Project Plan and Product Specifications

Team 4

High Speed Motor Test Rig

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Sponsor: Danfoss Turbocor

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Abstract

This is the Senior Design Team 4 Product Plan and Specification report. Team 4 is partnered with Danfoss Turbocor and has been tasked with designing a flexible coupler for the High-Speed Motor Test Rig that can be used on a shaft with magnetic bearings and that can help minimize the shaft misalignment that will be observed at 13,000-40,000 rpm. The team has met with William Sun and Dr. Hollis (separately) to define and discuss the problem in order to conduct the proper background research and identify the needs of this project. So far the team has identified the need, researched the current market for a high speed coupler, made a house of quality, and created a Gantt chart schedule to delegate the work and time frame the team will put in this term on the project to possibly reach completion. The team is in the process of acquiring a set of Danfoss Turbocor Compressors in order to envision the design of the rig and prepare a prototype design. The design and project specifications, scheduling, and task delegation are in the works.

1.0 Introduction

Senior Design Team 4 has been tasked with designing Danfoss Turbocor's High-Speed Motor Test Rig. Danfoss Turbocor is different from other companies because it uses high-speed rotation (up to 40,000 rpm) in their compressors. To do so the compressors can't use regular bearings due to the high heat caused by friction and the low lifecycle caused by the fatigue and the magnitude of the strains. To solve this the company uses magnetic bearings, which create an air film between the shaft and the bearing. With this system the friction is highly reduced; this solves mainly the problems mentioned above. However, this system doesn't support radial strain.

Danfoss Turbocor is looking for a way to test their compressor models at very high speeds and maintain the speed for longer periods of time. This project is still in the beginning stages. What that boils down to is what is known and unknown.

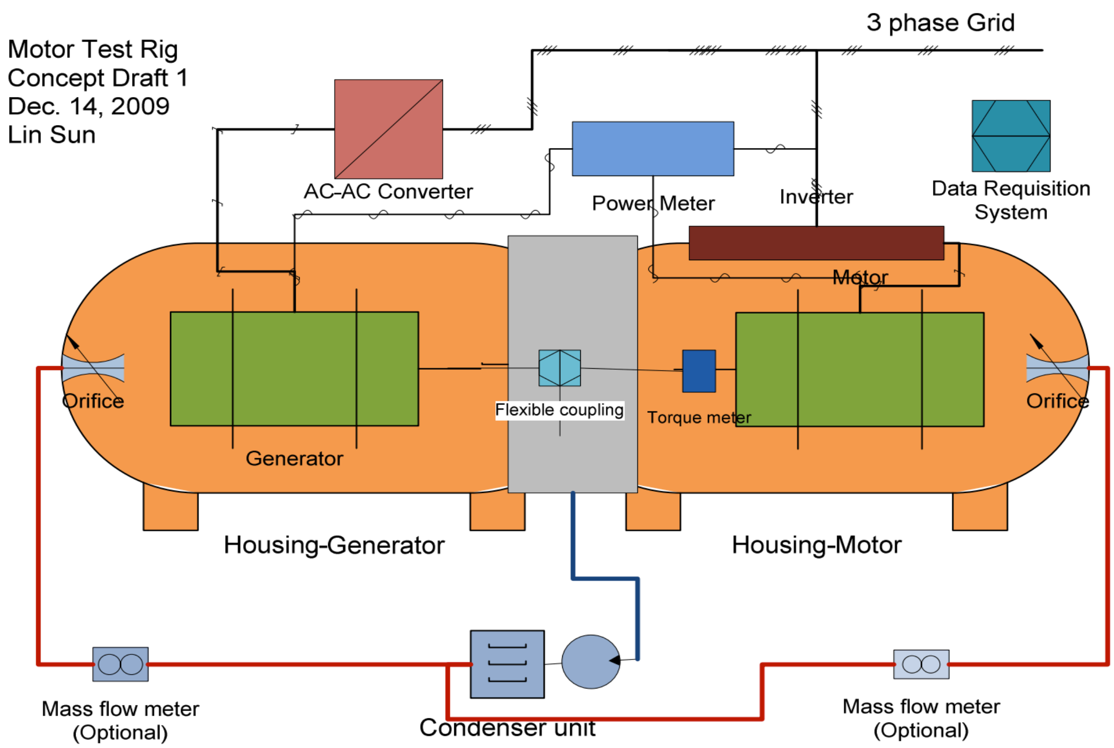


Figure 1: Motor Test Rig

Danfoss Turbocor (Figure 1 above) has provided a rough sketch of what they would like to incorporate in this test rig. Team 4 has had two meetings with the sponsor and, so far, what has been asked of the team at this time is strictly related to the coupling of the compressor's motor shaft to a generator (shaft to shaft). Though the sponsor has not given the dimensions of the shafts, the team has still been researching about shaft misalignment and the different types of high-speed flexible couplers, which do exist in the market, which can withstand the given angular velocities of 13,000-40.000 rpm. It is known that the compressor motor will be coupled to another compressor, either the same model or a different model, and that the second compressor will be considered as the generator. Knowing that these compressors use magnetic bearings and shaft levitation to operate, many questions need to be addressed and answered in order to proceed with coupling the motor and generator shafts and the alignment of these two shafts. Since the focus now becomes what type of coupler can withstand such speeds and still run for longer periods of time in the rig, Team 4 has identified the problem and is taking the necessary steps to resolving the issue.

2.0 Project Definition

2.1 Constraints

Foreseen requirements that the motor test rig must meet pertain to the motor-generator shaft alignment, coupler, and torque transducer. It is important to note that a budget constraint was not given, as the sponsor contact did not have a maximum limit for the team, but instead advised the team to use their best judgment. Shaft alignment must be done to the best ability of the team. Alignment tools are available for purchase, but the early purchase of such expensive equipment may not leave much budget for purchasing near the deadline of the project. Regardless of the method to align the shafts, it has been identified that with poor alignment, there is a risk of too much radial load on the shaft that may overcome the magnetic bearing forces that keep the shaft spinning true.

Possibly the most crucial piece of the project, the shaft coupler must meet five criteria: price, balance, strength, flexibility, safety, and weight. The team must use good judgment to determine a fair price for a coupler. This includes doing analysis to determine if it will be more cost efficient to build the component in house, or to outsource and purchase a pre-fabricated coupler by a supplier. The balance of the coupler is crucial do to the high speeds it will be spinning at. If the coupler is emitting severe vibrations during its use, it may become a hazard to people and the motor-generator test rig. Coupler strength must withstand the rpm and torque range in the test rig. While the sponsor has not answered questions relating to the torque range, the rpm range is known to be from 13,000 rpm to 40,000 rpm. Flexibility is another coupler constraint. Too little and the radial load will be directing to the magnetic bearing forces. Too much and there will be a compromise for coupler strength against high torque levels. Due to frequent human interaction with the test rigs in the lab, the coupler must be safe to observe from a close distance. It is expected that if balance, strength, and flexibility constraints are met, safety will be as well. Lastly, a heavy coupler will put too much rotation resistance upon the compressor and risk fatiguing the internal motor and generator components prematurely. The team does not know an ideal weight currently, but with time a ideal weight range will be determined.

The torque transducer has similar but fewer constraints than the coupler. Since this component will not be being any crucial load in the shaft, strength is not major requirement of it. However, it is necessary that the transducer can withstand the previously stated RPM range. Although questions relating to the maximum expected torque output on the shaft have no been answered, the torque transducer must be capable of reading well up to that maximum torque level. Due to the nature of torque transducers generally making physical contact via shaft, it may be best to utilize a contactless transducer. Price of these contact free transducers are much higher than the common shaft to shaft style sensor and it is not yet known which style will fit the team's ideal budget.

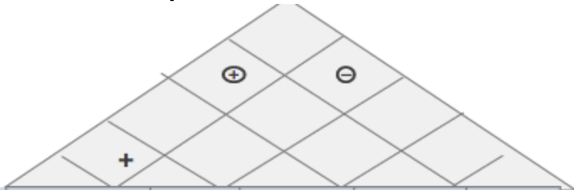
2.2 Methodology

The design team's school location is in close physical distance to Danfoss Turbocor's location. From this it is expected that frequent visits will be made to their location to discuss the on going efforts of the project. The sponsor contact, William Sun, expressed that he would like a very open discussion with the team throughout this project. He would like for the team the team to present their ideas, and receives feedback from Turbocor. Through these discussions, it is expected by William Sun that a final concept will be found that meets all the constraints and then executed. The team's assigned faculty staff advisor is Dr. Patrick Hollis. Contact with Dr. Hollis has already been established and it is expected that the team will heavily consult him with regards to the mechanical systems of the project.

Project progress within the team will be done following the Code of Conducts document. This essentially represents a fair and equal environment where each member is encouraged to equally contribute to the project and do so in a professional manner. The team will look ahead to the project deliverables lists and use this is as a general guideline to meet the sponsors needs. Additionally, the team will also think creatively to find new ways to accomplish goals. Currently, the team is working to reach out to coupling suppliers to see if the market can meet the expected constraints. This process will also be continued for torque transducers and shaft alignment. Once a direction is set for the component sourcing, steps will be made to insure correct integration with the motor-generator test rig. Ideally, this will then lead to the accumulation of components to fulfill the detailed design.

Through brainstorming, the team formed a House of Quality that represents and ranks Danfoss Turbocor's requirements, and shows what engineering characteristics will be used to meet these needs of the customer. It can be assumed that the torque transducer and the shaft coupler will share this House of Quality.

Table 1: House of Quality



Customer Requirements	Customer Priority	Machinability	Strength	Intuitive installation	Tight tolerances	Weight
		o	↑	o	↑	↓
Safe	3		10	4	7	4
Practical	4	10		10		
Durable	2		10		7	7
Accurate	1	10			10	
Cost	5		7	1	7	4
Versatile	6			1		
Importance Rating Σ(Priority X Relationship)		50	85	63	80	46

Correlations:
⊕ Strong Positive
\+ Positive
⊖ Strong Negative
− Negative

Relationships:
•• Strongest= 10
• Strong= 7
⊙ Fair= 4
○ Weak= 1

Technical Assessment

2.3 Design Spec:

The design team has derived two leading options for the project. It has not yet been decided which will be the better option, for it is primarily up to discretion of Danfoss Turbocor. The first plan the team has is a small prototype of the full-scale test rig. This would consist of two DC motors, much lesser in size than the actual compressors. These motors would represent the motor and generator in the test rig. The purpose of using DC motors and not compressors would be to give a platform to test various coupling designs and also learn key parameters to accurate shaft alignment. It is likely that the team would use a DC motor with a shaft of considerable size, unlike some small micro DC motors. The actual shaft of the compressor is roughly 16mm in diameter, therefore the selected DC motor set would need to have a similar shaft size to allow compressor compatibility with the coupler being tested.

Measures were also made by the team to account for shaft alignment in the prototype. Actual Turbocor compressors have four main bolt bosses for mounting. In the prototype test rig, the DC motors would be supported in machined Aluminum blocks that would be secured to a 20”x12” Aluminum base plate. At each mounting location to the base plate, a bolt protruding from the boss would guide through the base plate. On each side of the base plate, nuts would be threaded onto the bolt, to allow elevation adjustment. These bolts would then be tightened when the proper pitch alignment is reached. To further account for misalignment, the drilled holes in the base plate would be slightly larger than the bolts. This way, if lateral alignment is off, it could be minimized through small incremental nudges to the motors. (Figure of bolts and clamp)

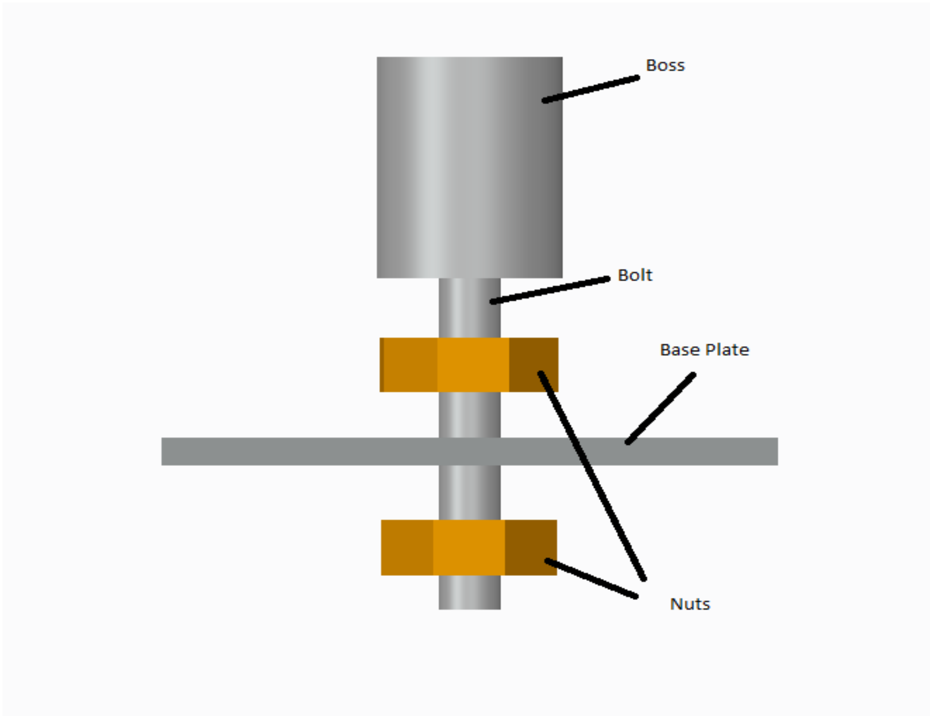


Figure 2. Mount assembly sample.

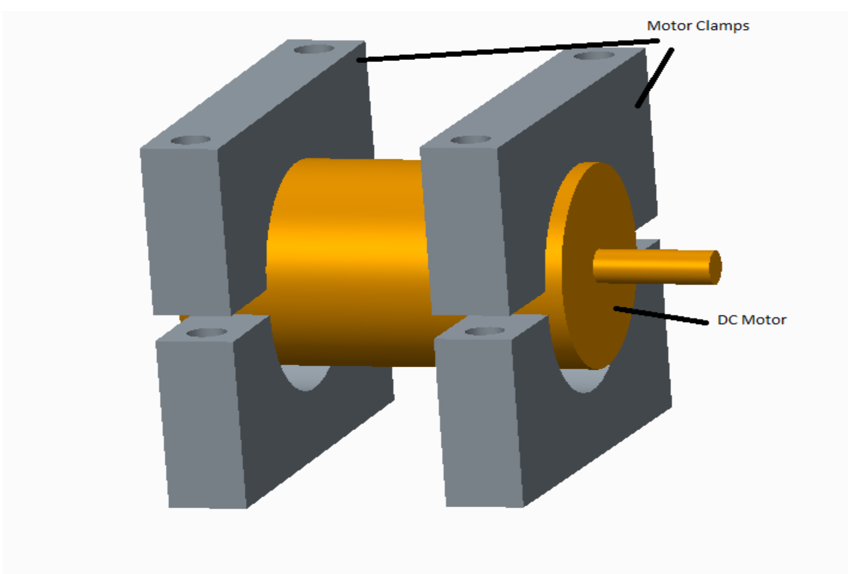


Figure 3. DC motor clamp sample.

The second plan in consideration consists of bypassing a prototype and using the actual compressors in the test rig, as originally proposed by Turbocor. A drawback of the small-scale prototype is that finding a DC motor that meets our requirements for a shaft diameter (16mm) and max RPM (40,000RPM) may be very costly and difficult to find. Therefore, by using the actual compressors, it would be an immediate way to test alignment and couplings. Alignment of the compressors would use the same procedure mentioned for prototype model. This alignment procedure was conceptualized after watching a video of a motor being aligned through the use of shims. It was decided by the team that to keep costs down, the use of bolts and nuts mounted to a base plate would allow all the needed shaft adjustment.

The drawback of this second plan is that in the case of coupling failure or shaft misalignment, the compressors may become severely damaged, which would severely hurt the teams budget and future relationship with Turbocor. The team has proposed some ideas, that outsourcing components in this test rig would minimize places for student error. For example, digital laser alignment tools could be purchased, as well as outsourcing the coupling designs to a company specializing in coupling design. The students would still be very involved with product qualification, in which parameters of the test rig would need to be thoroughly understood before making a purchase from an outside company. There would also be student design input into the baseplate design and adjustable mounting process design.

The final aspect to be integrated into either of these design paths is the torque transducer. Many torque transducers use a rotating shaft that leads into a box that takes calculations from it (Figure 3). Often times DC motors have a shaft that extrudes from both ends of the body, this would provide an open shaft that the torque transducer could be coupled to. In the situation of the compressors being used, it is unsure at the moment where the transducer would couple with the shaft. This is to be determined upon acquisition of a compressor for the team's use.

2.4 Performance spec:

For everyday use in the field, the test rig will require accuracy, durability and safety. These were the leading costumer requirements found from a House of Quality. Shaft alignment accuracy is crucial. If done correctly, it will greatly extend component life cycle in the test rig. It is expected that the alignment process will be intuitive. For example, if the alignment process became confusing to a user, they user may mistakenly increase shaft misalignment instead of correcting it. This would be very fatal to the test rig components. Therefore, a simple to use shaft alignment tool would be a huge benefit in this process.

It is important to note the direct proportional relationship between the three primary performance requirements. Increasing alignment accuracy will reduce unnecessary stresses upon the coupling, compressor internals, and compressor mounting points. Therefore, the durability of the test rig is being improved. Safety concerns stem from the high speeds that the test rig will be running at. If a coupling were to come free at 40,000 RPM it would be a dangerous projectile. Therefore, increasing the durability of the system will improve its safety.

Torque transducer performance expectations are still an unknown to the team. Although it must be operable under 14,000RPM to 40,000RPM, the maximum torque output of the compressors is unknown. However, whatever that torque value may be, the transducer should be able to read beyond that. This is because running a transducer close to it maximum RPM service limit may shorten its life cycle prematurely. Therefore, a torque transducer that can read beyond 40,000RPM is expected.

2.5 Assignment Resources:

Francisco Barreto

- Product ordering,
- Outsourcing.

Mathew Ketchum:

- Communication with sponsor,
- Communication with faculty advisor,

Leonardo Branco:

- Developing the website,

Durval Marques:

- Leading the prototype CAD design,

Theyasha Joseph:

- Co-Leading the prototype CAD design.

2.6 Deliverables and Project Plan:

The team has created a list from start to finish of how the semester will be planned. The schedule of tasks and deliverables can be seen in the Gantt Chart provided in Table 2 and Figure 4. The list is set so that when read top to bottom the chart shows the list in order of milestones, one must be complete before moving on to the other and so on. As far as the actual Danfoss Turbocor Motor Test Rig is concerned, the project is still in its conceptual stage. Once it is determined in the meeting with Danfoss Tuesday October 13th what test rig will be executed, (small or full size) the prototype stage can be initialized. All dimensions and calculations will be completed once the design is agreed upon since the motor specs will be known. From there the CAD drawings will commence and will ultimately lead to the CAD assembly. FEA will be run on Pro-E to determine where this rig will see the most effects due to forces and it will allow for fine-tuning and material selection. The design will then be fabricated and assembled for testing. It is not known what the timetable for prototype completion is just yet since the meeting has not occurred.

Table 2: Gantt Chart Breakdown

Task Name	Duration	Start	Finish
Ice Breaker Report	4 days	Thu 8/27/15	Tue 9/1/15
Code of Conducts Report	12 days	Thu 8/27/15	Fri 9/11/15
Needs Assesment	11 days	Fri 9/11/15	Fri 9/25/15
Market Research	22 days	Fri 9/11/15	Sat 10/10/15
Project Plans and Product Spec's.	11 days	Fri 9/25/15	Fri 10/9/15
Conceptual Design Planning	38 days	Sat 10/10/15	Tue 12/1/15
Web Page Design	9 days	Mon 10/5/15	Thu 10/15/1
Midterm Presentaion I: Conceptual Design	12 days	Mon 10/5/15	Tue 10/20/1
Midterm Report I	12 days	Thu 10/15/1	Fri 10/30/15
Peer Evaluation	3 days	Fri 10/30/15	Tue 11/3/15
Final Web Page Design	18 days	Mon 10/26/1	Wed 11/18/1
Final Design Poster Presentaion	12 days	Mon 11/16/1	Tue 12/1/15
Final Report	12 days	Mon 11/16/1	Tue 12/1/15

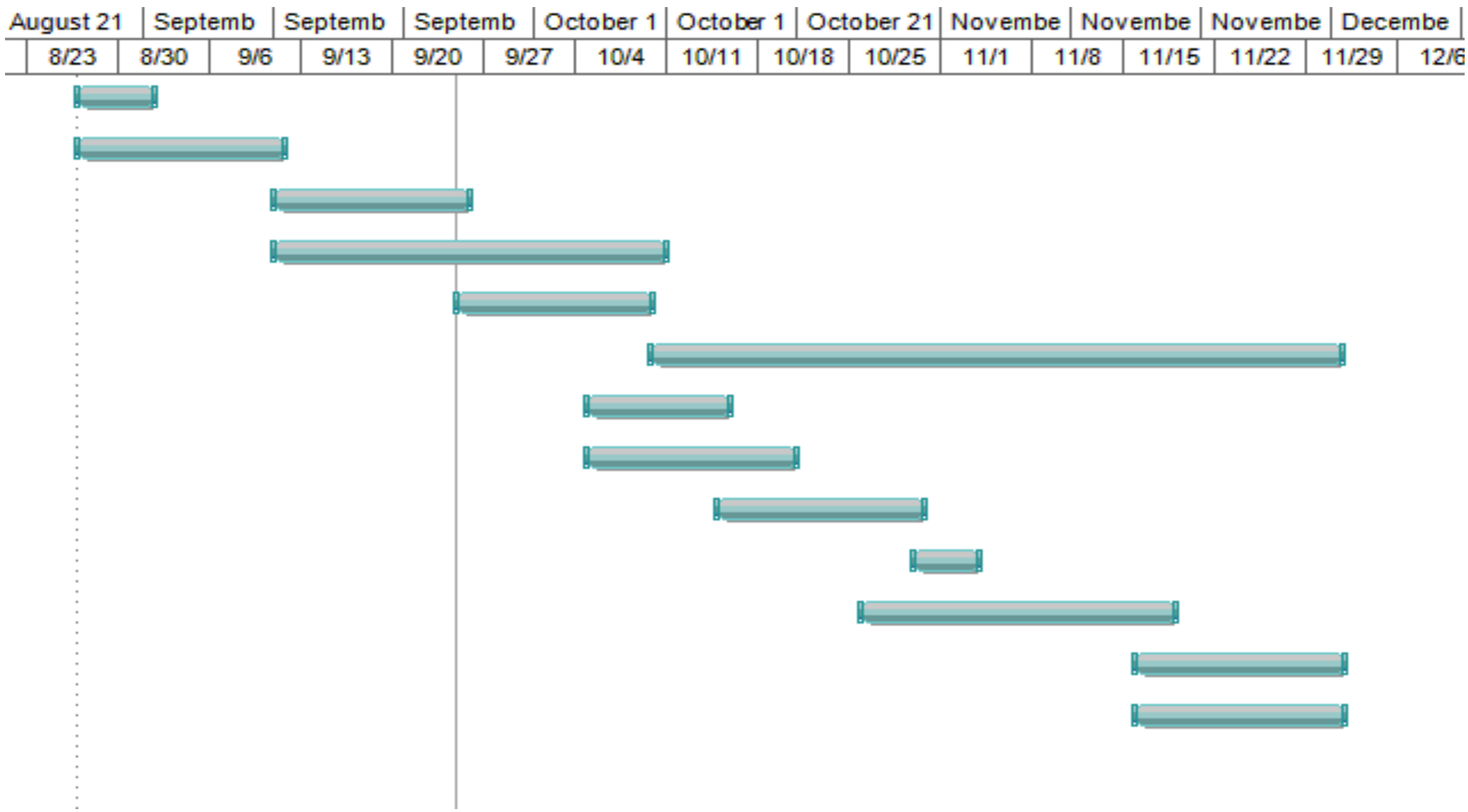


Figure 4 : Gantt Chart

3.0 Conclusion

Since the coupler for this high-speed test rig will have to sustain a high level of reliability at speeds that range between 13,000 rpm and 40,000 rpm, the team will really have to work at building a prototype that is representative of these speeds. This will allow for our test rig to perform efficiently without worry of the coupler failing at out 40,000-rpm limit and show the vibrational and force effects on a coupler due to the misalignment. The Gantt chart is an hoped to be an accurate representation of how the semester will go.

We are unaware of a torque output right now, but will inquire about that with William Sun in the Tuesday meeting. We also plan to contact Dr. Hollis for guidance on designing the system in regard to its mechanical components in the future. Taking into consideration our constraints and our projected goals, we plan to have a final design completed and submitted by December 1, 2015.

References

[1] "DANFOSS TURBOCOR." *Https://campus.fsu.edu/bbcswebdav/pid-7615116-dt-content-rid-43840675_2/courses/EML4551C-0001.fa15/Project%204-Turbocor-1.pdf*. N.p., 25 Sept. 2015. Web.