Midterm Report

Team 4

High Speed Motor-Generator Test Rig

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Although Turbocor started out in Australia back in 1993, they did not install their first compressor (the TT300) until 2001 in California, USA. Today, however, they stand as a leader in the oil-free centrifugal compressor product market and have been supplying the world with the most efficient refrigerant compressors for the HVAC industry.

Problem Statement and Project Scope

Danfoss Turbocor needs a system to qualify their compressor performance. The parameters in which they are interested in are the motor's power, efficiency, and heat management of the system. For the purposes of this project specifically, the heat management aspect will not be exhibited due to time constraints. Currently there is not a way for Danfoss Turbocor to qualify their motors due to a couple of factors. The first being that the system contains magnetic bearings and second being that the system exhibits speeds up to 40,000 rpm. Danfoss Turbocor has tasked Senior Design Team 4 with constructing the High Speed Motor-Generator Test Rig that can properly qualify the motor performance accurately without damaging the system.

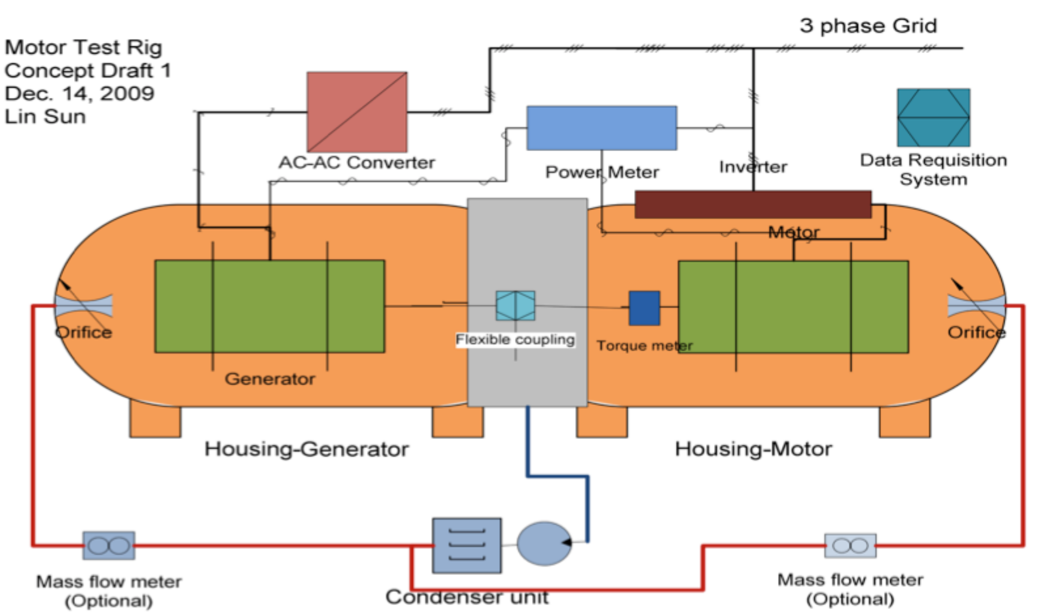

Figure 1: Motor Test Rig Draft[1]

In figure 1 above, the concept draft designed by Lin Sun is shown. As you can see, the motor (in green) on the right is to be coupled to another motor of the same or similar type, which will be acting as a generator. A torque transducer will be placed between the two shafts in order to monitor the torque being applied to the shaft from the motor. These two motors must be properly mounted to a stand which can separate the motors at the proper distance and make the alignment as simple as possible, this is to be accomplished by the senior design team. Notice that the coupling is to be flexible. This is a given parameter from the experts at Danfoss Turbocor since this rig will be experiencing such high speeds. The high speeds combined with misalignment between the shafts, will induce severe vibrational effects. The flexible coupling will help to cope with this, as the use of a rigid coupling will not tolerate any misalignment. The other components such as the data acquisition, power grid, and cooling unit will not be designed by Team 4. Danfoss Turbocor has deemed it challenging enough to properly align and couple the system. This will be enough for the system to be run but just not for longer periods of time.

Goals and Objectives

It is evident that the overall goal of this project is to deliver this test rig to Danfoss Turbocor by the end of the Spring 2016 semester. The way this will be achieved is by meeting all sub goals and objectives for the remainder of the Fall 2015 and Spring 2016 semesters. Team 4's objectives are extensive as this is a very complicated system. For starters, the team believes that accuracy should be of most importance. By achieving an acceptable level of accuracy, particularly in the alignment and balancing, then the desired standard of durability and safety will also be achieved.

The safety of the team and those who will be operating, building, or maintaining the system is of priority. To achieve this safe system, the team will need to focus upon three areas to eliminate errors that could propagate to safety failures. These areas are the conceptual design phase, design selection and analysis phase, and product production phase. If extensive focus is made in those phases, it will remove the likelihood of failures to occur. Team members are also aware of the dangers during the test rig construction that could be inflicted. Those risks can be from the improper use of tools or the heavy weight of the compressors and other test rig components. During test rig operation, a safety shielding will be in place to stop possible projectiles that could be flung from the system.

Another objective is to keep the system and maintenance simple. Danfoss Turbocor has demanded that this system work for a range of compressor sizes. Since their TT series has a standard housing, the compressor mounts can be made universal on the overall test rig stand and this will allow for Danfoss Turbocor to interchange the compressors to test. This also makes it easier on Team 4 with construction of the system since only one style of mount will be made. Unlike many senior design teams with budget constraints, the High Speed Motor-Generator Test Rig is under no budget constraint. This is because Danfoss Turbocor does not want to limit the quality or performance outcome, as this will be an actual product used in their test labs. By restricting the team to a budget, it is possible that the team would not be able to execute all areas proposed for design. Project goals and objectives may alter over time, but at this point, this is where Team 4 and Danfoss Turbocor stand.

Background Research

Turbocor's compressors excel in four main areas: magnetic bearings, variable speed, digital control, and centrifugal compression. Magnetic properties are used to cushion the compressors' rotor shaft and impellers, providing contact-free levitation. With one axial and two radial bearings, as well as sensors that provide real-time orbit feedback, the shafts are centered with high precision. When the bearings are not powered, touchdown bearings of carbon composite provide contact support for the shaft will it is not in rotation. Figure 2 represents the shaft being supported by front and rear radial bearings, as well as an axial bearing. The sensor rings are the devices providing feedback that will control the magnetic fields produced by each bearing.

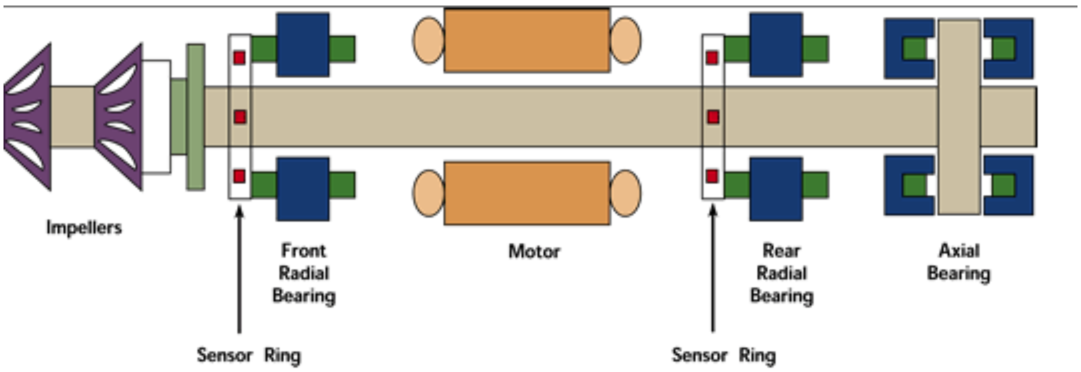

Figure 2. Illustration of compressor shaft relative to the magnetic bearings.[2]

Like the active control of the magnetic fields, the Danfoss Tubocor compressors can also actively adjust the speed of the compressors. This is done to maximize the power consumption efficiency. Compressor load and/or temperature can vary from each application in the field. By monitoring these variables, the system can make immediate adjustments to carry on its performance, thus eliminating downtime. These live feedback controllers (figure 3) use microprocessors, which self-diagnose possible errors within the system. Customer usability is improved through the capability to check compressor performance through web-enabled monitoring. These "smart" compressors add to the list that makes Danfoss Turbocor a worldwide name.

Figure 3. Digital Control through microprocessors.[3]

Through the use of centrifugal compression, the system can achieve high aerodynamic efficiency in comparison to other compressors on the market. Two impellers are mounted directly on the motor shaft thus creating a two stage compression system. When these impellers are spun at high speeds, the gas within the impeller veins is compressed in a radial direction. This process is significantly efficient due to the high volume of processed gas versus the amount of material needed to make the impeller[4].

Recently, the team visited the Center for Advanced Power Systems (CAPS building) in Tallahassee Florida. While there, they spoke with PE Michael Coleman and viewed one of the facility's motor test rigs. This test rig can be seen in figure 4, similarities with this rig can be drawn with the rig that Danfoss Turbocor is requesting, but the CAPS test rig operates below 2000 RPM. The two motors are coupled together by two Love Joy brand couplings and a drive shaft extension between the couplings (figure 5).

Figure 4. CAPS building low speed motor rig with yellow safety shield.

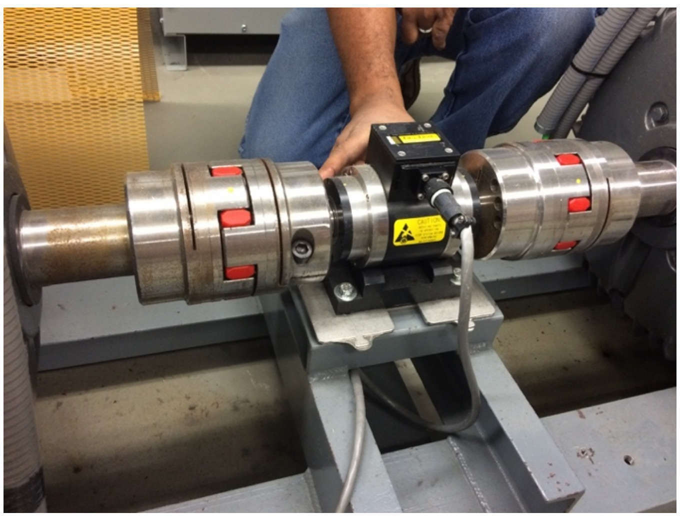

Figure 5. Couplings with torque transducer on shaft extension piece.

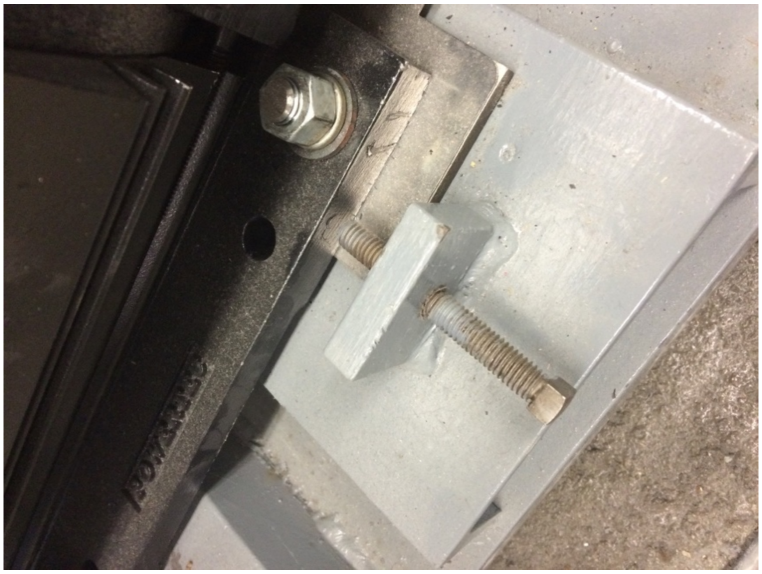

Figure 6. Lateral adjustment with set screws and motor mounting bolt.

The motor in this rig uses shims for adjusting the pitch in all four corners of each motor. To determine the width of the shim to use, a laser alignment tool was used and relayed shaft alignment inaccuracies. When this idea was presented to Turbocor, it was recommended to not use shims because the tolerances on the High Speed Motor-Generator Test Rig would be beyond shim adjustment capabilities. Lateral adjustment of the motor is done by set screws (figure 6) that can push the motor in forward/backward and side to side directions. To account for the adjustments, the motor mounting bolt holes are drilled to be larger than the bolts, this allows small position shifts to be made for shaft alignment. Safety measure in this system are accounted for by the yellow metal mesh guard (figure 4). This mesh guard is flexible and bends over the couplings and torque transducer. Due to the lower RPM's of this system, this particular safety shield would not be sufficient for the rig. Currently, safety shielding will be accomplished through the use of a high impact resistant transparent polycarbonate. This shielding is common in lab facilities that utilize machining equipment where there are risks of harmful projectiles. Figure 7 exemplifies a polycarbonate safety shield that could be used for the High Speed Motor-Generator Test Rig.

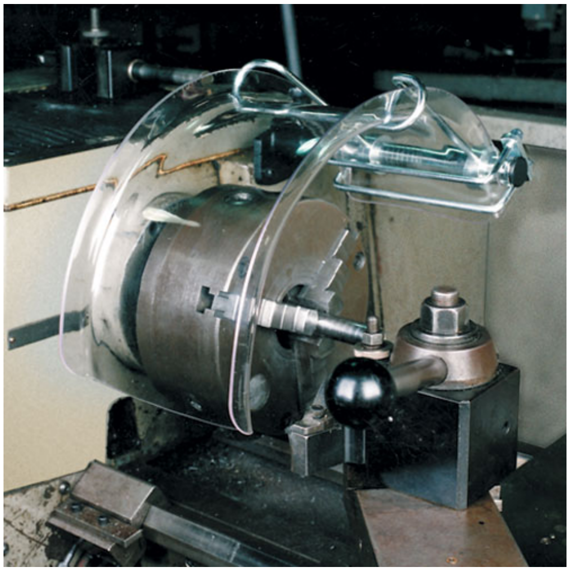

Figure 7. Transparent Polycarbonate safety shield on a lathe.[5]

Design and Analysis

From a House of Quality, customer requirements and technical requirements were chosen and ranked. In order of importance, it is necessary that the chosen design is accurate, durable, safe, practical, cost efficient, and versatile. The technical requirements showed that by increasing machinability of the system, the tolerances will improve. By increasing tolerances, the overall strength of the system will be improved, therefore a positive correlation was made with machinability and strength (figure 8). By increasing the strength of the test rig it is likely that the weight may also increase due to the addition of higher strength steels. This negative relation is not of high concern, the test rig will remain stationary and does not need to be frequently transported.

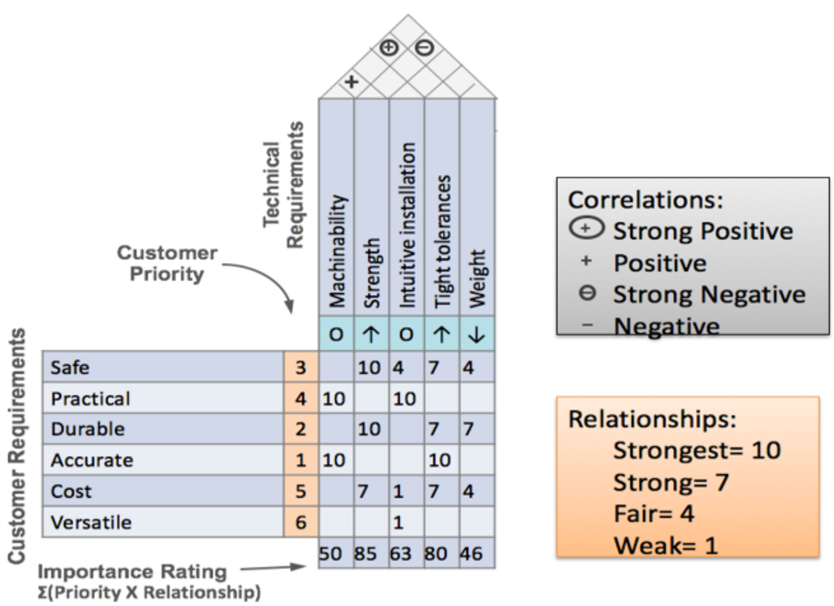

Figure 8. House of Quality.

From the uniqueness of the Danfoss Turbocor compressors, there are unique constraints that are presented. To achieve high speeds and also remain an oil-less system, the compressor uses magnetic bearings that levitate the internal shaft of which has the two stage compression impellers mounted. These magnetic bearings actively work to support the shaft radially and axially. If a radial force of 200lb is experienced, the shaft will make physical contact with the compressor and the system will be shut down. It was predicted that when the compressors are in their final mounting positons of the test rig, only roughly 1.5 inches of shaft will be extending out of the compressor. This presents clearance challenges for assembly and disassembly, particularly with the tooling. At 40,000RPM, it is impetrative that components in rotation be precisely balanced. With the addition of couplings and possibly a shaft extension, all parts must be balanced accordingly. An example of this solution is presented in figure 9. By recommendation of Lin Sun at Danfoss Turbocor, it is desirable to have the least amount of components added to the system. In turn, this will keep the system's Eigen value higher, therefore reducing the likely hood of vibration induced damage.

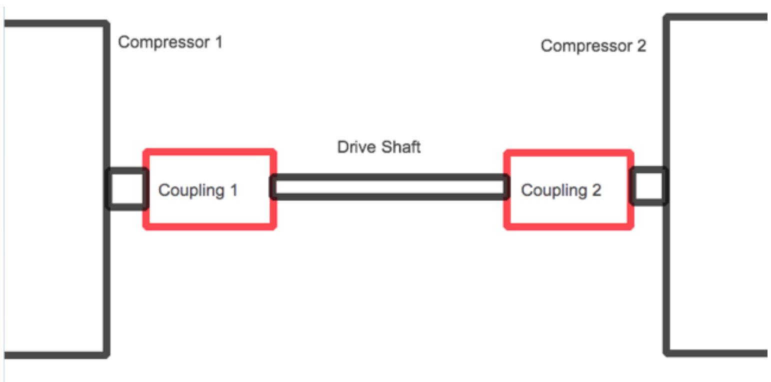

Figure 9. Dual couplings with shaft extension.

A small scale prototype was the first concept generated and considered by the design team. From recommendation of faculty, the concept composed of two DC motors coupled together. One motor would receive power and drive the other DC motor. By using a prototype, the system could be used to qualify coupling designs and give insight to shaft alignment procedures. To secure the motors, clamps were designed and can be seen in figure 10. Mounting holes in a base plate would be precisely cut by a water jet. To account for elevation adjustment, there would be a threaded bolt in the 4 corners of the motor that would extend through the base plate and feature two nuts to clamp to the base plate (figure 10). This would allow for pitch adjustment in all four corner of the motors.

Figure 10. Left: DC Motor Camps. Right: Elevation adjust system.

Ultimately, it was concluded that using a small scale prototype would not be a productive use of time. It is unlikely that a DC motor can be found to operate up to the same RPM's as the compressors, and also have similar shaft dimensions. Turbocor expressed their concern that because the compressors use magnetic bearings, the DC motors will not give a realistic test platform for qualification. Although DC motors will not be utilized, the elevation adjustment system will be carried over and implemented in further designs.

Once it was decided that the full scale compressors would be used, the challenge of how the compressor would be brought together was taken on. Through the use of a track system, a compressor could be moved laterally in X and Y directions. This track system would use simple caster wheels that would roll though a channel on a base plate. Only one compressor would be needed to move on the track system, while the other could remain fixed. Figure 11 illustrates this concept design, the black tracks allow movement front and back and the purple allows movement left and right. To account for adjustments in the vertical (Z) direction, the method illustrated in figure 10 would also be implemented.

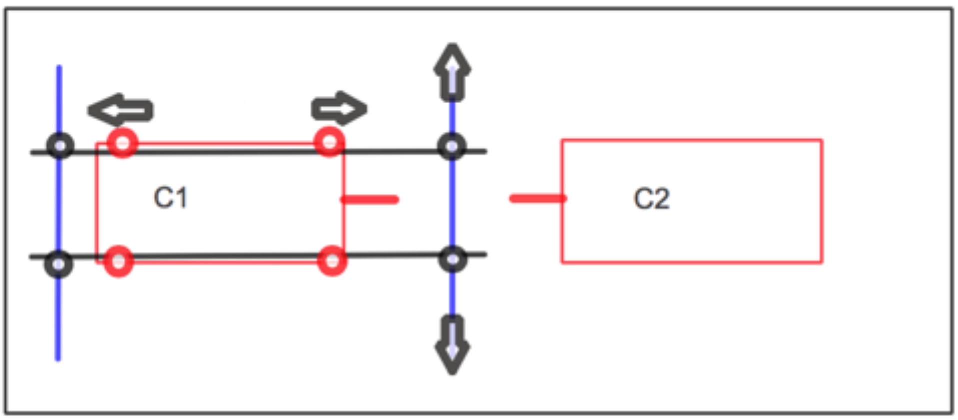

Figure 11. Test rig using tracks and rollers, compressor two (C2) is fixed while compressor one (C1) moves.

However, the track system does pose risks. There is no clear way for how C1 would lock into a rigid position on the track, which is significant when at high RPMs. A possible solution would be to use a long threaded rod, which would position the compressor by rotating the rod in either direction. An illustration can be seen in figure 12 which shows a past design project. The manual operational wheel on the left positions the apparatus lineally along the platform by threading the fixture onto the rod.

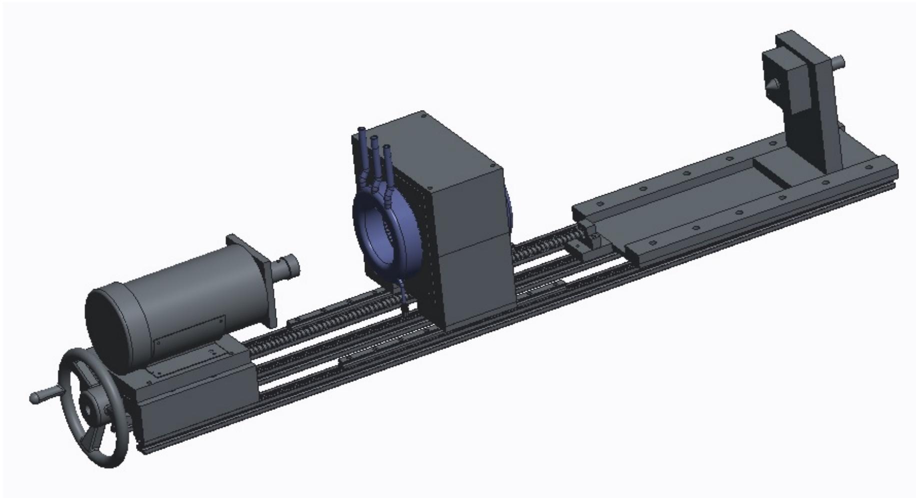

Figure 12. Back EMF Test Fixture for Danfoss Turbocor.[6]

There are two methods to check the misalignment of shafts to be coupled together, visually though the use of levels and dial indicators, and digitally with laser alignment tools. To determine which system can be used, it is important to know the tolerances. The closest tolerance for the shaft is roughly 200 microns, this shows that under no circumstance should the misalignment get near that value. It is imperative that the accuracy of the alignment tool be far lesser than 200 microns (0.00787 inches). A tool manufactured by SKF called the TSKA 11 (figure 13) is a laser alignment instrument that syncs with a mobile phone for shaft alignment. The system works by clamping onto one of the shafts and extending the laser measurement lens over the opposite shaft. By rotating the clamped shaft, the lens will measure the distance at multiple locations of the stationary shaft. Next, it will immediately calculate which direction the shaft adjustment should be and by how much. SKF lists the accuracy of the TSKA 11 at 10 micrometers, which would be adequate for the high-speed test rig. The cost of this tool is roughly $2,000.

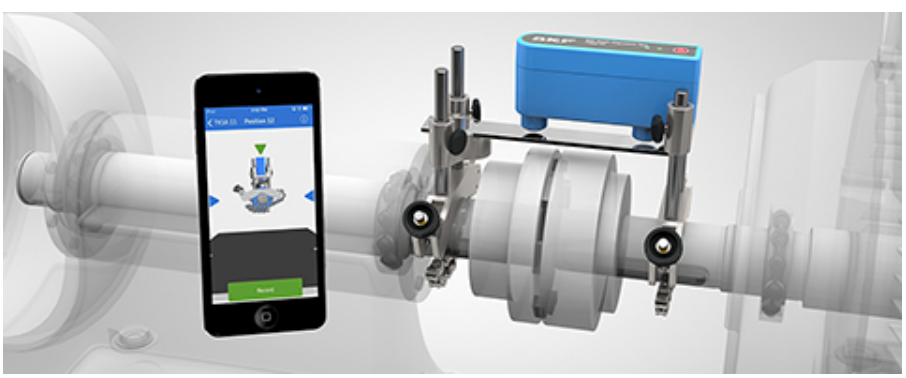

Figure 13. TSKA 11 laser alignment tool.[7]

During operation of the High Speed Motor-Generator test rig, the operators need to monitor the torque output. To solve this, a torque transducer must be integrated into the shaft coupling design. This transducer must be able to operate at 40,000 RPM and not add any further safety risks to the system. The TMH series torque transducer by Magtrol (figure 14) can operate up to 50,000 RPM has a maximum error of 0.1%. As the figure shows, this transducer would likely fit between the two couplings, by doing so, the need for a shaft extension piece would be eliminated. By removing this shaft and using a pre balanced apparatus like the TMH transducer, the likelihood of a severe imbalance is reduced. A unique aspect of the TMH is the contact free measuring device, which allows the electronics to remain fixed and not subject to rotation. By doing so, it eliminates the possibility of an electrical component becoming a dangerous projectile.

Figure 14. TMH series torque transducer[8].

Schedule

Through the use of a Gantt chart, the team has devised an orderly representation to show goal milestones for the fall semester. In addition to these deliverables, the "Benchmarking from CAPS" and "Danfoss Turbocor Training" show the two main first propositions that will be conducted during the fall semester. "Product Ordering and Outsourcing" will include further insight into the industry for tooling and supplies to meet parameters from Turbocor.

"Alignment System Design" planning will draw from the resources acquired during the research phase and lay a foundation for component design and/or selection. The "CAD Initial Drafts" and "CAD Final Design" will be conducted mainly by the Lead ME and, as it is going to be explain later, will be a result of cohesive teamwork.

By achieving these goal objectives, the deliverables to be given to our faculty staff will also be achieved. The "Final Web Page Design" as also the "Final Report' will unite all the information from the previous work developed through the fall semester to provide overview of project progress. Although the schedule is well defined, it is important to realize that it can be subject of change. To make this project smooth and successful, it is essential that all the deadlines be respected and every small delay be reported in order to achieve a better environment in both ways, professional and social.

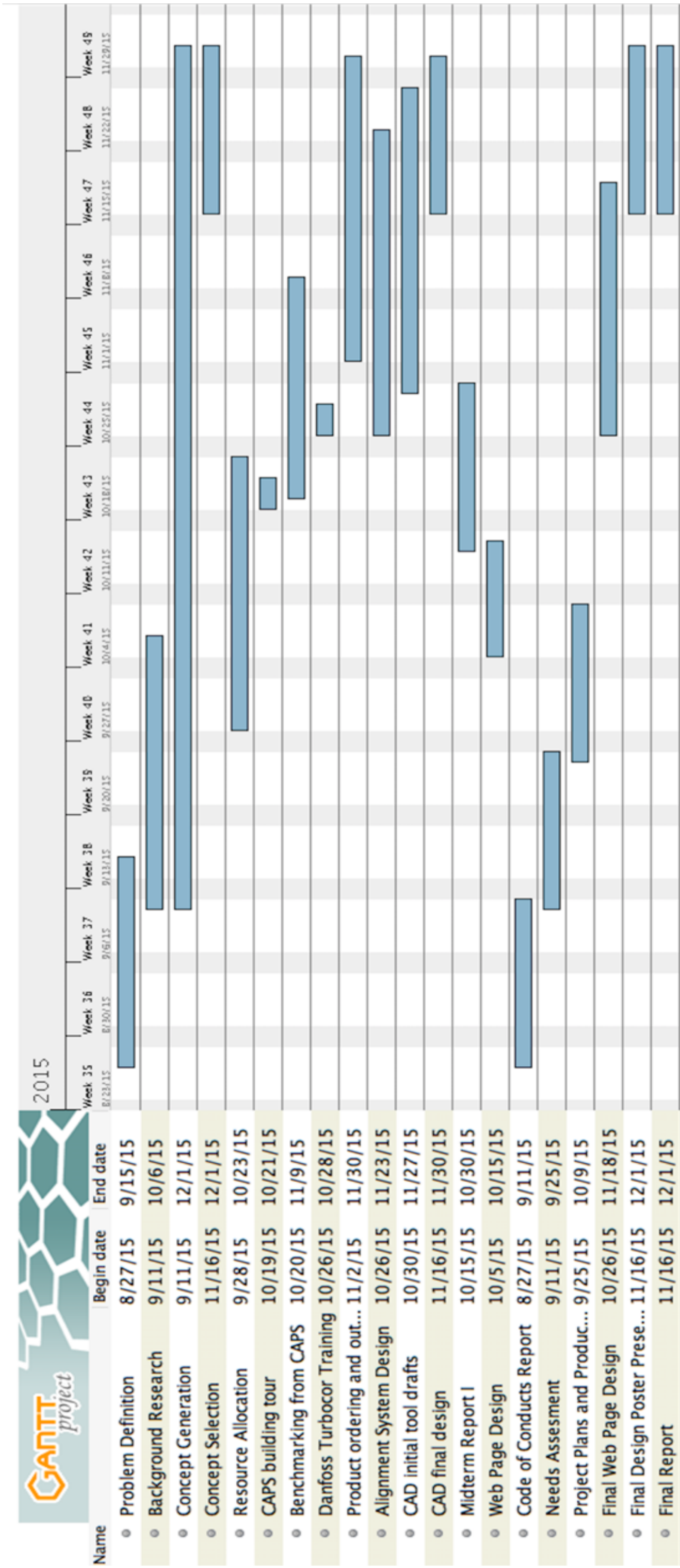

Figure 15. Gantt Chart.

Resources Allocation

Our team has to deal and manage different kind of resources. It's important to classify and stipulate how the team will manage them in order to achieve the results expected for the project. Essentially, the team resources' can be classified as financial resources (economic part of the project), physical resources (facilities and equipment available), human resources (people to work directly on the project), and social resources (individuals providing support and technical knowledge to the team).

Financial Resources

Turbocor is responsible to provide financial support to the team. The budget is open ended. Support will be used to acquire equipment, materials, components, and tools. All expenses must be proven to be beneficial to the project in order to receive financial backing. Although the budget has not limit, it was advised to the team to make educated decisions with purchases to ensure that the expense can be well justified. Up till now, the team has not made any purchases yet. However, there is a current need for Allen wrenches to aid in the compressor disassembly process. This purchase will be made through the coordination with the financial office at the College of Engineering (COE) to insure proper protocols are followed.

Physical Resources

The team can use the facilities from Turbocor as well the facilities from FSU College of Engineering to work on the project. For example, on October 19 the team visited the CAPS building to see an actual test rig. The team will work mainly in the Senior Design Lab at the COE, but this facility doesn't have the requirements to fully operate Turbocor's compressors, such as the power output needed, so the real tests must be made at Turbocor's facilities.

Human resources

The team split tasks between the team members, even though each member is responsible for a single task the team has to work cohesively in order to achieve the results. The tasks split like following: Matthew is responsible for the communication with sponsors and with our faculty advisor, Dr. Hollis. Francisco is responsible for product ordering and outsourcing. Leonardo is responsible to develop and do the maintenance on the team website. Thyeasha and Durval are responsible for leading the CAD design. All the team members are working together on the product design.

Social resources

Our project is new and there is no related project available on the market, so the team is developing a new system that has yet to be done. To do so, the team has a network of people who have technical knowledge to help on the project. Dr. Patrick J. Hollis is the team' faculty advisor, responsible for helping the team to develop design concepts among all other technical concepts. Willian Zun is the team contact in Turbocor, responsible for providing the specification for the product as well acquire the equipment requested from the team. Michael Coleman from the CAPS building explains concepts about the test rig that the building has and provides ideas for shaft alignment. Julio Lopez is an engineer at Turbocor and is responsible for providing specifications and technical knowledge about the compressor that the team has and how to work with it. Dr. Shi and Dr. Gupta are responsible for evaluating the overall team project and providing feedback for areas of improvement.

Conclusion

To summarize the designs analyzed, there are numerous promising aspects being presented. Analysis will continue, which will deepen understanding of the constraints, background research, and current designs. It is a common desire of the team to find the most cost effective solution while also meeting all criteria for Danfoss Turbocor. Efforts will be made to strive for a balance between originating unique solutions, while also understanding which aspects require outsourcing. While working on the design, communication will be made with College of Engineering faculty and Danfoss Turbocor to insure the product progression is feasible and satisfactory. If this can be accomplished, the outcome will be a successful product design for Danfoss Turbocor that also meets a high level academic requirement.

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