High Speed Motor Test Rig

Team 4

Submission Date: 10/09/2015
Submitted to: Dr. Gupta
Faculty Advisor: Dr. Hollis
Authors:
Matthew Ketchum (mrk13g@my.fsu.edu)
Francisco Barreto (fjb11b@my.fsu.edu)
Thyeasha Joseph (tlj11f@my.fsu.edu)
Leonardo Branco (lc15d@my.fsu.edu)
Durval Marques (dm15s@my.fsu.edu)

Table of Contents

Table of Figures

Table of Tables

Abstract

This is the Senior Design Team 4 Needs Assessment 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 to rate the engineering characteristics and customer requirements, 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 next steps in this project are obtaining the dimensions for torque calculations and constraints in order to possibly come up with a prototype design for this coupler.

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.

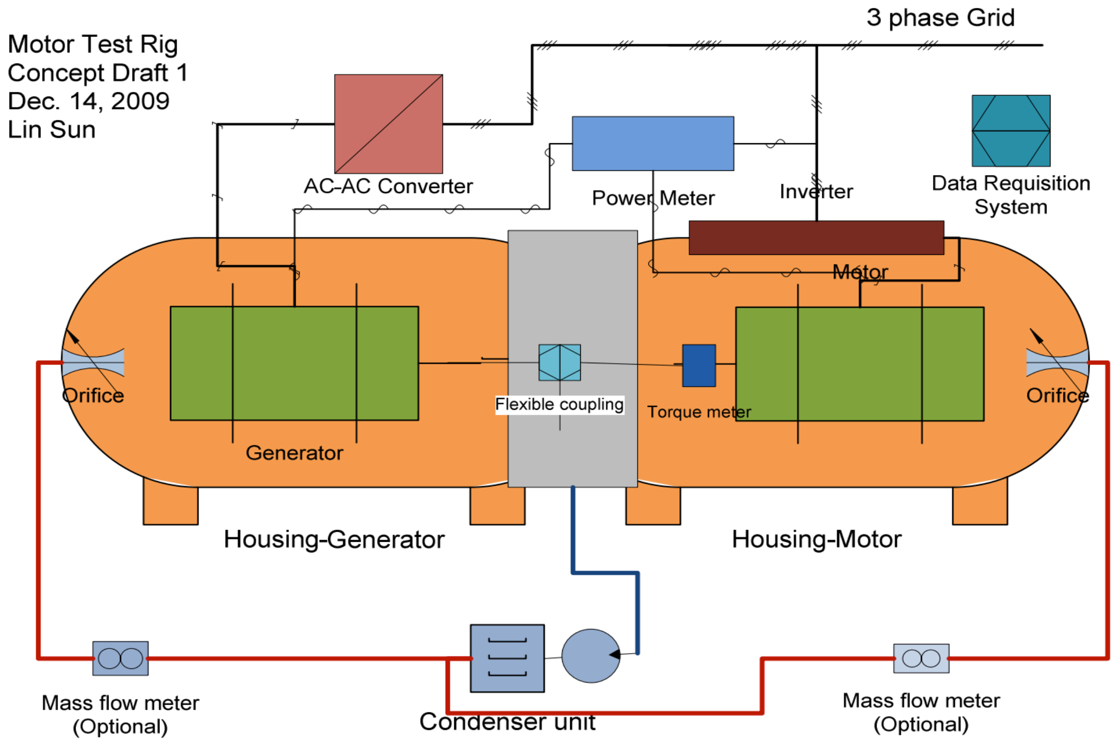


Figure 1: Motor Test Rig

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. After the most recent meeting and after viewing the actual compressor unit, 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 Background research

High-speed couplers are mainly used in high tech products. For example, an F1 engine car rotates at an average of 18,000 rpm [1] . There are different types of couplers available in the market nowadays, such as rigid, flexible and fluid couplers.

Rigid couplers [2] can only be used on perfectly aligned shafts. It could potentially be the perfect solution, if we can guarantee the required aspects. Even though Turbocor has a great alignment and balancing system, our team has to consider small misalignments in order to prevent accidents. Due to the due the high-speed constraint, we can't use this system.

Current trends in the design of rotating machinery at higher speeds show that manufacturers are tending to produce machines, which operate closer to lateral critical speeds. Consequently, the effect of coupling upon the critical speeds and its misalignment on vibration amplitudes of such machines is becoming an increasingly important consideration for rotor-bearing systems [3].

One of the best solutions is the flexible coupler. There are different kinds of flexible couplers. Some are designed for big misalignment and small rotations such as the Hooke's-type joint [1]. Other couplers some are designed for high speeds, low levels of misalignment, and low levels torque, which is our case. The "fast" flexible coupling consists of two hubs [2].

The dynamic performance analysis of the HSFC can be investigated through the finite element analysis (FEA) and so an experimental validation must be carried out [4]. Therefore, the coupling can be designed to accommodate more parallel misalignment by positioning the flexible elements with optimized articulation length. The axial misalignment capability of the shaft is the sole function of axial stiffness of the flexible elements. This observation will be useful in the design of compact flexible coupling where higher misalignment capability within the available space has to be met.

There are commercial high-speed flexible couplers for sale that can resist up to 50,000 rpm [4]. Team 4 will study the possibility of using such kind of coupler.

2.2 Need Statement

Danfoss Turbocor requires a high-speed motor test rig capable of measuring efficiency and power/heat management more accurately while utilizing little power consumption. The motors that are going to be analyzed in this test rig have rotation speeds that range from 13,000 rpm to 40,000 rpm. This value causes the misalignment between the shafts and can cause issues involving mechanical vibrations and even excessive radial load on bearings. A motor/generator coupling and a torque transducer will be required to fulfill the test rig's needs.

2.3 Goal Statement & Objectives

The Main goal for team 4 is to design and construct a Test Rig for Turbocor, focusing on how to deal with the high speed while choosing the proper coupler and alignment system. The objectives are as follows :

- Simple maintenance;
- High alignment precision;
- Simple construction;
- Safety (while operating and building);

2.4 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.

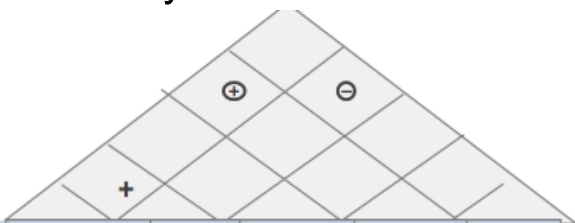
2.5 Methodology

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 / Technical 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

2.6 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 addition of “market research” and “conceptual design planning” show the two main modes of work during the fall semester. Market research will include further insight into the industry for tooling and supplies to meet parameters from Turbocor. Conceptual design planning will draw from the resources acquired during the research phase and lay a future foundation for component design and/or selection.

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 10/15/15
Midterm Presentaion I: Conceptual Design	12 days	Mon 10/5/15	Tue 10/20/15
Midterm Report I	12 days	Thu 10/15/15	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

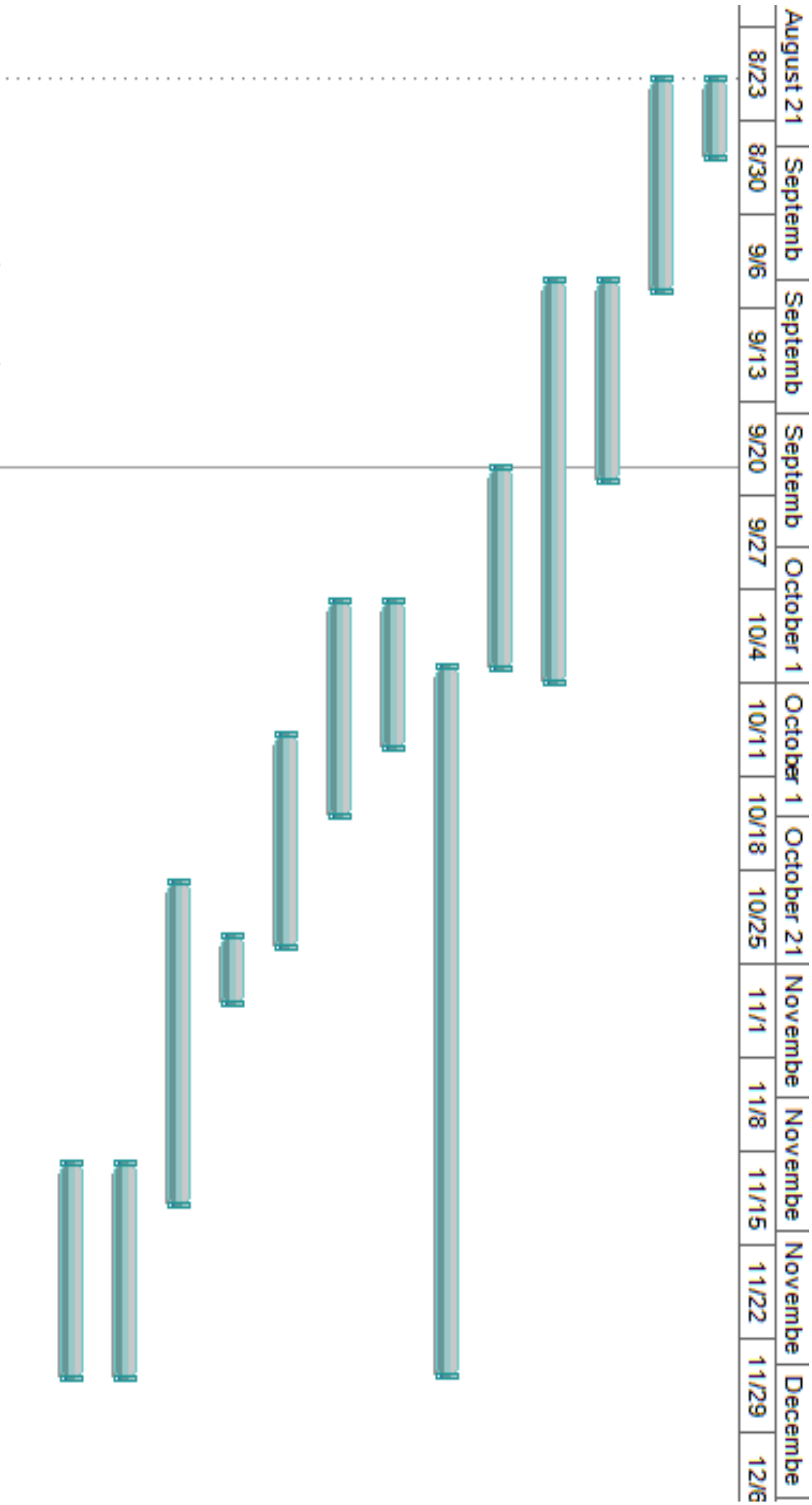


Figure 2 : Gantt Chart

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, team 4's best options must come from a pool of couplers that can resist up to 50,000 rpm. This will allow for our test rig to perform efficiently without worry of the coupler failing at out 40,00 rpm limit. Due to the nature of torque transducers generally making physical contact via shaft, it will be best for us to use a contactless transducer in order to avoid system/coupler failure

We are unaware of a torque output right now, but will inquire about that with William Sun. We also plan to contact Dr. Hollis for guidance on designing the system in regard to it's mechanical components. in the future. We have designed a house of quality with engineering characteristics (weight, tight tolerances, intuitive installation, strength, and machinability) and customer requirements :(safe, practical, durable, accurate, cost, and versatile) that place safety, durability, accuracy, and strength as the design's highest priorities. 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] "Car Facts." *F1*. N.p., n.d. Web. 25 Sept. 2015.

[2] “Marks' Standard Handbook for Mechanical Engineers”. N.p.: n.p., 1987. Print.

[3] SEKHAR, A.S., PRABHU, B.S., *Effects of coupling misalignment on vibrations of rotating machinery*, 1994

[4] SAMIKKANU, N., BASHA, A., *Effects of Misalignment of High Speed Flexible Coupling on the Fighter Aircraft Transmission Characteristics,* 2012

[5] "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.