Danfoss Turbocor
High Speed Motor Test Rig
Team 5
Operation Manual

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1 Abstract

Since Danfoss Turbocor's compressors run at high RPM's, individuals have to take numerous safety precautions to prevent irrevocable damage to operators and the highly expensive machinery. Before an individual begins working with this High Speed Motor Test Rig, they should familiarize themselves with all the included components, processes, and risks. This project demands a high level of shaft alignment, to achieve this, the assembly process must be followed closely. Operators should thoroughly understand the alignment processes, and seek assistance if they need a better understanding. This system will require attention to component condition throughout its life. Operators must familiarize themselves with certain components that could become prone to structural failure. It is highly important that safety comes first, operators must follow instructions to protect themselves and others involved. Write Something

2 Functional Analysis

As delegated by Danfoss Turbocor, the High Speed Motor Test Rig designed by Senior Design Team 4 in 2015-2016 and Team 5 in 2016- 2017 at FAMU/FSU College of Engineering was developed with the purpose of qualifying motor performance while allowing a precise alignment method. This is capable to work with all the TT-series of Turbocor compressors. In order to calculate motor performance, the test rig needs, besides the precision in the alignment process, has an end goal of reaching speeds-around 40,000 rpm - and be compatible with the specific features that constitutes Turbocor compressors. Taking safety into consideration, this year's goal was to calculate the efficiency of Turbocor's compressors at 10,000 rpm. One the compressors main and distinguished features is the use of magnetic bearings; magnetic bearings are used to maintain these engines as oil free but at the same time it supports a limited value of radial load - around 200 lbs - what requires a certain level of attention when we are talking about mechanical vibrations at high speeds.To provide a feasible solution attending all the requirements already mentioned and making possible a future qualification in terms of power, efficiency and heat management of these motors, the high speed motor test rig came up as a possible solution in this specific situation. Initially, the test rig was completely designed to allow the integration of a torque transducer and a laser alignment tool. But due to unforeseen budget constraints and product lead time, the overall design has to be changed to validate the validity of the design by producing a mock transducer. The following is a breakdown of each subsystem, its components, and their functions.

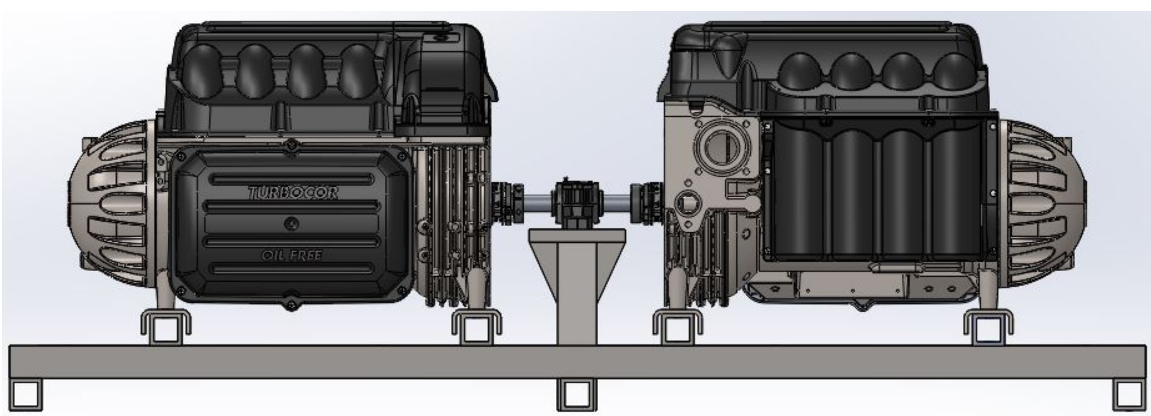

Figure 1: High Speed Motor Test Rig assembly with TT-500 compressors

3 Project Specifications

3.1 Base Frame

The base frame is composed of two parallel long runners 2x2 inch square (boxed) steel (1/4 inches thick), four upper cross members also made of the same material, and three lower cross members for supporting purposes. The objective of the base frame is to support both compressors, function fulfilled basically with the upper cross members, and also allow the positioning of all other components needed to align the motors. All the details about the alignment system and the other subsystems of the base frame can be found in the section Product Specifications. The base frame dimensions can be visualized in Figure 6. Of the three lower cross members, the middle one is welded at mid length of the long runner, the other two lower cross members have two holes drilled in each and will be welded under the long runners at each end. The four upper cross members are going to be bolted to the frame with 1/2”-13 5.5” long cap screws. The supporting frame uses concrete fastening bolts to ensure their stability to the ground.

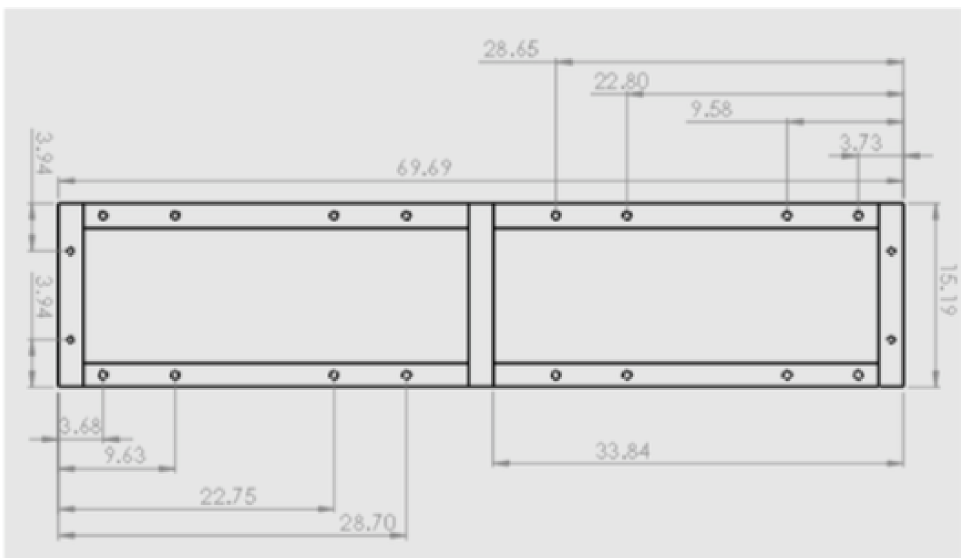

Figure 2: Top view of support frame without upper cross members[units in mm]

3.2 Rotating assembly

Composed of two double flex disc couplers and a mock torque transducer, the rotating assembly is responsible for connecting both compressors. Each component was selected/designed to attend all the requirements demanded by the specific characteristic of Turbocor TT-series of compressors. It was necessary the selection of a double flexible coupler in order to support axial, radial/angular misalignment, as well as reducing vibrations within the system. The rotating assembly will have an end goal of reaching speeds around 40,000 rpm, therefore a specific natural frequency analysis was done to ensure that this rotating assembly will not bring problems related to mechanical vibrations or any other misalignment issues.

Figure 3: Zero-Max double flex disc coupler

One side of the coupling will be connected to the 25 mm shaft that extrudes out of the impeller of the compressor. The other side will be fitting onto a 20 mm shaft that extrudes out of the mock transducer. The coupler has an adjustable collar not a key lock. Therefore the coupler opens to fit around the shaft, then tightened to securely fit around the shafts.

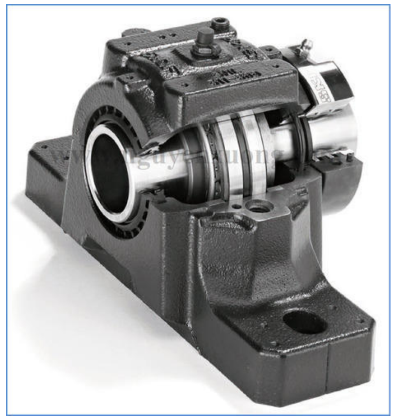

Figure 4: SKF Bearing Housing that represents a Mock torque Transducer

Since the torque transducer could not be purchase due to cost and lead time, a bearing housing was purchased to act as a mock transducer and verify the validity of the design theory. The bearing housing will act identical to the actual torque transducer, however it wont have the ability to calculate the efficiency of the compressors. The mock transducer will be mounted in the center between the two compressors and act as a rigid reference point for alignment purposes.

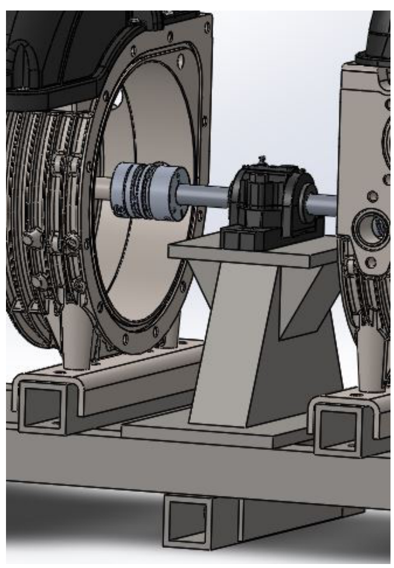

Figure 5: Mock transducer stand that acts as rigid reference point

3.3 Alignment system

The method to measure the misalignment is through the use of a laser alignment tool (SKF TSKA 31). This will provide more accuracy, precision and also to avoid the possibility of human errors.

Figure 6: SKF TSKA 31 Laser Alignment Tool

Other features of the alignment system include vertical and horizontal alignment adjustment. To adjust the compressors horizontally the test rig uses set screw brackets and to vertically adjust it utilizes shims of different thickness. The set screws (eight in total) press into the upper cross members. Shims can be inserted in eight locations, under the upper cross member and between the long runners. The shims will add additional material between the compressor and stand, which will raise the stand vertically. Considering the compressors are extremely heavy (approximately 300 pounds), it's recommended to use a car jack to lift the compressors while the shims are being placed between the stand and compressor.

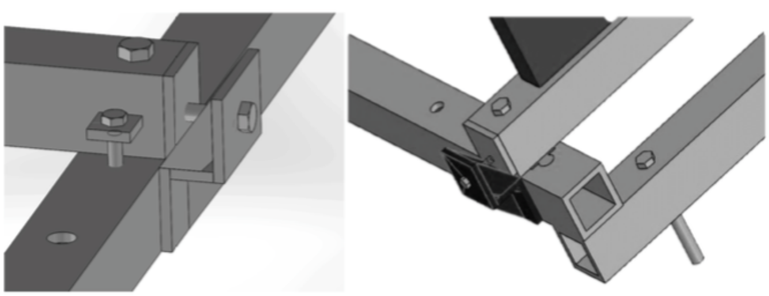

Figure 7: Alignment system: set screw brackets for horizontal adjustment and shims for vertical adjustment

The alignment system is basically the integration of the set screw brackets with the supporting frame. To adjust the system horizontally the screw brackets are utilized and to adjust vertically the insertion of shims is used. Brackets are composed of three triangular supports, two 2”x3” parts and one 1.25”x3”. The set screw brackets are going to be welded on the long runner, as it will be explained on the Project Assembly section. A cap screw will allow the horizontal movement and a screw jack will allow the cross member elevation for shims insertion.

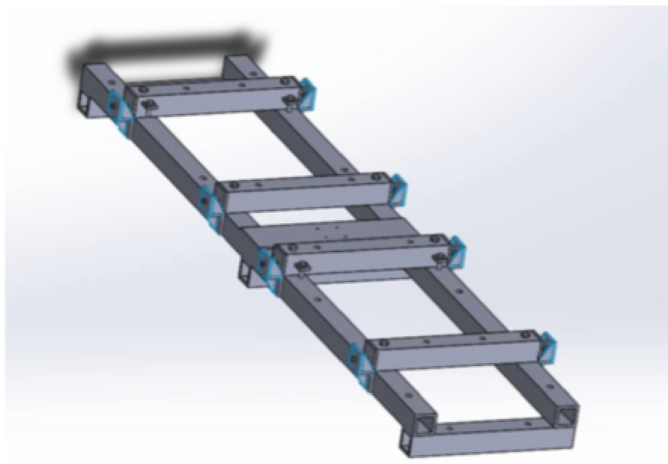

Figure 8: Horizontal and vertical alignment mechanisms integrated with the test rig base frame

The shims are made of brass and stainless steel and their thickness varies on a range from 0.001 inches to 0.031 inches. The dimensions of each shim are A=57 mm, B=51 mm and C=11 mm as on the figure below.

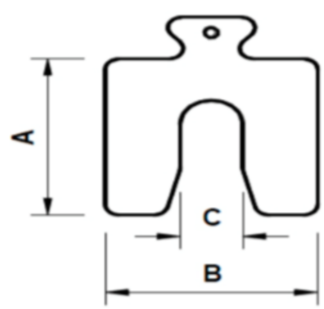

Figure 9: Shim upper view

3.4 Safety Shield

The safety shield was designed to prevent accidents due to possible failures as well as to provide much better conditions to the operators of the motor test rig. The safety shield is made out of Acrylic glass with a thickness of 0.5". The shield will cover the rotating assembly and will fit in between the compressor. The figure below shows the safety shield.

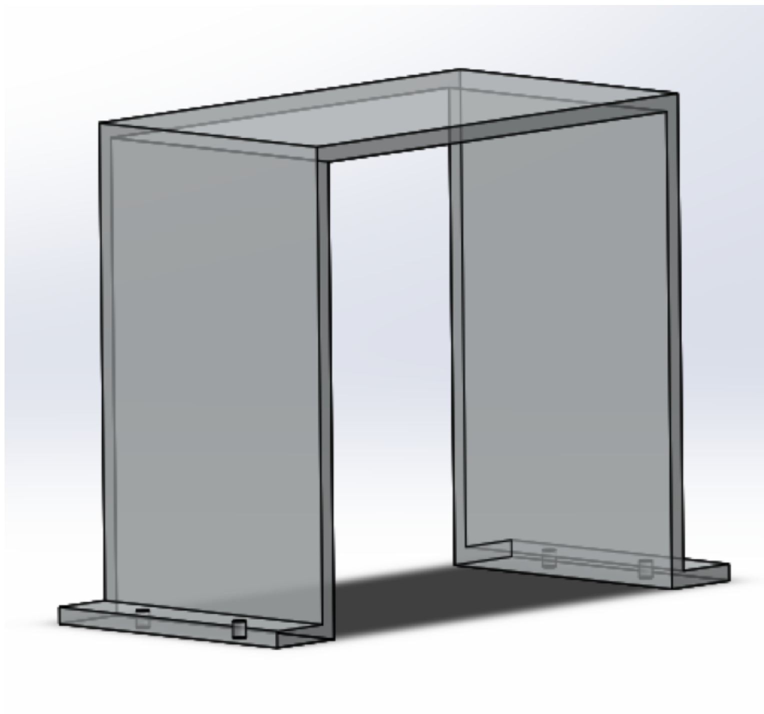

Figure 10: Acrylic Safety Shield

The length of the top portion of the safety shield is 504 mm. The height of the middle portion of the safety shield is at 355.60 mm. The bottom portion of the safety shield is 50.80 mm in length. The width of the safety shield is 228.60 mm for the bottom, middle, and top portion of the safety shield. The thickness of the safety shield is 0.5" or 12.70 mm throughout the entire design.

4 Project Assembly

This section will cover tools and equipment, and the assembly procedure that must be followed in the given order. By not using the necessary equipment and assembly process, error during alignment or structural failures may occur. Drawings of components and assemblies can be found in the appendix.

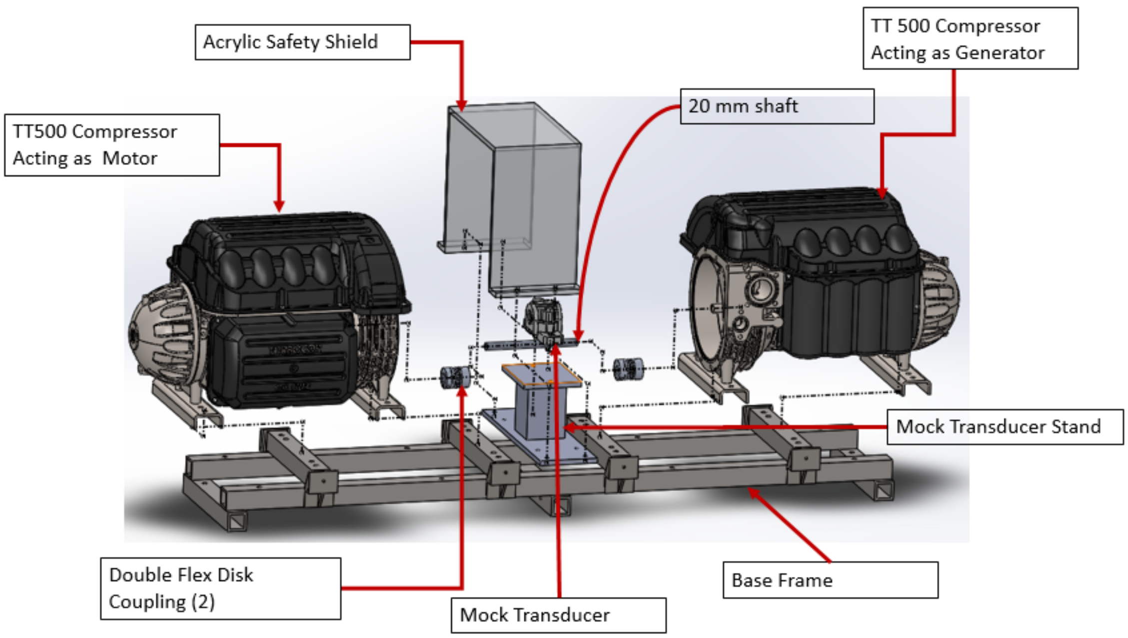

Figure 11: Exploded View

4.1 Recommended Tooling and Equipment

Those preforming the assembly will require assistance from multiple items. These following items are given in order that the user may need them during system assembly. Once the three lower cross members and two long runners are cut and their holes drilled, they can then be welded together. The materials are of low carbon steel, the recommended welding equipment varies, and can be decided upon by welder. It is important that the welder is aware that steps be made to avoid warping the frame. Warping will cause the frame to lack straightness and the top surface will not be a level surface. Multiple wrench fittings will be required to secure the fasteners within the test rig. Eight cap screws that will fasten through the four upper cross members and two long runners have a 1?2? socket head. Each of the eight set screw brackets have cap screw that will require a 3/8? hex key. Eight compressor mounting bolts will be fastened with a 12mm socket fitting. Two cap screws in the flexible coupler will require 10mm hex key. The two rigid couplers have four cap screws each and will require a 5mm hex key. Four anchor bolts will secure the frame to the concrete floor and will also use a 12mm socket fitting, these also require a hammer for their installation. The screw jack screw will require an 8mm socket fitting. To hoist the compressors onto the frame, it is recommended that the individuals use the assistance of an overhead pulley or winching system. To avoid injury and damage to the system, it is not advised to lift the compressors without mechanical assistance.

4.2 Laser Alignment Tool

The TKSA 31 uses two sensors in which both have a laser diode and a CCD detector. When the sensors are on the motor test rig itself, the shaft will be rotated through 180 degrees. As they are being rotated any parallel or angular misalignment will cause the two laser lines to deflect from the initial relative position. The measurements taken from the sensor will be used to determine the misalignment that is in the motor test rig. The measurement method that Team 5 will be using will be the 9-12-3 method. This refers to the sensors being in the 9, 12, and 3 o'clock position. If there is any misalignment, the TKSA 31 will guide Team 5 through the vertical and horizontal correction steps. It is important to note that if the TKSA 31 is not properly installed then the measurements taken can be very inaccurate. The measurements can also be off if Team 5 does not follow the proper instructions when actually taking the measurements.

As seen in the figure 12, each dimension input box can be clicked at any time. With this device, two custom tolerances can be setup at any time. Fill in the angular and parallel misalignment and click on the corresponding blue button. The units English or Metric can be selected from the settings menu before the alignment is started. The next step is to go into the measurement screen by clicking on the next arrow.

The next phase in the alignment process is to take the measurements with the sensors. The following steps can be visualized with the figure below. The first step is to select the measurement type by via the Settings then Measurement Settings. The 9 o'clock position is the first position that a measurement will be taken from. This is determined from looking behind the moveable machine, or in other words the machine that team 5 has determined to be the motor of the motor test rig. The

Figure 12: Laser Alignment Dimension

three measurements are to be taken in three different positions. These positions are the 9 (-90 deg), 12 (0 deg), and 3 (+90 deg) o'clock positions.

On the screen, a blue triangular wedge will indicate the required position of the measuring units during each step of the way. When prompted on the screen, the sensors will be rotated accordingly to the 9 o'clock position. Once the sensors are positioned within the blue wedge the wedge will then turn green. This indicates that the sensors are in the right position and a countdown will occur before the actual measurement is taken. Once the measurement is taken, the next arrow is clicked and on the screen it will indicate that the sensors need to be moved to the 12 o'clock position. Like before, once the sensors are within the blue wedge the wedge will turn green followed by a countdown to take the measurement. Click on the next arrow and the screen will indicate that the sensors will need to be moved into the last spot, which is the 3 o'clock position. Once the sensors are in the wedge it will turn green followed by a measurement after the countdown. It is important to note though that while this is going on that two things can't happen. One of them is to not move or touch the measuring units or the chain brackets while a measurement is occurring. The other is to not use the actual measuring equipment as a handle to turn the shafts in which these sensors are connected to. Another important note is that the two sensors should be less than 2 degrees apart in angle difference in order to get an accurate measurement. This is indicated by the S and M angle numbers as shown in the figure below.

Once all the necessary measurements are taken, the results page will appear on the screen. It will show the coupling and feet adjustment values. The symbols that are shown next to the results compare them to the selected tolerance range that was input earlier. What is also displayed is the line in which the motor should be one.

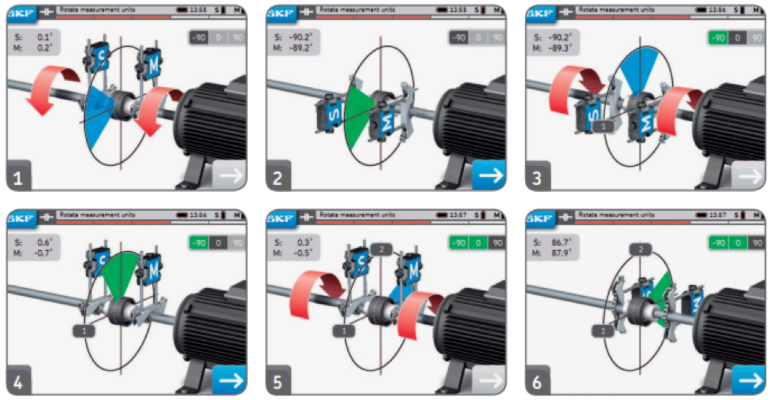

Figure 13: Measurement Process

The black line represents where the motor should be, while the blue line represents where the motor currently is. This can be seen from the figure below.

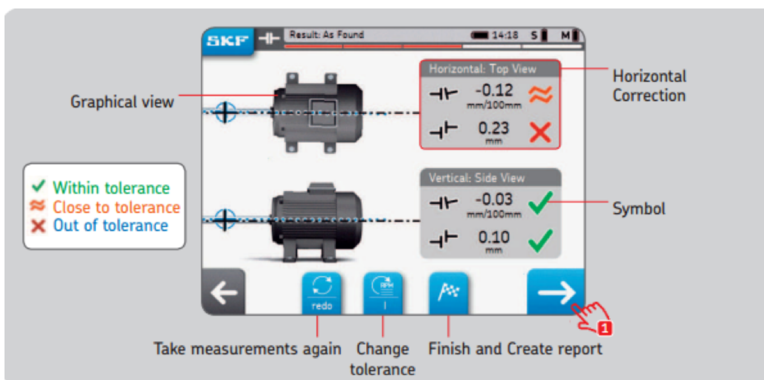

Figure 14: Results Screen

If the results given are out of tolerance, they will need to be corrected by Team 5. Upon hitting the next arrow as shown in the figure above, the screen will go into the vertical correction screen which can be seen in the figure below. For the vertical portion of the alignment adjustment, shims will be added or removed to adjust the height of the compressors in order to be within tolerance that was given earlier. The alignment system will calculate the correction values based from the feet of the compressor. To start the correction, the sensors will need to be moved in either the 12 o'clock (0 degrees) or the 6 o'clock (180 degrees). This can be seen in the figure below. Then once the wedge turns green , the next arrow is selected in order to validate the position in which the sensors are located.

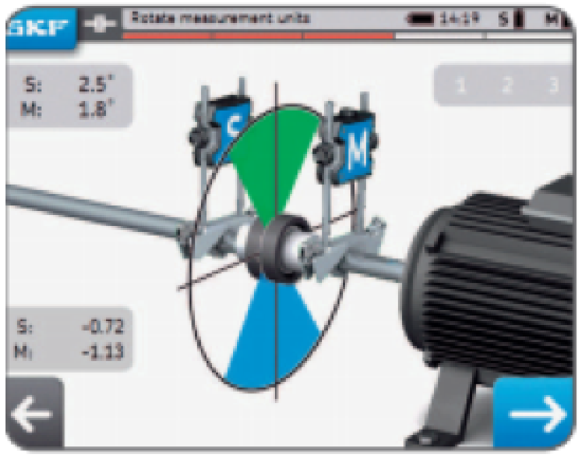

Figure 15: Vertical Correction

The next display that is shown is the live feed of the misalignment that is currently occurring in the motor test rig. The arrows that are shown on the feet of the compressor indicate in what direction an adjustment has to be made. The values on the feet are calculated based upon the distances that were input earlier when setting up the laser alignment into the motor test rig. The benefit of the TKSA 31 is the fact that the values are updated live as shims are added to the compressor to make it be within the tolerance given. Once the tolerance is given, then a green checkmark will appear next the the misalignment and offset as shown below.

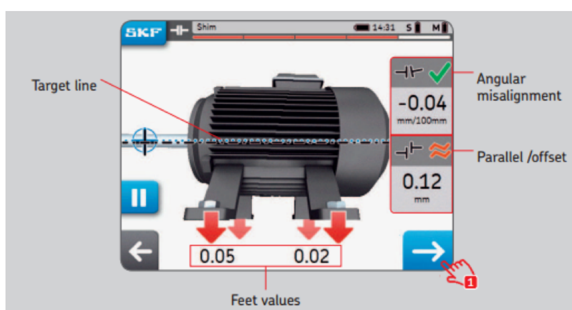

Figure 16: Vertical Corrections Live Feed

Once the vertical correction are done, then upon hitting the next arrow the horizontal corrections will appear if the measurements taken are not within the accepted tolerance. The sensors in this case will be placed in either the 3 o'clock (-90 degrees) or the 9 o'clock (-90 degrees) position. Once that position is confirmed by the team, it will be validated by hitting the next arrow button that will move on to the next display ass seen in the figure below.

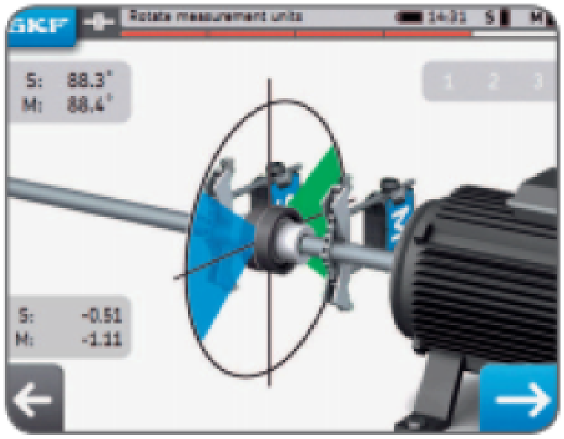

Figure 17: Horizontal Correction

The live feed of the misalignment in the horizontal direction is shown in the figure below. The image shown is from the top of the compressor with the arrows indicating where an adjustment needs to be made in both the front and back legs. It's important to note that it is best to start moving the side of the compressor that has the highest correction value displayed on the screen. When the values of the misalignment and offset are within range of the tolerance, a green checkmark will appear on both. Then the team can click the next arrow to continue as shown in the figure below.

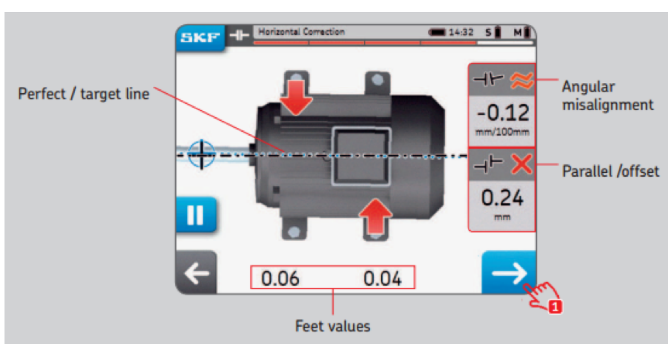

Figure 18: Horizontal Correction Live Feed

4.3 Frame

The supporting frame is composed of three lower cross members, two long runners, and four upper cross members. After these materials have been cut and their holes drilled, they can then be assembled. Two of the lower cross members have two holes drilled in each, these will be welded on the opposing ends of the long runners (see figure). The middle lower cross member is to be welded mid length of the long runners. The eight upper cross members are comprised of two different pieces, these are called "upper outter" and "upper inner" cross members. The "inner" pieces are bolted to the frame with 1/2"-13 5.5" long cap screws, and will be between, or "inside" the "outer pieces" (see figure). The four upper cross members will have end cover pieces, cut from 1/4" steel, welded to the open ends. The "outer" cross members will bolt to the long runners with the same cap screws, and be outside of the inner cross members. At each of these bolted junctions, there should be 1/2" washers. One washer under the head of the cap screw and one on the 1/2" nut that will be threaded onto the cap screw. At these junctions, the bolts should be torqued to 15Nm, but not until after the alignment process has been completed. Once the frame has been moved to its desired location, fasten it to the concrete using the concrete fastening bolts. Drill the concrete at the diameter of the M12 bolts. Use a hammer to punch the bolts through the lower outer cross members and into the concrete, be sure to leave bolt threads exposed above the surface of the cross member. Once they have tapped to the desired depth, thread the accompanying bolt onto the threads and tighten.

4.4 Set Screw Bracket

The set screw brackets should be assembled by welding its seven sub parts together, following the prescribed assembly drawing (see appendix). Brackets consist of two 2"x3" parts, one 1.25"x3", and three triangular supports. Once the eight brackets have been completed, they can be welded to the long runners of the assembled frame (see figure appendix for exact locations of set screw brackets). These brackets should be oriented so that the tapped hole is aligned with the center of the cross member end cover. Through each set screw bracket, thread a 3/8"-24 2" cap screw.

4.5 Rotating Assembly

Components that comprise the rotating assembly are two steel shafts, two double flex disc couplers, and one mock torque transducer coupler. Starting first with the

Zero-Max double flexible coupler, loosen the two clamping screws. Slide each shaft extruding out of the impeller of the compressors into each end of the flexible coupler. Tighten the couplers screw to 70Nm (it may be easier to tighten these after the rotating assembly is connected to the compressors. Next, slide the couplers onto the exposed ends of the shafts extruding out of the mock torque transducer (see figure). The screws in the rigid couplers should be torqued to 70Nm. Note: due to possible inaccuracies where the upper cross member supports are bolted, it may be necessary for the rotating assembly to extend further out or in to reach the compressor shafts.

4.6 compressors

The High Speed Motor Test rig is designed around the use of the Danfoss Turbocor TT series compressors, and is not design to work with other series. For the system to function, the impellers must be removed from the compressor. To mount the compressors, it is recommended to use an over head mechanical lifting system. Mount the first compressor onto one side of the frame, it does not matter which side is first. Be sure that the compressor shaft faces towards the center of the frame and not away. Align the mounting feet holes of the compressor with the holes in the upper cross members. Use the M12 bolts to fasten the compressor to the upper cross members (torque to 20Nm). Once the first compressor is mounted, the next step is to attach the rotating assembly. Begin by taking the assembled rotating assembly and fixing one of the exposed rigid couplers to the exposed compressor shaft. These screw should be tightened to 70Nm. The second compressor should be mounted to the system in the same manner as the first. Caution must be practiced when inserting the shaft into second exposed rigid coupler of the rotating assembly. The flexible couplers can allow for one degree of angular misalignment. Do not force the flexible coupler into a position that may exceed this, permanent damage may occur. Once the second compressor is fastened to the frame and rigid coupler, proceed in the assembly.

5 Operating Instructions

Before the system is ran, shaft alignment should always be preformed. This insures a safer and more efficient transfer of rotation from the driving motor to the generator motor. The greater the misalignment, the higher the chance of mechanical failure during rotation. The operation of the test rig after alignment requires control of the compressor motors and is beyond the realm of this user manual.

6 Trouble Shooting

Following the order of assembly, this section will address possible issues that could arise. During the installation of the upper cross members and compressors, if the mounting holes do not align, it will be necessary to use a power drill to drill the bolt holes to a larger diameter. Only use small increments when increasing the hole size. While assembling the rotating assembly, if the fit between the couplings and shaft is too tight, turn down the corresponding shaft end diameter in small increments until the desired fit is reached. While doing vertical alignment, if the laser alignment mounting position is disturbed after the readings have begun, the alignment process must start over. Maintaining the same position of the indicator is imperative to an accurate alignment. While preforming horizontal adjustment alignment, if the compressors does not want to shift, stop set screw rotation. Excess load upon the set screw may shear the threads. When a compressor cannot move laterally anymore, the bolts are being restricted by the frame hole diameter. If the opposing compressor cannot be adjusted instead, then the junctions at the long runners and cross members must be drilled to a larger diameter. After the system has been aligned and motor ran, if the shafts do not maintain alignment, check the break away torque on the frame and compressor. Due to the bolts relaxing from tensile load over time, the break away torque may be lower than the initial torque values. In this case, follow the alignment process and re-torque screw. If screw nuts become loose during system operation vibrations, apply Loctite 242 Blue Medium Strength Threadlocker to the threads. If any cracks 10 are found within the frame or rotating assembly, replace the part immediately. If the safety shielding is found to have any significant impact damage, replacing before system operation.

7 Regular Maintenance

Before and after the system is ran, the shaft alignment should be checked. During this time the torque on all fasteners should be checked to their intended values. If rust is found in frame, use an abrasive material to removed the rust and repaint the exposed metal. Inspect safety shielding before system operation for defects, replace if damage is found.

8 conclusion

The team was tasked with designing a system that would test compressor efficiency by coupling two compressor shafts together. This system is referred to as a motor-generator system, and because of the high speeds Danfoss Turbocor compressors reach, accurate shaft alignment is critical. This alignment was the primary focus of the project. The operations manual should be followed in the order the steps are presented. Failure to do so could jeopardize the success when preforming alignment and the safety during system operation.

References

[1] Previously Written Report from Senior Design Team 4 2015-2016,Senior Design Team 4 2015-2016

[2] laser alignment guidelines,http://www.skf.com/us/services/customer-training/classroom/WE240.html

Appendix

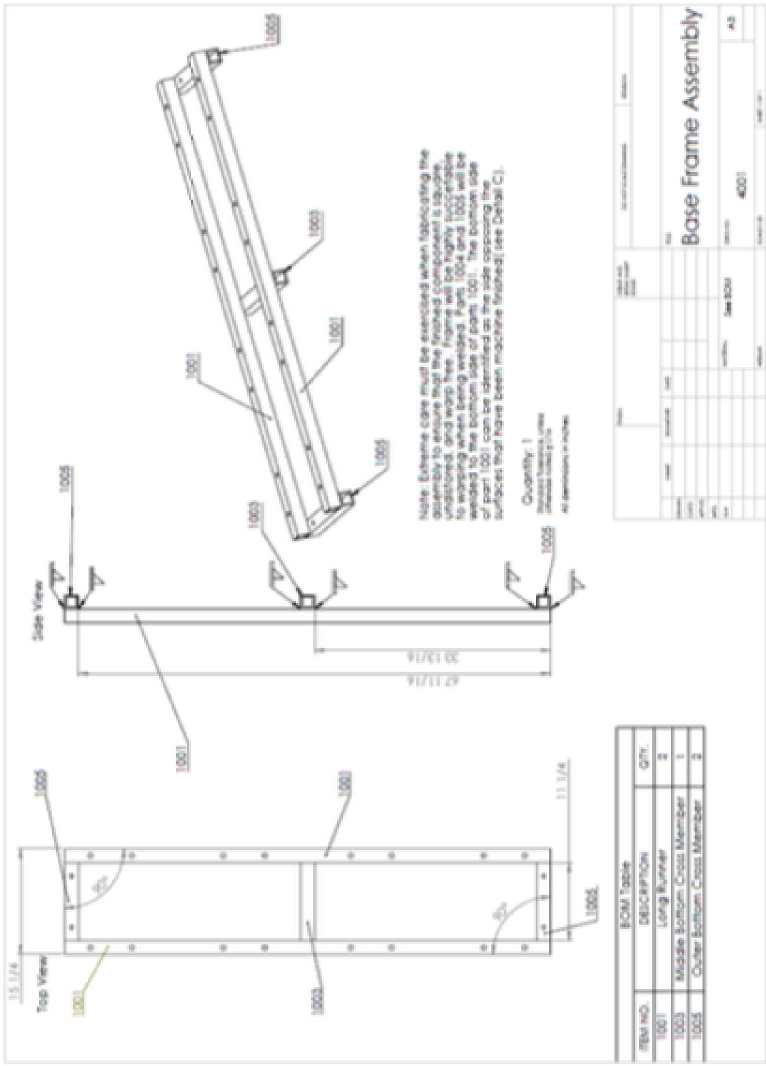

Figure 19: Base Frame Assembly

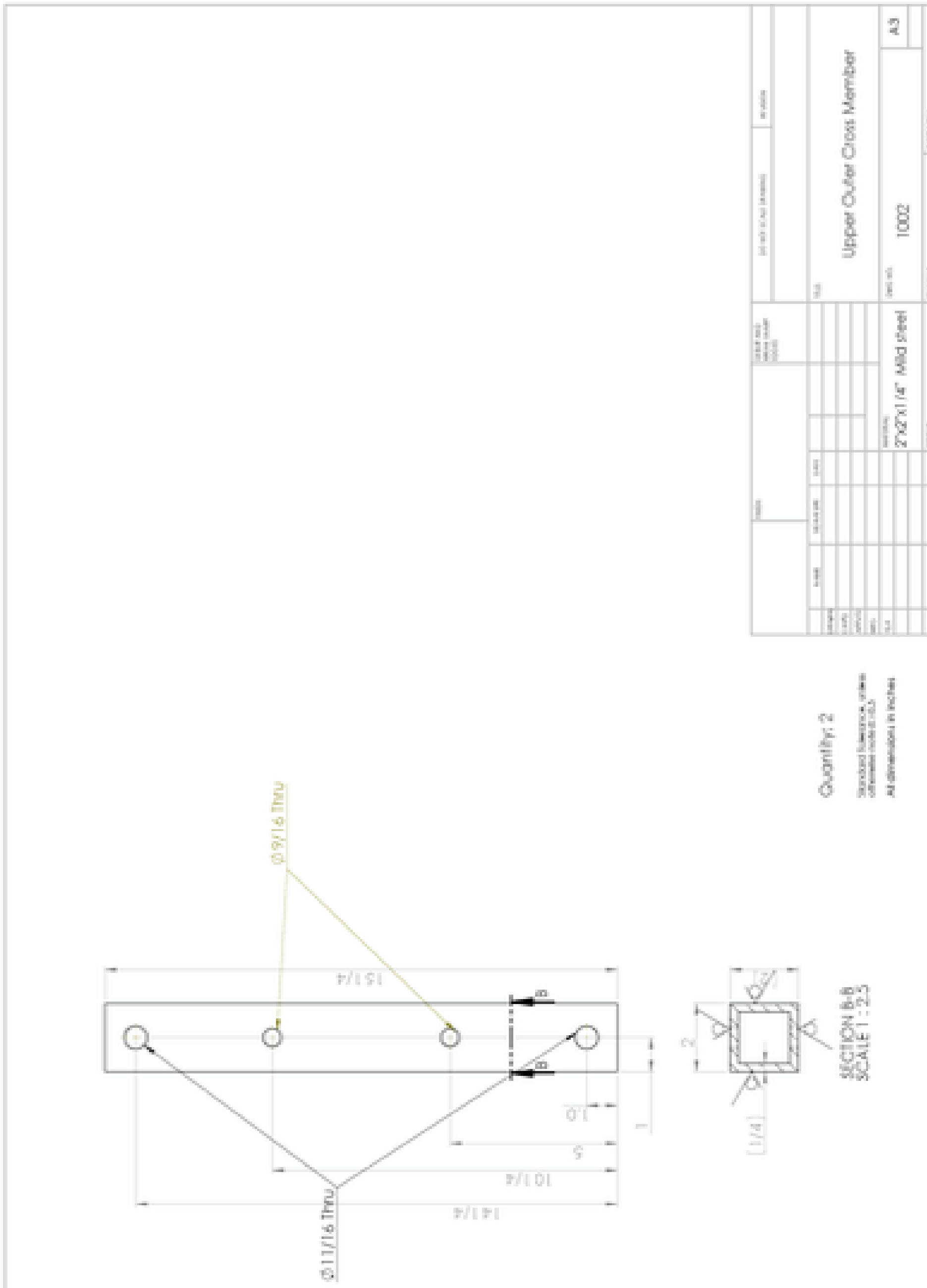

Figure 20: Upper Outer Cross Member

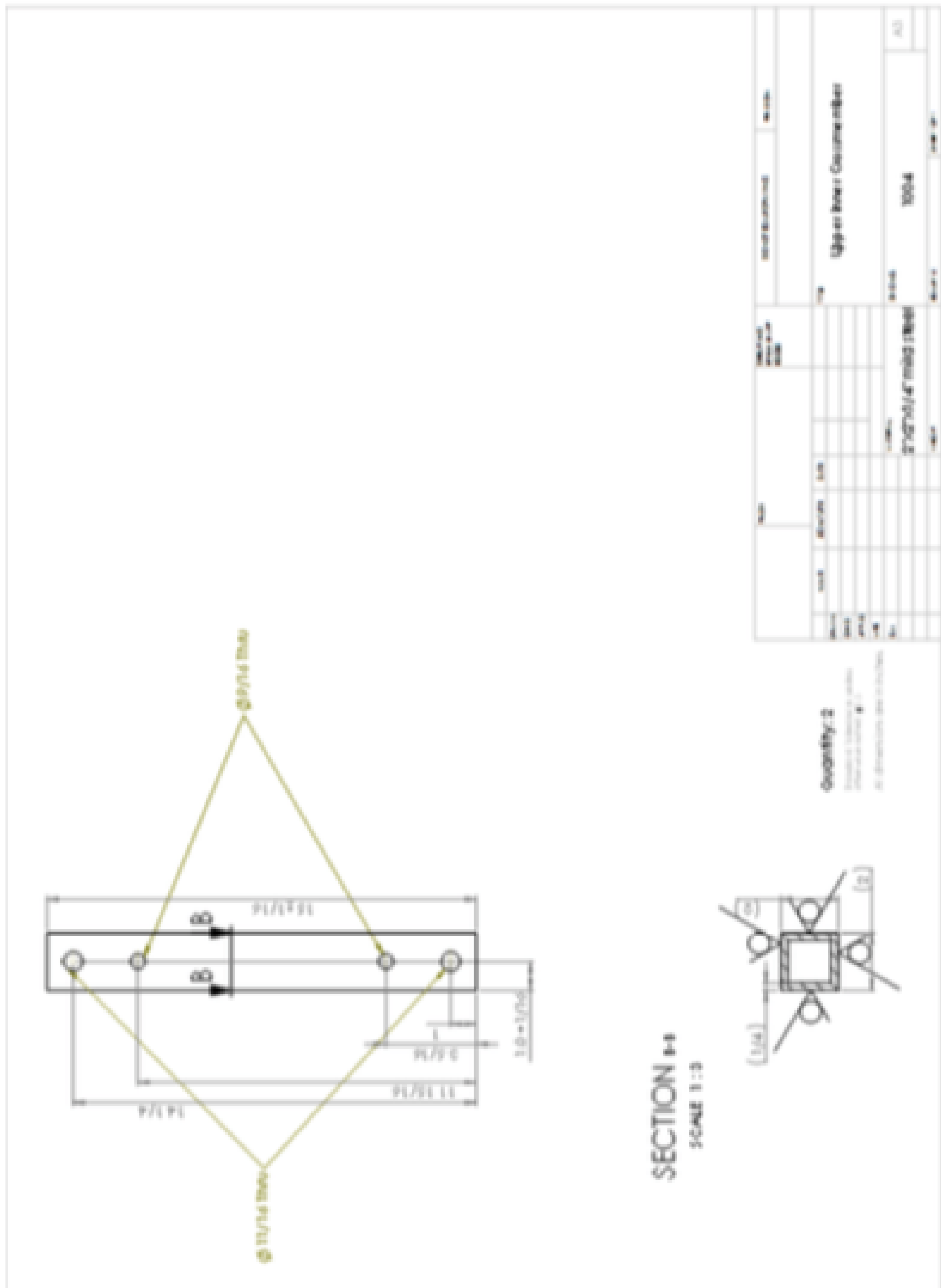

Figure 21: Upper Inner Cross Member

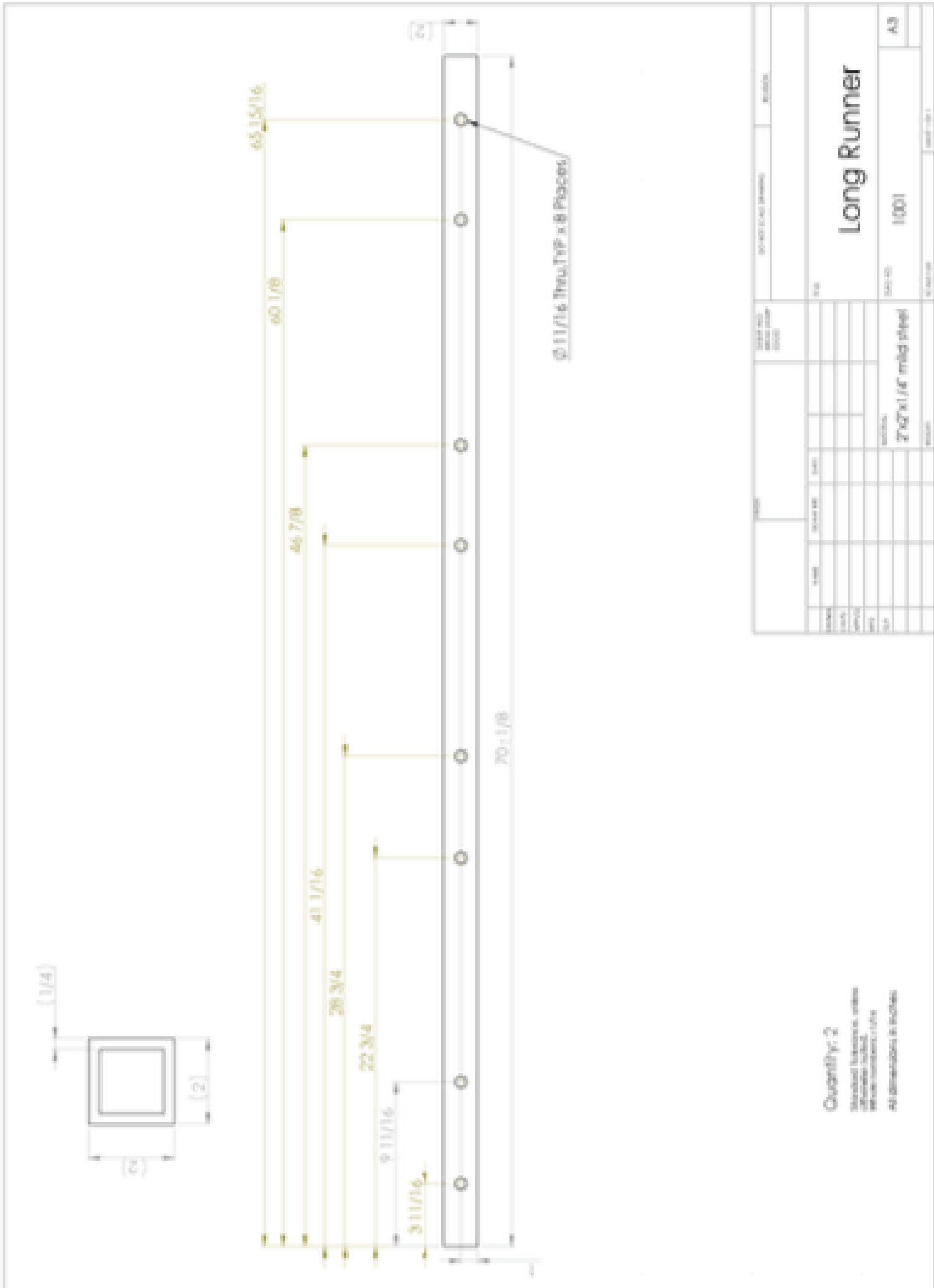

Figure 22: Long Runner

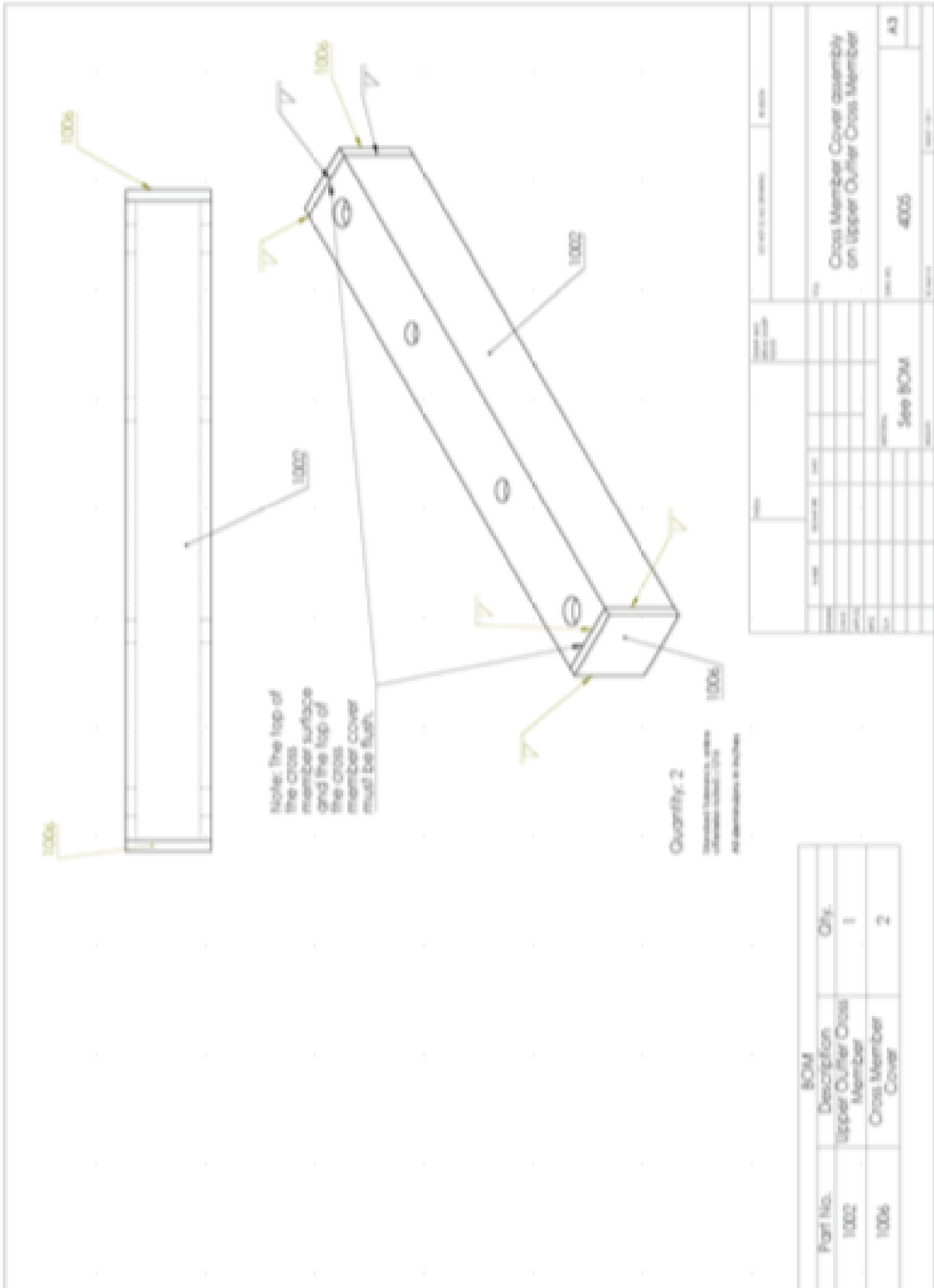

Figure 23: End Cover on Upper Outer Cross Member

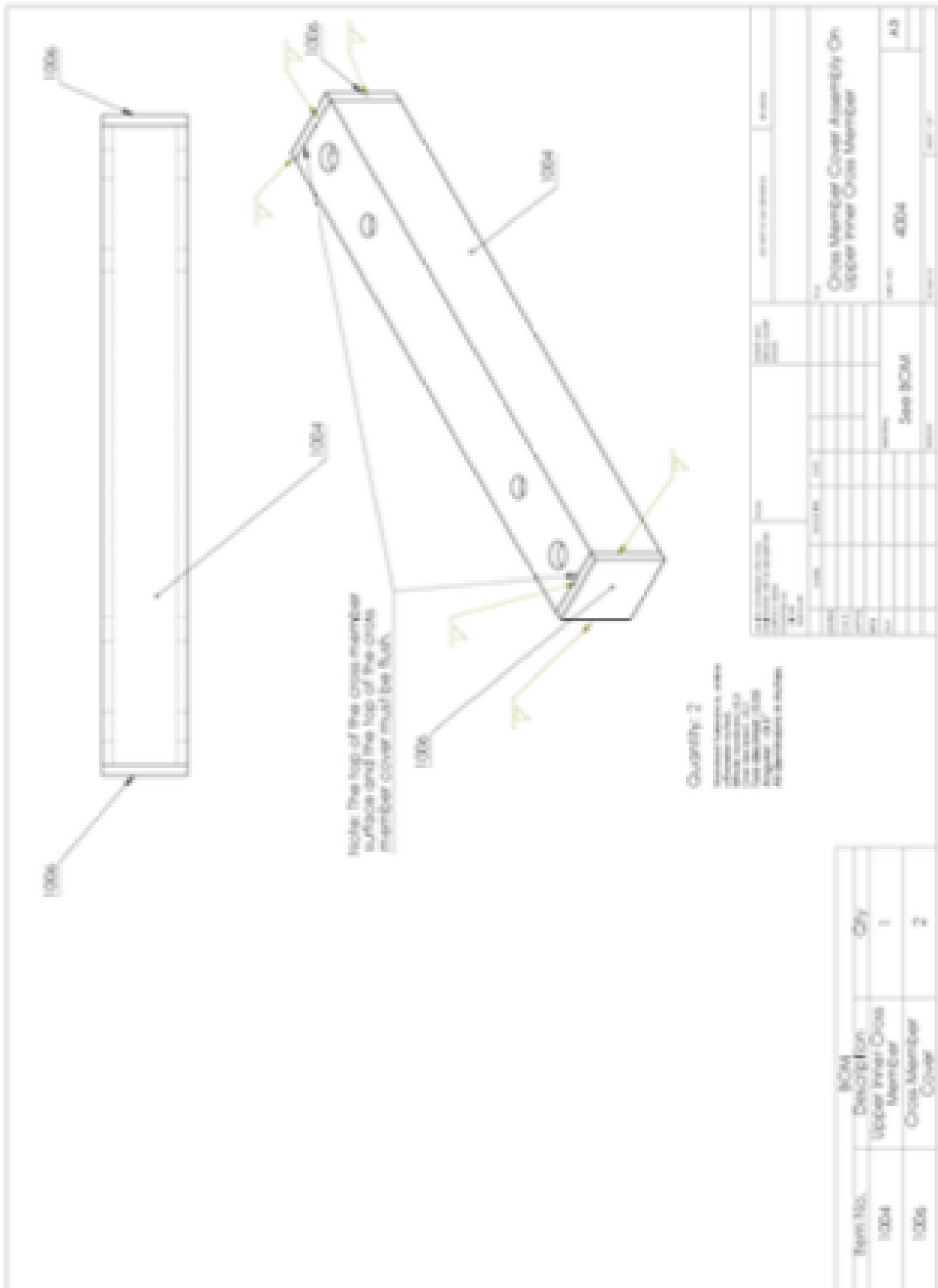

Figure 24: End Cover on Upper Inner Cross Member

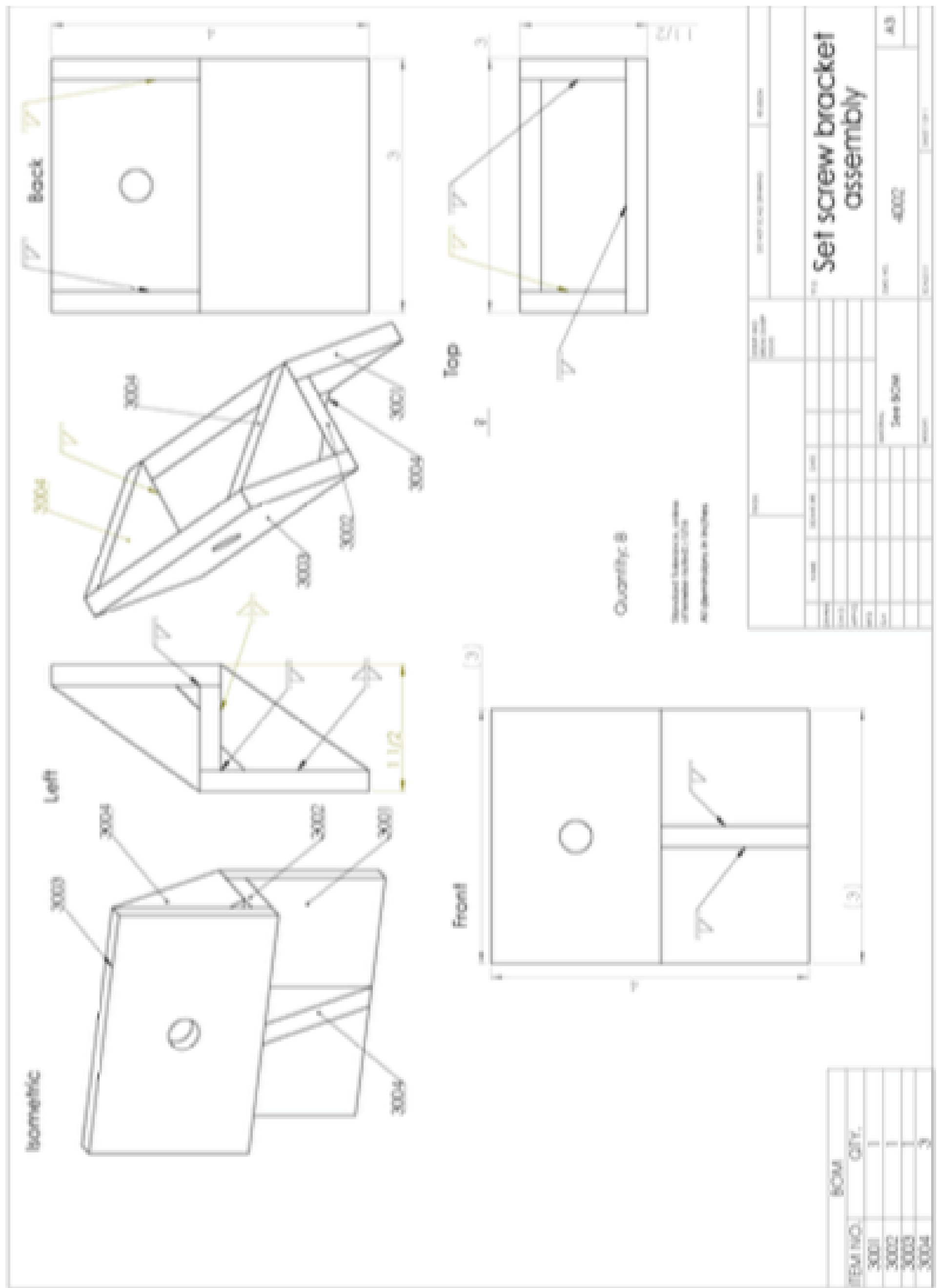

Figure 25: Set Screw Bracket Assembly

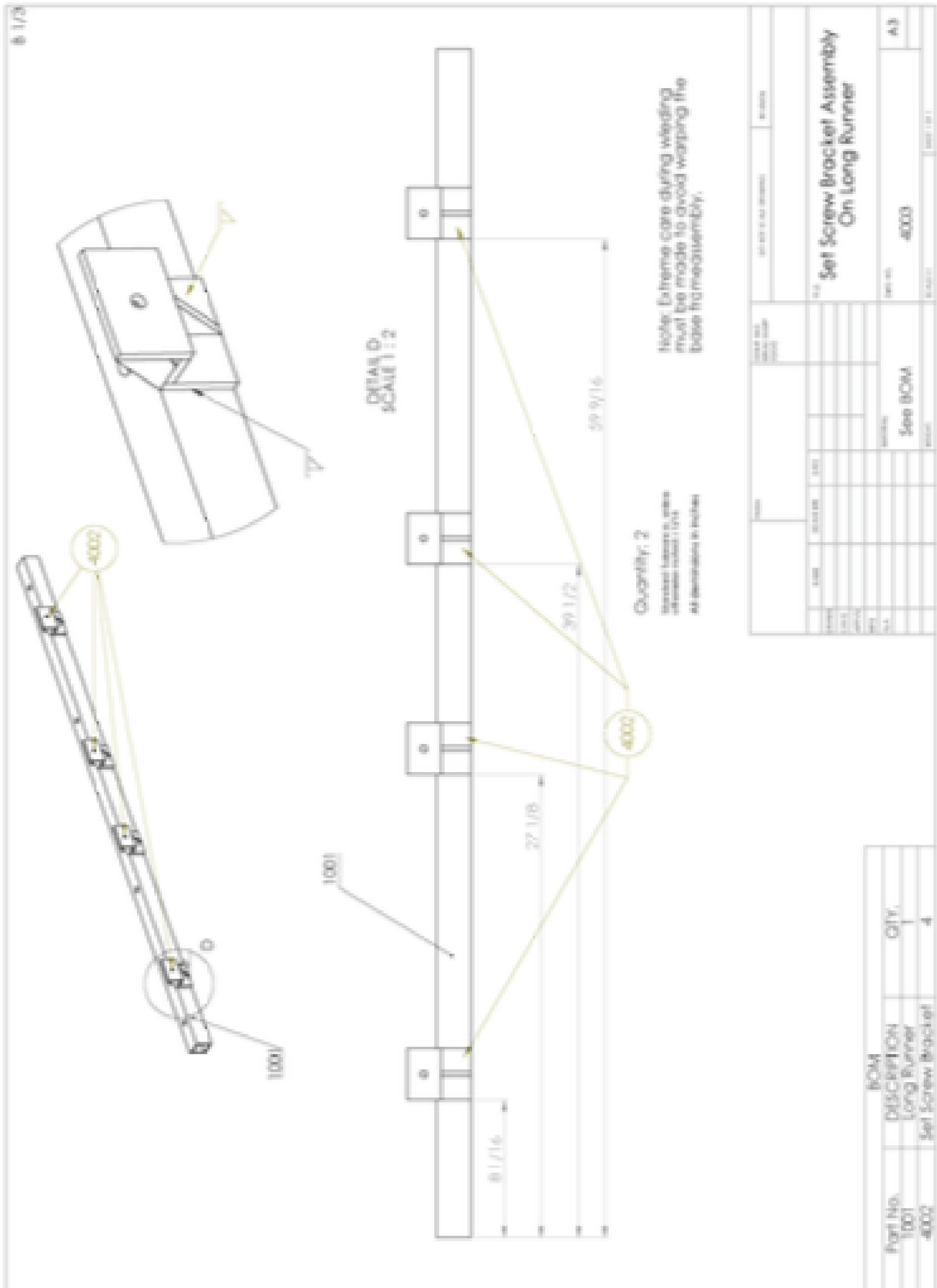

Figure 26: Set Screw Bracket Assembly on Long Runner

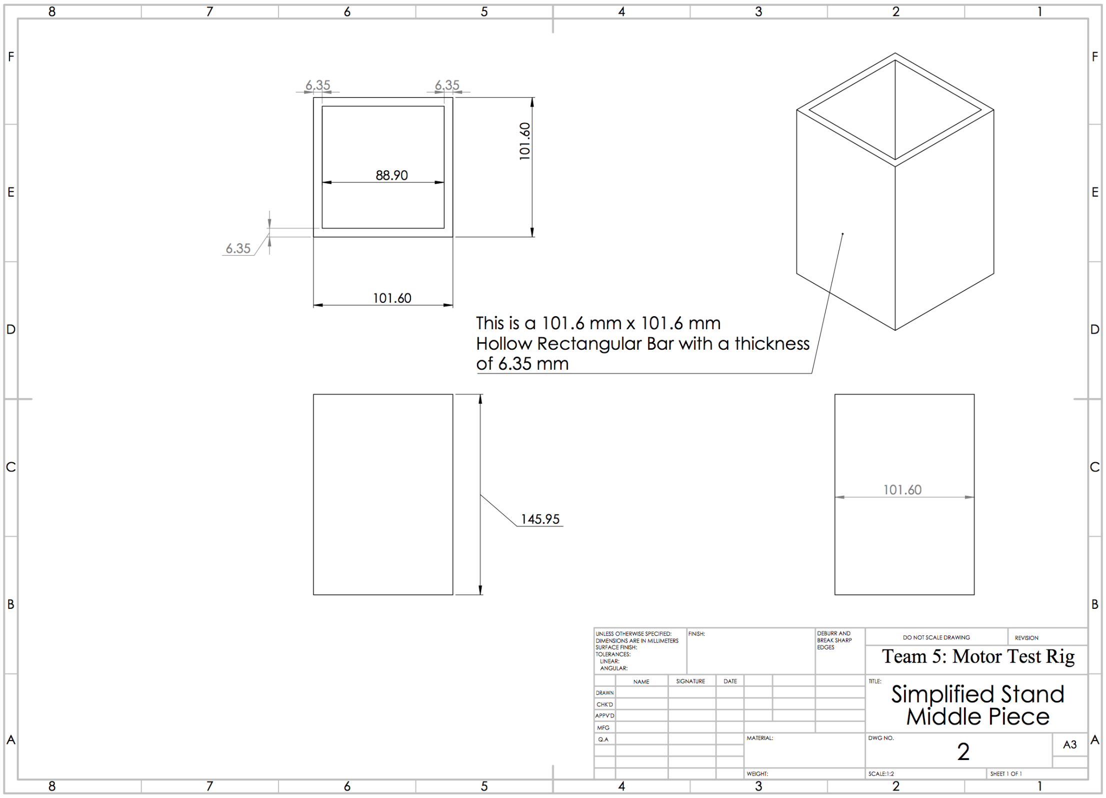

Figure 27: Acrylic Safety Shield

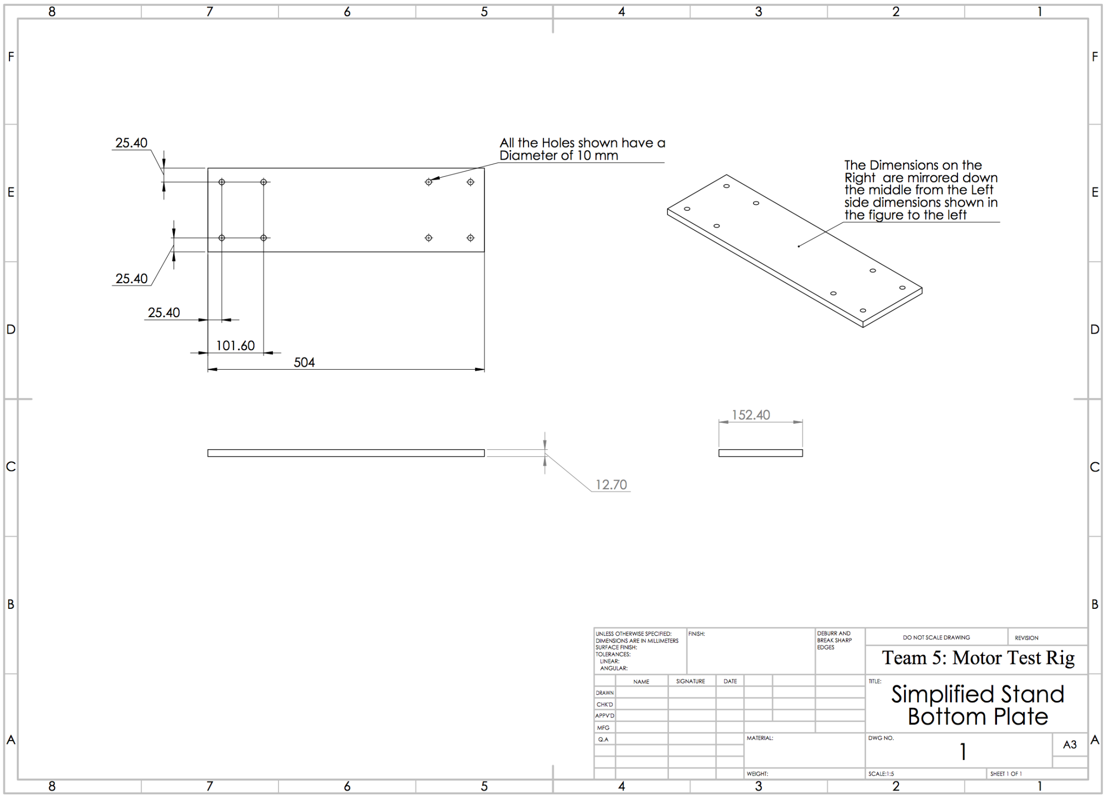

Figure 28: Mock Transducer Stand

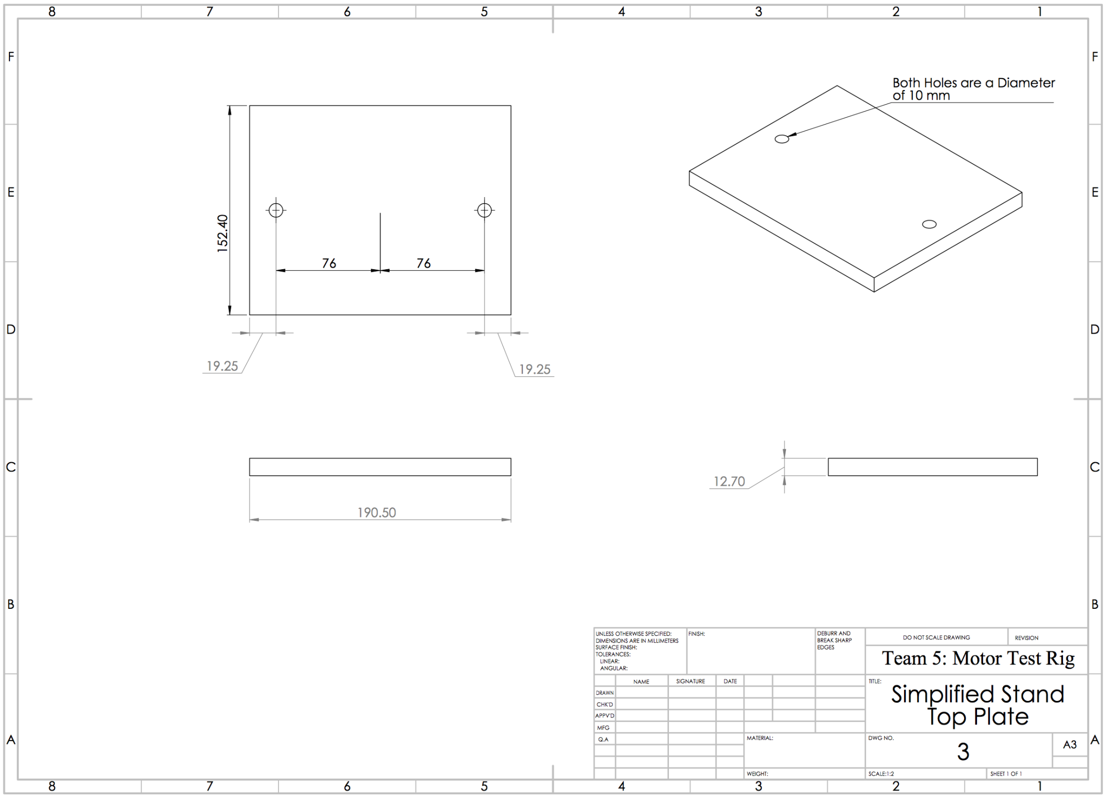

Figure 29: Mock Transducer Stand

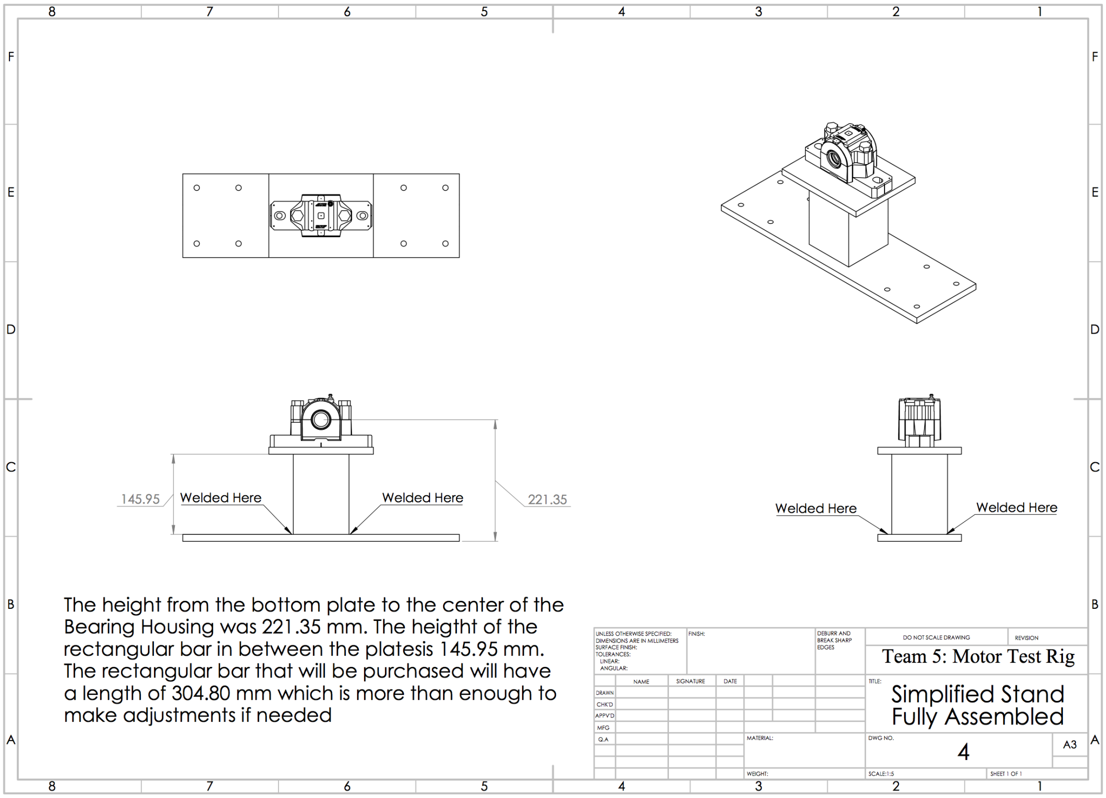

Figure 30: Mock Transducer Stand Assembled