Midterm 1 Report

Team 5

Motor Test Rig – Improving Alignment and Incorporating Transducer

Members:

Alexander Jurko adj13c

Jonathon De La Rosa jgd12

Fehintoluwa Aponinuola fehintoluwa1.aponinu

Jack Pullo jap12c

Faculty Advisor/s

Dr. Patrick Hollis

Sponsor

Danfoss Turbocor

Instructors

Dr. Gupta and Dr. Shih

10/21/2016

Table of Contents

Table of Figures

Table of Tables

ABSTRACT

Danfoss Turbocor is the only company that manufactures compressors with magnetic bearings. Magnetic bearings eliminate friction on the shaft inside the compressor, so it's extremely efficient and requires significantly less coolant to run at high speeds in comparison to other compressors. Turbocor's compressors use a process called "levitation" where the magnetized shaft literally levitates inside the compressor via electromagnets, and then it is ready to run. Turbocor approached the FSU-FAMU College of Engineering with the goal of receiving a high-speed motor test rig where they could test the power, efficiency, and heat management of their compressors. Instead of connecting a motor to the compressor, they will be connecting identical compressors while treating one as a motor and the other as the generator in the rig. Last year's senior design team did a very good job in creating an adjustable frame for the 300lb compressors to sit on. They also managed to get the two compressors to run, however it was at low speeds due to multiple issues they came in contact with. Budget constraints restricted their availability for equipment, which is important when dealing with compressors that shut down when Another of their main struggles was dealing with the levitation of the shaft, this became an issue only when an external shaft was introduced(which is necessary when connecting a transducer as well as another compressor). The sensors on the compressor are dealing with the microns in terms of displacement, so any small issue with vibration or misalignment will cause the compressor to shut down or not even achieve levitation to start. With our increased budget this year, we plan to incorporate ideas from last year's team with our own to align the compressors as best as possible with a laser alignment tool, eliminate the issue in axial displacement with a jaw coupling system, as well as incorporate a transducer to actually test the compressor as it runs.

ACKNOWLEDGMENTS

Thank you to Danfoss Turbocor, for giving Senior Design Team 5 the opportunity to tackle the task of the high speed motor test rig. Special thanks to William Sun, Kevin Lohman, and Julio Lopez for the time and effort they've spent teaching us about their compressors and how to use the software to run them.

1. Introduction

Danfoss Turbocor is a leader in compression technology, and is interested in running tests on their compressors to observe how they act when the speed increases. Normally Danfoss runs their magnetic bearing compressors with internal shafts (inside of the compressor). The company designs compressors for heat, vacuum, and air conditioner industry. Turbocor achieves a high efficiency due to a combination of magnetic bearings, which uses 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.

Danfoss Turbocor is still looking for a way to be able to test their compressor models at very high speeds along with maintaining the speed for longer periods of time. This year's team is currently building off of what last year's senior design team produced.

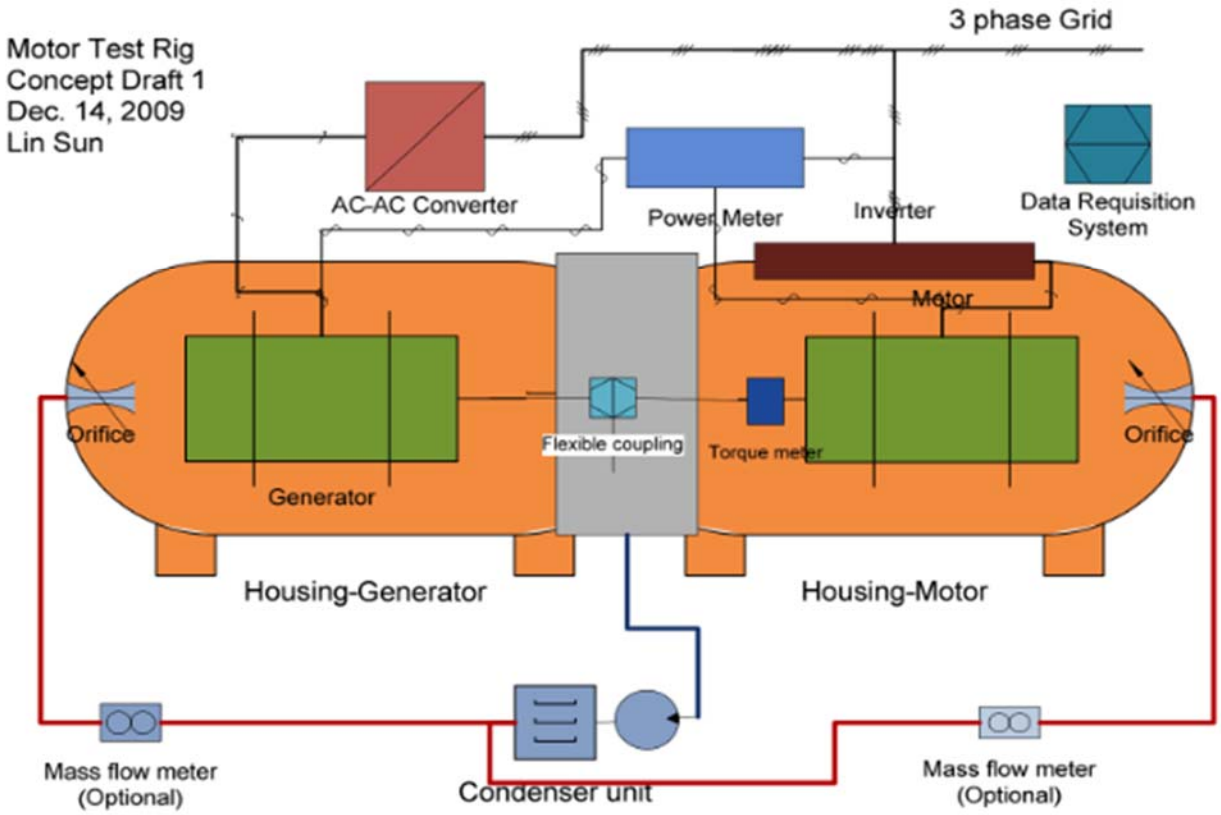


Figure 1 Motor Test Rig [1]

The senior design team that was tasked with this project last year was able to create a design that ran at low speeds. Last year's team designed an adjustable 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 coupler, which accounted for a certain amount of misalignment, but that caused problems later on in their project.

Instead of having a laser alignment tool, team 4 ended up buying a dial alignment system to align the shafts with the compressors. This may have been a cause as to vibration issues occurred when testing the design. Although they were able to stay levitated for a short amount of time, the vibration was bad enough that it caused the compressors to completely shut down. Last year's team improvised and added duct tape in order to dampen the vibration. This was done in order to be able to attempt to operate the machine. With the help of Julio Lopez, the test rig was able to run up to about 700 rpm before the vibrations caused the system to shut down.

The figure below is the CAD drawing of the final design that last year's team ended up creating.

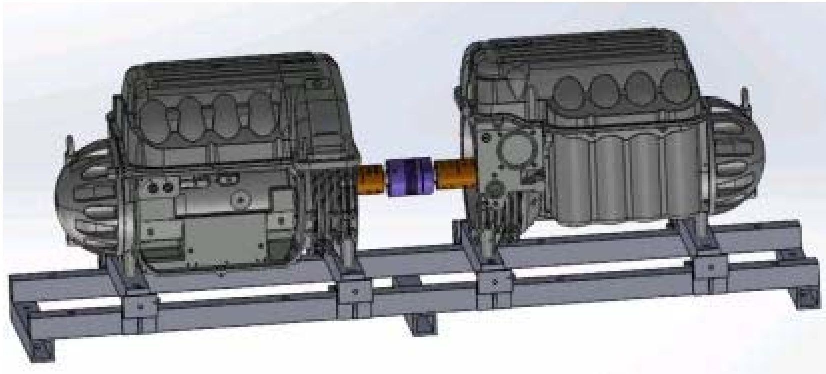


Figure 2 Last Year's Team's Final Design

The overall goal for this project is to be able to have the high speed motor test rig up and running without any issues by the end of spring 2017. In order to achieve this, all sub goals and objectives that are in place for Fall 2016 and Spring 2017 semesters will need to be met. Team 5's objectives are somewhat straightforward due to the achievements that last year's senior design team accomplished with the many constraints that were placed upon them. Team 5 has stated that having consistent levitation to allow the compressors to operate properly is the most important item. Following this would be having accuracy in regards the alignment and balancing in the test rig, then the desired durability and safety will be achieved as well.

The safety of team 5 and those who will be operating and maintaining the system is a priority. In order to achieve this safe system, team 5 will be doing different analyses when improving on or making changes to the last year's design. A way to do this is by doing an FMEA on parts that could potentially be bought to be added to the rig. An FMEA, Failure Mode and Effect Analysis, is a step by step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service . By doing an FMEA on every part that is considered for the design, then the likelihood of failures to occur will be reduced. Team 5 members are aware of the dangers during the test rig assembling that could occur. This risks can occur from improper use of tools and also the weight of the compressors and other test rig components. When the test rig is in operation, safety shielding will be put in place to stop any potential projectiles that could be flung from the system. For any high-speed system, a loose part can cause serious injury or death. Therefore we take this very seriously and will not only double check all of our connections, but have multiple supervisors from Turbocor present during testing.

2. Background Research

Turbocor's compressors excel in four different areas: magnetic bearings, variable speed, digital control, and centrifugal compression. Magnetic properties are used to cushion the compressor's rotor shaft and impellers, providing contact-free levitation. Having one axial and two radial bearings, as well as nine sensors that provide real-time orbit feedback, the shafts are centered with very high precision. The sensors will shut down the compressor if a load of 200 lbf, roughly 270 Nm, is placed on the shaft that the magnetic bearing is holding The figure below represents the shaft beings supported by the front and rear radial bearings along with an axial bearing. The sensor rings are the devices that provide feedback that will control magnetic fields produced by each bearing.

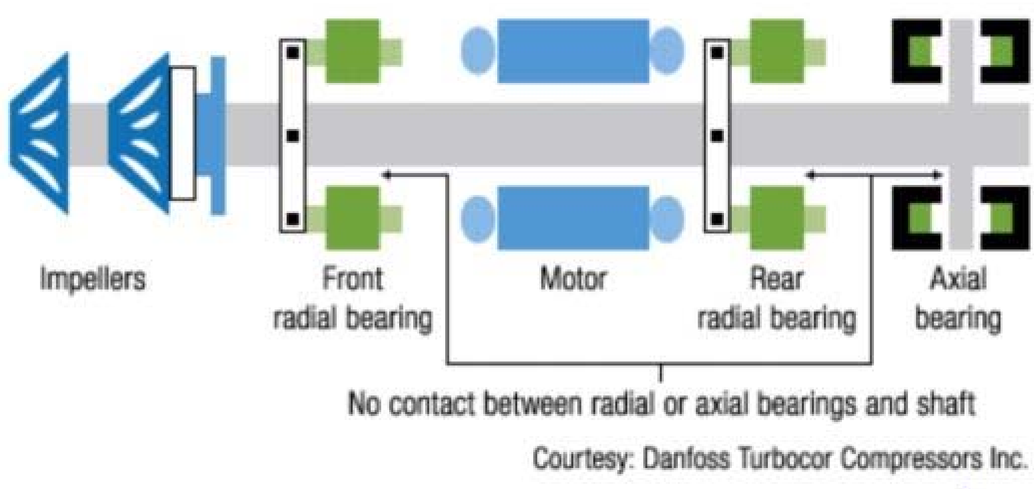


Figure 3 Schematic of Magnetic Bearings

The alignment between two of these magnetic bearing compressors is extremely important. Any misalignment will be amplified when running at high speeds, and this in turn can shut down the compressor. The previous design team used a dial alignment system to align the shafts, but that has a significant amount of human error. They researched and would have liked to use a laser alignment tool, but due to budget constraints that was impossible. This year, team 5 has used their insight to select a laser alignment tool appropriate for the project. The figure below shows the SKF TKSA 31 Laser Alignment Tool, which is around $3,250.00. This works by using three points, rotated around the shaft, to create a plane and determine the offset.

Figure 4 SKF TKSA 31 Laser Alignment Tool

Team 5 has made a design matrix that has the flexible coupler along with two other couplers to compare iit with. This is in order to see whether or not the flexible coupler is the ideal coupler needed for the motor test rig. The other two couplers that team 5 is looking into disc couplings and jaw couplings to put into the design matrix.

Looking into disc couplings we were able to find some with the company LoveJoy. LoveJoy is a company that is a worldwide leader in coupler technology since 1900. A disc coupling is a great consideration for this project. Disc couplings eliminate the need for any lubrication and coupling maintenance. This type of coupling allows for an easy assessment in regards to any misalignment that could possibly occur. When properly aligned and sized, the coupling has a long life span. These disc couplings in particular are made with high grade stainless steel (AISi-301), ensuring high strength, high endurance to fatigue, and resistance to most environmental conditions [].

After the latest meeting with the sponsor, it was determined that Jaw couplings could be a potential alternative to the flexible coupler that the test rig currently has. This is due to the desired rpm reached this year is lowered from 40,000 rpm to 10,000 rpm. Even then, the experienced engineer, Julio Lopez, who is overseeing the project doesn't believe that even 10,000 rpm will be achieved. There are several types of Jaw couplings that can be taken into consideration.

The reason that team 5 is looking into Jaw couplings is because of the fact that they are versatile and robust. They operate in a wide variety of temperatures, can handle angular misalignment, can handle reactionary loads due to misalignment, have good torque to outside diameter capability, have good speed capability, good chemical resistance (spider dependent), and decent dampening capability. A Jaw coupling just consists of 3 parts which makes it easy to install. It consists of two hubs and elastomeric spider/insert. Jaw couplings come with a failsafe that allows the coupling hubs to continue to carry the load when the elastomeric spider fails or wears out, though it isn't recommended for continued system use without replacing the spider. Jaw couplings also tend to be relatively cheap compared to other types of couplings. In this instance, team 5 is taking a look into Curved Jaw couplings that can help out with misalignment issues.

The table below is the design matrix that was created to compare the three different type of couplers. The three conditions that were being compared were the Vibration control, axial displacement compensation, and rigidity. Based on the highest score, the Jaw coupling ended being the best coupling needed for this project.

Table 1 Coupling Decision Matrix

	Vibration Control	Axial Displacement Compensation	Rigidity	Total
Flexible Coupling	1	1	0	2
Jaw Coupling	**1**	**1**	**1**	**3**
Disk Coupling	1	0	1	2

When researching curved jaw couplings, LoveJoy produces two different types of curved jaw couplings; the CJ and GS series. The elastomeric spider that is in between the two hubs varies depending on what the coupler is being used for. The uses for the elastomeric spider is different for the CJ and GS series.

The CJ series is the european standard shaft coupling for curved jaw couplings. It has torsional softness and can deal with angular misalignment of up to 1.3 degrees. It has a failsafe in place where it would continue to operate if the elastomeric spider failed. As stated previously, there are four different types of elastomeric spiders that can be used. The 80 shore A (Blue) is used when good damping properties are needed for the coupler on whatever motor it is being used on. The 92 shore A (Yellow) is used when general and hydraulic applications are applied to the coupler. The 95/98 shore A (Red) is used whenever there is a situation in which the coupler is under high torque. Lasty, the 64 shore (Green) is used when the coupler is in a high humidity environment. More information regarding the different types of elastomeric can be found in Appendix A. The figure below shows how a CJ series jaw curved coupler would look like.

Figure 5 CJ Series Curved Jaw Coupling

Based on what the coupler needs to endure in this project, the best suited elastomeric spider for the CJ jaw curved coupler would be the 95/98 Shore A (Red) in order to handle the amount of torque load that the compressor will put on the coupler. The figure below show an expanded view of the CJ curved jaw coupler with the selected elastomeric spider.

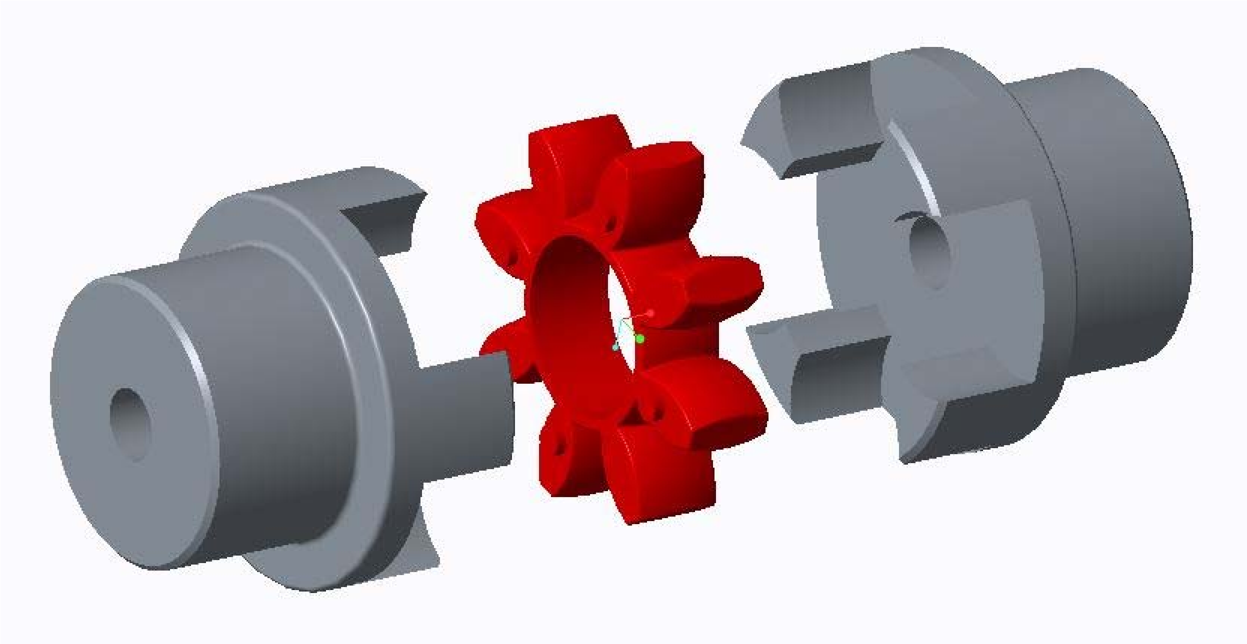


Figure 6 CJ Series Curved Jaw Coupler Expanded

The GS series, seen in the figure above, is somewhat similar to the CJ series with some key differences. The Gs has backlash free capability which is very helpful for application that require high precision and accuracy. It is also fail-safe, no metal to metal contact, and is resistant to oil, dirt, sand, moisture, and grease [].The GS series jaw curved coupling also has four different elastomeric spiders to choose from. The 80 Shore A GS is typically used in a coupler in electronic measuring systems. The 92 Shore A GS is used in a coupler that is used in electric measuring systems and control systems. The 95/98 Shore A GS is on a coupler that is used for positioning drives, main spindle drives, and high load applications. Lastly, the 68 Shore D GS is used with a coupler in high load applications torsionally stiff material.

Figure 7 GS Series Curved Jaw Couplings

Based on what the coupling needs to be able to do in this project, the elastomeric spider is the 95/98 Shore A GS. The figure below shows the expanded view of the GS jaw coupling in detail. The hub design in the figure is just the standard one that is given. However, there are several different types of hub designs that could be considered. More information regarding the types of hub designs can be found in Appendix A.

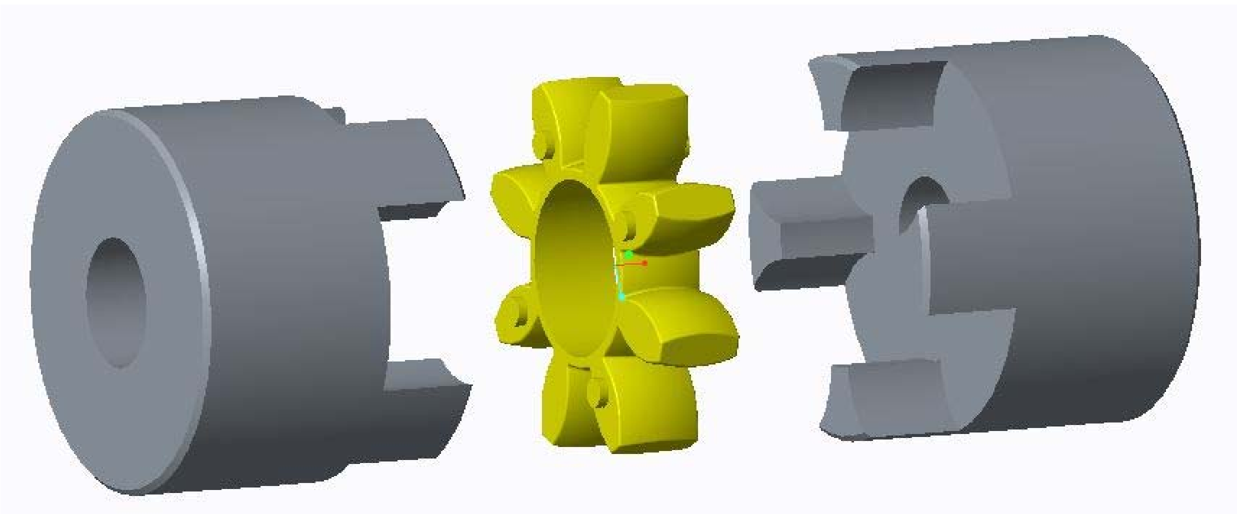


Figure 8 GS Series Curved Jaw Coupler Expanded

Though the curved jaw couplings are looking like a real potential replacement for the flexible coupling that is currently in the hands of Team 5, a big issue will rise up because of this. When having the coupler attached to the shaft which connects to the compressor, the frequency has to match or there will be issues that will occur. The shaft that is inside the TT500 compressor has a frequency of 904 Hz. When adding the curved jaw coupler, the shaft would still have to resonate at 904 Hz in order for the software in the compressor to register it. To test this, the Hammer test is performed on the shaft with the attached coupler to see what the frequency reading is appearing. This situation would need to be covered in the FMEA to see whether not the coupler would work out.

Figure 9 Torque Transducer

Along with replacing the current coupler, a torque transducer will be added on this year. A torque transducer is used in order to gather data on the forces being applied to it from the motor and generator of the test rig. Team 5 has been thoroughly researching for different types of torque transducers that could be used. The conditions that the torque transducer must be able to withstand are as follows; high speed of 10,000 rpm and a force of 100 Nm while the motor test rig is operational. The transducer should be able to withstand such conditions for a long duration of time. A potential torque transducer that could be selected is the T25 High speed from the company Interface. This particular transducer can withstand a force up to 5,000 rpm and up to 30000 rpm.

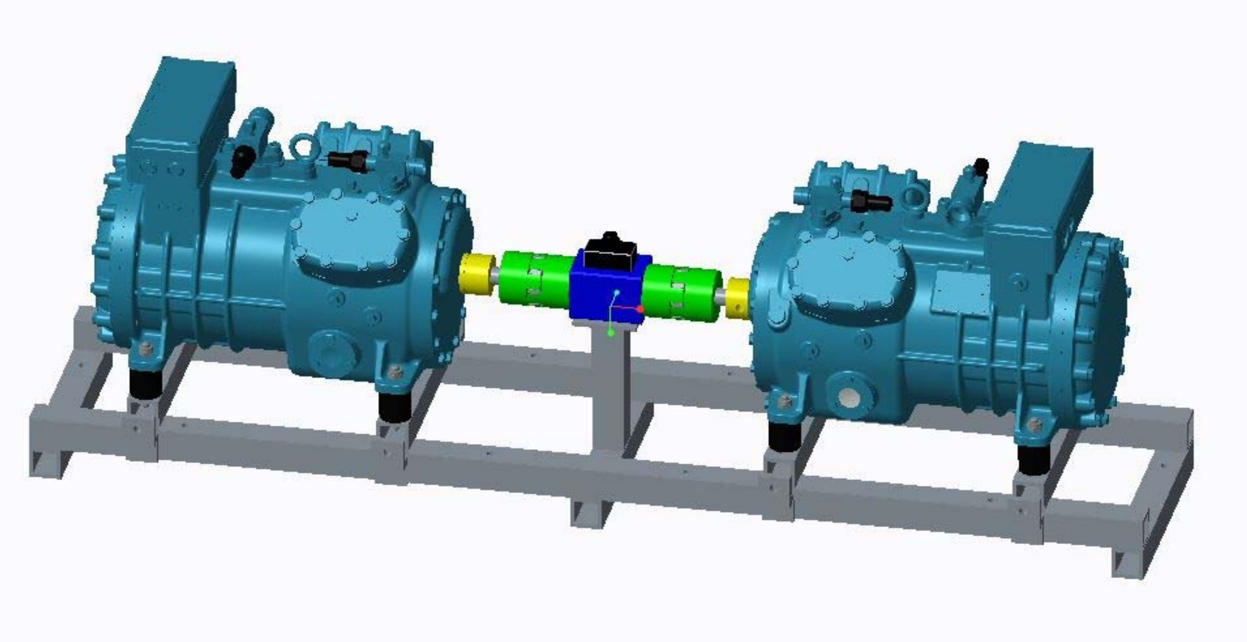


Figure 10 Initial Design For This Year

Based on all the information that has been gathered, team 5 has come up with an initial design of what the motor test rig would look like. A torque transducer would sit on a stand in the middle of the frame. From there two curved jaw couplers would be attached on both sides of the transducer. A shaft is then attached on both ends of the couplers that are then attached to the rigid couplers from last year. The rigid couplers are then attached to the compressors as seen in the figure above.

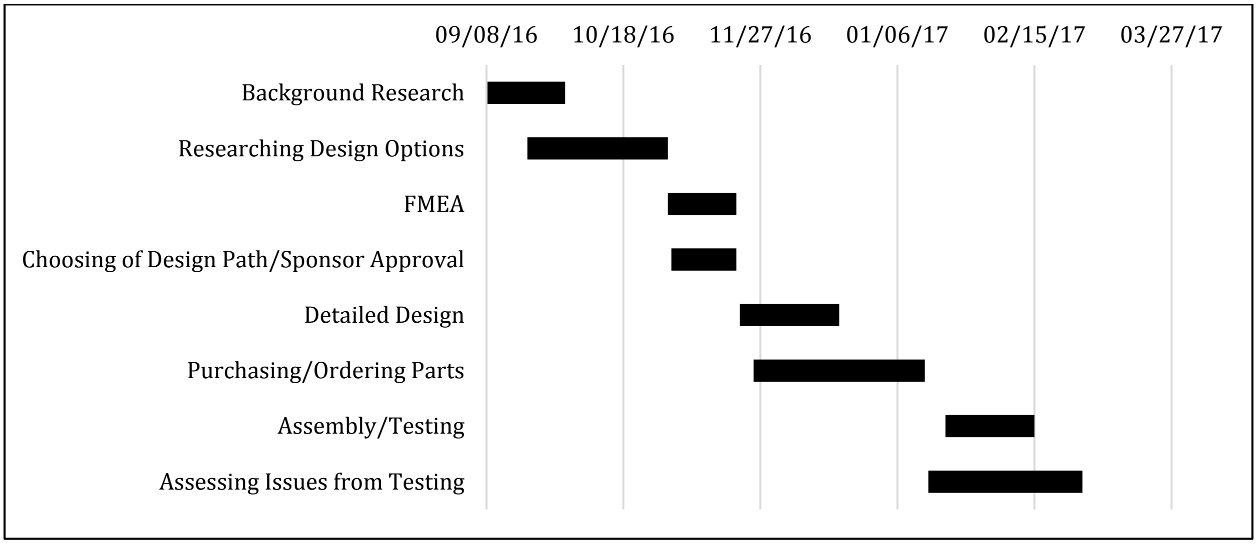
3. Methodology

Throughout the process of designing and building this motor test rig, the following team members have been delegated to specific tasks in order to maintain a consistent work environment:

- Alex Jurko is the team leader, assigned with communicating clearly and frequently with both sponsors and advisors as well as keeping the team focused on the task at hand while staying on schedule.
- Jonathon De La Rosa is the lead mechanical engineer, assigned with designing CAD or Pro E drawings of our design as well as doing most calculation work with assistance of the other members.
- Fehintoluwa Aponinuola is the lead web designer, assigned with keeping the senior design team's website up to date with deliverables as well as being delegated to whatever task needs assistance if the website is up to date.
- Jack Pullo is the financial advisor, assigned with managing the budget of the project while researching alternative options for cost-effective solutions as well as being delegated to whatever task needs assistance at the time.

The following Gantt chart, Table 2, has been created to show the design team's hopeful schedule for the remainder of the fall and spring semesters ahead.

Table 2 Gantt Chart



4. Conclusion

Senior Design Team 5 plans to have their rig up and running around the middle of February 2017. The tools that the team plans on using are the SKF TKSA 31 Laser Alignment Tool, which will improve upon the alignment process in comparison to last year's design team which used a dial alignment system. The laser alignment tool eliminates the problem of "eyeballing" the dial readings, and reduces human error in the alignment process. Team 5 also plans to use an approved* torque transducer to analyze the speeds (up to 10,000rpm) and the torque (up to 100N*m) for the rig in order to observe how the compressors react to an external shaft at high speeds. In order for team 5 to overcome the obstacle of levitation, they plan to use jaw couplings to connect the shafts. Jaw couplings were deemed the best option for this project because they are resistant to vibration and are able to adjust in the axial direction. This axial direction displacement is believed to be the issue that the previous design team faced when testing their rig, and prevented the system to run properly.

References

1. http://asq.org/learn-about-quality/process-analysis-tools/overview/fmea.html
2. http://www.lovejoy-inc.com/products/disc-coupling.aspx
3. http://www.lovejoy-inc.com/products/curved-jaw-couplings/cj-type.aspx
4. http://www.lovejoy-inc.com/products/curved-jaw-couplings/gs-type.aspx
5. http://www.couplinganswers.com/2014/10/jaw-coupling-overview-features-benefits.html
6. http://www.interfaceforce.com/index.php?mod=product&show=188

Appendix A

Table 3 Coupling Spider Data

CJ Series Elastomer Recommendation Chart

Spider Type	Application types requiring:
80 shore A (Blue)	Good dampening properties
92 shore A (Yellow)	General & hydraulic applications
95/98 shore A (Red)	High torque requirements
64 shore (Green)	High humidity environments

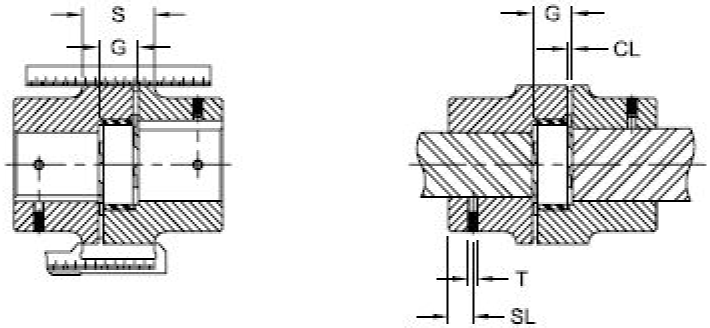
CJ Series Elastomer Performance Data

Spider Type	Color	Material	Temperature Range		Stock	Misalignment (inches)			Typical Applications
			Normal	Maximum	Sizes	Angular	Parallel	Axial	
80 Shore A	Blue	Polyurethane	-40° to 212° F	-40° to 248° F	14-180	.9 - 1.3 deg	.008 - .027	.039 - 252	Good dampening properties
92 Shore A	Yellow	Polyurethane	-40° to 212° F	-50° to 248° F	14-180	.9 - 1.3 deg	.008 - .027	.039 - 252	General & hydraulic
95/98 Shore A	Red	Polyurethane	-40° to 212° F	-40° to 248° F	14-180	.9 - 1.3 deg	.008 - .027	.039 - 252	High torque requirements

CJ Series Special Elastomer Data

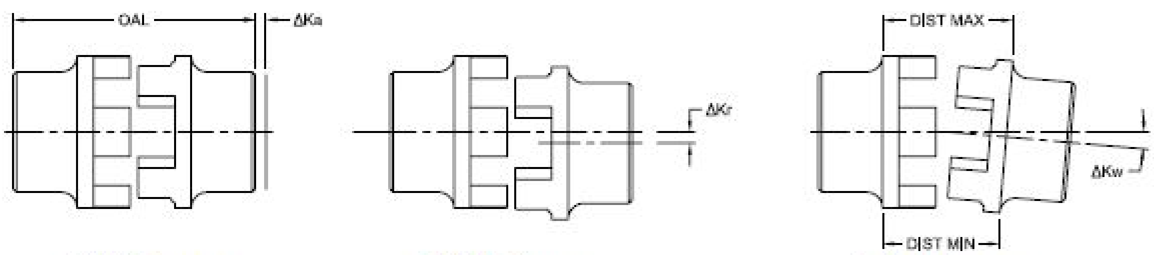
Spider Type	Color	Material	Temperature Range		Stock	Misalignment (inches)			Typical Applications
			Normal	Maximum	Sizes	Angular	Parallel	Axial	
64 Shore D	Green	Polyurethane	-30° to 230° F	-30° to 266° F	14-180	.9 - 1.3 deg	.008 - .027	.039 - 252	Highly humidity environments

Table 4 CJ Misalignment Data



CJ Series Installation and Misalignment Capabilities

Size: / Dimensions	14	19	24	28	38	42	48	55	65	75	90	100	110	125	140	160	180
G	0.51	0.63	0.70	0.79	0.94	1.02	1.10	1.18	1.38	1.57	1.77	1.97	2.17	2.36	2.56	2.95	3.35
CL	0.06	0.08	0.08	0.1	0.12	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.35	0.41
H	0.39	0.71	1.06	1.18	1.50	1.81	2.01	2.36	2.68	3.15	3.94	4.45	5.00	5.79	6.50	7.48	8.66
S	—	1.02	1.18	1.34	1.57	1.81	1.97	2.20	2.48	2.83	3.27	3.62	4.06	4.57	5.00	5.71	6.42

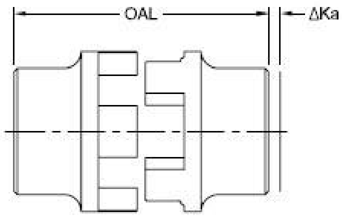


Axial Displacement Radial Displacement Angular Displacement

CJ Series Displacement For Displacement / Misalignment (inches)

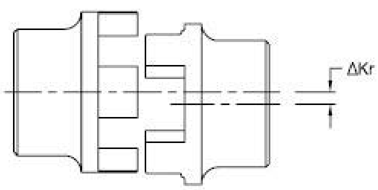
Size:	14	19	24	28	38	42	48	55	65	75	90	100	110	125	140	160	180
Max Axial Displacemnet (Ka)	0.04	0.047	0.055	0.06	0.07	0.079	0.082	0.87	0.102	0.12	0.133	0.15	0.165	0.18	0.19	0.22	0.25
Max Radial Displacement (Kr)	0.007	0.008	0.009	0.01	0.011	0.012	0.014	0.014	0.016	0.018	0.019	0.02	0.021	0.024	0.024	0.025	0.027
Kw Max angular displacement n=1500 [1/min] in deg (Kw)	1, 2	1,2	0, 9	0, 9	1, 0	1, 0	1, 1	1, 1	1, 2	1, 2	1, 2	1, 2	1, 3	1, 3	1, 2	1, 2	1, 2
Angular Displacement	0.03	0.03	0.04	0.05	0.07	0.07	0.08	0.09	0.11	0.13	0.17	0.19	0.22	0.25	0.26	0.3	0.35
Set Screw Information																	
Set Screw Size (T)	8-32	10-24	10-24	5/16-18	5/16-18	5/16-18	5/16-18	3/8-16	3/8-16	3/8-16	3/8-16	1/2-13	5/8-11	5/8-11	—	—	—
Set Screw Location (SL)	0.2	0.39	0.39	0.59	0.59	0.79	0.79	0.79	0.79	0.98	1.18	1.18	1.38	1.57	1.77	1.97	1.97

Table 5 GS Misalignment Data



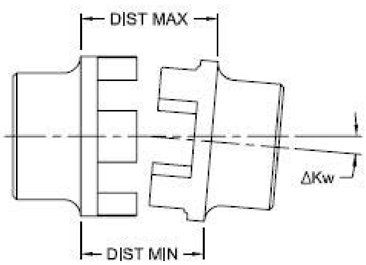
Axial Misalignment

Axial misalignment can be caused by different shaft tolerances or by thermal expansion of shafts. The GS Series coupling handles axial misalignment while keeping reactionary forces low.



Radial Misalignment

Radial misalignment can be defined as a measure of the offset distance between the centerlines of the driving and driven shafts. This type of misalignment, due to the forces involved, causes the highest stress.



Angular Misalignment

Angular misalignment can be defined as a measure of the angle between the centerlines of the driving and driven shafts, where those centerlines would intersect approximately halfway between shaft ends. The GS Series coupling can handle a specific amount of angular misalignment for each given size (refer to chart on right).

GS Series Misalignment Data

Size	Spider Shore	Misalignment		
		Axial	Radial	Angular
14	80	+0.039 -0.019	0.008	1,1
	92		0.006	1,0
	98		0.003	0,9
	64		0.002	0,8
19	80	+0.047 -0.019	0.006	1,1
	92		0.004	1,0
	98		0.002	0,9
	64		0.001	0,8
24	92	+0.055 -0.019	0.005	1,0
	98		0.004	0,9
	64		0.003	0,8
28	92	+0.059 -0.027	0.006	1,0
	98		0.004	0,9
	64		0.003	0,8
38	92	+0.070 -0.027	0.007	1,0
	98		0.005	0,9
	64		0.003	0,8
42	92	+0.078 -0.039	0.007	1,0
	98		0.005	0,9
	64		0.004	0,8
48	92	+0.082 -0.039	0.009	1,0
	98		0.006	0,9
	64		0.004	0,8
55	92	+0.086 -0.039	0.009	1,0
	98		0.007	0,9
	64		0.005	0,8