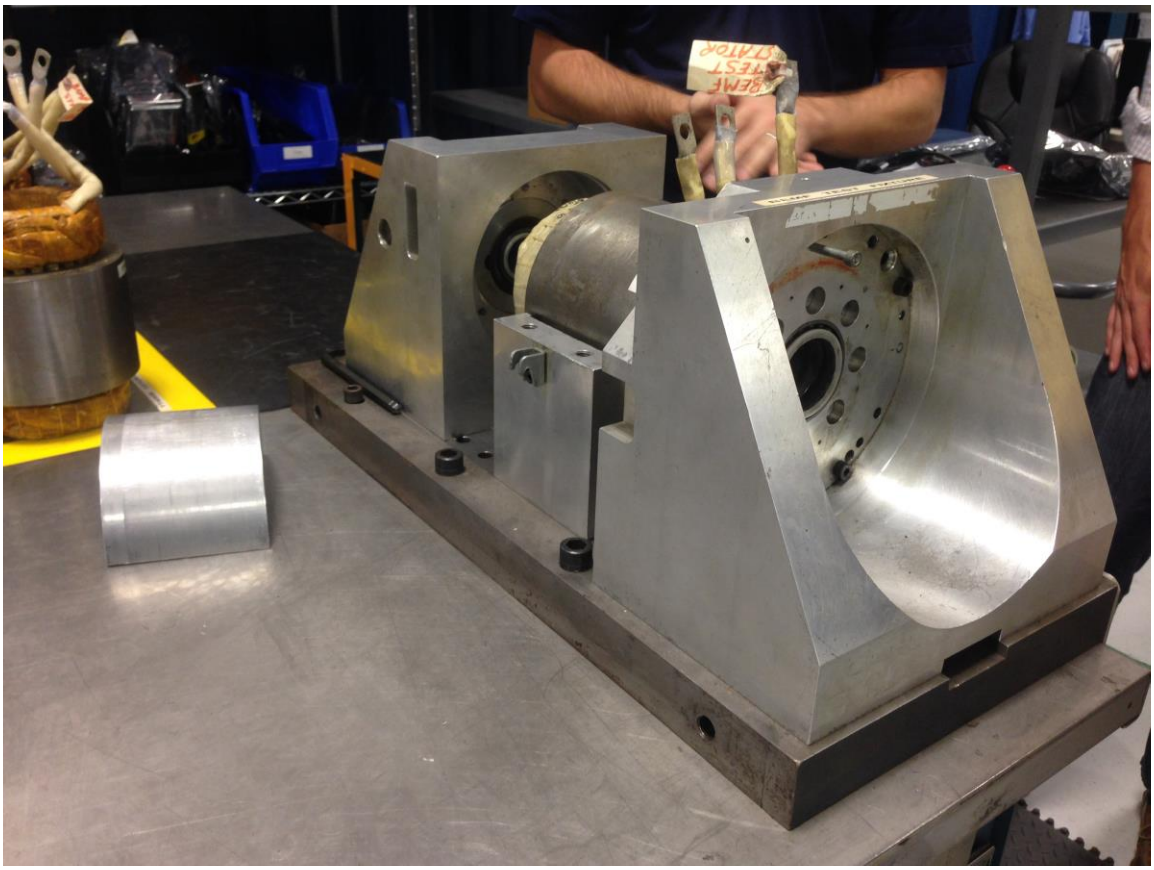

Figure 1: Previously designed Back EMF Test Fixture for smaller compressor model

In the test fixture for the smaller compressor model, there is a locking feature that locks the stator into place and can be unlocked, should the stator need to be replaced. This is an essential feature of the new design. The old design utilizes a bearing to ensure the centering of the rotor within the stator. This is an effective way to ensure that the rotor is centered; however, there is a high cost associated with the replacement of bearings over the life cycle of the test fixture, and thus an alternative method of centering should be developed. One key feature of the larger rotor is a key-like-hole centered on the end of the rotor. An isometric view of the rotor can be seen below in Figure 2, and this key like hole can be seen on the top left of this figure.

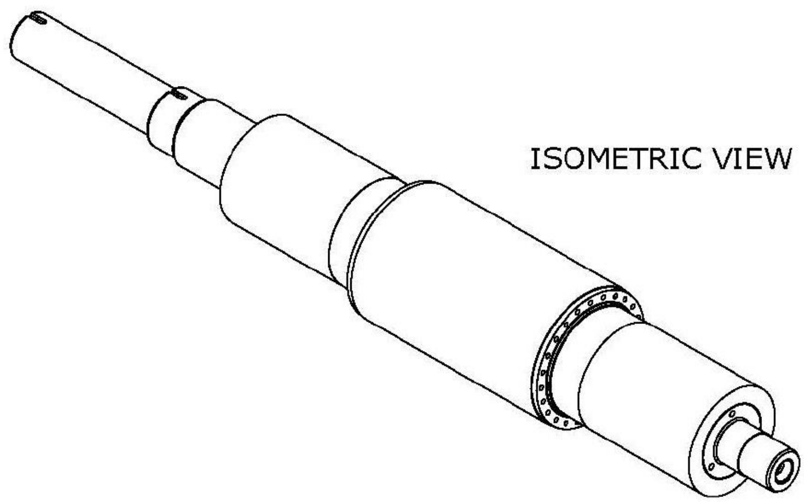

Figure 2: Isometric view of rotor showing key like hole for live center

The most effective way to center the rotor within the stator may be through the use of a live center. A live center, or lathe center is a tool that has a conical shape that is typically used in lathe work in order to provide a stable axis that can be easily replaced, while also providing an accurate method of centering. A live center typically consists of a sixty degree conical shape on one end that will align with an opening on the work piece that is shaped to accept the conical end at the given angle. The advantages of using a live center include the enabling high speed rotation while handling heavy loads, centering the work piece accurately from work area to work area, and feasibility of replacement.[4] The shape of the point will also have to be determined based on the work piece being used; the rotor that will be provided has a point angle that will accept a sixty degree conical shape.

Figure 3: Picture of an example live center

There are several design considerations that will need to be determined when designing this test fixture. The method for rotating the rotor will need to be decided upon. Several different methods will be evaluated in the design process to determine which method is the most suitable. As previously mentioned, due to the large size of the rotor, the magnetic force due to the magnetic field of the stator is significantly large. A design feature must be implemented that will assist the operator in manually loading the rotor into the stator. Because magnetic material cannot be used in the design, aluminum will be the most effective material for the test fixture housing as it is non-magnetic and low cost. Aluminum 8020 has been recommended to the senior design group as it is readily available in the Turbocor facility.

2.2 Need Statement

Danfoss Turbocor plans to launch a new compressor model before the end of 2014. Current production plans call for the use of a rotor that will be manufactured by a third party company. Danfoss Turbocor has a need for an ergonomic, efficient, and reliable device to test the back EMF of these third party manufactured rotors in a production facility. This is required because Turbocor uses a third party company to manufacture their rotors, and there is no other way to ensure the rotors are up to Turbocor's standards prior to implementation. The design of a back EMF test fixture will allow Danfoss Turbocor to properly evaluate the quality of the rotors they are receiving from the third party manufacturer and ensure their compressors will meet performance requirements when implemented.

"Turbocor does not have a method to verify the quality of third party manufactured rotors for their new compressor model"

2.3 Goal Statement & Objectives

"**The goal of this project is to have a fully designed, manufactured, and tested back EMF test fixture that meets Danfoss Turbocor's requirements prior to the conclusion of the senior design class in the spring**.**"**

Objectives:

- This test fixture will be able to be implemented on Danfoss Turbocor's production line with a design life of seven years minimum.
- The submission package to Danfoss Turbocor will include a 3D prototype of the final design with a drawing package for each individual part sufficient for a re-creation of the test fixture should that be desired by Danfoss Turbocor.
- The final product will conform to all size and weight requirements outlined by Danfoss Turbocor (see constraints section)
- The back EMF test fixture will have a feature that centers the rotor within the stator to a specified tolerance.
- The back EMF test fixture will have a feature that aids in the manual insertion of the rotor into stator and provides a sufficient force to overcome the magnetic force generated.
- All other performance requirements outlined by Danfoss Turbocor will be met or exceeded.

3 Constraints

Although the previous existing version may serve as a template, there are several improvements that must be made in order for it to be effective in this application. The design must be strengthened and enlarged to support the weight and size of the new rotor and stator. Because of the magnetic nature of the stator and the rotor, magnetic materials may not be employed within 200mm surrounding the carbon fiber sleeve as they can affect the output given by the oscilloscope that will be used to measure the back EMF of the stator. Because this will be implemented in a manufacturing setting, it is important to optimize the spatial footprint of the test fixture so that easy movement between work cells will be possible. The size limitations imposed on this design are summarized in the design specifications section below.

There must be a method for measuring the voltage and waveform of the back EMF, and this is discussed in performance specifications section. Finally, but perhaps most critically, all Occupational Safety and Health Administration (OSHA) safety standards must be met. Specifically, OSHA 29 CFR 1920 must be met at all times and noise levels must be maintained less than 80 dB.[5] Dangerous areas of the test fixture must be clearly labeled with internationally recognized symbols, which may include pinch or shock points. Due to the magnetic nature of the compressors manufactured at Turbocor, stored energy may present an issue. For this application, the stored magnetic energy should not be significant; however, if the fixture is powered off, it may remain rotating at a high angular velocity for some finite amount of time prior to stopping. Because this may present a safety hazard, proper warning labels shall be attached to the test fixture.

3.1 Design Specifications

There are several design specifications that have been imposed on the back EMF test fixture and most of these are related to the size and weight of the design. The design must include a worktable, and spatial limitations of the design have been provided, which can be seen below in Figure 4. There should also be sufficient space for an oscilloscope on the workstation and a control panel that should be integrated into the design.

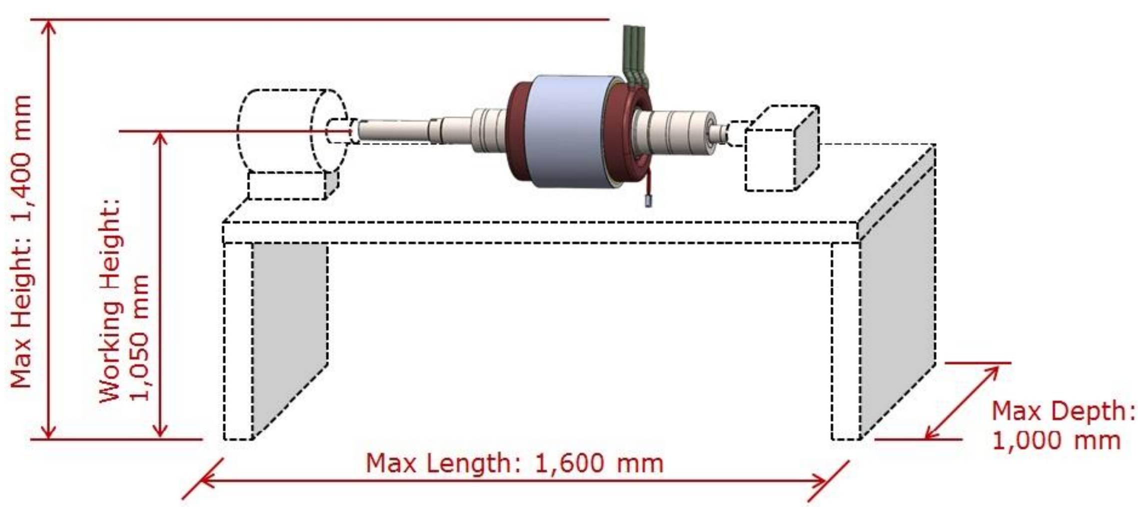

Figure 4: Spatial footprint requirements of test fixture

The spatial limitations are also summarized in Table 1, which includes the need for the center of the fixture to be oriented at a working height of 1,005 mm for ergonomic purposes.[5] There is no maximum weight of the test fixture outlined by Turbocor; however, it has been discussed that for both cost and ease of use purposes, the overall weight of the design shall be as low as reasonably possible.

Table 1: Summary of design constraints

Design Constraint	Requirement	Units
Max Bench Height	1,400	Length (mm)
Max Bench Length	1,600	Length (mm)
Max Bench Depth	1,000	Length (mm)
Bench Working Height	1,050	Length (mm)

3.2 Performance Specifications

The performance specifications have been briefly mentioned in previous sections, and will be addressed in detail here. The method of centering utilized in the design must ensure that while the motor is rotating the rotor, the rotor is centered within the stator within a tolerance of 0.1 mm. If the rotor is offset, two issues arise: the magnetic force exerted on the rotor by the stator will no longer be equal on all sides, and the back EMF voltage and wave form outputted by the stator will not be accurate. In addition to the centering mechanism, the test fixture must be capable of overcoming the magnetic force that is exerted by the magnetic field when the rotor is inserted into the stator. This is an estimated 60-80 pound force according to Turbocor. This must be addressed by using a design feature that will allow for the operator to manually insert the rotor into the stator in an efficient manner. The design life of the test fixture must exceed seven years.

Finally, there are performance requirements of the motor's performance. A 120V or 208V motor is preferred, and the motor must be capable of rotating the rotor within the stator at a constant angular velocity that exceeds 1,000 rpm.[5] It is important that the angular velocity is consistent between tests so each test is repeatable and can be compared to a standard value. The output given by the test fixture shall include the back EMF voltage, and the waveform for three different phases. This allows for verification of the angular velocity of the rotor, and this output provides the basis for rejection or acceptance of the rotors.

4 Methodology

For this project, specific dates for the major deadlines of this project have already been identified, which will be discussed more in depth in the subsequent section. Weekly meetings have been setup with the representative from Turbocor, Brandon Pritchard, who is the liaison handling this project. This will ensure that the project is moving along at a pace that will allow for the completion of the project in a timely manner. Specific tasks have been assigned to the group members which are also discussed in the subsequent sections.

Once the preliminary design has been approved by Turbocor, all team members will contribute to the CAD design and analysis of the test fixture. The team leader will be in charge of all deliverables and delegating tasks to the group that come up over the course of the semester. A final design review has already been scheduled at Turbocor for November 20th, 2014. This date was chosen so that if any changes needed to be made to the design, there would be ample time prior to the winter break for these changes to take place. To ensure that no problems arise during the manufacturing stage of the spring semester, all parts and materials needed for the assembly of the test fixture shall be ordered prior to the end of the fall semester. One of the team members has been given the assignment of financial advisor and will be in charge of maintaining the budget of the project and insuring that funds are properly allocated.

Proper communication throughout the year will be an essential factor to the success of this project. Communication via telephone, text messaging, and email will ensure that all team members are aware of all meetings and deadlines. The weekly check-in meetings with the sponsor shall ensure that everyone involved in the project is on the same page and aware of any issues that may come up. The mentor for this project, Dr. Louis Cattafesta, shall be utilized as a technical advisor as needed. The senior design group has decided to aim for a project completion date of April 1st, 2015. This date was chosen so that if a delay in the design or manufacturing stage of the test fixture arises the project will be able to be completed within the timeframe of the class.

4.1 Schedule

A Gantt chart is used to insure that the project remains on schedule, and provides a view of the project progress. The Gantt chart is broken down into three design stages, and can be seen in the Appendix in Figure 5. The first design stage is the preliminary design stage, which encompasses the initial design conception, design development, and redesign. The Initial design conception is brainstorming where each group member comes up with ideas that accomplish the objective using different methods. Design Development is choosing the best ideas that accomplish all of the goals in the most efficient manner. Redesign is the last step of the preliminary design stage and allows evaluation of the design prior to it being presented to the sponsor.

The second design stage consists of design analysis. This stage involves taking the feedback from the sponsor, and adding it to the existing designs that were developed during the preliminary design stage, thus making the designs work more efficiently, save space, and perform better. Once two advanced designs have been developed, they will be evaluated by Brandon, and reworked to be improved. This brings the schedule to the final design stage, which is essentially the creation of all the necessary drawings, dimensions, tolerances, and part development so the materials can be ordered, and the spring semester can consist of building the test fixture. The final design stage is the most critical design stage, as this is the portion of the project were the parts will be drawn with dimensions, stress analysis will be performed, and the final test fixture design will be prepared and ready for construction the following semester.

4.2 Resource Allocation

There are several tasks that need to be completed in order to successfully design and manufacture the back EMF test fixture and fulfill the requirements of the senior design class. The following roles have been assigned to each team member, and will be discussed more in depth in the subsequent paragraph:

- Team Leader – Russell Hamerski
- Webmaster – Andre Steimer
- Secretary – Thomas Razabdouski
- Financial Advisor – Tim Romano
- Lead Engineer – Andrew Panek

The team leader will be responsible for keeping the team on schedule, delegating responsibilities, and keeping all team members accountable for their responsibilities. The team leader is also responsible for ensuring all deliverables that need to be completed are of high quality, which includes reports, designs, CAD work, and presentations. The secretary acts as the assistant to the team leader, and he is responsible for maintaining minutes of all meeting which include internal, external, and staff meetings. Additionally, the secretary is responsible for the proofreading and editing of all deliverables as a secondary check after the team leader. The financial advisor is responsible for maintaining the budget of the project and working with Turbocor to order all parts and materials required for the back EMF test fixture. The webmaster is required to build and maintain the project's website; he needs to ensure the website will exhibit sufficient information regarding the project's goal and progress.

There is significant engineering design and analysis required for this project. The lead engineer will be in charge of ensuring this design and analysis is completed in a timely manner and meets the constraints given to us by Danfoss Turbocor. All team members will be involved in the analysis of the design; however, major engineering decisions will be made by the team leader and lead engineer with input from the other team members. There is significant CAD work that will need to be done to create a prototype of the back EMF test fixture. This responsibility will fall on the lead engineer; however, he may delegate certain components to be completed by either the financial advisor or the secretary as their primary responsibilities are not as time consuming as the time leader or webmaster role. Once the designed is finalized the different sections of the design will be broken down and assigned to the various group members. Tentatively, the different sections of the design are as follows: live center support, power screw, tabletop, stator housing, the track system, and the test fixture base plate.

5 Conclusion

Danfoss Turbocor plans to launch a new compressor model by the end of 2014, and this new model will utilize a different rotor than the ones used in past compressors. Current plans will call for the use of a rotor that is to be manufactured by a third party company. Because of this, a method for quality assurance needs to be put in place, which is where the motivation for this senior design project stems. The goal is to develop a back EMF test fixture that can be used on Turbocor's production line. This test fixture would allow for the operator to manually insert the rotor into the stator and then spin the rotor at a constant angular velocity which exceeds 1,000 rpm. The test fixture would measure the back EMF and based on this reading, the operator will be able to qualify the rotor. There are several design constraints imposed on the back EMF test fixture that have been discussed in detail in the previous sections, which include limitations on lifetime, size, and weight. The senior design team will analyze and design a test fixture capable of meeting all of Danfoss Turbocor's performance requirements. The final submission to Danfoss Turbocor will include a 3D prototype of the final design and a drawing package for each individual part. In order to keep the project on schedule, the senior design team members have been delegated various responsibilities. A Gantt chart has been constructed to keep the team on schedule throughout the semester. The most important deadline for the fall semester is the Final Design Review with Turbocor which has been scheduled to take place on November 20th, 2014. This date was chosen so that any adjustments deemed necessary can be made, and all parts may be ordered prior to the end of the fall semester. Currently, the senior design group is within the design phase of the schedule after completing the initial design selection. The goal finish date for the construction of the project was set for April 1st so that if any delays occur during the manufacturing or design phase the project will still be completed within the timeframe of the class.

6 References

[1]Danfoss. "About Danfoss." Danfoss, Engineering Tomorrow. Danfoss, 2014. Web. 23 Sept. 2014. <http://www.danfoss.com/Home>.

[2]Danfoss Turbocor, and Royco Web Design. "OEM Customers." Danfoss Turbocor Compressors Inc. Danfoss Group Global, 2014. Web. 23 Sept. 2014. <http://www.turbocor.com/>

[3] Acroname. "Back-EMF Motion Feedback." Acroname. Brainstem, 2014. Web. 23 Sept. 2014. <http://www.acroname.com/articles/emf-motion-feedback.html>.

[4] Riten. "Live Centers." Riten Industries, Inc. Riten Industries, Inc., 2014. Web. 23 Sept. 2014. <http://www.riten.com/products/live-centers.html>.

[5] Pritchard, Brandon. VTT Rotor Back EMF Test Fixture Equipment Specification. Rep. no. A.0. Vol. 1. Tallahassee: Danfoss Turbocor, 2014. Print.

7 Appendix

Gantt Chart for Fall 2014 referenced in text.

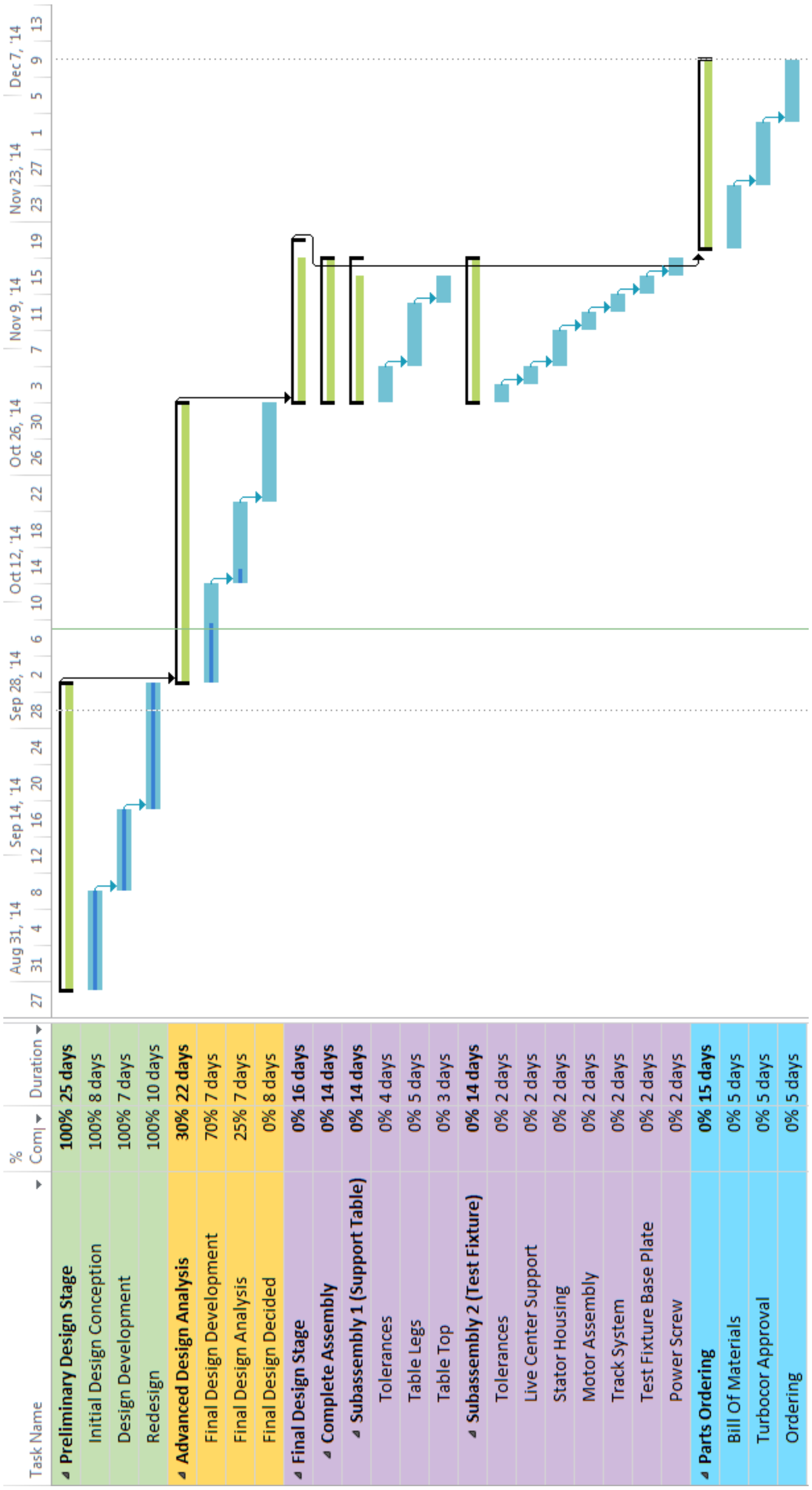

Figure 5: Fall 2014 Gantt Chart