Final Report

Team 4

VTT Rotor: Back EMF Test Fixture

Members:

Russell Hamerski – rh10g

Andrew Panek – ajp11k

Thomas Razabdouski – trs09

Tim Romano – tr10j

Andre Steimer – as10f

Faculty Advisors: Dr. Lou Cattafesta

Sponsor: Brandon Pritchard

Instructors: Dr. Nikhil Gupta, Dr. Chiang Shih

Date Submitted: Friday, April 10th, 2015

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ABSTRACT

Senior Design Team 4 of the FAMU-FSU College of Engineering was tasked by Danfoss Turbocor to create a test fixture that can measure the back EMF of rotors manufactured by a third party company. The test fixture needs to be able to take in an 80-pound rotor into a stator and rotate at at least 1000 RPM. Through meetings with Turbocor, the specificcations, design, technical drawings, and prototype were agreed upon. Separate components were ordered and custom parts were machined from raw materials. These were assembled and put together on schedule and under the $4,000.00 budget given to the senior design team. The test fixture is expected to run reliably and with minimal needed maintenance on a manufacturing line at the Turbocor plant. This report outlines the creation of the test fixture through meetings and design selection in the fall semester and assembly and testing in the spring semester.

ACKNOWLEDGMENTS

Senior Design Team 4 is pleased that this Final Report, given by Dr. Nikhil Gupta and Dr. Chiang Shih, was completed in conjunction with the FAMU-FSU Mechanical Engineering department's senior design course. This report could not have been completed without the cooperation and combined effort of all of the senior design team, namely Russell Hamerski, Andrew Panek, Thomas Razabdouski, Tim Romano, and Andre Steimer. Team 4 would also like to thank the instructors, Dr. Nikhil Gupta and Dr. Chiang Shih, and our faculty advisor, Dr. Lou Cattafesta, for their guidance and assistance in reaching the end of the course. Finally, Team 4 would like to thank the sponsor of this project, Danfoss Turbocor, and our project liaison, Mr. Brandon Pritchard, for assisting us throughout the fall and spring semesters and answering any and all questions posed by the senior design team.

1. Introduction of Project

Danfoss Turbocor is releasing its latest and largest bearingless compressor for HVAC systems, known as the VTT compressor, later this year. These compressors utilize a magnetic rotor (seen in Figure 1) that levitates within a stator. This allows for the compressor to have a longer lifespan and operate more efficiently due to the lack of friction. A third party is currently manufacturing this rotor and the quality of each rotor must be checked before use in the compressor. Currently this process is long and difficult, as it must be done by installing the rotor into the compressor and testing the entire system. To alleviate this process, Turbocor has enlisted the help of our senior design group to design, build, and test a test fixture to make this process easier, faster, and more accurate.

Figure 1: The dimensions of the rotor to be used in the new VTT compressor.

The test fixture that is to be delivered to Turbocor must be able to test this VTT rotor. It must be capable of inserting the magnetized rotor into a stator. It must spin the rotor inside the stator at a constant speed at a minimum of 1000 RPM. It will also have to record the generated motor voltage and waveform for all three phases as well as meeting all safety standards set by OSHA for prototypes. On top of these requirements, it must be designed to ensure a minimum life span of 7 years in production. The goal for this project is to meet all of these requirements and deliver a working prototype to Turbocor by April 14, 2015. Along with the prototype, an operations manual and bill of materials will be submitted to ensure that the prototype can be fixed and operated properly.

2. Background Research and Literature Review

During operation of this test fixture, there will be a back electromotive force generated by the relative motion between the stator and the rotor. This force refers to the voltage generated due to the magnetic rotor spinning within a stator[1]. This voltage pushes against the current that induces it. The voltage is proportional to the length of the wire in the windings of the stator, the magnetic field, and the speed that the rotor moves within the stator. The stator and rotor act as a generator through Faraday's Law of induction. The voltage in the stator is opposite the original applied voltage.

Turbocor currently has a test fixture that was designed to test their smaller rotors that go in their smaller compressors. This test fixture can be seen in Figure 2. It utilizes bearings to support the rotor within the stator during testing. In this smaller test fixture, the rotor can be inserted manually as its magnetic field is not as powerful as the VTT rotor. Once the rotor is halfway in the stator, the force that was opposing the insertion process reverses and actually pulls the rotor in. This means that the rotor is self-centering within the stator. Once the rotor is in place, a drill is attached which spins the rotor. The stator is connected to an oscilloscope, which can read the voltage output. This test fixture is crude and not designed to test the new VTT rotor as it is much larger.

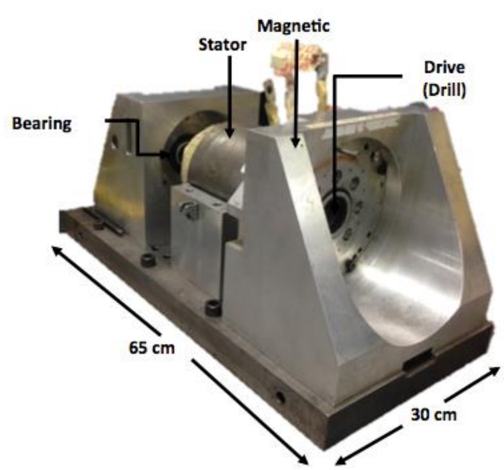


Figure 2: The old test fixture that is used by Turbocor for the smaller compressor.

The new test fixture must use a form of mechanical advantage to overcome the magnetic force that resists the insertion of the rotor into the stator. This force is now nearly 80 lbf and cannot be done by hand. The test fixture must also be able to meet all requirements mentioned in the introduction. These include that the rotor must be spun at a constant speed of at least 1000 RPM. It will also need to use an oscilloscope to measure the three phase voltage generated as well as meet safety standards set by OSHA for prototypes. It will also meet size constraints set by Turbocor that can be seen in Figure 3 below[2].

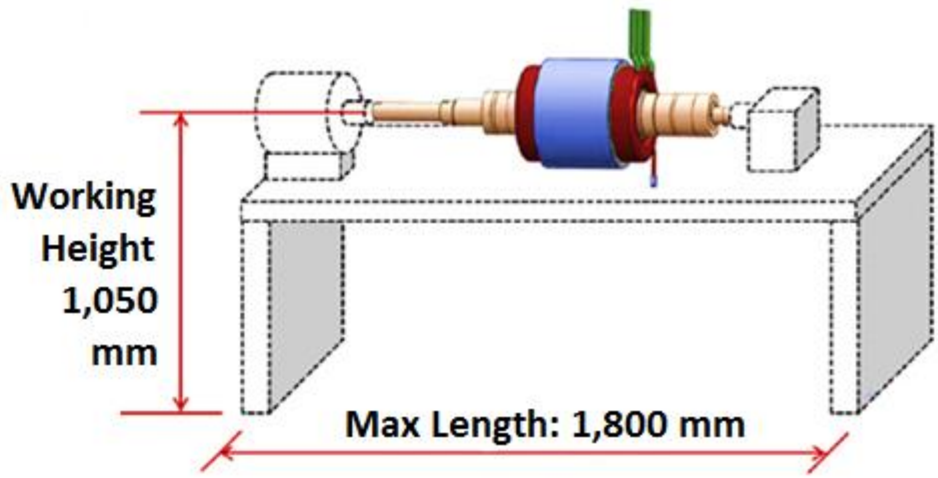


Figure 3: Size constraints set by Turbocor. The depth is not listed as that is not a concern for this test fixture.

3. Concept Generation

Concept generation is an integral part of the design development process, and can aid in cutting cost, ease of manufacturing, and ease of assembly or repair. One of the biggest debates that group four had been the movement of the stator versus the rotor. Either design was possible but in the end it was design that the easiest method was to move the stator into its working position as opposed to moving the rotor. This was found to be the case after much deliberation mainly due to the fact that moving the entire rotor would require more parts being moving parts as opposed to moving the stator into position alone. If the entire rotor was to be moved, this would mean that the rotor would have to be locked into the motor connection and live center, then both the motor and live center would have to adjust position, such that the rotor is within the stator and thus the working position, bringing more moving parts and complexity to the design.

By moving the stator housing alone into the working position, the design becomes less complex and there are fewer moving parts compared to the alternative. Also moving the stator housing allows for the operator to provide one input motion to get the test fixture into the working position as opposed to moving both the motor and live center into the working position. This will provide test fixture longevity by having fewer moving parts, and lower complexity, as well as lower cost due to the less complex parts required to make the test fixture operable.

After deciding that it is more sensible to move the stator as opposed to moving the rotor into the working position, the topic was shifted towards what will cause the movement of the stator. This is where the employment of the decision matrix below in Table 1 comes into play. This decision matrix is a tool that is used to select the most feasible option when it comes to providing the force applied to the stator housing. The most important characteristics of the device responsible for providing force to the stator were utilized in the decision matrix and are safety (30%), accuracy (25%), ease of use (20%), durability (15%), and finally cost (10%). Safety is no doubt the most critical category within the decision matrix for obvious reasons, the second most important category is the accuracy category, because of the precision required to accurately place the stator relative to the rotor. Ease of use, durability, and cost are the remaining categories and are important for all their own reasons. Ease of use was rated the highest to keep the design as simple as possible, and typically having a simpler design leads to higher durability along with lower cost.

The three methods that were investigated where a ball screw, a pneumatic device such as a pneumatic piston, and finally a rack and pinion. The ball screw consists of a long threaded rod that turns rotary motion into linear motion by use of a hand crank that rotates a threaded rod and pushes a bearing block attached to the stator housing. This method was determined to be the most cost effective, safest and most accurate method of delivering the stator housing into the working position. The next method was the pneumatic actuator, which was the least safe option because of the high-pressure air utilized by the pneumatic piston, and safety is a high priority in this test fixture. The final option was the rack and pinion, which provides fair safety, but ease of use is less than that of the ball screw. Thus after reviewing all the categories within the decision matrix and the weight those categories provide, it was determined the ball screw would be the safest, most accurate, user friendly and cost effective delivery method for placing the stator housing into the working position.

Table 1: Comparison of ball screw, pneumatic device, and rack and pinion.

Design (1-10)	Safety (30%)	Accuracy (25%)	Ease of Use (20%)	Durability (15%)	Cost (10%)	Total
Ball Screw	9	8	7	6	6	**7.6**
Pneumatic Device	3	5	2	6	3	**3.75**
Rack and Pinion	7	3	5	4	5	**4.95**

4. Final Design

The final design posed many challenges throughout the design process, and each challenge brought a unique design solution. The first major design challenge was overcoming the magnetic resistance during the insertion process of the rotor into the stator before the test can begin. The resistance force was approximately 80 pounds, but to provide a higher factor of safety, all calculations and parts were selected using 200 pound (890N) to insure that there is no chance of failure. To overcome this magnetic resistance force, a ball screw will be used that will drive the stator down the length of the rotor and move it into the working position. Once into the working position, the stator will be surrounding the magnetic portion of the rotor. The axial alignment must be concentric between the two parts for the test to be successful and provide accurate results. This is the responsibility of the live center and the motor connection, and is the second design challenge that the group faced. The alignment of the rotor down the axis of the stator will be held in place by the live center and the motor connection, both of which will be fixed vertically and will support the rotor during the test. The location of the rotor within the stator is extremely critical, and thus the live center housing and the motor connection base, which are responsible for the vertical and horizontal alignment of the rotor, were machined in-house by Turbocor in order to provide the most accurate alignment possible. The live center is more than capable of supporting the rotor with its ability to support 660 pound (2936N) and rotate at 5,500rpm, and will be locked into place using linear guide clamps to prevent the live center from sliding back and releasing the rotor.

One of the most important parts of the test fixture is the baseplate that will support all of the components, and will be the main building block of the test fixture. The base plate will consist entirely of extruded aluminum that is 90 mm tall, 180 mm in width, and 1750 mm long, and can be seen in Figure 4 below. This extruded aluminum design is intended for high rigidity and low deflection down the length of the extrusion, which is a necessity in order to maintain concentricity between the rotor and the stator during operation of the test fixture. Extruded aluminum also comes with slots that accept a small fastener so that a bolt can be inserted into them and pulled tight against the aluminum. Extruded aluminum is also considerably lighter and cheaper than a comparable plate of milled aluminum that would be used for the same purpose, thus making the extruded aluminum option the logical choice. The majority of the components of the final design are off-the-shelf items that were purchased through the parts retailer Misumi. The only parts that were not purchased from Misumi were the live center housing, stator housing, and motor support. Having fewer custom parts is beneficial as it reduces the overall cost of the project. Should parts need to be replaced, there is no necessity for drawings or access to a machine shop because the parts can be ordered and assembled. One of the more unique parts will be the nylon motor connection, which will be responsible for transferring torque from the motor to the rotor. This part is critical because it must be strong enough to handle the startup torque provided by the motor but soft enough to not damage the rotor while the loading process is occurring. The live center adaptor is another part that simplifies the design as it allows the hole in the live center housing to be drilled with a constant diameter instead of a tapered one, thus making the machine work for the live center housing considerably less expensive.

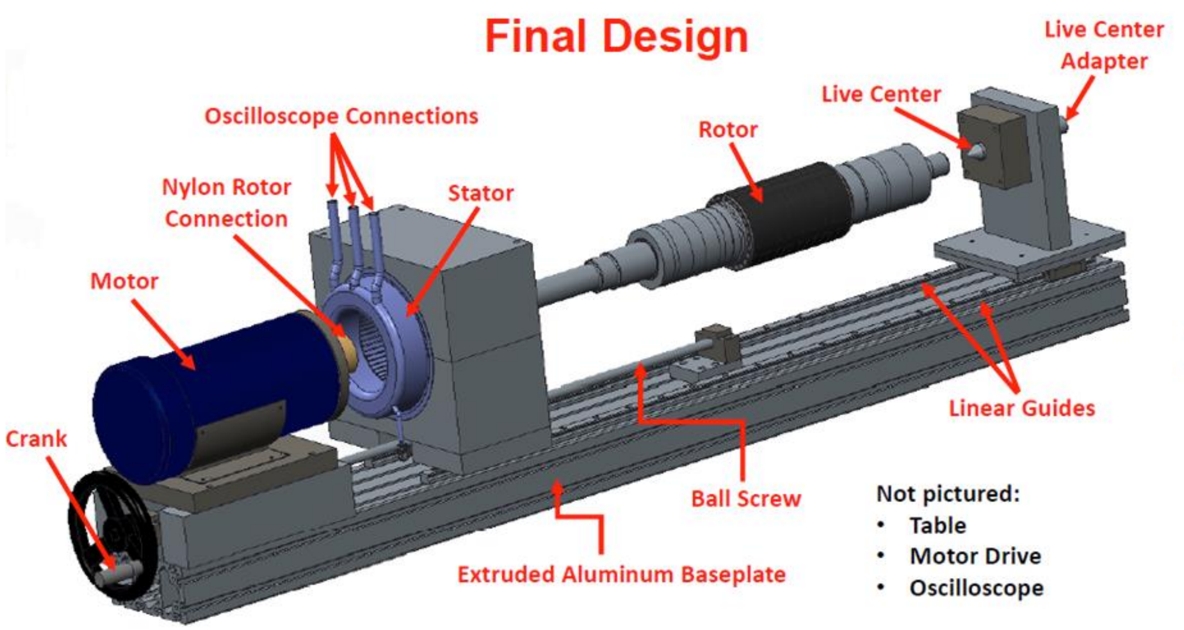


Figure 4: The final design of the test fixture.

The aluminum stator housing was machined from large blocks of aluminum, and a rough cut was provided by the water jet at High Performance Materials Institute here at Innovation Park. The water jet at HPMI had the capability to handle such a large piece of raw aluminum and made the final cut easier for the Turbocor machinist by reducing the bulk of the material. The stator housing are mounted to stator housing spacers that were also machined from aluminum. The Stator housing spacers have been mounted to the linear guide carriages. There are two sets of linear guide carriages, one set for the stator, and one set for the live center housing. The live center housing will be locked into place using one linear guide clamp to constrain the live center during the operation of the test fixture.

Procedure

The first step is to have the rotor lowered into position between the stator and the live center using nylon straps, these two straps will support the rotor on both ends and are capable of being removed once the rotor has been locked into place. The long, non-magnetic portion of the rotor will be navigated through the center of the stator and will be locked into the nylon motor connection via built in tabs on the rotor. The live center is now ready to be moved by hand into position, and a linear guide stop will then be placed so that the linear guide housing will not move. Next, the nylon straps will be removed from the rotor, as it will be held into place by the coupler and live center. Next, the wheel attached to the ball screw will be rotated, thus rotating the ball screw and moving the ball screw bearing block down the length of the threaded ball screw rod until the stator is in place over the magnetic section of the rotor. The drive will then ramp up the angular velocity of the motor until it reaches a minimum of 1,000 rpm. Subsequently, the user will verify if the rotor is within specification by looking at the oscilloscope output. Once verification is complete, the operator will ramp down the angular velocity by use of the variable frequency drive until the motor stops, at which point, the user will turn the wheel so that the stator moves back to its initial position. Nylon straps will then be put around the rotor, the linear guide stop will be removed and slid back, and the rotor will then be removed.

Live Center

The most effective way to center the rotor within the stator is through the use of a live center seen in Figure 5. A live center, or lathe center is a tool that has a conical shape that is typically used in lathe work in order to provide a stable axis that can be easily replaced, while also providing an accurate method of centering. A live center typically consists of a sixty-degree conical shape on one end that will align with an opening on the work piece that is shaped to accept the conical end at the given angle. The advantages of using a live center include the enabling high-speed rotation while handling heavy loads, centering the work piece accurately from work area to work area, and feasibility of replacement. The live center chosen for this application is rated for 5,500 RPM and has the capability to support 660 pounds. It will be placed in an adapter to make the tapered end straight and then placed into a custom-designed housing that will hold the live center at an appropriate height to keep the rotor level. The adapter ensures that the hole drilled in the housing for the live center can have a constant diameter rather than a varied one that a tapered end would require. This reduces the accuracy and machining required for the live center housing, and thus, reduces the cost.

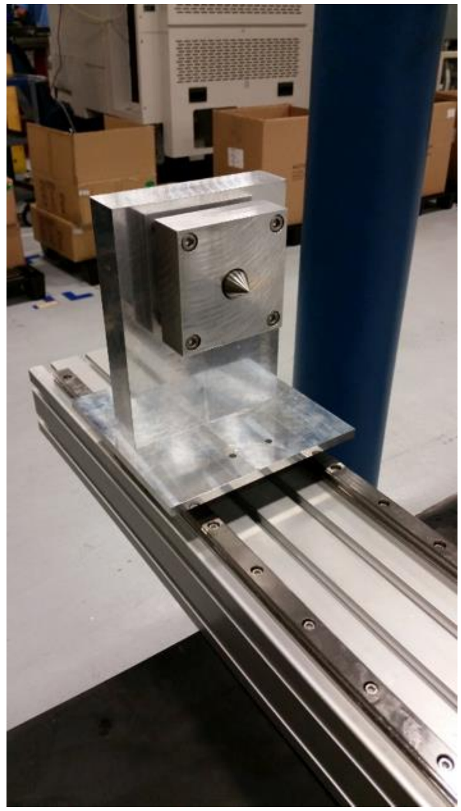


Figure 5: The live center assembly.

Linear Guides

The linear guides allow the stator to move over the rotor, as well as moving the live center into place on the rotor. The linear guide consists of a carriage riding on a track, usually through the use of bearings. Linear guides significantly reduce friction, and thus, ensure that a heavy part can be easily pushed or pulled. A total of two linear guides will be used, and each linear guide will have two carriages, one for the stator and the other for the live center. The linear guides are both from Misumi, and the track is 1240mm long, with a carriage length of 67mm and width of 48mm.

Stator

Provided by Turbocor, the stator resides within the custom-made stator housing. The stator itself weighs roughly 70 pounds and has a diameter of 230mm. When the stator is pushed over the magnetic portion of the rotor, there will be a resistive force of approximately 70 pounds. The force will then reverse itself and become an attractive force once the stator is halfway over the magnetic section of the rotor. This attractive force will aid in automatically aligning the stator relative to the rotor.

Stator Housing

The stator housing will have to be custom-made, as the stator will have to rest within the housing with no chance of allowing the stator to rotate. The housing consists of two pieces—an upper piece and a bottom piece. Connected by four screws; the two pieces are tightened so that the stator will not rotate. The stator housing is 166mm long, 320mm wide and 280mm tall. The stator housing is fastened to stator housing spacers that will allow the linear guides to be bolted directly to the stator housing. These spacers are necessary because without them, the bolts for the linear guides would have to be screwed down through the top of the entire height of the stator housing, which is not cost efficient due to the excessive machining time and the cost of the large bolts. The stator housing also required extensive machining time due to its size and thickness, which is why the water jet at the High Performance Materials Institute here at Innovation Park aided with making the first rough cut for this piece. The water jet at HPMI was capable of handling the size and thickness of the stator housing, unlike the College of Engineering water jet, and reduced the material such that it would reduce machining time on Turbocor.

Extruded Aluminum

The extruded aluminum like most of the parts was purchased through Misumi, and is the base plate and mounting point for all the other components of the design. The aluminum extrusion is 1750mm long, 90mm high and 180mm wide and is the backbone of the design. The use of the aluminum extrusion has been extremely cost effective when compared to other methods of providing a structural frame for the test fixture. This aluminum extrusion is designed for high rigidity and low deflection which is critical for the project, as a lack of concentricity between the stator and rotor will yield unusable test results.

Ball Screw

A ball screw, in contrast with a lead screw, utilizes ball bearings whereas the lead screw is strictly metal on metal. Thus, the ball screw is more efficient as it requires less effort to move and has lower wear properties. The intent of the ball screw is to provide the operator with the mechanical advantage required to move the stator into the working position by transferring rotary motion into linear motion and was purchased from Misumi. It has a 15mm diameter with a 10mm lead, and costs $344.91 for just the ball screw. This ball screw also requires the use of bearing blocks, which come at a combined cost of $218.54, for a total of $563.45. The bearing blocks will sit on either side of the ball screw and aid in the alignment of the ball screw.

Motor

The motor used in the design is from Marathon Electric and can be seen in Figure 6. It is a 2 HP, 1800 RPM, 3 phase AC motor. The shank diameter is 0.875 in (22.225 mm), and has a start-up torque of 24.5 foot-pounds. The cost of the motor is $455.00. In order to control the motor, a GS2 AC drive was selected. It operates at 230 V, is 3 phase, and 2HP, and has a cost of $255.00, for a total of $710.00 for the motor and drive. The purpose of the drive is so that the operator can slowly ramp up the angular velocity of the motor during operation. This motor will also have an attached external bearing located on the face of the motor that is intended to reduce the load on the internal bearings of the motor. This design will help with maintenance in the future and will extend the operating life of the motor.

Figure 6: The motor chosen for the test fixture.

Failure Mode Effects Analysis

Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. In Appendix A of this report there is a detailed FMEA report that goes into detail about all the high use areas of this test fixture. This FMEA report also includes all the parts that have high potential to fail, how they may fail, and the symptoms those failures may bring about. This analysis is intended to aid in diagnosing any problems that may arise in the operation or use of the test fixture, in order to keep the machine in operating condition as much as possible.

Finite Element Analysis

The nylon motor to rotor connection is one of the most critical pieces within the test fixture due to its direct contact with the rotor and the high angular velocity it rotates at. This part is expected to not only be a high use part, but also a high stress part. In order to check the integrity of the part prior to construction, finite element analysis was performed on the motor to rotor connection to check for stress levels and deflection under load. The results shown in Figure 7 below reveal that the stress levels and deflection of the material are negligible as this nylon connection is extremely rigid and designed for this kind of use.

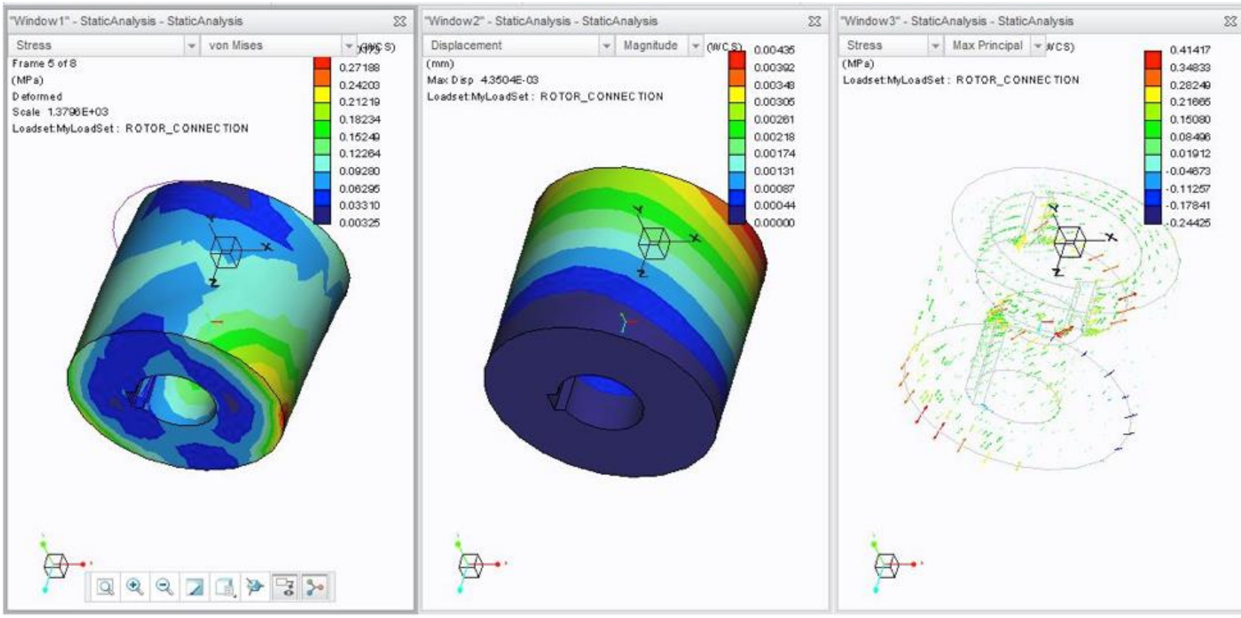


Figure 7: Finite element analysis done on the nylon connection.

Custom Machined Parts

This test fixture is a one of a kind design and as such requires many custom components. These custom components were almost exclusively made out of aluminum with the exception of the nylon rotor to motor connection. All of the custom aluminum parts had to be machined out of aluminum in house by the Turbocor machine shop. The stator housing is the responsible for providing the support of the stator and is the largest part that was machined out of aluminum. This part was taken to the High Performance Materials Institute (HPMI) where it was given an initial rough cut before being taken to the Turbocor machine shop for its final cut. The tolerance for all the machined parts was roughly ±0.005mm in order for the parts to fit together seamlessly. It is estimated that the entire collective machining time executed by the Turbocor machinist was roughly 30 hours of machining time. All the drawings for the custom machined parts can be found in Appendix B.

Operations Manual

The operations manual is intended to answer any questions the operator may have, and to provide a brief background on the test fixture, as well as operating procedure and troubleshooting.

The manual covers in depth the standard operating procedure (SOP) for using the test fixture and how to complete a successful test run with a live rotor. The operation manual goes into detail about the motor output ratings and emergency stop procedure, FMEA of the entire test fixture, and a troubleshooting guide should problems arise. The operation manual does not however provide information about what to expect for oscilloscope readings provided from the test as this is a procedure developed by Turbocor.

Regular Maintenance

When being utilized continuously there should be routine maintenance provided to the test fixture. The highest wear item on the test fixture is the nylon rotor-to-motor connection. This piece may need replacing at some point during the life of the test fixture considering that the rotor will be inserted and removed from this piece for each test. There should also be a general inspection done per the operations manual, or every five uses of the test fixture. This general inspection should consist of a look over of the entire test fixture for any wear or noises that may lead to an investigation of other parts. High expected wear areas are in the sliding locations such as the heavy duty linear guides, or the live center baseplate. It should also consist of greasing the linear guides to insure smooth continuous operation. The live center is also another high use item and should be inspected regularly as it must support the entire weight of the rotor, along with the rotor-to-motor connection. The bearing on the motor face should also be inspected regularly for smooth continuous operation to avoid damage.

5. Assembly

Several problems were encounter throughout the assembly process. Initially there were delays in the ordering process, followed by the lead-time at the Turbocor machine shop. This was proceeded by complications with using the water jet in the College of Engineering’s machine shop, as well as issues with screws for the live center assembly and problems with the linear guides, and finally, the various press fits required.

In order to procure parts through Turbocor, purchase orders must first be filled out and receive approval. The purchase orders for the McMaster-Carr aluminum and dowel pins, Misumi extruded aluminum, extruded aluminum fasteners, raw aluminum, ball screw, ball screw hardware, ball screw crank, linear guides;,Trident aluminum stator housing chunk; and the Automation Direct motor and VFD, were all given to Turbocor in mid-December of 2014. The sponsor for the team had the purchase order, but did not order the parts until February 19, 2015. This resulted in a massive delay in not only receiving the parts, but also the completion of the assembly and its testing. While the parts were finally ordered in February, it wasn’t until March when parts began arriving.

Despite a majority of the parts arriving in March, the assembly still could not begin until the Turbocor machine shop finished machining the raw aluminum from Misumi and McMaster-Carr. The machine shop was experiencing delays, however the parts to be machined were worked on as soon as possible. The custom-made parts could not be finished all at once however, as the stator housing needed to be cut.

The stator housing can be seen in Figure 8 with a mechanical pencil as a reference. It measured 7x12.75x11.5 in. The machine shop at Turbocor did not have the necessary equipment to cut such a large aluminum chunk. In order to proceed, the machine shop at the College of Engineering was contacted. Initially, they had claimed to have the ability to cut the aluminum chunk with the tolerances required. However, once the time had come, the offer was withdrawn and an alternative was required. The High Performance Materials Institute was then contacted and used with much success, despite a delay of approximately two weeks.

Figure 8: The raw aluminum for the stator housing, ordered from Misumi.

The issue with the live center assembly was the two screws attaching to the bottom of the upright live center and the live center—linear guide connector. Two screws attach the upright live center to its base plate, with the heads of the screws resting in the live center-linear guide connector. This was malfunctioning, as the holes in the live center—linear guide connector were slightly too small. The simplest method to correct for this was to use a lathe at Turbocor to quickly cut down the head of the screws, which can be seen in Figure 9. The heads of the screws were once solid black, and now the aluminum has a sheen to it. The alternative method would have been to recut the live center—linear guide connector. While this method would have served as a long-term solution, it was not time effective and thus, not cost effective. Having the part reworked could have also introduced more error in the part, as the larger hole would not be perfectly aligned with the original hole.

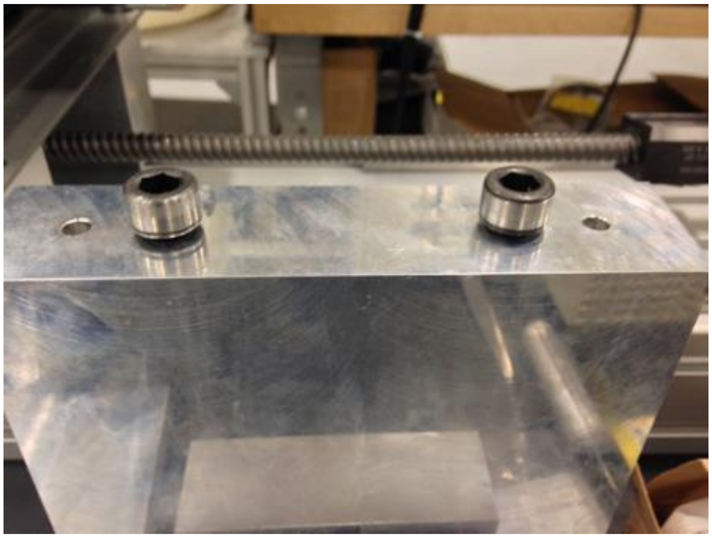


Figure 9: The heads of the screws that had to be cut using the lathe.

Another problem encountered involved attaching the linear guides to the extruded aluminum. The group intended to use M6 screws, and thus, bought M6 fasteners for the linear guides. The only issue was that the M6 screws had a slightly larger head diameter than what the linear guides allowed. Thus, M5 screws were used, but they did not fit into the fasteners bought. M5 fasteners were obtained and implemented so that the assembly could continue. Figure 10 has the two fasteners side by side for comparison.

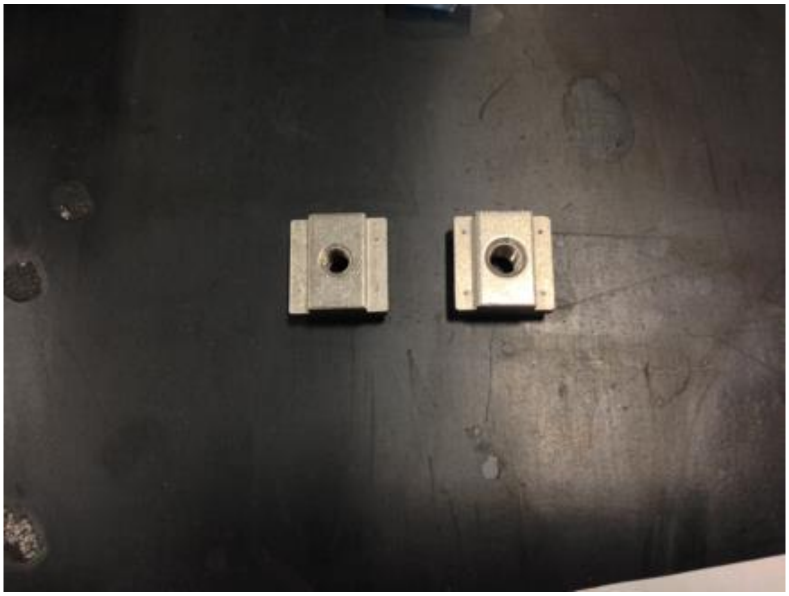


Figure 10: The M5 fastener (left) and the M6 fastener (right).

Finally, there were a few press fits that caused the team grief. In order to ensure that the motor can support the weight of the rotor, a bearing was attached to the motor shank, which was held in place by an aluminum cylinder attached to the motor itself. The issue being that the bearing has to be press fit onto the motor shank, however the bearing has to be press fit into bearing support. To perform this, the bearing was first inserted into the bearing support by heating the support, causing it to expand. The bearing was then slightly heated, as to avoid causing any damage to the bearing's internal structure. The slight increase in temperature was enough to allow the bearing to fit on the motor shank. There was an issue when the bearing and the bearing support were removed from the motor. What followed was an arduous process of heating the support up to slide back onto the motor shank, which took several attempts to ensure that the bearing support was flush with the motor. The support was then screwed to the motor, which can be seen in Figure 11, so that it would never accidentally come off the motor shank again.

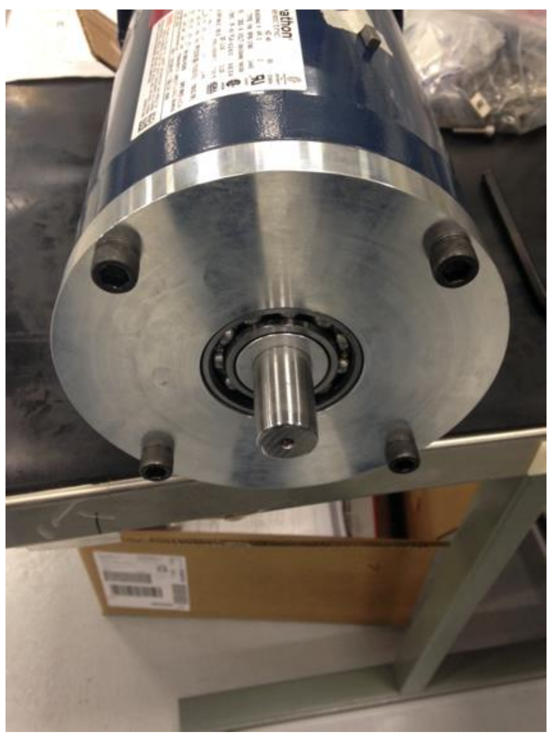


Figure 11: The motor with the motor bearing support.

Another press fit issue occurred between the live center—linear guide connector and the live center base plate. Two dowel pins in the live center—linear guide connector were deformed upon insertion into the heated live center—linear guide connector. The dowel pins that were deformed had to be ground down so that they could fit into the live center base plate. The base plate had other locational fits for dowel pins so having these two ground down did not negatively affect the alignment of the assembly. The last press fit that caused trouble was that of the live center into the live center upright. There was much concern due to the permanence of such a fit, and should the live center be misaligned, the part would have to have been scrapped. To prevent such an error, the live center upright was heated on a hot plate until it had expanded a few millimeters past the diameter of the live center. The live center was promptly inserted and held against a flat surface, ensuring that it was flush against live center upright part, and then left to cool.

6. Design of Experiment

Before the Back EMF Test Fixture can be used to ensure that a rotor is within plant specifications, a few tests must first be ran on the fixture itself. The alignment of the test fixture must be tested for each part of the assembly. This includes ensuring that each part is parallel to the extruded aluminum as well as having each side perpendicular to the extruded aluminum. Each individual assembly needs to be tested in order to ensure that they won't fail during operation. Once those tests have been performed, a test using a dummy rotor will be used, and then finally, the entire fixture will be tested using an actual rotor.

The alignment of the test fixture is crucial—if a part is 0.5mm misaligned, whether it be higher, lower, to the left or right, or even slightly rotated, it could cause a perfectly good test fixture to fail the quality test, or even cause a bad rotor pass the test. The aluminum base plate attaches to each assembly, and thus dictates what is considered "level". If the base plate is inclined, every assembly will be on that slope will be inclined. As long as each part is aligned with the extruded aluminum, the test fixture will work. Therefore, the alignment of the test fixture will be measured against the extruded aluminum. Ultimately, there are three key features that must be aligned as accurately as possible—the motor, the stator, and the live center. Each of these depend on their subassemblies, which were machined with as small of a tolerance as possible. Should the vertical alignment be off, height can easily be taken off of the motor height or even removed from the stator housing height. If the horizontal alignment is incorrect, the motor has the ability to slide left and right to be better centered. Horizontal alignment is not a concern for the stator housing or the live center, as they both reside on the same linear guide track, which is directly connected to the extruded aluminum.

Each assembly and subassembly needs to be tested for functionality before the fixture itself is tested. This involves testing the linear guides to ensure that they can support the weight of the stator assembly, as well as the live center assembly. The stator assembly must be tested with a stator to make sure that it can hold the stator when a force is exerted against it so that it won't get pushed out of its housing. This way, when the stator is moved over the rotor, the housing will not fail. The live center assembly must be able to lock into place without moving, as to help resist any force exerted on it when the stator moves over the rotor. In addition, the live center itself must not fail when it is connected to the rotor. These tests will mostly occur with a dummy rotor—a rotor that does not contains magnets. This rotor would simulate the weight of the rotor without the danger of destroying the stator provided something fails.

After each test has been performed, the entire process will be run through with an actual rotor. This will be the final stage of the assembly, and will ensure that the test fixture functions properly. The rotor will be ran multiple times to determine the repeatability of the test fixture results. At this point, the test fixture will be ready for implementation in the assembly line at Turbocor.

7. Considerations for Environment, Safety, and Ethics

The main concerns for the project were those involving the safety of the operator. Naturally, Turbocor adheres to all the necessary Occupation Safety and Health Administration (OSHA) guidelines. This includes, but is not limited to, having an emergency stop, clearly showing the required safety label, as well as staying well within the required noise level, so as to not damage the operator's hearing.

Emergency stops are ubiquitous at Turbocor, as they should be to ensure the safety of both the operator and the part being worked on. The emergency stop is also required by certain OSHA guidelines, and there are a great many guidelines regarding their employ and wiring.[1] In order to clarify what was needed, a safety advisor and electrician employed by Turbocor were consulted by the team to determine how the plant usually takes care of OSHA requirements when it came to wiring. After much discussion, the wiring diagram seen in Figure 12 was decided upon. The TJN-25 is a 25A, 300VAC fuse, the AGC-1 is a 0.1A, 250VAC fuse, with a 24 VDC, 3.75A power supply to power the emergency stop and the on button (CR1 and PBI-LT). The box in the middle, with the L1 through L3 and T1 through T3 is the motor drive.

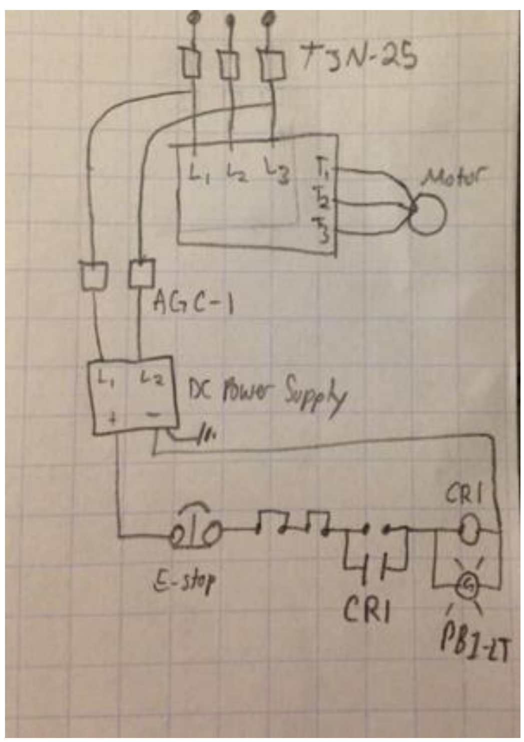


Figure 12: The wiring diagram used for the test fixture.

Turbocor will provide the safety label required by OSHA warning the operator of any potential danger at the implementation of the test fixture on the assembly line. The test fixture should also not exceed 115 dB according to OSHA regulation[2]. While it is unlikely that the noise generated will come close to 115 dB, in the case that it does, noise-canceling headphones will be provided. These headphones are already in use at Turbocor, and will be no challenge to acquire.

8. Project Management

This senior design group consists of five team members. Originally, the team member roles were as follows: Russell Hamerski as team leader who directed tasks and acted as a liaison between the group and Danfoss Turbocor, Tim Romano as financial advisor who kept track of the group's budget, Andrew Panek as lead mechanical engineer who, Thomas Razabdouski as secretary, and Andre Steimer as webmaster and lead CAD engineer. These roles were kept through the fall 2014 semester until the start of the spring 2015 semester, where changes were made to the leadership of the senior design group. Thomas Razabdouski and Russell Hamerski exchanged roles of secretary and team leader, respectively, due to the fact that Russell Hamerski had outside obligations that limited his time available for leadership duties as compared to the fall 2014 semester. Russell assumed the role of secretary while Thomas took over team leadership duties.

The senior design group utilized Gantt charts throughout both the fall and spring semesters in order to stay organized and know where the current work being done was in relation to the entire project. The original and modified Gantt charts for the fall and spring semesters can be found in Appendix C. The fall semester was mainly composed of designing the test fixture while the spring semester mainly focused on getting parts, assembling, and testing the test fixture. While the group stuck fairly close to the schedule for the fall semester, the spring semester was pushed back due to delays in ordering the parts and getting the drawings done, as discussed earlier.

Several resources were available to the senior design group that helped make the senior design project possible. A shared Dropbox was setup for immediate and easy file sharing between group members, which simplified CAD work and made drawings and documents easy to find. Two machine shops were available to the group. One of these was the one located at the FAMU-FSU College of Engineering. Due to the project being sponsored by Danfoss Turbocor, the resources, manpower, and tools located in Turbocor's machine shop were also made available to the group. Having Turbocor's machine shop available enabled the machining of the custom components for the test fixture, as the degree of accuracy needed to prevent a deflection of under 0.5 mm in the rotor during the use of the test fixture would not have been possible with the machine shop located at the College of Engineering, as the college's tools did not allow for machining accuracy as high as Turbocor's.

The final budget is available in Appendix D. The final price came out to $3734.49. This is well under both the $4,000.00 budget imposed and supplied by Danfoss Turbocor, and the cost of the rotors being tested, which come in at $12,000.00 each. It is important to note that this cost does not include the cost of labor and machining the raw materials into the custom designed components. The machine shop at Turbocor completed approximate 30 hours of work while Florida State University's High Performance Materials Institute completed approximately three hours or work turning the raw aluminum block into the upper and lower parts of the stator housing using their water jet. As described in the Design for Manufacturing, Reliability, and Economics Report, at a going rate of $20.00 an hour, 33 hours of work would cost $660.00, putting the project above the given $4,000.00 budget if labor needed to be included. As far as research can tell, there is not a comparable test fixture available, making this test fixture "1 of 1". A summary of how the budget was spent on different component categories is available in Table 2. The most expensive category was the hardware at $816.53 while the least expensive was the ball screw at $344.91. All component order forms are available in Appendix E.

Table 2: Categories total budget was spent on

Category	Amount Spent
Raw Materials	$620.42
Linear Guides	$616.66
Motor	$455.00
Ball Screw	$344.91
Extruded Aluminum	$391.12
Electrical Supplies	$456.75
Hardware	$816.53

The team communicated using a variety of methods. The two most used methods were emails and texting. The group favored emails as it leaves a record of all communications and was formal enough to be used with advisors, the sponsor, and the instructors for the course. However, if an immediate answer was needed or quick plans were drawn up to meet somewhere, texting would be used as it would be the fastest and would usually garner the fastest response. Phone calls would also be conducted between group members to clarify information. For example, if one group member is assembling a portion of the test fixture but is not sure what order the components attach together in, a quick phone call to the person last working on the assembly would quickly clarify this issue.

Although many senior design groups had issues getting in touch with advisors and sponsors, this senior design group did not run into the same problems. Dr. Lou Cattafesta was utilized as both a technical advisor and the primary judge of the formal presentations for the group, as he would see them before anyone else and give presentation tips and advice. Meetings with him were always scheduled weeks in advance and would take place on Wednesday afternoons. The consistent time of the meetings and the fact that they were typically placed on his schedule before other conflicts could come up meant that there were no issues with speaking with him during both semesters. Likewise, meetings were always set up with Turbocor at 3:45 on Thursdays. These would be weekly or biweekly depending on the status of the project at that time. Just as with meeting with Dr. Cattafesta, the fact that these were scheduled far in advance and fairly regularly meant that there were not any issues in meeting with Turbocor, and both the group and sponsor never had to cancel on each other.

As dictated by the syllabus, the group met for staff meetings with the instructors for the class. These meetings were used to get the instructors up to speed on the current project status and future work required. These were scheduled online and gave the senior design group helpful feedback on the design of the test fixture and the presentations and reports submitted throughout fall and spring.

9. Conclusion

Danfoss Turbocor tasked senior design team 4 with designing and assembling a test fixture for measuring the back EMF of a rotor manufactured by a third-party. The group has delivered a test fixture using the design and components agreed upon with Danfoss Turbocor. The fall semester was mainly centered around designing the test fixture while the spring semester had a focus on assembling the device. Although the assembly of the test fixture was pushed further back than originally anticipated, the assembly itself took about as long as originally planned. All of the custom components and electronics came together as originally conceived and should perform reliably on the Turbocor manufacturing line. The test fixture was under budget, even with a few unexpected challenges in the assembly like the extruded aluminum fasteners not fitting the M6 screws as originally imagined. The final steps in this project center around implementing the test fixture in the manufacturing line in conjunction with ensuring maximum reliability based on the test fixture's surroundings.

There are a few recommendations that can be made for a similar project, and they center on the communication with and use of machine shops. It is extremely important to look at the lead-time of a machine shop, especially when a project that one may be working on is considered to be of low priority. This essentially means that as other projects come up, the components or machining one may expect to get done may take longer than quoted, and this could be disastrous for a group on a tight schedule. In addition, it is critical to get in touch with the machine shop in order to see how they want the drawings for the work they have to do. A large amount of work had to be scrapped or rewritten due to the machine shop wanting more clarification on the technical drawings before they would complete the machining required. These unforeseen delays could also dramatically hold up a project and should be avoided entirely when possible. If the group were to do this project again, priority would be given to opening up communication with the machine shop. Although this senior design group now knows the machinist and who to ask questions to, this wasn't known at the beginning of the project and may have helped speed up some aspects of the spring semester.

References

[1] Acroname. "Back-EMF Motion Feedback." Acroname. Brainstem, 2014. Web. 23 Sept. 2014. <http://www.acroname.com/articles/emf-motion-feedback.html>.

[2] Pritchard, Brandon. VTT Rotor Back EMF Test Fixture Equipment Specification. Rep. no. A.0. Vol. 1. Tallahassee: Danfoss Turbocore, 2014. Print.

Appendix A

FMEA for the test fixture:

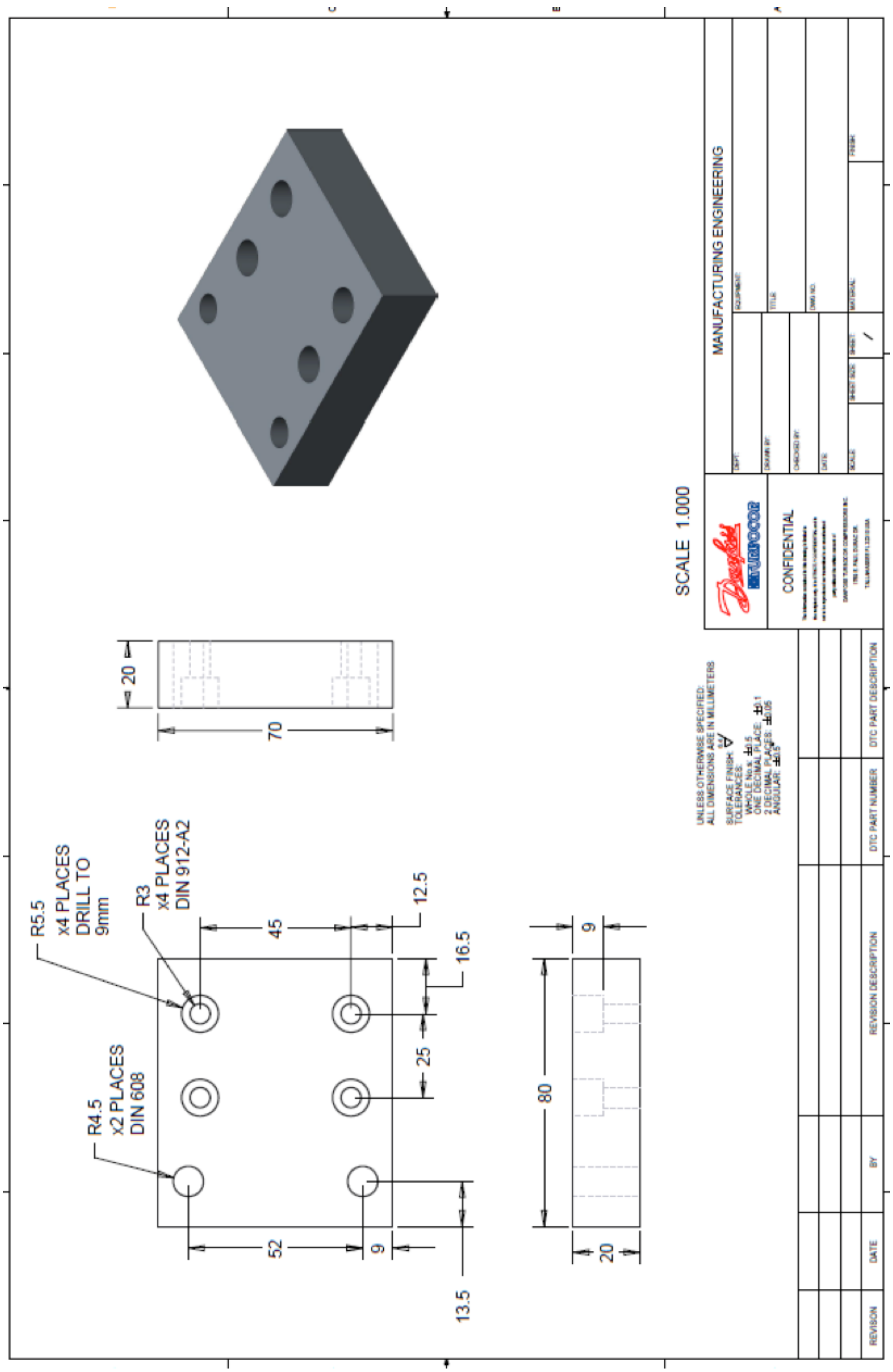
Failure Modes Effects Analysis

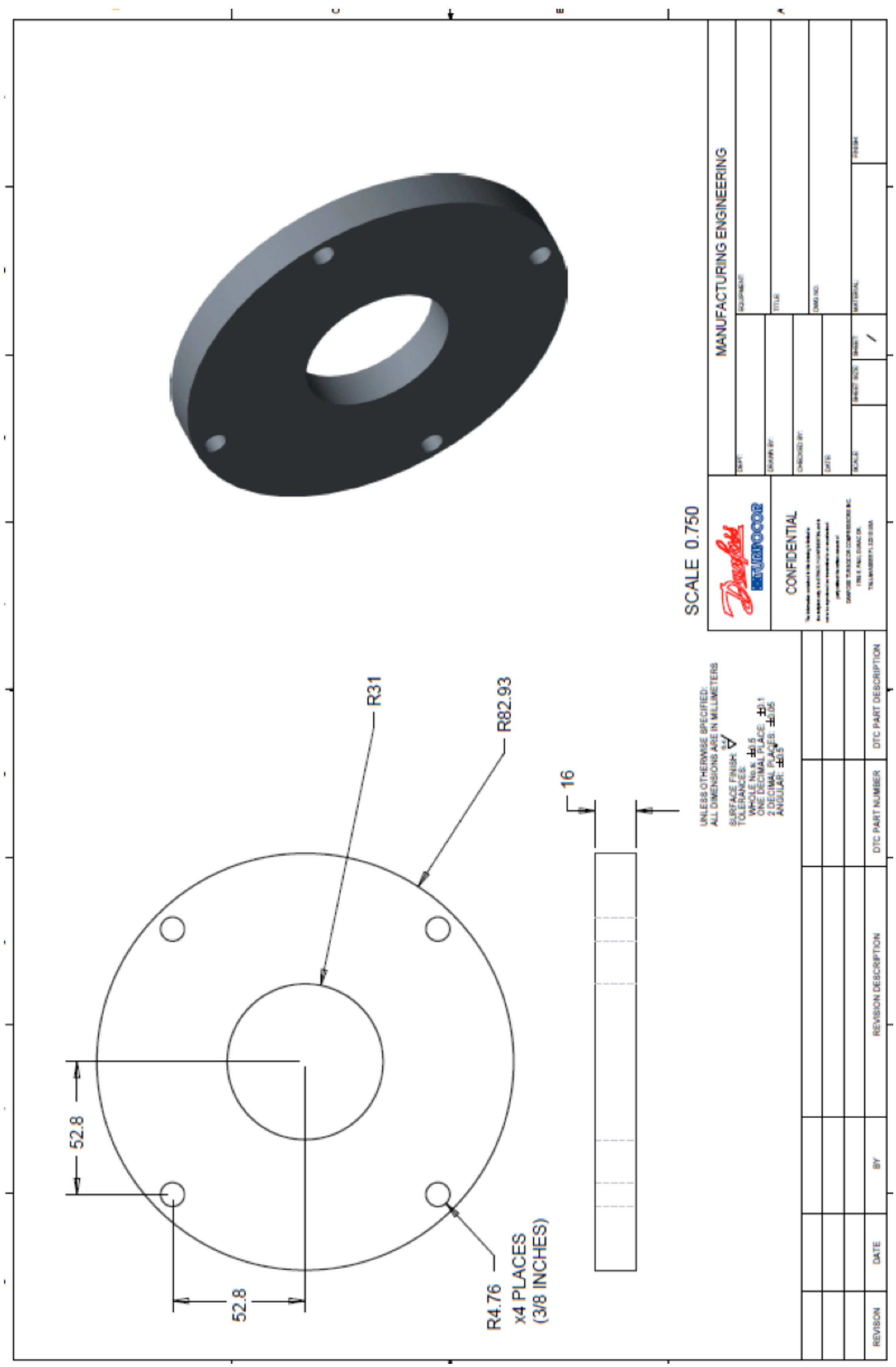
Team #:	Group 4
Project Title	Back EMF Test Fixture

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.				
Variable Frequency Drive (VFD)	Fails to provide EMF to the motor	Test fixture cannot be used	3	Possible wiring issue or bad groud.	2	Checking all electrical connections before operation	1	6	inspect all electrical wiring every ten uses for loose wires, exposed wires or bad grounds.	Test Fixture Operator (Danfoss Turbocor)	N/A	3	2	1	**6**
Motor Internal Bearings	Binding, Excessive wear	Motor can fail to operate	8	Excessive load or wear	4	inspect motor and listen for internal bearings binding or grinding	6	192	inspect motor and listen for internal bearing grinding.	Test Fixture Operator (Danfoss Turbocor)	N/A	8	4	6	**192**
Motor Shank	Bending under load or torque, Failure due to Shear	Motor can fail to operate	8	Excessive load or wear	1	inspect motor shank before operation and avoid excessive or unintended loading	9	72	inspect motor shank before operation and check for shank deviance	Test Fixture Operator (Danfoss Turbocor)	N/A	8	1	9	**72**
Motor Drive	Motor Fails to operate	Rotor cannot be tested	8	Wiring issue or bad ground, motor burned out	1	Avoid motor stalls or excessive loading, slowly ramp up VFD	5	40	test motor for operation prior to rotor loading and check for smooth operation	Test Fixture Operator (Danfoss Turbocor)	N/A	8	1	5	**40**
Ball Screw Crank	Crank Breaks or strips	Ball Screw will faill to rotate	2	Ball screw binding	1	Check for smooth ball screw operation before use	9	18	check ball screw for binding prior to operation to avoid damage to ball screw crank	Test Fixture Operator (Danfoss Turbocor)	N/A	2	1	9	**18**
Linear Guides	Bend due to load, excessive bearing wear	Linear Guides Carriages will fail to move	7	Overloaded, excessive bearing wear	2	avoid excessive loading	6	84	avoid excessive loading and inspect linear guides for warping or excessive wear prior to use	Test Fixture Operator (Danfoss Turbocor)	N/A	7	2	6	**84**
Stator Housing	Clamping screws not torqued	Stator can move to undesired position	7	bolts not torqued	1	check stator for movement prior to test	9	63	ensure that stator housing is secured prior to rotor loading	Test Fixture Operator (Danfoss Turbocor)	N/A	7	1	9	**63**
Ball Screw	Ball Screw Stripped, bent, or binding	Ball Screw will fail to rotate smoothly	6	Overloaded, excessive bearing wear	1	avoid excessive loading, check ball screw for smooth operation before use	7	42	check ball screw for binding prior to operation to avoid damage to ball screw	Test Fixture Operator (Danfoss Turbocor)	N/A	6	1	7	**42**
Live Center	Internal Bearing Falure, Cone Breaks off	Live center cannot be supported or rotated	6	Overloaded, excessive bearing wear	4	avoid excessive loading, listen for internal bearing failure prior to operation	6	144	avoid excessive loading and live center for excessive wear prior to use	Test Fixture Operator (Danfoss Turbocor)	N/A	6	4	6	**144**
Live Center Upright	Bends under load, Fractures	Rotor cannot be supported	4	Overloaded	2	avoid excessive loading and inspect before each use for deviance	5	40	avoid excessive loading of live center and inspect live center upright for fatigue	Test Fixture Operator (Danfoss Turbocor)	N/A	4	2	5	**40**
Rotor to Motor Connection	Connection can fail under operatio, excessive wear	Rotor can fall during operation	9	Excessive load or wear	3	Remove and check for fatigue prior to operation of test fixture	6	162	check for fatigue prior to rotor loading by removing and inspecting the connector	Test Fixture Operator (Danfoss Turbocor)	N/A	9	3	6	**162**
Linear Guides Brake	Fails to Brake	Live Center will drop Test Rotor	2	Excessive load, improper use, or wear	3	inspect linear guide brake prior to use	6	36	check for strong clamping prior to use	Test Fixture Operator (Danfoss Turbocor)	N/A	2	3	6	**36**
Motor Shank Support Bearing	Binding, Excessive wear	Motor can fail to operate	1	Excessive load or wear	4	listen for bearing wear prior to operation, inspect bearing before each use	7	28	Inspect the shank support bearing for excessive wear prior to operating the motor and listen for grinding	Test Fixture Operator (Danfoss Turbocor)	N/A	1	4	7	**28**
Extruded Aluminum	Warps, Bends or Crack	Complete test fixture failure	9	Fatigue over time or excessive load	1	inspect extruded aluminum for fatigue every ten uses of test fixture	5	45	inspect extruded aluminum every ten uses for fatigue	Test Fixture Operator (Danfoss Turbocor)	N/A	9	1	5	**45**
Ball Screw Bearing Blocks	Internal Bearing Failure	Ball Screw will faill to rotate	4	Excessive load or wear	2	listen for internal bearing failure prior to use of ball screw	6	48	check for bearing grinding or ball screw binding	Test Fixture Operator (Danfoss Turbocor)	N/A	4	2	6	**48**

Appendix B

Drawings for all of the custom components:

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16
52.8
52.8
R4.76
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(3/8 INCHES)
SCALE 0.750
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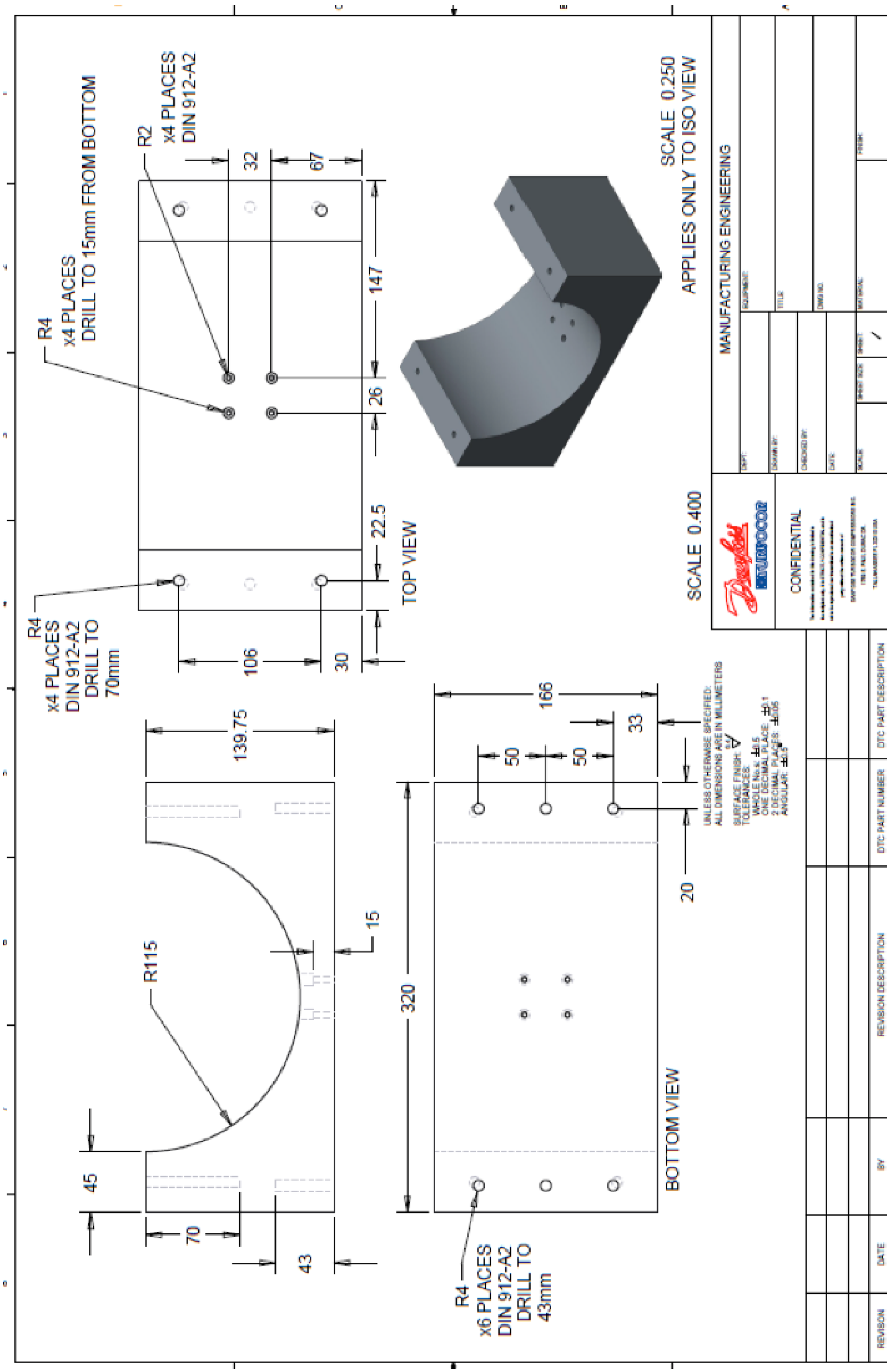
CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
REVISION
DATE
BY
REVISION DESCRIPTION
DTC PART NUMBER
DTC PART DESCRIPTION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BOTTOM VIEW
SCALE 0.400
SCALE 0.250
APPLIES ONLY TO ISO VIEW
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x4 PLACES
DRILL TO 15mm FROM BOTTOM
R2
x4 PLACES
DIN 912-A2
R4
x4 PLACES
DIN 912-A2
DRILL TO
70mm
R4
x6 PLACES
DIN 912-A2
DRILL TO
43mm
R115
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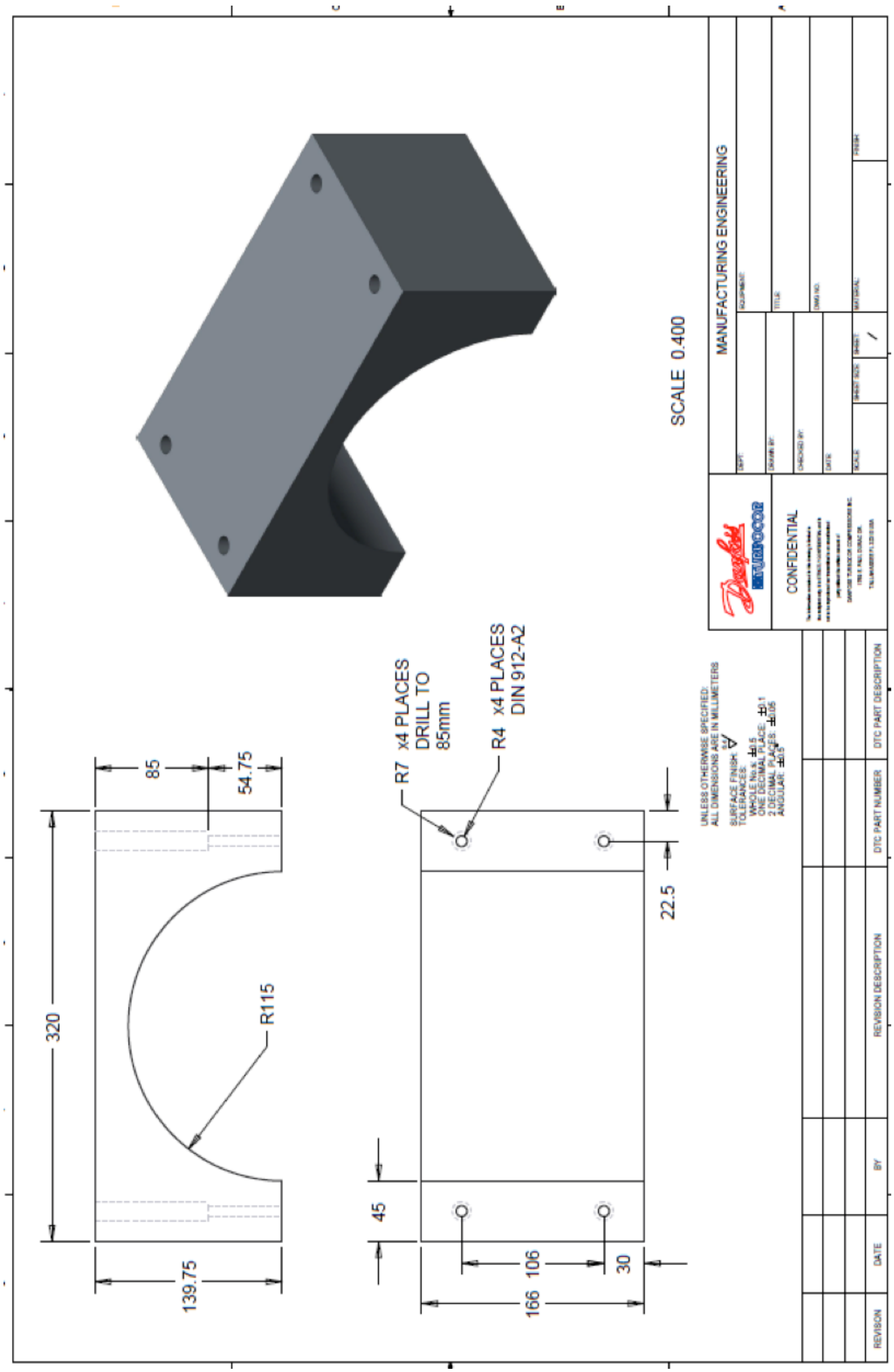
REVISON
DATE
BY


MANUFACTURING ENGINEERING
SCALE 0.400
R7 x4 PLACES DRILL TO 85mm
R4 x4 PLACES DIN 912-A2
R115
320
85
54.75
139.75
45
106
30
166
22.5
CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE IN MILLIMETERS
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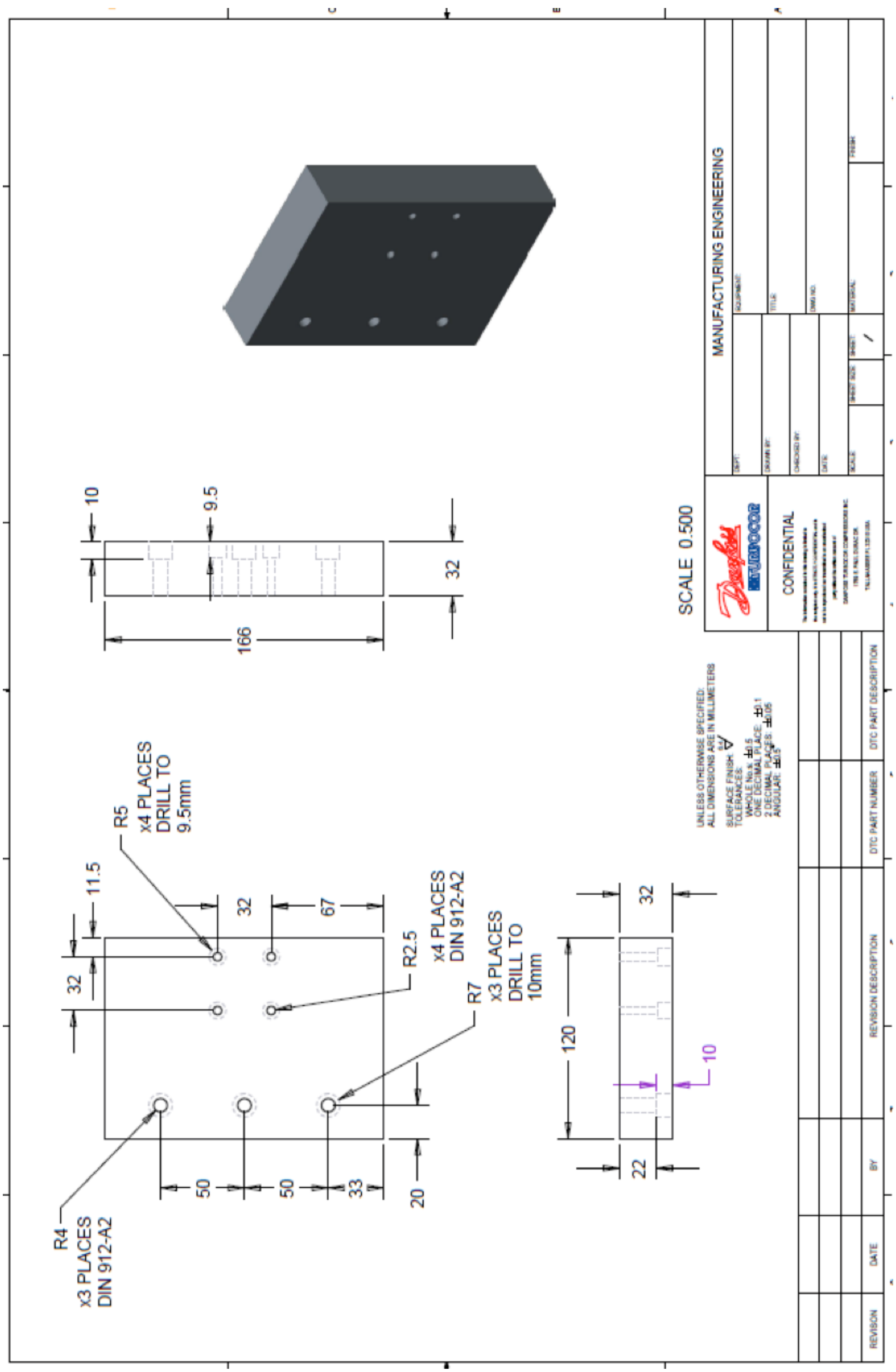
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DRILL TO
9.5mm
R2.5
x4 PLACES
DIN 912-A2
R7
x3 PLACES
DRILL TO
10mm
R4
x3 PLACES
DIN 912-A2
166
32
10
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11.5
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DATE
BY
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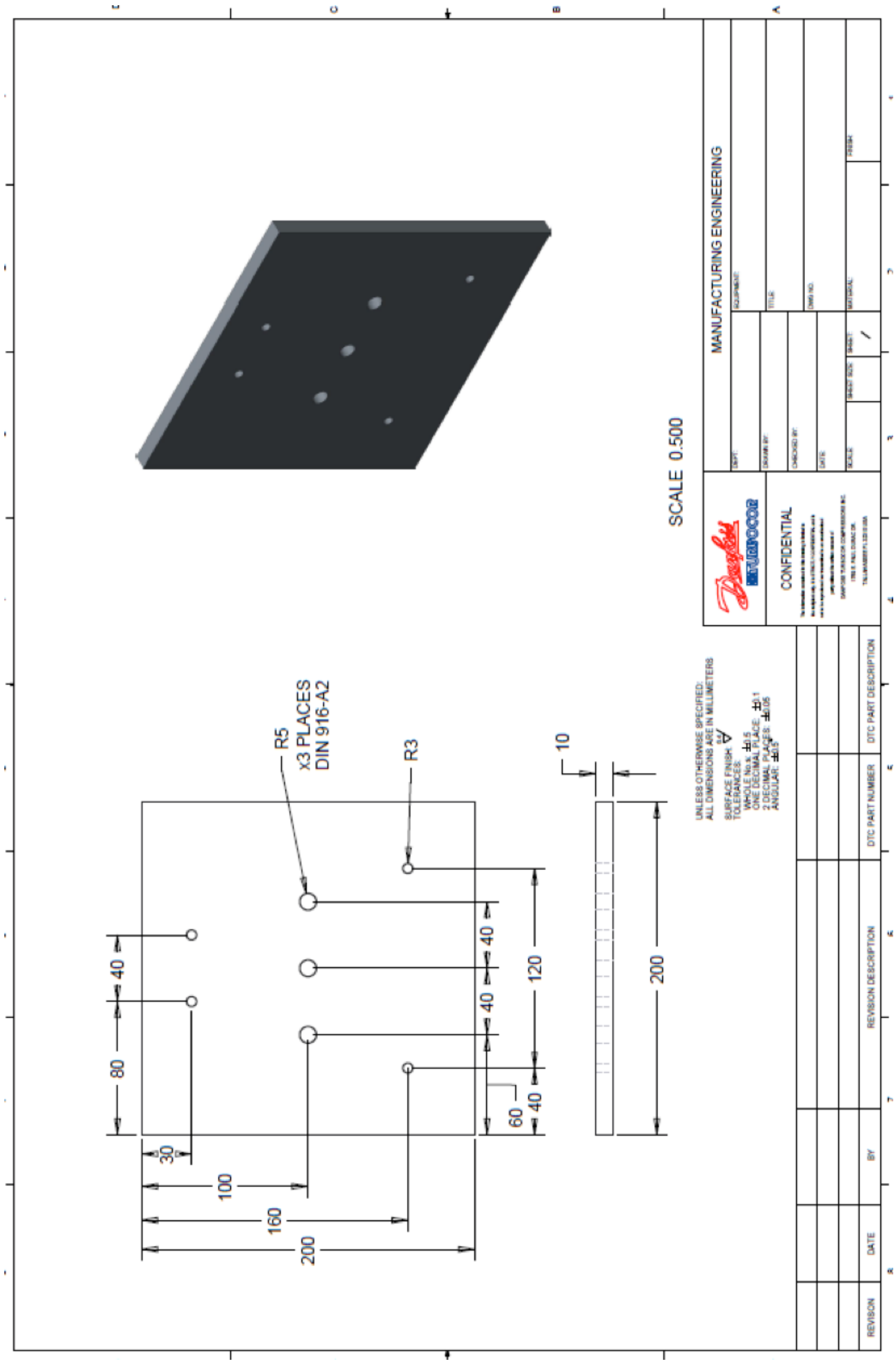
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40
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60
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100
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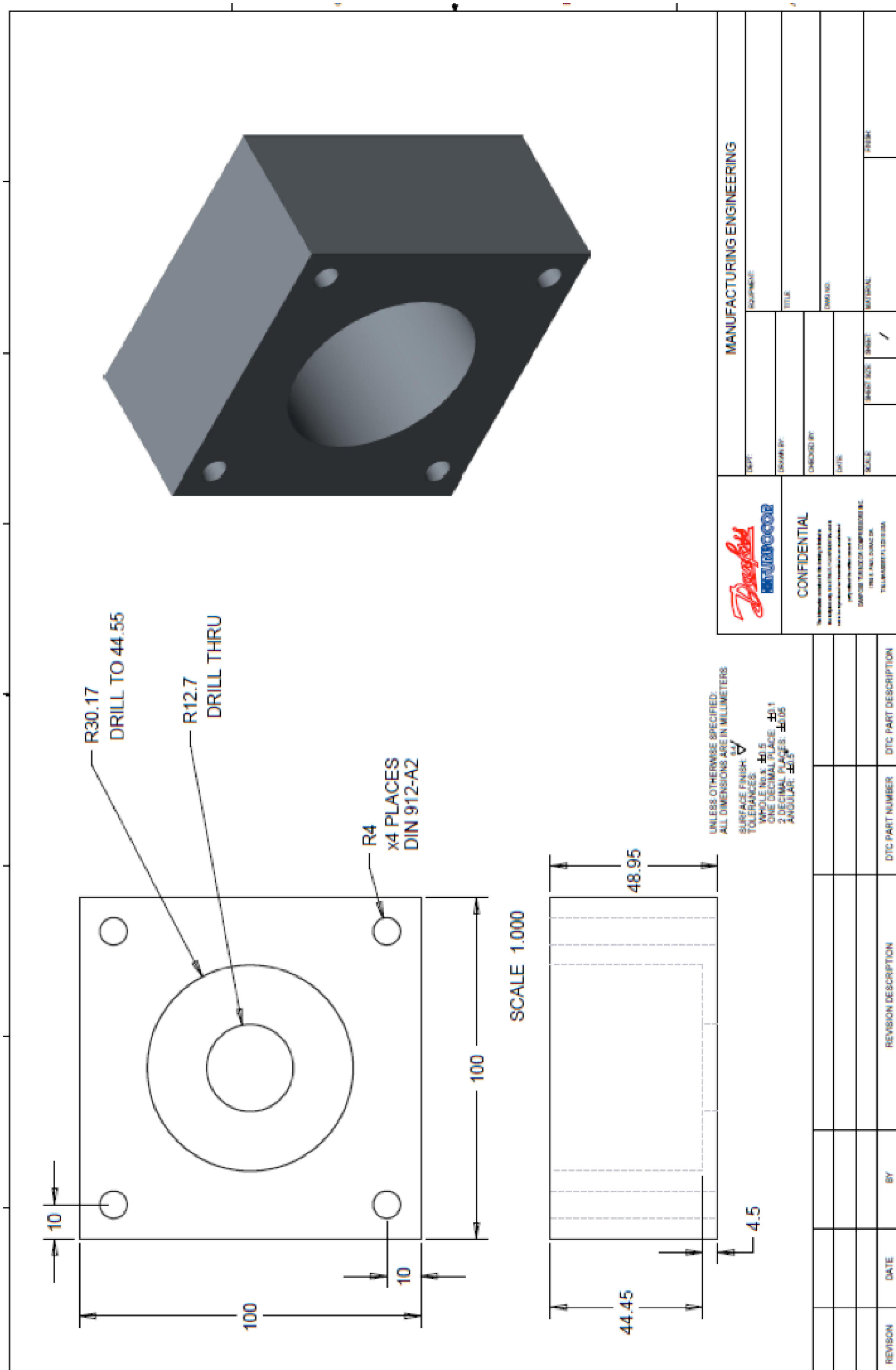
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10
10
100
44.45
4.5
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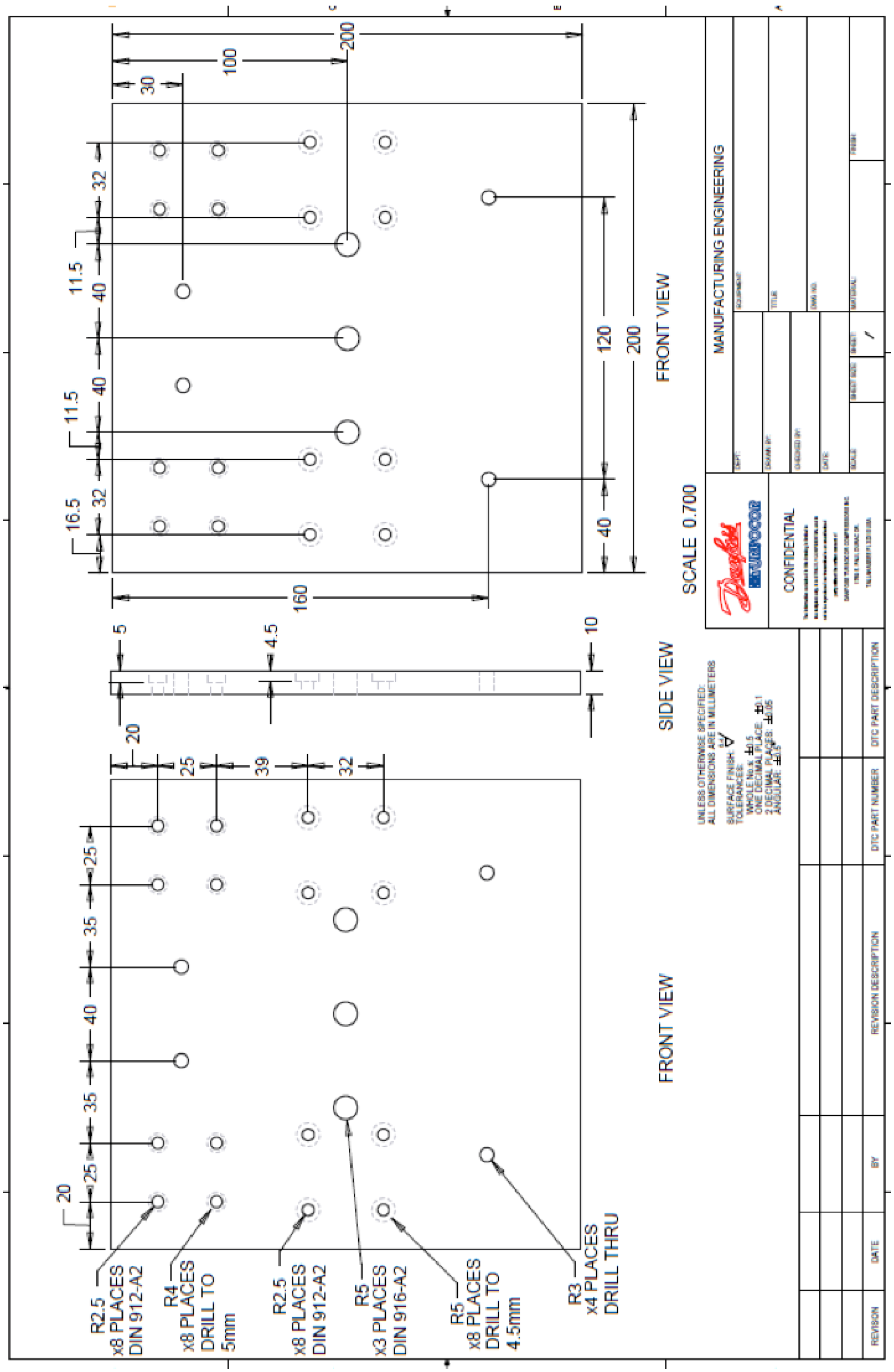
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SIDE VIEW
FRONT VIEW
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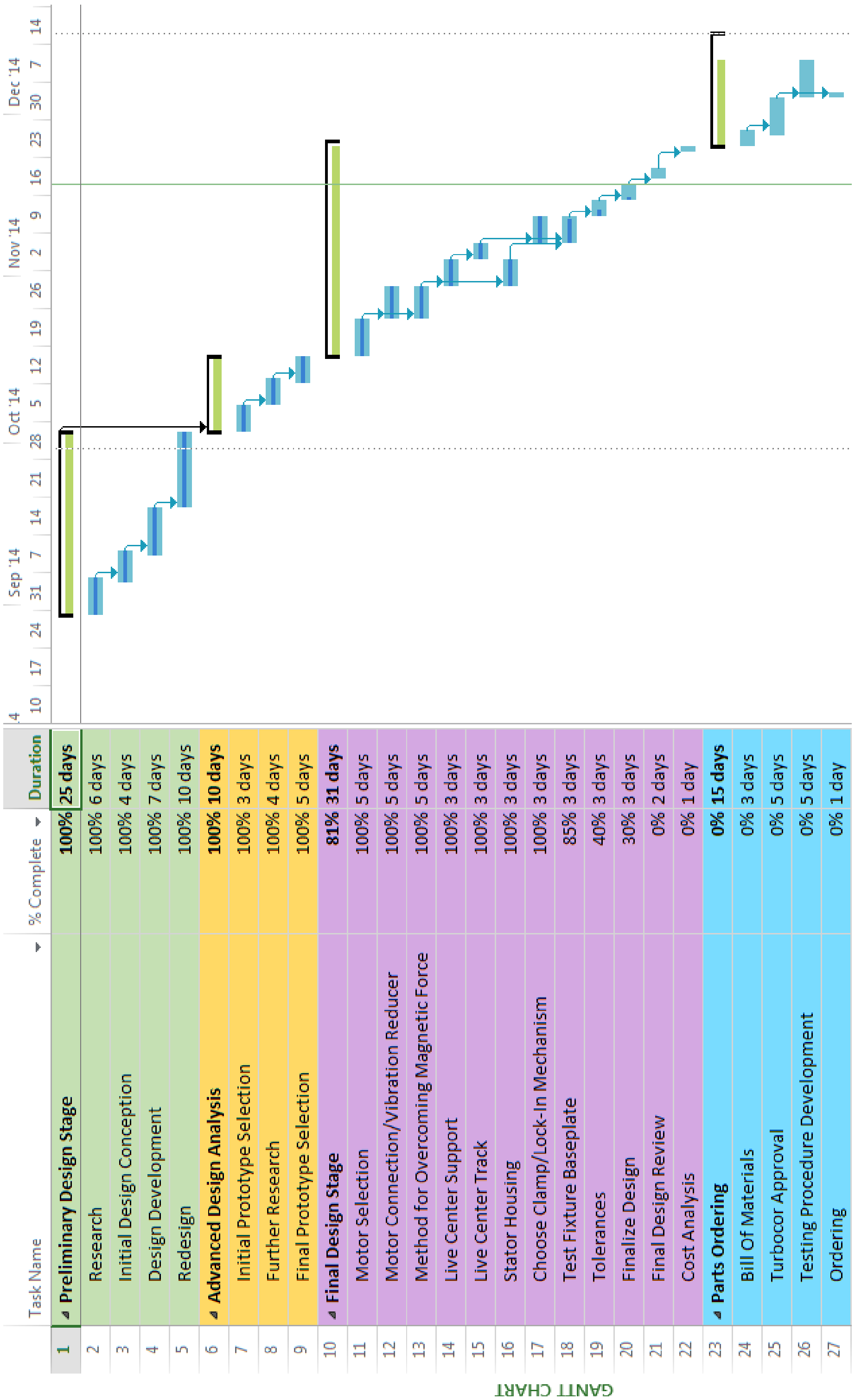
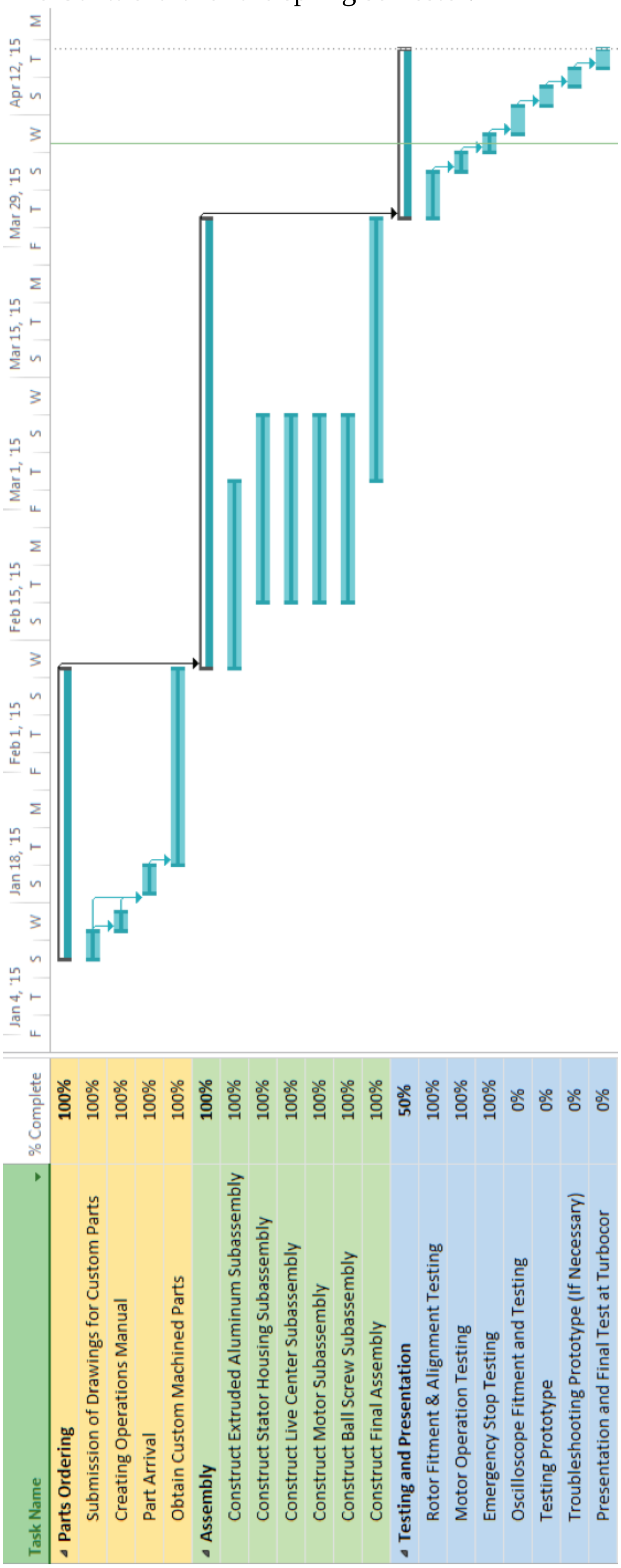
R2.5 x8 PLACES DIN 912-A2
R5 x3 PLACES DIN 916-A2
R5 x8 PLACES DRILL TO 4.5mm
R3 x4 PLACES DRILL THRU
UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE IN MILLIMETERS
REVISION DESCRIPTION
DTC PART NUMBER
DTC PART DESCRIPTION

Appendix C

The Gantt chart for the fall semester:



The Gantt chart for the spring semester:



Appendix D

Budget allocation for different ordered components for the test fixture:

Description	Vendor Part Number	Quantity	Unit Price	Total Price
Heavy Load Linear Guides	SX2R28-1240	2	$308.33	$616.66
Linear Guide Claming Units	SVCK28	2	$78.18	$156.36
Extruded Aluminum Baseplate	HFS8-90180-1750	1	$391.12	$391.12
M5 Extruded Aluminum Fasteners (x100)	PACK-HNTTSN8-5	1	$33.10	$33.10
M6 Extruded Aluminum Fasteners (x100)	PACK-HNTTSN8-6	1	$33.10	$33.10
Handwheel	PHLW200-17	1	$86.46	$86.46
Rolled Ball Screw (1100 mm)	BSBR1510-1100	1	$344.91	$344.91
Fixed Side Support Unit	BSWE12	1	$87.14	$87.14
Support Side Support Unit	BTN12	1	$90.59	$90.59
2 HP AC Motor, 1800 RPM	E2007A	1	$455.00	$455.00
2 HP AC Motor Drive, 3 Phase	GS2-22P0	1	$251.00	$251.00
Adjustable Motor Base, 145T Frame	MTA-BASE-W145T	1	$18.00	$18.00
Live Center	ZLC 07018-MT2	1	$128.95	$128.95
Live Center Adapter	185041	1	$23.93	$23.93
6061 Configurable Plate	A6061P-6F-MMA-NNN-212-160-38.1-CAR	1	$119.63	$119.63
6061 Configurable Plate	A6061P-6F-MMA-NNS-166-120-32-CAR	2	$71.09	$71.09
6061 Configurable Plate	A6061P-6F-MMA-NNS-80-70-20-CAR	2	$29.36	$58.72
6061 Configurable Plate	A6061P-6F-MMA-NNS-200-200-10-CAR	2	$55.06	$110.12
6061 Configurable Plate	A6061P-6F-MMA-NNS-100-100-49-CAR	1	$67.30	$67.30
6061 Configurable Plate	A5052P-6F-MMA-NSN-210.4-80.5-49.1-CAR	2	$96.78	$193.56
Fuse 25A 300VAC Class T 10 Pack	TJN25	1	$71.75	$71.75
Fuse 0.1A 250VAC Class A 5 Pack	AGC-1	1	$6.50	$6.50
VFD Remote Keypad Mount	GS-CBL2-IL	1	$28.50	$28.50
Power Supply 24 VDC 3.75A (90 Watt)	PSM24-090S	1	$99.00	$99.00
MUSH PB 30mm Metal Red NC Push-Pull	HT8 CBRB	1	$62.00	$62.00
Guarded PB 30mm Metal Green 24V MOM LED-3H	HT8 GDF3	1	$68.00	$68.00
Legend Plate 30mm On/Off Plastic	HT8 SP25	1	$4.50	$4.50
Legend Plate 30mm E-Stop Plastic	HT8 RP79	1	$4.50	$4.50
N12 30mm COVER 8X3.25X2.81 IN PUSH BUTTON	PB3	1	$53.00	$53.00
			Total:	$3,734.49

Appendix E

The complete purchase orders for the Back EMF Test Fixture.

Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

DATE: 23-Jan-15

DATE REQUIRED:

Vendor: Misumi USA
http://us.misumi-ec.com/

CAPITAL EXPENDITURE (please tick):
$1,000 but less than $4,500 Complete Below

	CAPITAL EXPENDITURE INFO: <4,500			
	Completion Date		**Budgeted (Y/N)**	
	Functional Area		**Budget amount**	
Contact: Customer Service: 847-843-9105	**Originator**		**CapEx / Asset #**	
	Repair/Replacement/New		**Accountant**	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Heavy Load Linear Guides	SX2R28-1240	2	$ 308.33	$ 616.66		
	Linear Guide Clamping Units	SVCK28	2	$ 78.18	$ 156.36		
	Extruded Aluminum Baseplate	HFS8-90180-1750	1	$ 391.12	$ 391.12		
	Nuts for Extruded Aluminum (100x)	PACK-HNTTSN8-6	1	$ 33.10	$ 33.10		
	Handwheel	PHLW200-17	1	$ 86.46	$ 86.46		
	Rolled Ball Screw (1100 mm)	BSBR1510-1100	1	$ 344.91	$ 344.91		
	Fixed Side Support Unit	BSWE12	1	$ 87.14	$ 87.14		
	Support Side Support Unit	BTN12	1	$ 90.59	$ 90.59		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 1,806.34

Special instructions:

Prepared by: (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

DATE: 23-Jan-15

DATE REQUIRED:

Vendor: Automation Direct
http://www.automationdirect.com/adc/Home/Home

CAPITAL EXPENDITURE (please tick):
$1,000 but less than $4,500 Complete Below

	CAPITAL EXPENDITURE INFO: <4,500			
	Completion Date		Budgeted (Y/N)	
	Functional Area		Budget amount	
Contact: Sales 770-889-2858	Originator		CapEx / Asset #	
	Repair/Replacement/New		Accountant	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	2 HP AC Motor, 1800 RPM	E2007A	1	$ 455.00	$ 455.00		
	2 HP AC Motor Drive, 3 Phase	GS2-22P0	1	$ 251.00	$ 251.00		
	Adjustable Motor Base, 145T Frame	MTA-BASE-W145T	1	$ 18.00	$ 18.00		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 724.00

Special instructions:

Prepared by: ______________________ (Print name)

Approved by: ______________________ (Manager)

Approved by: (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

DATE: 23-Jan-15

DATE REQUIRED:

Vendor: Z Live Center
http://zlivecenter.com/

CAPITAL EXPENDITURE (please tick):
$1,000 but less than $4,500 Complete Below

	CAPITAL EXPENDITURE INFO: <4,500			
	Completion Date		**Budgeted (Y/N)**	
	Functional Area		**Budget amount**	
Contact: Customer Service: 909-274-7148	**Originator**		**CapEx / Asset #**	
	Repair/Replacement/New		**Accountant**	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Live Center	ZLC 07018-MT2	1	$ 128.95	$ 128.95		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 128.95

Special instructions:

Prepared by: ______________________ (Print name)

Approved by: ______________________ (Manager)

Approved by: (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

PURCHASE ORDER REQUISITION

DATE: 23-Jan-15

DATE REQUIRED: ____________

Vendor: MSC Industrial Supply
http://www.mscdirect.com/

CAPITAL EXPENDITURE (please tick): [ ]
$1,000 but less than $4,500 Complete Below

Contact: Customer Service: 800-645-7270

CAPITAL EXPENDITURE INFO: <4,500			
Completion Date		**Budgeted (Y/N)**	
Functional Area		**Budget amount**	
Originator		**CapEx / Asset #**	
Repair/Replacement/New		**Accountant**	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Live Center Adapter	185041	1	$ 23.93	$ 23.93		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 23.93

Special instructions:

Prepared by: ____________ (Print name)

Approved by: ____________ (Manager)

Approved by: ____________ (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

DATE: 27-Mar-15

DATE REQUIRED:

Vendor: Automationdirect.com
3505 Hutchinson Road
Cumming, GA 30040
Ph (800) 633-0405
Fax Sales: (770) 889-7876
Fax Accounting: (770) 844-4213

Contact:

CAPITAL EXPENDITURE (please tick):
$1,000 but less than $4,500 Complete Below

CAPITAL EXPENDITURE INFO: <4,500			
Completion Date		**Budgeted (Y/N)**	
Functional Area		**Budget amount**	
Originator		**CapEx / Asset #**	
Repair/Replacement/New		**Accountant**	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	FUSE 25A 300VAC CLASS T 10PK	TJN25	1	$71.75	$ 71.75		
	FUSE 0.1A 250VAC CLASS A 5PK	AGC-1	1	$6.50	$ 6.50		
	VFD REMOTE KEYPAD MOUNT	GS-CBL2-1L	1	$28.50	$ 28.50		
	POWER SUPPLY 24VDC 3.75A (90W)	PSM24-090S	1	$99.00	$ 99.00		
	MUSH PB 30mm METAL RED N.C PUS	HT8CBRB	1	$62.00	$ 62.00		
	GUARDED PB 30mm METAL GRN 24V	HT8GDF3	1	$68.00	$ 68.00		
	LEGEND PLATE 30mm ON/OFF PLASTI	HT8SP25	1	$4.50	$ 4.50		
	LEGEND PLATE 30mm E-STOP PLASTI	HT8RP79	1	$4.50	$ 4.50		
	N12 30mm COVER 8X3.25X2.81 IN PUS	PB3	1	$53.00	$ 53.00		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 397.75

Special instructions:

Prepared by: Ryan Sievers (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

PURCHASE ORDER REQUISITION

DATE: 23-Jan-15

DATE REQUIRED:

Vendor: Misumi USA
http://us.misumi-ec.com/

CAPITAL EXPENDITURE (please tick):
$1,000 but less than $4,500 Complete Below

	CAPITAL EXPENDITURE INFO: <4,500			
	Completion Date		**Budgeted (Y/N)**	
	Functional Area		**Budget amount**	
Contact: Customer Service: 847-843-9105	**Originator**		**CapEx / Asset #**	
	Repair/Replacement/New		**Accountant**	

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Heavy Load Linear Guides	SX2R28-1240	2	$ 308.33	$ 616.66		
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	Nuts for Extruded Aluminum (100x)	PACK-HNTTSN8-6	1	$ 33.10	$ 33.10		
	Handwheel	PHLW200-17	1	$ 86.46	$ 86.46		
	Rolled Ball Screw (1100 mm)	BSBR1510-1100	1	$ 344.91	$ 344.91		
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FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 1,806.34

Special instructions:

Prepared by: (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

Purchase Requisition, 3A0-0070-F-90, Rev A, 20 July 2012

Biography

Thomas Razabdouski - Team Leader

e: trs09@my.fsu.edu p: (904) 710-3312

Thomas Razabdouski is a Mechanical Engineering senior originally from Jacksonville, Florida. He has always been interested in how things work, and he began taking things apart at a young age. He currently works at O'Reilly's Auto Parts and his interest in cars and aircraft is where his interest in Mechanical Engineering stems from. In his free time, he plays basketball and works on his car.

Tim Romano - Financial Advisor

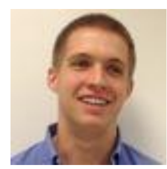
e: tr10j@my.fsu.edu p: (904) 322-0372

Tim Romano is a senior studying Mechanical Engineering from Jacksonville, Florida. He attended high school at the Bolles School, gradutating in 2010. He has spent many years as a swimmer and even swam on the FSU Varsity team. After graduating, Tim plans on working in either the field of sustainable energy or in the automobile market.

Andrew Panek - Lead ME

e: ajp11k@my.fsu.edu p: (352) 874-2166

Andrew Panek is a Mechanical Engineering senior going into the Florida State University BS-MS program to pursue his Master's Degree, while also working part-time at Danfoss Turbocor. Andrew has studied abroad in Paris, France.



Russell Hamerski – Secretary

e: rh10g@my.fsu.edu p: (207) 317-7267

Russell Hamerski is a Mechanical Engineering senior originally from Cape Elizabeth, Maine. He has particular interest in Fluid Mechanics, Thermal Fluid Design, and Subsea Engineering. After graduation, he plans to work for Shell Oil Company as a Subsea Engineer in Houston, Texas.

Andre Steimer - Lead CAD engineer, Webmaster

e: as10f@my.fsu.edu p: (407) 492-9830

Andre Steimer is a Mechanical Engineering senior from Zurich, Switzerland. His interests include technology in the amusement industry and robotics. Outside of engineering, he enjoys long-distance running and scuba diving. He currently works at the Florida State University Center for Intelligent Systems, Control, and Robotics and Florida State University Libraries.