

Restated Project Definition, Scope, and Project Plan

Team 4: High Speed Motor Test Rig



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1.0 Problem Statement

Danfoss has desires a system to qualify their compressor motor performance specifications. To complete this qualification, Danfoss must evaluate a motor's life cycle and efficiency while in operation. This must be done in a test rig that will accommodate the compressors. Unfortunately, there is not a current test rig on the market that can handle the speeds at which their compressor shafts spin (up to 40,000 rpm). These high speeds that are experienced will require a system that must be aligned to the utmost precision (up to 0.1mm axially and 1mm radially) and be finely balanced. Senior Design Team 4 has been tasked with designing a High Speed Motor Test Rig to qualify motor performance for Danfoss Turbocor.

2.0 Background

The HVAC market has been increasing in size and has been continuously producing new compressor systems. Danfoss Turbocor has been continuously innovating to stand out as one the leaders in such a market. Despite the fact that Turbocor started out in Australia back in 1993, they did not go about installing their first compressor (the TT300) until the year of 2001 in California, USA. In recent years, however, Turbocor stands as a leader in the oil-free, centrifugal compressor product market. They have been supplying the world with the most efficient refrigerant compressors for the HVAC industry (over 35,000 compressors to be exact).

Danfoss Turbocor is in need of a motor-generator system that can be used to qualify compressor motor performances. They seek to qualify the efficiency, power, and heat management. A motor-generator functions by coupling the shaft from a motor to a generator. This typically is used to produce power from the generator. Turbocor wishes to use two compressors in place of the typical motor and generator. One compressor will use its motor to back drive the other compressor by coupling their shaft together. For this project the impellers will be removed. Motor generator systems usually use a simple method that involves special tools to align the shafts together. The compressors that will be used in Turbocor's system will reach speeds much higher than average motor-generator systems. Therefore this project requires special design efforts to be made to the alignment process.

3.0 Objective

Turbocor has delegated Team 4 with the task of designing and constructing a High Speed Motor Test Rig. Team 4 has been focusing on how to deal with the high speed of the compressors (12,000 - 40,000 RPM) that Turbocor produces while choosing the proper coupler and alignment system that can efficiently work with said systems. Detail must be focused upon the alignment system. This is because the compressors use magnetic bearings, which by nature have different tolerances to load versus typical ball bearings. The area enclosed by the red circle in Figure # is the area that team 4 has been focusing on. It includes the drive shaft, the flexible coupling (highlighted in teal), and the torque meter (highlighted in blue). The team's main objective is to construct a system with all the components highlighted in Figure 1 and do so in the safest and most effective manner. It must also be noted that Team 4 was fortunate to have their sponsor be a local business. This made it easy for the team to be trained on how to run the

compressors. The team was also able to keep a TT500 compressor on the FAMU-FSU College of Engineering's campus for experimental purposes.

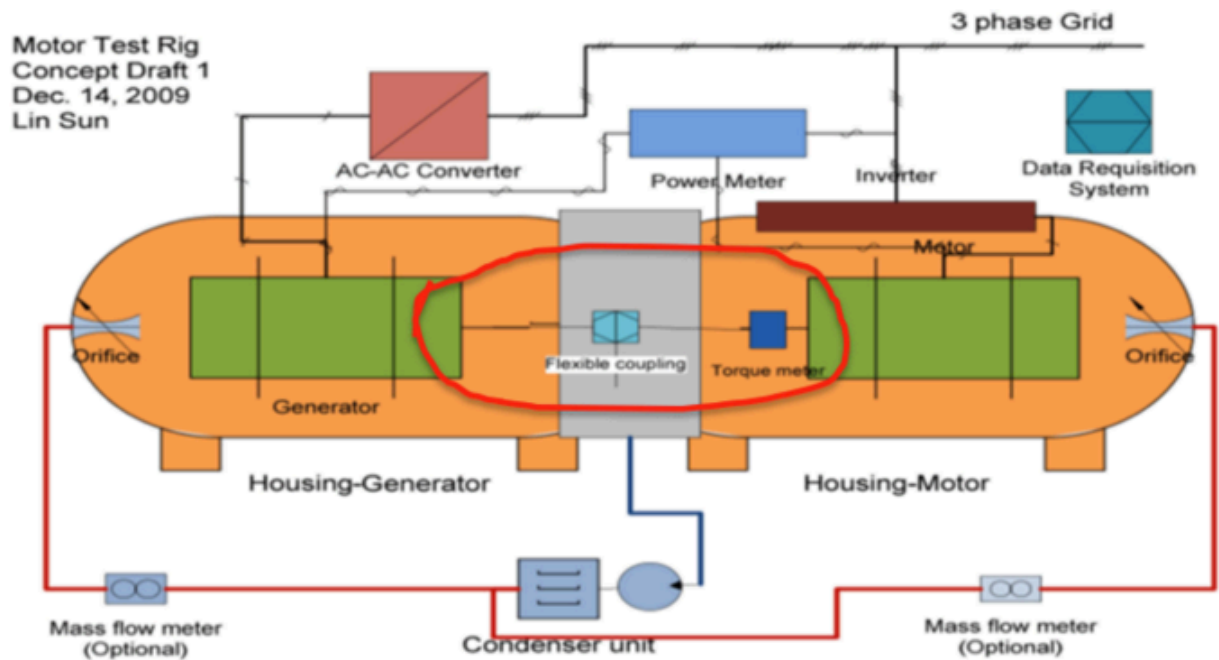


Figure 1: Motor Test Rig Draft

During this spring semester, Team 4 will be aiming to reach a new objective than the previous semester. Fall semester was focused upon design, and this spring the ordering of parts will begin which will then begin the assembly process. To reach the precision alignment objective, the team will order shims, set screws, and a TKSA 31 Laser Alignment Tool. Supporting the entire system will be a steel frame 2"x2" square tubing with 1/4" thick walls. An inline style torque transducer will be between each compressor, and the transducers' shafts will connect via flexible coupler and rigid coupler to a compressor shaft. From figure 1, it shows that between the compressor (green boxes), is where the couplers and torque transducer will be placed. Figure 2 shows the latest design from Team 4 that shows the frame design, and implementation of the flexible and rigid couplers, as well as the torque transducer. Note, figure two does show the compressor in place.

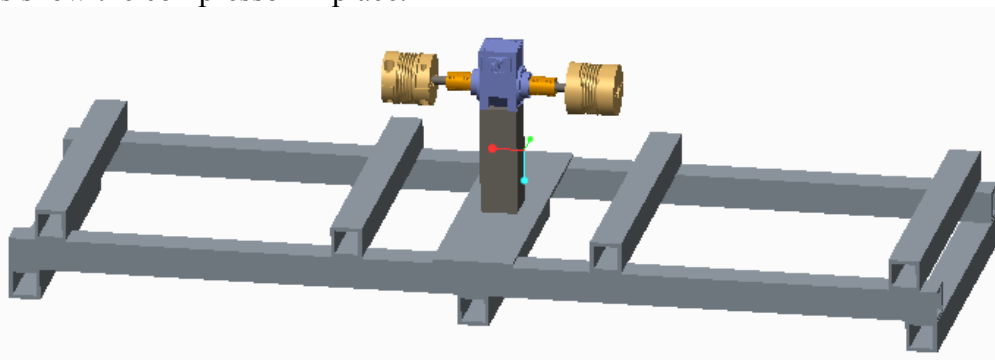


Figure 2. Test rig assembly. Transducer (blue), rigid couplers (gold), flexible couplers (tan).

4.0 Construction Process

The test rig is comprised of a steel base plate, 8 setscrews, shims, standard bolts, torque transducer, and two TT Series compressors. Figure # shows the most updated design. First and foremost, the frame must be constructed as precisely as possible. Being that it is made of steel it can be bolted or welded. Team 4 has decided that the lower cross members in the frame are to be welded and the rest fastened with ½” hex bolts. The reason for deciding to not weld the entire frame is simple, warping. Being that this frame is to be built as precisely as possible, the warp from welding could affect the straightness of the steel tubing and also compromise the alignment process. It has recently been brought up to the attention of the Team that in the event of the disapproval of the torque transducers, due to price, the team would have to adapt the design and construction. Team 4 will carry on as if the transducer will be approved but come up with an alternate “mock-transducer” to mimic the stand of the transducer and still be able to assemble the design according to plan. Once the transducer or mock transducer is mounted, the compressors will be mounted with the shims resting underneath. The couplers will be fastened to the transducer shafts and then one at a time will be aligned to the compressor shaft using the laser alignment system purchased. This alignment system will be used to qualify the alignment process and once the team feels that the alignment is complete the testing will ensue.

5.0 Methodology

In order to ensure that the Team delivers on this project and that it goes smoothly, the team met the first week of the semester to set goals for the project. The first goal was to have all parts ordered by mid January. This is important because of the delays associated with ordering parts and the team wants to be sure that there will be sufficient time to collect all of the parts and test this design. In the time that will be spend waiting on parts, the team will still continue to conduct further research into the alignment process. As the parts start to come in they will be assembled and once all parts arrive the full system construction process begins. As stated before, testing will begin once the system's alignment is complete. The team will also work comprehensively on all deliverables and prepare diligently for all presentations.

6.0 Expected Results

The team aims to satisfy the expectations of William Sun from Danfoss Turbocor. This will be accomplished by constructing a test rig that successfully aligns the compressor shafts, tolerates the possible harmonic vibrations induced from high-speed rotation, and proves to be safe and durable. This will allow for Danfoss employees to use the rig to qualify motor performances. To achieve this, the team will pursue the design they developed from the previous fall semester, and begin to order the correct components to begin construction. From the alignment system the team has designed, it is expected that the compressor shaft and the torque transducer will be aligned with an accuracy of 10 microns. The team also expects to purchase and then balance a remanufactured rigid coupler. Once all pieces’ subject to rotation are balanced, it expected that the system will be able to operate up to 50,000 RPM. in the event of a

failure, the safety shielding, which surrounds the couplers and transducer assembly, will shield operators from projectiles.

7.0 Constraints

Last semesters constraints were primarily relating to the design of the High Speed Motor Test Rig. While those constraints still stand, the team will be encountering new constraints in this spring semester. It was discussed with William Sun from Danfoss that the purchase of the torque transducers may not be approved for our team. This is because the cost of the TMHS 308 is \$8,000 and the TMHS 311 is \$8,250. Danfoss would first like the team to achieve successful results with their alignment system. In the event that the transducers are purchased, there is roughly a 10 week wait after the order is place until the equipment arrives. This proves that this semesters biggest constraint will be timing.

8.0 Updates

Some slight design changes have been made since the end of last semester. In order to reduce costs, the four alignment adjusters positioned at the corners of the compressor will be supported with mild grade steel bar, instead of steel tubing. This will add to the total time required to fabricate, but will reduce weight and save money. A second update that has been made is the decision to use Polycarbonate material for the safety shield, instead of Plexiglass. Polycarbonate can sustain harsh impacts much more effectively than Plexiglass. This will mean that in the event of a failure, the Polycarbonate will likely be capable of being reused. Due to the high cost of the transducer, it's possible that it will not be purchased for this semester. This mean that the team will spend more time upon qualifying the shaft alignment.

9.0 Work Breakdown Structure

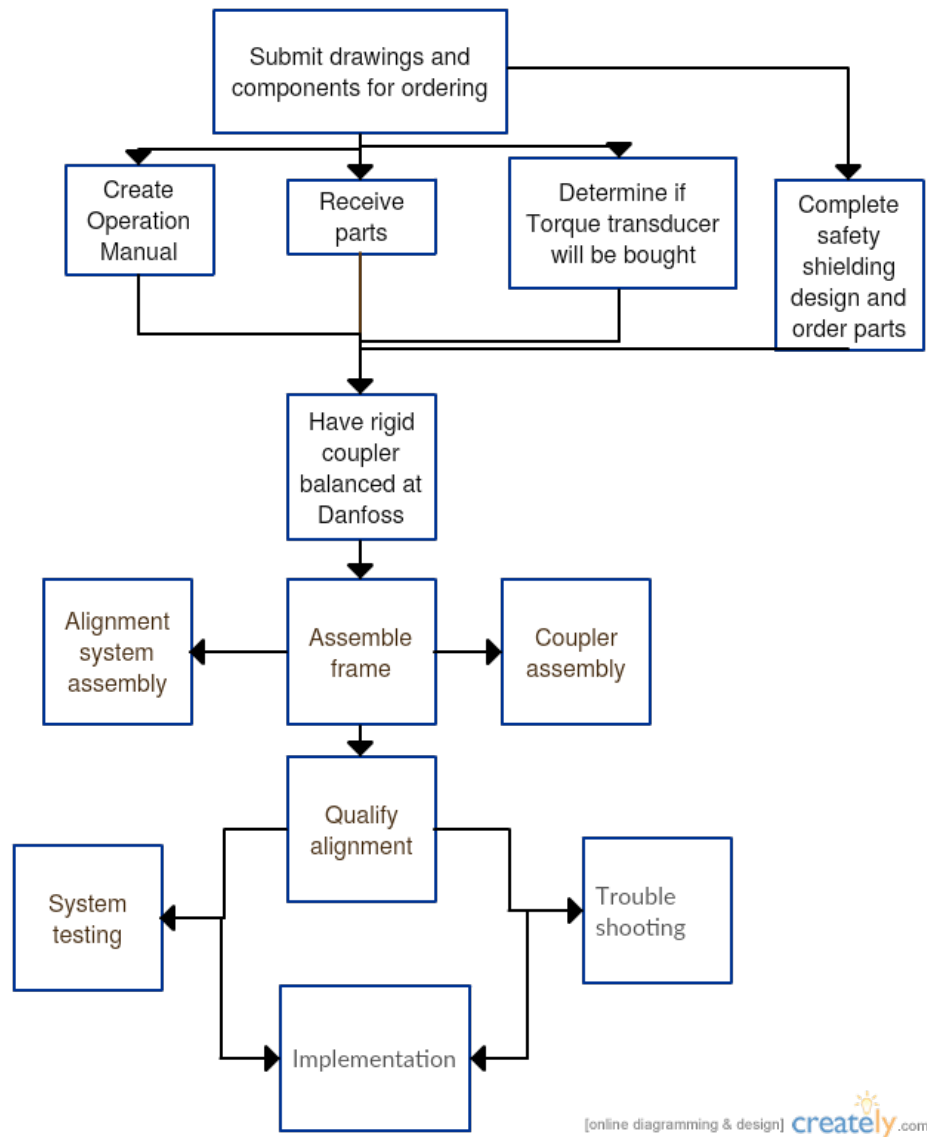


Figure 3. Work Breakdown Structure for Spring 2016

In the fall semester, a high amount of research was done to find methods and components that would suit the test rig. It was found that most manufacturers cannot supply components rated to the high RPM standard that Danfoss desires this rig to achieve (50,000 RPM) as well and the high torque value (100 Nm). Despite this, the team designed a steel frame that was proven through Finite Element Analysis to sufficiently support the test system. The team also collaborated with vendors to select the appropriate components and used their understanding of material properties and dynamic systems to verify results.

The figure above presents the work breakdown structure for the spring semester. Things will kick off by ordering the steel for the frame of the test rig and the necessary fasteners for assembly. Flexible and rigid couplers, as well the alignment equipment can also be ordered.

While waiting for components to arrive, the team can begin working on the operation manual. This operation manual will comprise of instructions for assembly, operation, and safety concerns. Once a decision is made from Danfoss concerning the torque transducer, the team can decide how it will either implement it into the rig, or design a prototype transducer that will not be functional. The previous semester the team decided to finish the safety shielding selection and design during first few weeks of the spring semester. This is because it is possible that the team may not come to the point of running the entire system at full speed, this allowed the team to more efficiently focus on the alignment and coupler designs during the fall.

Once the ordered parts arrive, the next phase can begin. Danfoss will take the rigid couplers and machine the openings to 20mm on one side, and the other ends to 10mm. They will next use a machine to balance the couplers up to 50,000 RPM. During this time the team can begin constructing the frame. Assistance will be given from danfoss to make material cuts, drill holes, and weld required pieces.

With the frame in place, the actual or mock transducer will be used with the compressor to prove the alignment process. the team is confident that with the laser alignment tool and the position adjusts (shims and set screws), the shafts will align accurately. Once this is proven, the couplers will be integrated into the system, which will attach each compressor shaft to the torque transducer in the middle of the system.

Assuming the TMHS torque transducers are purchased, the system will be ready for operational testing. Beginning with slower RPM/s, the team will work slowly up to full speed operation. If any imbalances or weaknesses in the components are found, the team will halt testing and begin troubleshooting to find a remedy. Once all the possible issues are resolved and the system reaches full speed operation, it will need approval from Danfoss to be implemented into their product testing lab.

10.0 Gantt Chart

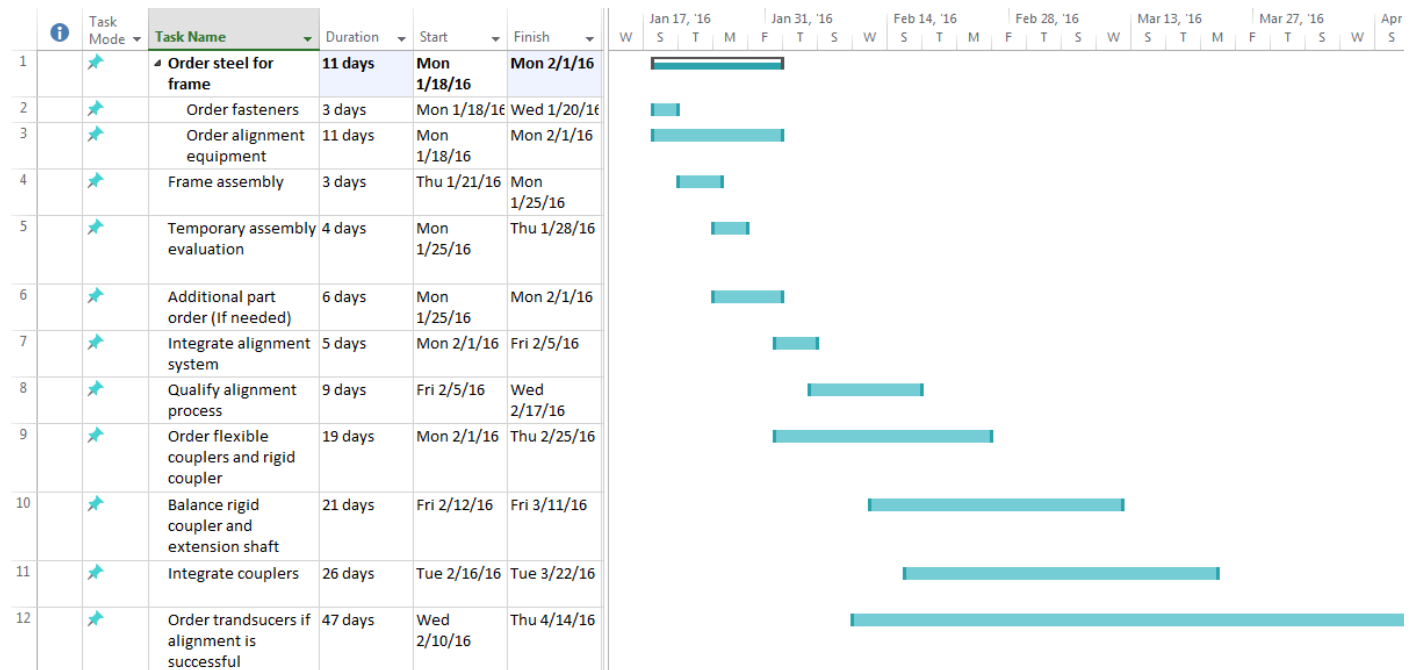


Figure 4. Gantt Chart, Spring 2016

Spring semester's Gantt Chart begins with ordering the frame steel, fastener, and alignment equipment. It is the goal of the team to have the frame assembled ASAP. The Gantt chart shows that the team has a total of 11 days to have this equipment ordered, and then 7 days for the assembly and evaluation to occur. If a shortage of parts is experienced, the team has 6 days to make necessary orders. Alignment integration testing can begin next, with 14 days allotted. Flexible and rigid couplers have a total of 40 days from the time of ordering until the rigid couplers are machine and balanced and ready for integration. This much time is given because the team is unsure how quickly Danfoss will be able to make time for the coupler balancing. There is also the possibility that the rigid couplers are insufficient, therefore the team will have a small amount of time to make adjustments to the design. The team has left off test rig performance testing because of the high possibility that the torque transducer will not be approved for purchase. If the transducers are approved, it will take approximately 10 weeks for them to arrive, which will last until roughly April 14. This is within a day of the team's final presentation of their Senior Design class, and therefore the team may not have time to achieve performance testing with the transducers. Although this scenario is likely, the team is still optimistic and will continue to pursue the possibility that the transducers will be purchased in time.

11.0 Conclusion

The team is ready for the steel to be ordered, it is expected to be approved within a week by Danfoss. Roughly week is given for the steel to arrive. At the time the steel is ordered it will be best to have the laser alignment tool and couplers to be purchased as well. After acquiring the

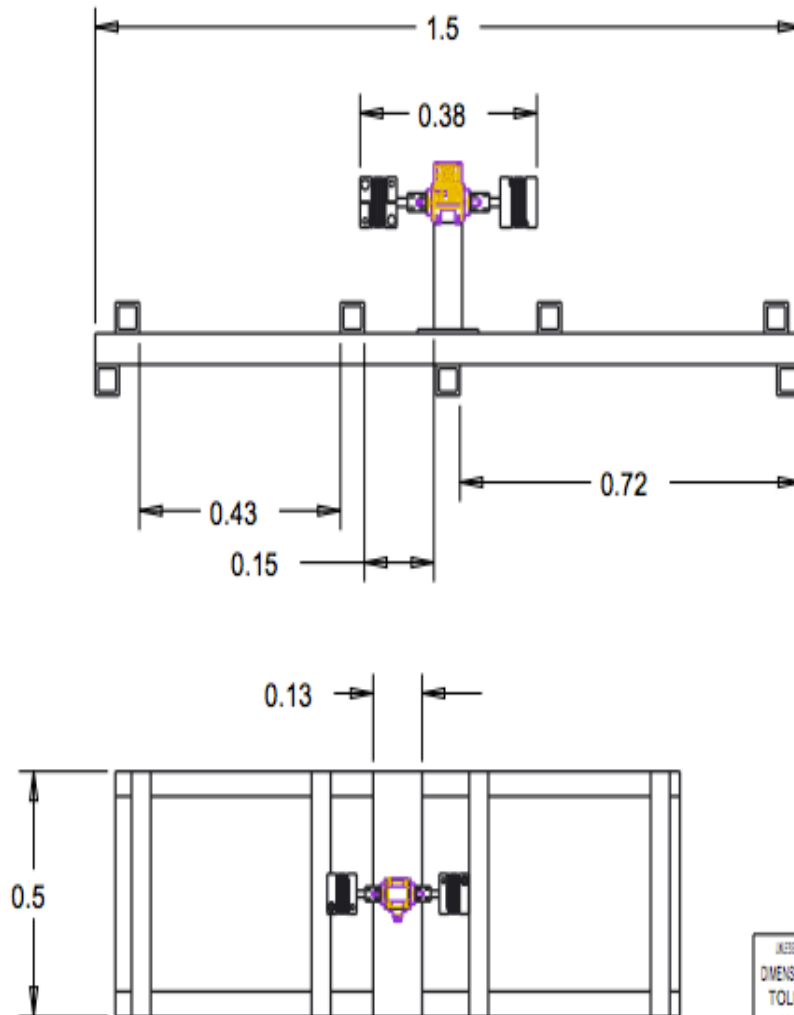
High Speed Motor Test Rig - Team 4

steel and fasteners, the frame will be built. After the frame is built a mock transducer will be used to align with a compressor, this will be done to prove the success of the alignment system. After proving alignment, the couplers will be integrated. The rigid couplers will need additional machining and balancing to prepare them for integration. System testing will begin at slow speed and work up incrementally to full speed operation. Once performance is proven, the system will be ready for integration into the testing lab at Danfoss. The Work Breakdown Structure and Gantt Chart will be used to direct the teams work in a productive direction. Tasks will be distributed amongst the team to involve all members efforts.

REFERENCES

- [1.]"Shaft Alignment Tool TKSA 31." *SKF Laser Alignment System*. N.p., n.d. Web. 15 Jan. 2016.
<<http://www.skf.com/us/products/maintenance-products/alignment-tools/shaft-alignment-tools/shaft-alignment-tool-tksa31/index.html>>.
- [2.]"Torque Transducers - TMB, TM and TMHS Series." *Torque Transducers - TMB, TM and TMHS Series*. N.p., n.d. Web. 15 Jan. 2016.
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Appendix A: Test Rig



<small>UNLESS OTHERWISE SPECIFIED</small> <small>DIMENSIONS IN INCHES</small> <small>TOLERANCES:</small> <small>XX± 0.1</small> <small>XXX± 0.01</small> <small>XXXX± 0.003</small> <small>ANGLES ± 0.5°</small>	PART NAME:	PROJECT NAME:	
	Test Rig	HSMTR	
	DRAWN BY:	DATE:	MATERIAL:
	MATTHEW KETCHUM	1-14-2016	Various
SCALE:	REV:	SHEET NUMBER:	PART NUMBER:
	0	1 OF 1	