# Team 4: VTT Rotor Back EMF Test Fixture


## FAMU/FSU College of Engineering

## Department of Mechanical Engineering


## <u>Needs Assessment</u>


**Names:**

| | |
|---|---|
| Russell Hamerski | (rh10g) |
| Tim Romano | (tr10j) |
| Andre Steimer | (as10f) |
| Andrew Panek | (ajp11k) |
| Thomas Razabdouski | (trs09) |



**Submission Date:** 9/26/2014
**Submitted to:** Dr. Scott Helzer and Dr. Nikhil Gupta

## Table of Contents



## Table of Figures



## Table of Tables

## 1.0 Abstract

The objective of this senior design project is to design a text fixture that will measure the back electromotive force generated when a 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 it is receiving from the third party manufacturer. The goal of this project is to have a fully designed, manufactured, and tested back EMF test fixture prior to the commencement of the senior design class. This test fixture will be able to be implemented on Danfoss Turbocor's production line and 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 recreation of the text 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.

## 2.0 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.[1] Danfoss Turbocor is a wholly owned subsidiary of The Danfoss Group and is one of the pioneers of the oil-free centrifugal compressors.[2] 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. They offer the world's first completely oil-free compressors designed for the Heating, Ventilation, and Air-Conditioning (HVAC) industry.[2] There are several things that set Danfoss Turbocor apart from other compressor manufacturers; but, this can mostly be attributed to their magnetic bearing which makes totally oil-free operation possible and significantly reduces the sound signature. Danfoss Turbocor has their headquarters and manufacturing facility in Tallahassee, FL, and sales around the world.[2]

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.[3] 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.[4] The reason it is referred to as a back EMF force is because the voltage pushes against the current that induces it. 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 in-house, they require this method of quality assurance.

To successfully and efficiently carry this testing procedure out, 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 assembling the rotor into the compressor.[3] A similar test fixture has been developed in the past 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 be overcome by human force; however, in the new larger compressor model this force is significant and it not safe to manually load the rotor. Due to the magnetic nature of the components used in the assembly of Danfoss Turbocor's compressors magnetic material should not be used in areas within the magnetic field of the rotor. Additional constraints imposed on the design of this include the lifetime, weight and size of the test fixture. The constraints that have been introduced in this section are discussed in more detail in the subsequent sections.

# 3.0 Project Definition

The following sections outline the problem being addressed by this senior design project, including additional background information, the motivation for this project, constraints of the design, the end goal, and how that goal will be achieved.

## 3.1 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.

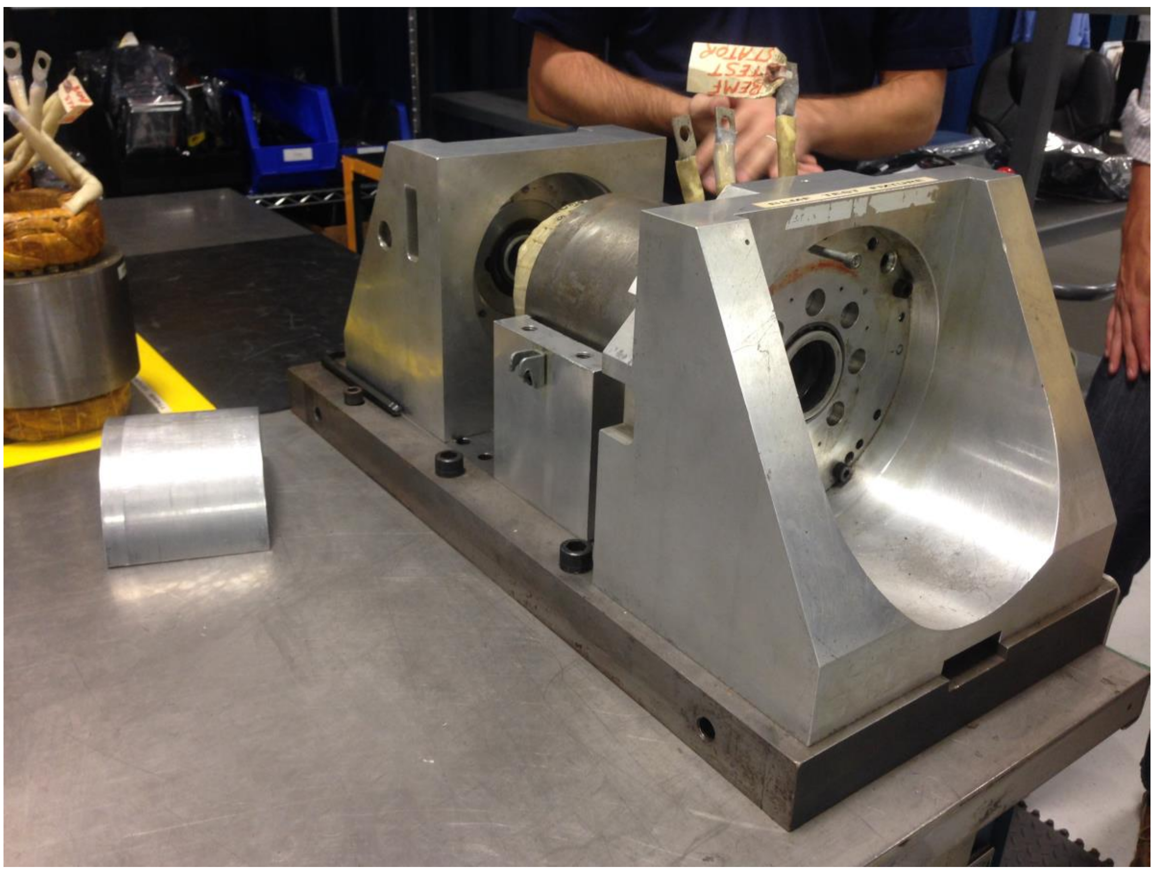

*Figure 1: Previously designed Back EMF Test Fixture for smaller compressor model*

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 will be 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 centering; however, there is a high cost associated with the replacement of bearings over the life cycle of the test fixture so there is significant motivation for an alternative way to center the rotor. 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 bottom right.

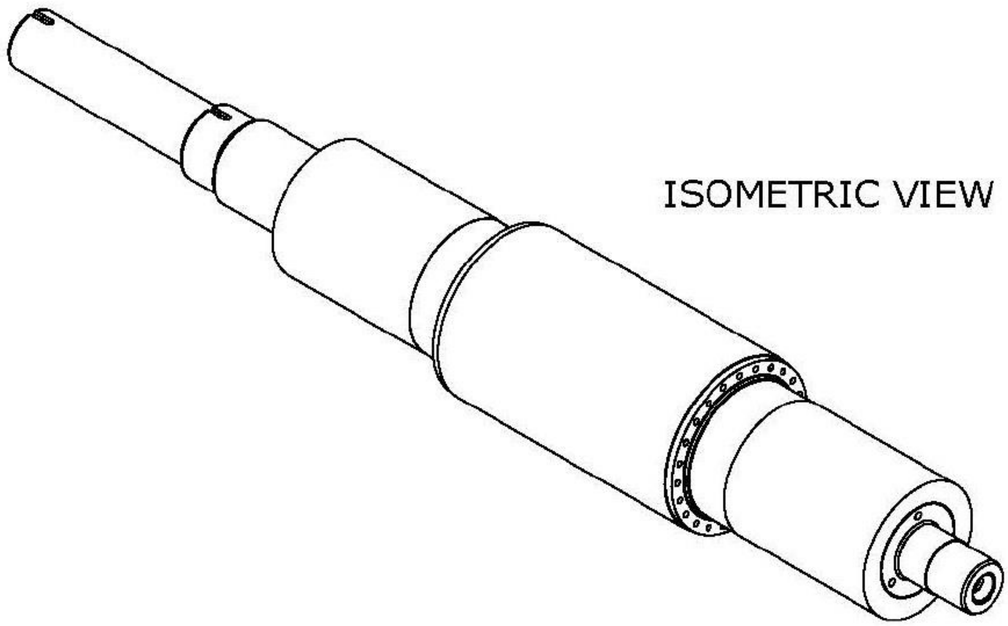


*Figure 2: Isometric view of rotor showing key like hole for live center*

The most effective way to center the rotor within the stator may be through the use of a live center. A live center, or lather 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 and provide an accurate method of centering the work piece.[5] 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.[5] 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.

## 3.2 Need Statement

There is a need for an ergonomic, efficient, and reliable device to test the back EMF of third party manufactured rotors in a production facility. This is required because Turbocor uses this 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 it is receiving from the third party manufacturer** and ensure their compressors will meet performance requirements when implemented.

## 3.3 Goal Statement

**The goal of this project is to have a fully designed, manufactured, and tested back EMF test fixture prior to the commencement of the senior design class**. 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, and a drawing package for each individual part sufficient for a recreation of the text fixture should that be desired by Turbocor. Additionally, references will be made to where all individual parts and materials were purchased from to aid in the process of creating another test fixture. The final product will conform to all size and weight requirements outlined by Turbocor, and will have mechanisms to both center the rotor and aid in the manual insertion of the rotor into stator. All other performance requirements outlined by Danfoss Turbocor will be met or exceeded.

## 3.4 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 which have already been introduced but will be discussed further in this section. The design must be strengthened and enlarged to support the weight and size of the new rotor and 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 design must include a worktable, and spatial limitations of the design have been provided which can be seen below in Figure 3. There should also be sufficient space for an oscilloscope on the workstation and a control panel should that be integrated into the design. Additionally, it is required that there is sufficient overhead space to provide clearance to allow the operator to load the rotor using overhead lifting equipment.[3]

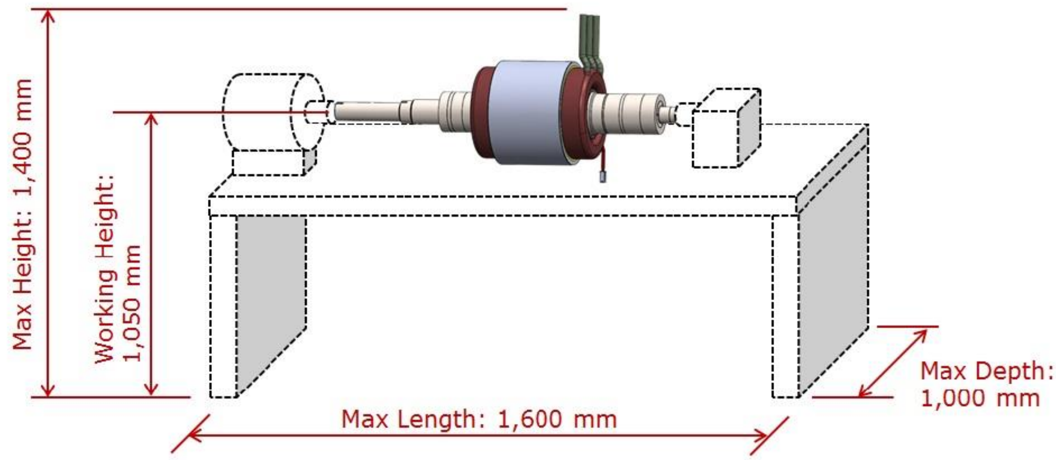


*Figure 4: Spatial footprint requirements of test fixture*

The current design for the smaller compressor uses bearing as a method of centering the rotor within the stator. To avoid the constant replacement of bearings, it is preferred by Danfoss Turbocor that the bearings be omitted from the design and a live center will be employed instead. The rotor has a feature that this live center may be applied to which has been introduced already and seen in Figure 2 in the previous section.

The rotor is larger and will generate a higher magnetic force upon insertion and will require an alternative insertion method using mechanical advantage. This will need to allow for the operator to manually insert the rotor into the stator in an efficient manner. Related to this constraint is the need for the center of the fixture to be oriented at a working height of 1,005 mm for ergonomic purposes.[3] Magnetic materials may not be employed within 200 mm surrounding the carbon fiber sleeve, and the stator must be easy to remove.[3] The rotor must be able to spin at a minimum of 1,000 revolutions per minute (rpm) while being used; however, It is acceptable for the angular velocity to not be equal this 1,000 rpm as long as the angular velocity to be constant for each test. This will allow Danfoss Turbocor to have a standardized method for testing these rotors.

While the testing takes place, the motor voltage and waveform must be able to be recorded for all three phases. This will be done using an oscilloscope connected to the stator lead wires which will be provided by Turbocor. Finally, but perhaps most critically, all 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.[3] Dangerous areas of the test fixture must be clearly labeled with internationally recognized symbols which may include pinch or shock points.[3] Due to the magnetic nature of the compressors manufactured at Danfoss Turbocor, stored energy may present an issue. For this particular test fixed, the stored magnetic energy should not be significant; however, if the fixture is powered off during a test, it may remain rotating at a significant 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. Table 1 below summarizes these constraints.

*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) |
| Minimum Angular Velocity (Rotor) | 1,000 | Revolutions per minute (RPM) |

## 3.5 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. The team leader will be in charge of coordinating all meetings and ensuring all reports are of high standards and submitted on time. To keep organized, the secretary will be utilizing Microsoft Excel to document the results of all meetings both internal to the team as well as meetings with Danfoss Turbocor and the senior design faculty. All group members will contribute design ideas which will be presented to Danfoss Turbocor over the course of the next two weeks. Weekly meetings have been setup with the representative from Turbocor, Brandon Pritchard, who is the liaison handling this project. This will ensure that we are moving along at a pace that will allow for the completion of the project in a timely manner. Once the design has been approved by Turbocor, all team members will contribute to the 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. 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 commencement 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.

## 3.6 Gantt Chart

# 4.0 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 from. 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 and they 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 preliminary Gantt chart has been constructed to keep the team on schedule throughout the semester. 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.

# 5.0 References


[1]Danfoss. "About Danfoss." Danfoss, Engineering Tomorrow. Danfoss, 2014. Web. 23 Sept. 2014. <http%3A%2F%2Fwww.danfoss.com%2FHome%2F>.

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

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

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