Motor Test Rig

Design for Manufacturing, Reliability, Economics

Team 5: Alex Jurko, Fehintoluwa Aponinuola, Jack Pullo, Jonathan De La Rosa

Sponsor: Danfoss Turbocor

Faculty Advisor: Dr. Patrick Hollis

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INTRODUCTION

Up until now, a major problem faces Danfoss Turbocor, a leader in compression technology: there is no system to measure the efficiency and torque load of their compressors. Danfoss Turbocor manufactures compressors for the heat, vacuum and air conditioner industry, and is a world leader in this technology because its compressors are oil-free. [1] Danfoss wants to have a good grip on the performance of their compressors at very high speeds, along with maintaining the speed for a longer period of time. The company’s compressors achieve high efficiency due to a combination of magnetic bearings, which use magnetic fields to create a contact-free system between the shaft and bearings, allowing high speeds (up to 40,000 RPM), and variable-speed centrifugal compression, which allows the use of the compressor with the rotation for the highest quality performance.

A motor test rig is a system that comprises of a motor and a generator and a device between them to measure the performance of the generator. In this case, Danfoss’ TT-series compressors serve as the motor and generator respectively. In the actual design of the test rig, a torque transducer is the device that is to be used to observe and measure the performance of the generator; due to the price of this transducer and its lead time, however, Mr. Sun, Danfoss’ representative to supervise this project, asked the team to come up with a mock transducer to prove the concept of the torque transducer. The team came up with a bearing and bearing housing block which will mimic the torque transducer and provide proof of concept.

The test rig is a quite complex system, in that it had to be designed to accommodate the mode of operation of Danfoss’ compressors; the compressors have sensors which keep the rotating shaft within them levitating, adjusting the shaft in the x, y and z directions, as needed. The test rig that is designed is made up of a base frame that is adjustable in the y and z directions through the use of set screws and shims, two double-flex disc couplings which can accommodate the compressors’ shafts’ response to misalignments, a stand for a mock transducer, a mock transducer, a shaft to link the mock transducer to the compressors and two TT-500 compressors.

This year’s senior design team is currently building off of what last year’s team designed. Last year’s team designed an adjustable base frame that was able to change the position of two compressors placed on it, align them, and run the compressors at low speeds. They designed a system with a flexible coupling, which accounted for only a little amount of misalignment. Also, instead of using a laser alignment tool to align their system, the team ended up using a dial alignment system. This may have been the cause of the vibration issues that occurred when testing their design. The test rig was able to run up to about 700 rpm before the vibrations caused the system to shut down.

The overall goal for this project is to be able to have the high speed motor test rig up and running up to about 10,000 rpm without any issues by the end of spring 2017. The safety of team 5 and those who will be operating and maintaining the system is a priority. In order to achieve a safe system, team 5 will be doing different analyses when improving on or making changes to the last year's design. This report addresses details about the manufacturing, reliability and economics aspect of our design.

DESIGN FOR MANUFACTURING

The basic component parts that made up the motor test rig include two TT-500 compressors, two double-flex disc couplings that can accommodate speeds of up to 9,500 rpm, an acrylic safety shield to protect against any failure that may occur, a 20 mm diameter shaft, an adjustable base frame, a bearing and bearing housing which can accommodate speeds of up to 10,000 rpm (representing the torque transducer that was initially to be incorporated in the system), and a mock transducer stand, as shown in figure 1. Of these nine components, only the two compressors and base frame were available at the start of this project; the two double-flex disc couplings, and bearing and bearing housing were purchased; and the acrylic safety shield, 20 mm diameter shaft and mock transducer stand were machined according to the needed specifications. Also, two basic tools - a laser alignment tool (shown in figure 2) and a car-type jack will be use to achieve accuracy in the alignment process, with the aid of shims and set screws.

The process of assembling the test rig is outlined as follows; figure 1 shows an exploded view of the motor test rig.

1. Base frame is set on 2-inch blocks, so that a jack can slide under it for easy lifting of the compressor during alignment.
2. Mock-transducer – bearing housing – stand is bolted onto the base frame.
3. Mock transducer is bolted on mock-transducer stand.
4. 20 mm shaft is put in the bearing and, then, the combination is set in the bearing housing.
5. Two TT-500 compressors are placed on the base frame on both sides.
6. Protruding shaft of each compressor is connected to the shaft passing through the bearing with the double-flex disc couplings.
7. Laser alignment tool is setup to align the test-rig components.
8. Compressors are adjusted using jacks to lift them, shims to keep them aligned in the z-direction and set screws to keep them aligned in the y-direction.
9. Compressors are powered on and calibrated, then ran at various speeds.
10. Acrylic safety shield is placed over the mock-transducer-shaft-and-coupling region for safety.

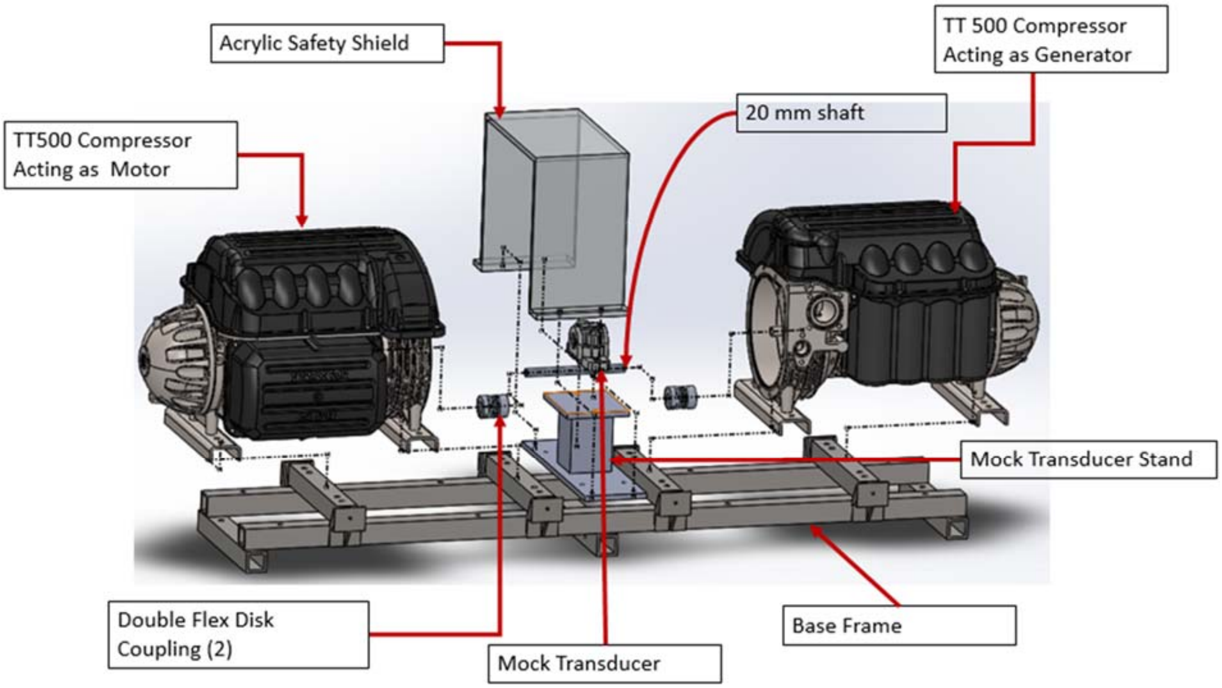


Fig. 1. Exploded view of the motor test rig

Although the setup time of the motor test rig was not given as an important factor, the sponsor emphasized that the alignment of the system should not be tedious, as the compressors weighed about 300 pounds. By using a jack to lift the compressors, instead of a crowbar, which was the method adopted by the previous senior design team, the setup of the test rig was simpler, easier and faster. [2] The design is as simple as possible, every component of the test rig is important and cannot be done without.

Fig. 2. Laser alignment tool [3]

DESIGN FOR RELIABILITY

The design created has still yet to be tested. A few parts have yet to arrive, so early next week the team will begin testing of the rig. The team had conducted an FEA and FEMA analysis in order to determine the loads and durability of the system they had designed. The FEMA was used to decide between multiple designs when the team was first examining last year's design and how they would improve on it. The team had met with an FEA specialist in the fall to determine what kinds of conditions the system could endure. Jack created a report for a finite element class, and on the next page are the findings he made.

The FEMA analysis was used progressively throughout the semester in order to select the right design for the project. An important part of choosing a design was the number of parts in order to maintain the natural frequency for the compressors to run at.

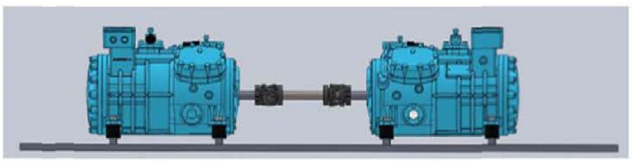
Finite Element Analysis of Motor Test Rig Components

Jack Pullo

12/4/16

Overview

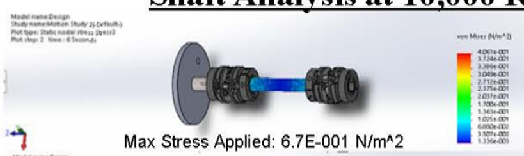
- Implementing a system to test performance of Danfoss Turbocor's TT500 Compressor
  - ❖ Before purchasing expensive components, specific parts were analyzed to determine if the design concept would fail
  - ❖ External conjoining shaft, base plate stand, selected couplings
- Used Creo Pro E and SolidWorks
  - ❖ Displacement, Von Mises Stress, and Factor of Safety diagrams were produced
  - ❖ Turbocor FEA Specialist verified results using ANSYS

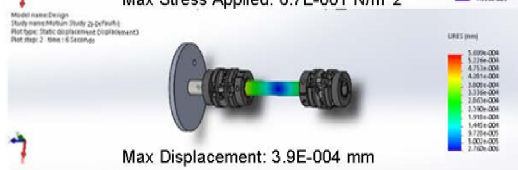


Procedure

- A motor was applied at 2000, 5000, 10000, and 30000 RPM on the internal shaft extruding out of the impeller.
  - ❖ The diagrams show results of external shaft connecting the two coupling to verify that the couplings would securely fasten the external shaft without causing alignment issues.
    - ○ Due to space issues. FEA diagrams of the shaft are only shown at 10,000RPMs
    - ○ Large displacement would effect alignment and result in the compressors shutting down.
    - ○ If the Von Mises Stress surpassed the yield strength, the shaft would rupture
    - ○ If a Factor of Safety under 1 occurred the design structure would fail
- A distributed load of 600 pounds was placed at the critical points on which the compressors located on the base stand
  - ❖ To assure the stand wouldn't collapse and drop the compressors during operation

Shaft Analysis at 10,000 RPM

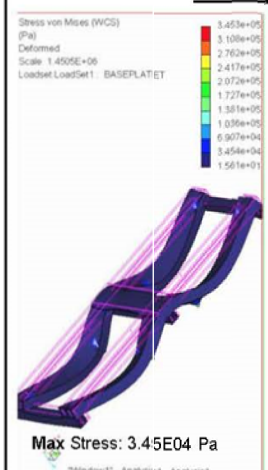


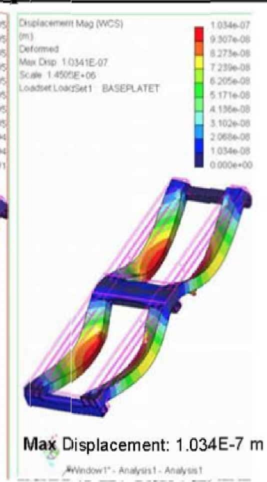


- The yield strength of the selected material is 220594000 N/m^2. Therefore the shaft would not fracture
- The torque applied from the motor doesn't't cause enough displacement to produce alignment concerns
- The factor of safety remains way above a value of 1
- At each speed the results verify that the couplings will work effectively

Confirms that the shaft will not fail during high speed operation

Compressor Base Stand Analysis





- The yield strength of the selected material is 513613000 Pa. Therefore the stand would not fracture
- The force applied from the load bearing of the two compressors doesn't produce enough displacement to cause failure in the design
- Can see the majority of stress and displacement occurs where compressor applies most of its weight

Confirms that the design of stand will not fail while compressors attached

DESIGN FOR ECONOMICS

The budget for this product was estimated around $20,000 but more or less the team was told that they should design for high speeds and then run all purchases through Danfoss Turbocor and they will be told if something it too expensive. The only piece of equipment that was not approved was the torque transducer which ran upwards of $10,000 and thus the bearing and housing was needed to replicate it in the design. Below is an economic breakdown of the whole project's purchases.

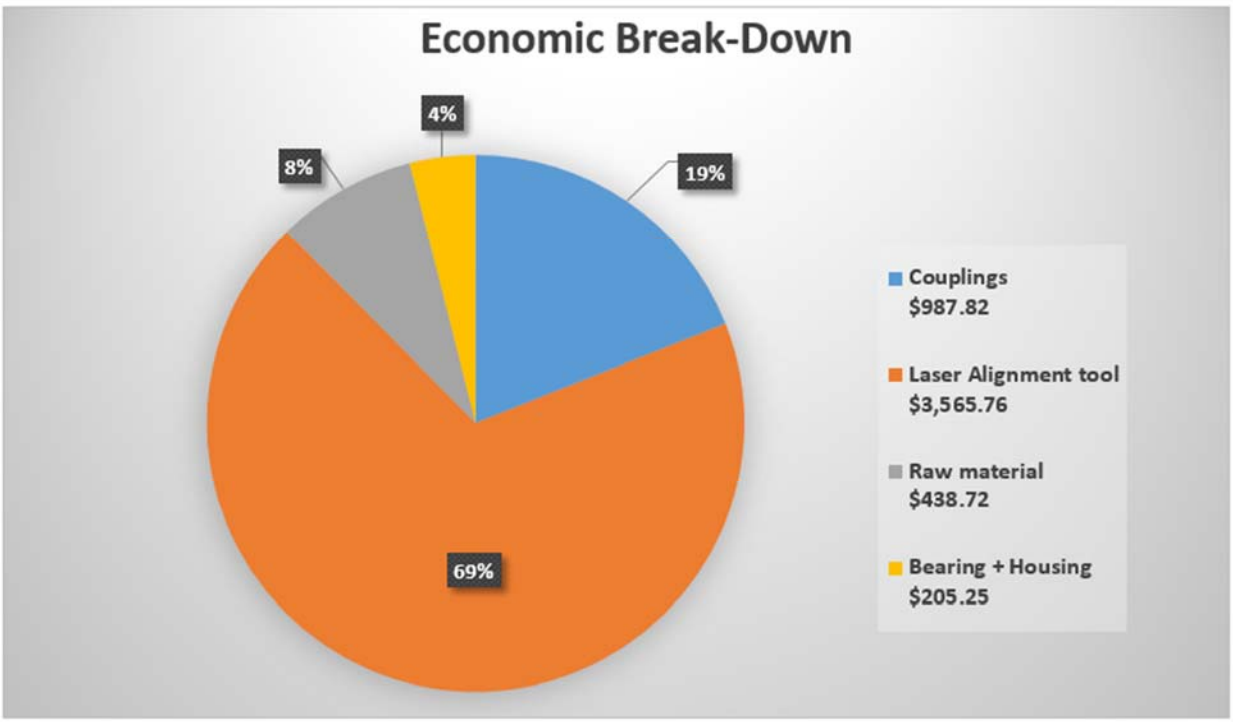


Fig. 3. Economic Breakdown

It is important to note that the majority of the purchases is made up of the laser alignment tool and the couplings. This is key because they will be consistent hopefully in terms of future additions to the motor test rig. If the desired compressor is chosen then these will stay the same in order to accommodate for the high speeds and reducing the risk of misalignment and failure.

REFERENCES

1. http://refrigerationandairconditioning.danfoss.us/products/compressors-for-air-conditioning-and-heating/turbocor/#/
2. http://www.eng.famu.fsu.edu/me/senior_design/2016/team04/DFM.pdf
3. http://www.mitchellinstrument.com/mechanical-testing/laser-alignment-systems.html

APPENDIX

Failure Modes Effects Analysis

Process or Product Name:	Design 4 (Selected Desgin With Transducer)	Prepared by:	Team 5
Process Owner:	Senior Design Team 05	FMEA Date (Orig):	11/10/2016

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Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur?**	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
SKF TKSA 31	Not properly installed correctly	Having the motor test rig misaligned, resulting in higher chance of failure	8	Handling Error	7	Reading the instructions. Along with watching videos from the manufacturer on how to install the equipment properly	7	392							0
	Faulty equipment	Not being able to have the motor test rig properly aligned resulting in a very high chance of failure	8	Manufacturer	3	Standard Operating Procedures	9	216							0
	Lack of understanding with properly operating the equipment	Not having the full potential of the device. This results in not having a proper alignment	7	Human Error	5	Properly reading the instructions and watching tutorials on the device to ensure proper use of it	8	280							0
	Not properly fitting	Failure to align	10	Lack of Research on the range in which the laser aligment tool can attach to	4	Extensive Research into what range the laser alignment tool can attach	8	320							0
Curved Jaw Coupling	Couldn't handle desired rpm	The coupling getting damaged. Compressor shutting down due to possible vibrations that would occur. Also potentially damaging other components on the test rig. Wouldn't meet the end result.	10	Lack of coupler diversity within the prexisting market with such desired rpm speeds	7	Contact distributors to see if it's possible to contrsuct a custom curved jaw coupling	4	280							0
	Not properly installed	Damage can occur	8	Human Error	7	Reading the instruction on how to install the curved jaw coupling correctly	8	448							0

	Exceeded displacement range of the coupler	Causes the compressor to shut down. Potentially damaging the couper itself	10	Selected coupler from research done by the team	4	Further research on the jaw couplings. Discussing with professionals in the industry to select the right coupler	7	280							
	Faulty Equipment	Wouldn't function properly in order to test the design	10	Manufacturer	3	Standard Operating Procedures	9	270							0
2 Rigid Coupling	Couldn't handle desired rpm	The coupling getting damaged. Compressor shutting down due to possible vibrations that would occur. Also potentially damaging other components on the test rig. Wouldn't meet the end result.	10	Lack of coupler diversity within the prexisting market with such desired rpm speeds	7	Contact distributors to see if it's possible to contrsuct a custom curved jaw coupling	4	280							0
	Not properly installed	Damage can occur	9	Human Error	7	Reading the instruction on how to install the curved jaw coupling correctly	8	504							0
	Faulty Equipment	Wouldn't function properly in order to test the design	10	Manufacturer	3	Standard Operating Procedures	9	270							0
Shaft	Improper Length	Won't be able to properly connect the couplers to the compressors	10	The deisgn team	5	Adjustment of the compressors on the frame. Checking the legnth in between the compressors beforehand to properly purchase the correct shaft	7	350							0
	Frequency Issues	The software inside the compressor wouldn't operate properly	6	Complexity of the design due to the additional components	10	The Hammer (Or Dong) Test to see the frequency with the additional components. (Hard to test without purchasing)	10	600							0