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EML4551-2

Team 05: High Speed Motor Test Stand

Operations Manual

David Balbuena, McLaren Beckwith, Charles Daher, Jacob Quigley, Emily Simmons

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

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Introduction

The goal of this section is to show the user how to set up the test stand before running a test. Before proceeding with the setup process, there is a review of the terminology that will be used.

<u>Terminology</u>

The term *compressor feet* will be used to refer to the steel bars mounted to the bottom of the compressor that are used for attaching the compressor. The *mock transducer* is the system that is simulating the torque transducers position in the assembly. The *compressor shaft* is the shaft that is driven by the compressor. The *shaft extender* is used to make it easier to couple the transducer shaft to the compressor shaft and is held on by the *shaft bolt*. The *coupler connector* connects the shaft extender to the *flexible coupling*, which then attaches to the mock transducer. See Figure 1 and Figure 2 for reference.

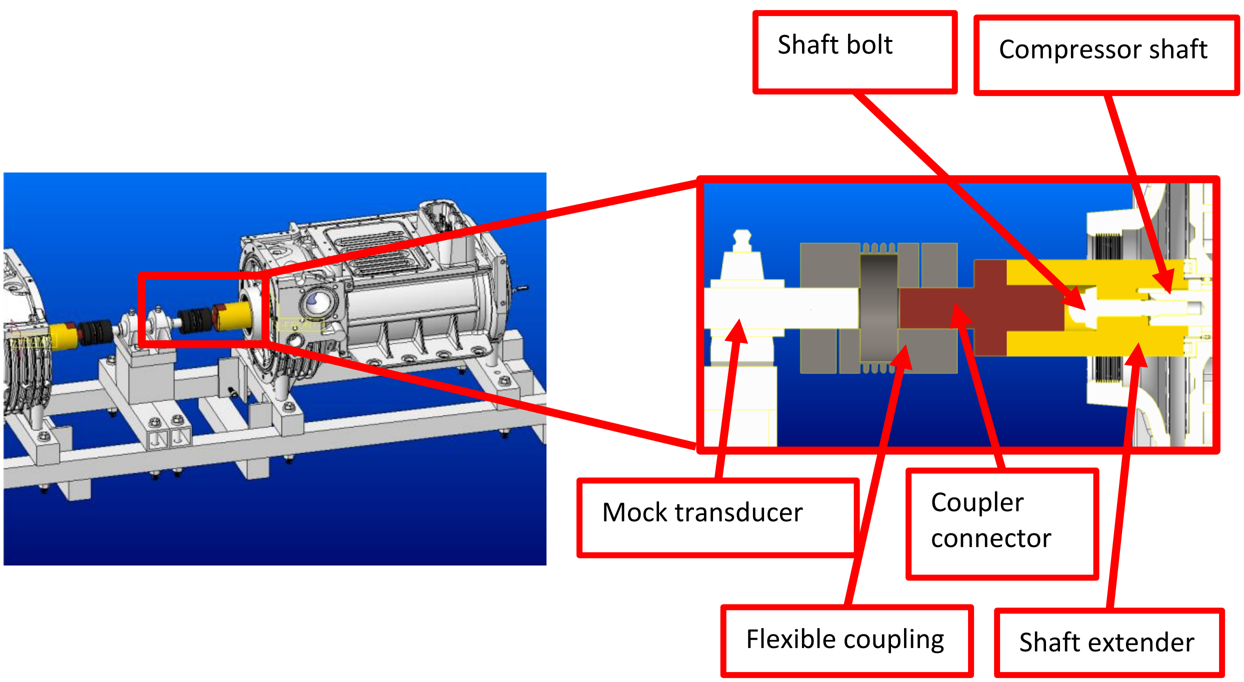

Figure 1: Summary of Terminology for Test Stand

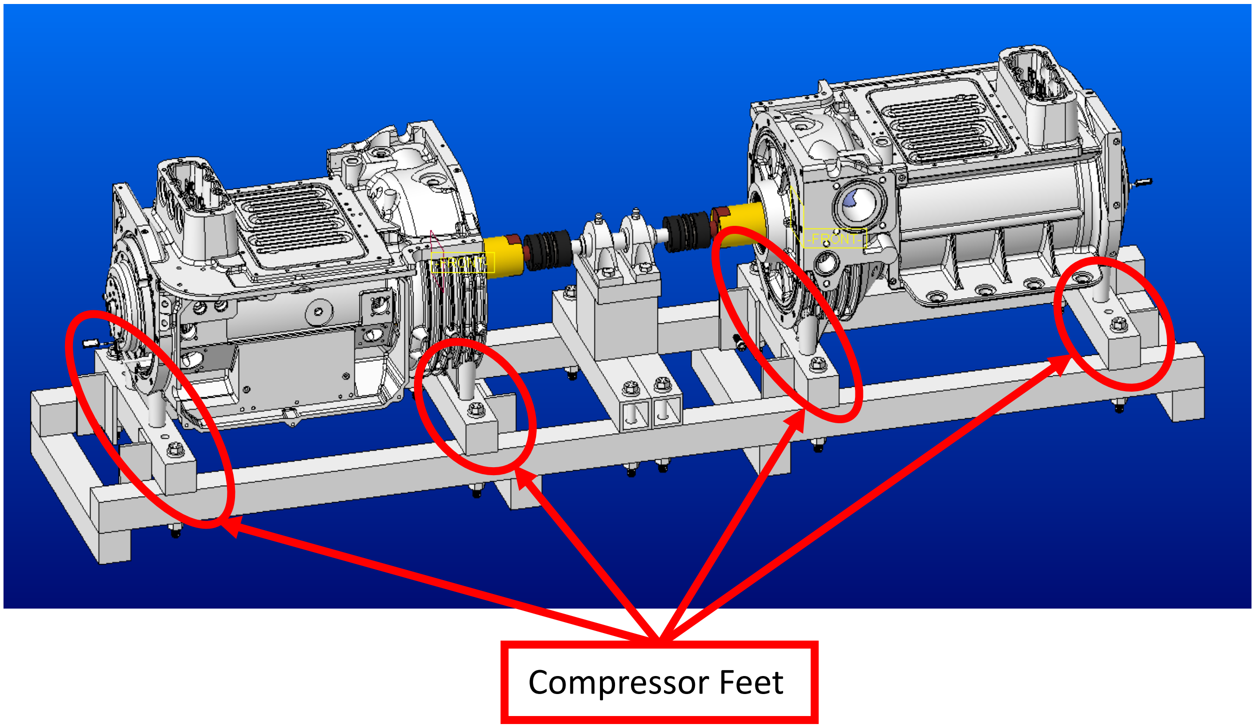

Figure 2: Compressor Feet Location

Setup Process

1. Place motors on test stand facing each other. Do not secure compressor feet to the test stand, because the compressor will have to be moved to assemble the parts.
2. Attach shaft extender to compressor shaft and torque shaft bolt down to specification. Note that this assumes the shaft has been balanced.
3. Slide the coupler connector into the shaft extender
4. Slide flexible coupling onto mock transducer, then slide the compressor forward so that the coupler connector mates with the flexible coupling. Tighten the screws on the flexible coupling to clamp onto the torque transducer and coupler connector.
5. Repeat for other side.
6. Use the laser alignment tool to adjust the motor positions using process outlined in the next section.
7. Place safety shield over rotating portion of the assembly
8. Verify that all bolts are securely fastened before operation

Parts List

- Shaft Extender (3000springb)
- Coupler Connetor (3001springc, 3001springd)
- BK2 couplers
- Zero-Max couplers
- Mock BK2 Shaft
- Mock Zero-Max shaft
- High speed bearing housing (2722T340)
- Mount for mock transducer plate
- Angle L1 & Angle L2
- Frame for Test Stand (1200 altered frame)
- Bolt Assembly (bolt, washer, nut)
- Base 4x4
- 4x4 tubing

Project Specifications

The main components that have been altered from previous years are the mock torque transducer, the BK2 coupling and the extension of the shaft to allow for the proper use of the laser alignment tool. The compressor shaft has been altered to allow for the proper use of the laser alignment tool. The shaft extender (3000springB) pictured (Figure 3) in yellow is an alteration of the 1st stage impeller. This is a major improvement to previous years because it allows for the shaft to be in its proper stack tolerance and for the shaft to be balanced in the balancing machine. Material is removed from the 1st stage impeller, in the previous years, the teams did not have the ability to alter the 1st stage impeller because it was removed to connect the coupling directly to the shaft. By doing this the previous teams also had to remove the shaft bolt, which caused its own set of issues, mainly that the shaft was not in its proper stack tolerance because the shaft bolt did not compress the shaft parts together to the proper torque of 50Nm.

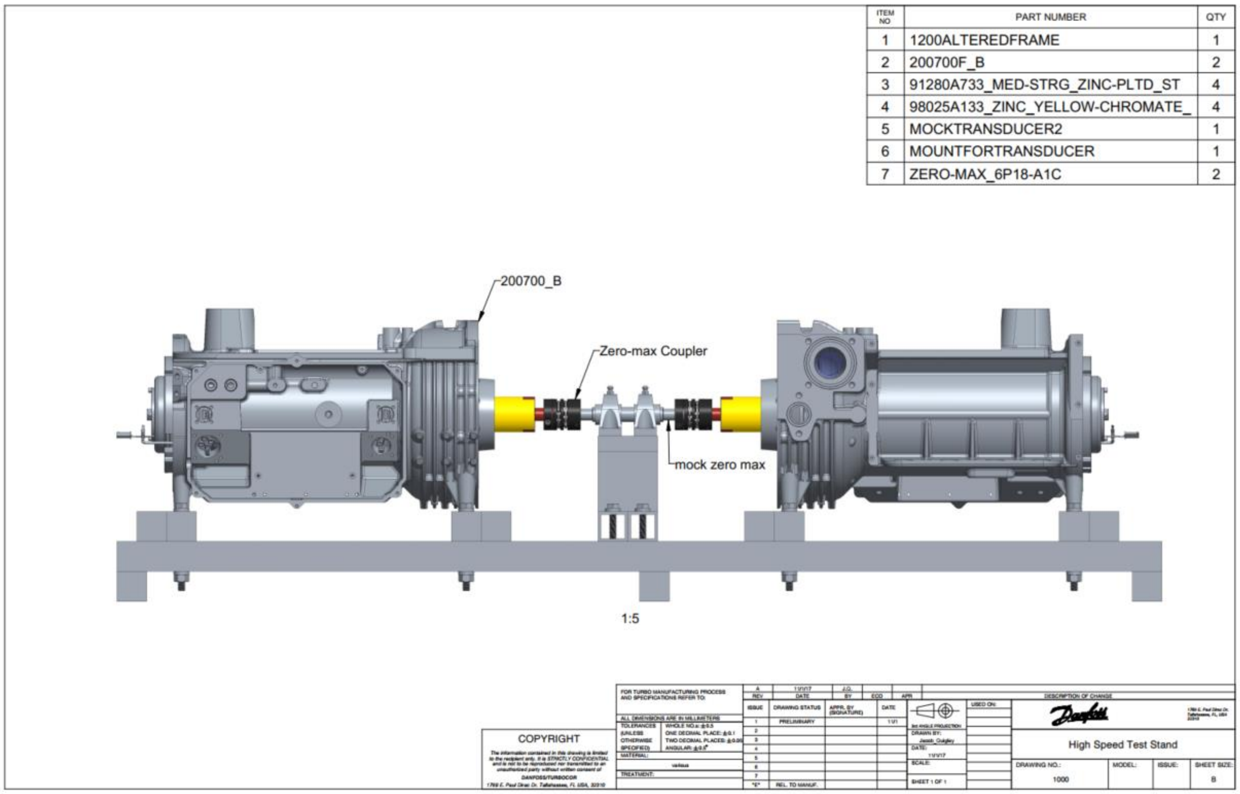

Figure 3: Zero-Max Variation Compressor Assembly

<u>Shaft Extender</u>

Figure 4 shows that the shaft extender acts as the 1st stage impeller, then the shaft bolt is used to torque the shaft extender to the shaft. The shaft extender has idential dimensions as the 1st stage impeller, which has now been replaced in order to allow for proper use of the laser alignment tool and also has a hole to toque down the shaft bolt to 50Nm as required. Since the outer diameter of the shaft extender is too large to connect directly to the coupler, a coupler connector had to be designed.

Figure 4: Connection of Coupler Connector to Shaft Extender

The shaft extender is the key component to our project, it allows for proper use of the laser alignment tool and makes it so the shaft is in proper stack tolerance.

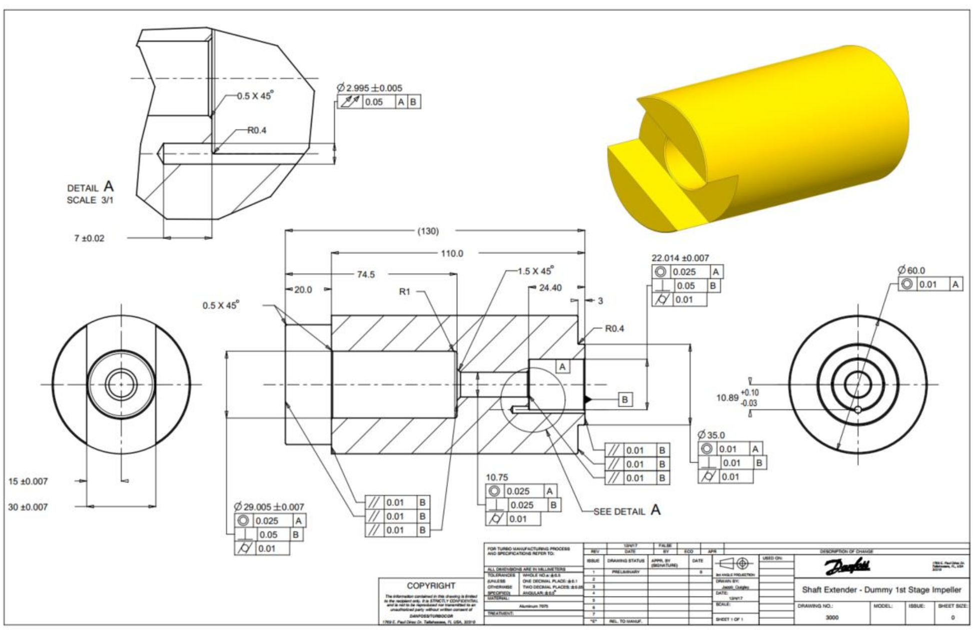

Figure 5: Shaft Extender

Coupler Connector

The coupler connector allows for the shaft extender to be connected to the coupler. Since we have two different couplings we are using to test, that have different bore diameters it was neccisary to create a coupler connector for both couplings. See the appendix for the other drawings for the zero max coupler connector.

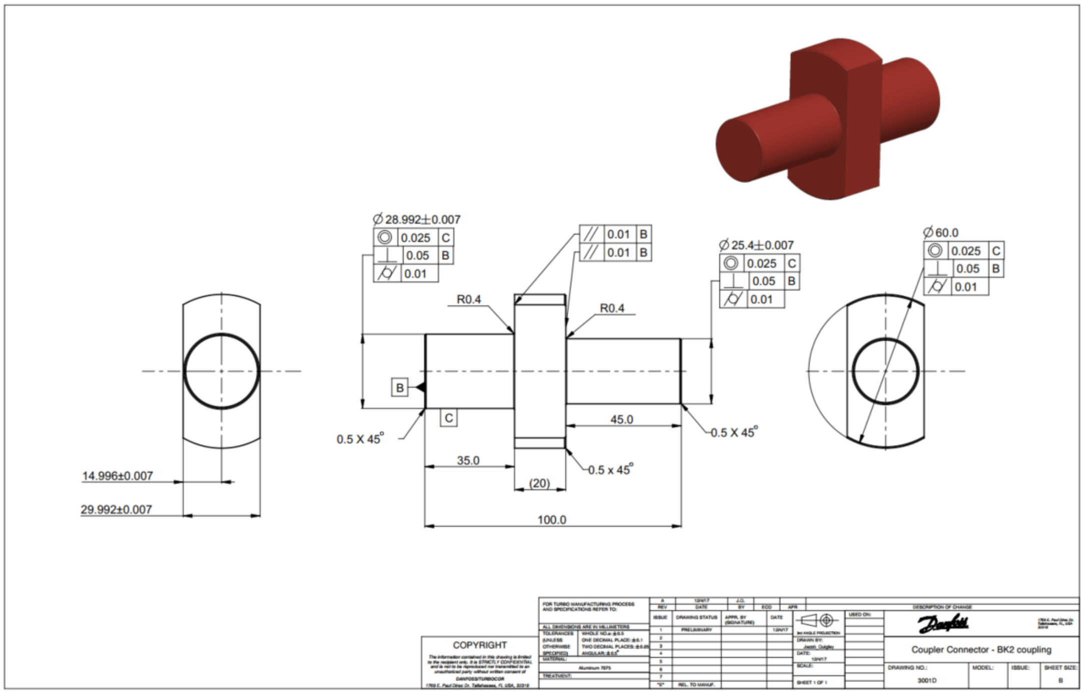

Figure 6: BK2 Coupler Connector

Mock Torque Transducer Mount

The crucial part of the mount for the mock torque transducer is that it allows for the mock torque transducer shaft to be properly aligned with the compressor shafts coupler connector. Alignment is critical to the success of this design, meaning this was an extremely important component to this project. It ensures the exact height needed for the mock transducer shaft to meet coupler connector shaft.

The mock torque transducer simulates the high speed torque transducer that we hope to buy in the future. It was the same dimensions as the TMHS311. Using two high speed bearings, it allows for a fixed position of the compressor shafts that make it so vibrations from one compressor do not transfer to the other. As seen in Figure 7 this is the assembly of the mock torque transducer and its high speed bearings attached to the mock shaft and the BK2 coupler.

Figure 7: Mock Torque Transducer with BK2 Mock Shaft and BK2 Coupling

<u>Angle L's and Bolt Assembly</u>

The angle Ls allows for the compressor feet to be adjusted axially for proper alignment. This is an improvement we made from the original design, since it had fixed axial alignement to the stand itself the feet could only be in one spot, with this design as long as there are holes to secure the feet, you can adjust the axial alignment anywhere which is crucial since we are using different couplings making the compressors slightly further apart from the BK2 coupler to the Zero-max coupler.

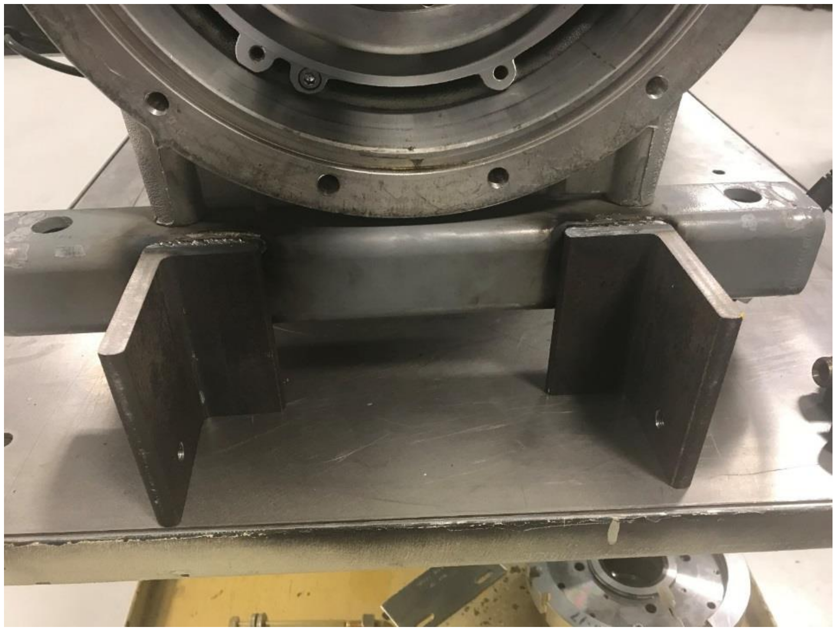

Figure 8: Angle L's

The compressor feet are secured using a ½" bolt 6" in length with a washer on each side and a nut to secure its position. This not only keeps the axial alignement from the angle L's in place, but it also keeps the compressor from vibrating during testing.

Figure 9: Bolt Assembly

Test Stand

As previously mentioned, it is important to allow for the the test stand to accommodate both couplings, with the alterations seen in the picture above we are able to do precisely that. The BK2 couplings will use the two holes to the right, when looking at the three holes in the center of the stand. The Zero-Max couplings will use the two holes to the left. The differences in distance between the compressors with the different couplings is accomodated with the ¾" holes which also allow for slight repositioning when using a ½" bolt assembly for securing based off the adjustments given by the laser alignment software.

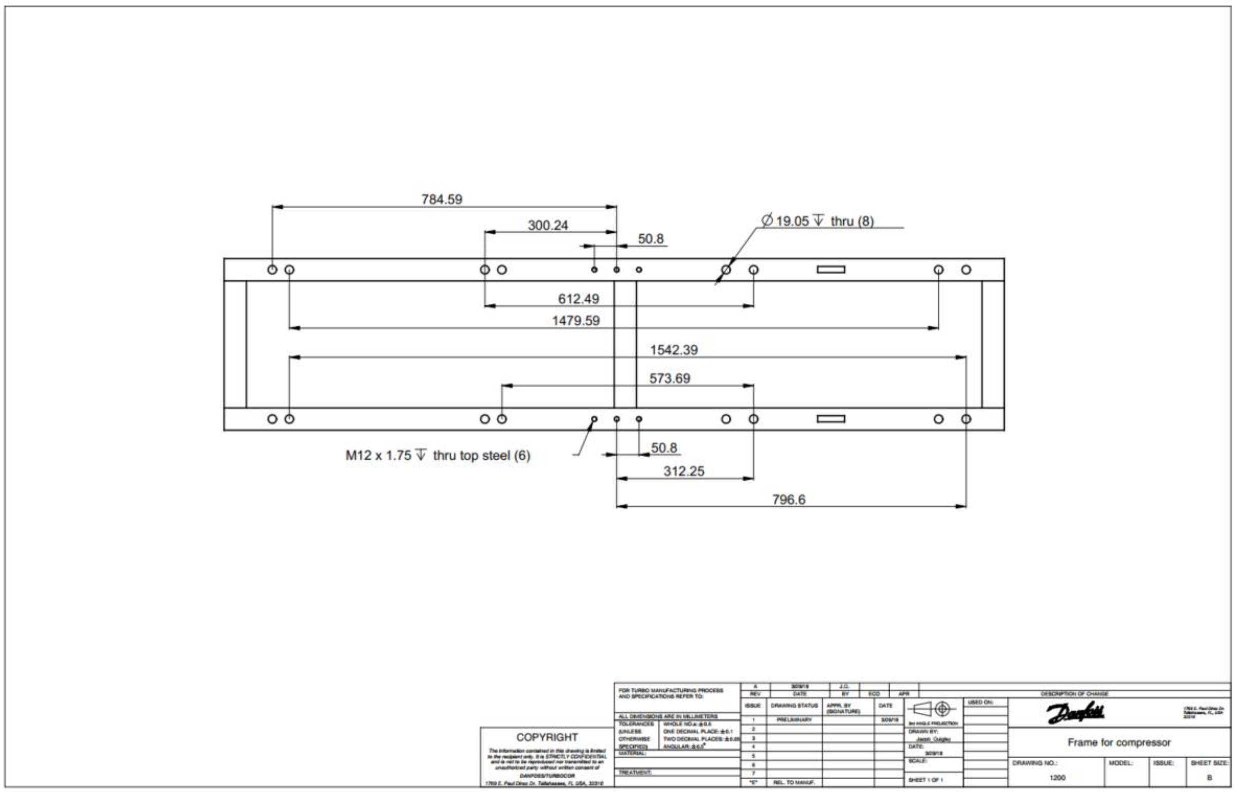

Figure 10: Altered Test Stand

Equipment Used

Horizontal Bandsaw

The horizontal bandsaw was used to cut the stock Aluminum 7075 for the shaft extender and coupler connector. It is used to roughly cut the material to size but does not have the precision required to cut parrallel to the other face. However, it was used to cut the 4”x4” steel to size and created the hight needed for the mount for transducer plate.

Figure 11: Horizontal Bandsaw

Programable Drill Press

The drill press machine was used to make the holes necessary for our shaft extender and mount for torque transducer parts. Because the tolerances of our parts were so precise, this machine provided the accuracy required and allowed for a piston fit between the shaft extender and the coupler connector. The drill press was essential in the making of our parts and a skilled machinist was required to execute the process.

Figure 12: Programable Drill Press

<u>Lathe Machine</u>

The lathe was used to turn down material on the shaft extender and coupler connector. It also created the radiuses and chamfers that were called out on the drawings. An experienced machinist was required in the process of making these parts because of the tight tolerances that were needed such as, concentricity and parallelism because the shafts' balance was so crucial to the success of this project.

Figure 13: Lathe Machine

Welding Machine

The welder is a machine that attaches two pieces of steel together by using fusion, done with a low temperature metal joining technique known as soldering, which does not melt or deform the metal structure you are attempting to use. This process allowed for the mount for torque transducer plate to be made possible attaching two 2”x2” rectangular steel tubes that attach to a 4”x4” rectangular tubing turned vertical to give the correct height needed for the mock torque transducer shafts to line up perfectly with the compressor shafts coupler connector.

Shaft Frequency Tester

The shaft frequency tester is used to verify the shafts frequency. The frequency of the shaft is important because the compressor has certain parameters it needs to meet in its software to run correctly without crashing. Since our shafts were modified with more mass and different material the frequency changed and a program in the software needed to be altered for the new frequency parameters that were calculated on the shaft frequency tester for the shaft to pass calibration and levitation. This was crucial to the success of our project because if the parameters weren’t changed then the shaft itself wouldn’t have even levitated in the compressor. Getting it to spin at any rpms would have been unachievable. Using the shaft frequency tester is common practice for any shaft that goes into a compressor at Danfoss, so thankful our team was given the guidance of an experienced technician before any testing was attempted.

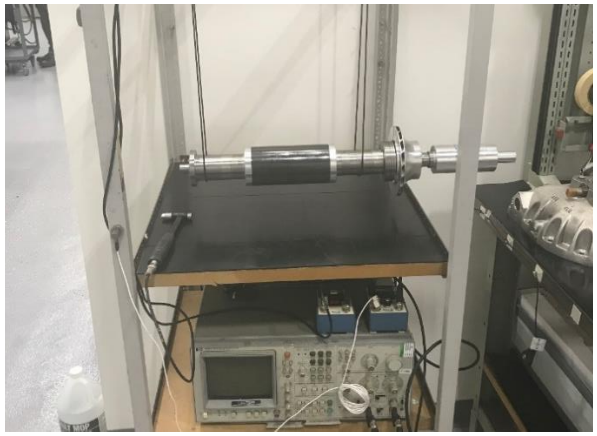

Figure 14: Shaft Frequency Tester

<u>Grinding Machine</u>

The grinding machine is used to remove material from the front and rear of the shaft to get it properly balanced. A grinder is used and is powered by compressed air. This process is done by a trained technician that is experienced in not only the process of balancing but also using a grinder with precision. This was a crucial part of the success of our project and without such expertise could not have been accomplished.

Figure 15: Grinding Machine

Balance Machine

The balance machine was crucial to the success of our project, once the shaft extender and coupler connector were made, they needed to be put back onto the shaft and get rebalanced. Since the modified first stage impeller aka the shaft extender had to be longer and more rigid than the 1st stage impeller, it had more mass, then adding the coupler connector at the end not only made the shaft much longer than a normal TT700 compressor shaft, it also moved the center of gravity because of its added weight. A new program was written in order to accommodate the new center of mass. Once the new program was written a technician used a grinding machine to reduce mass in the required areas. When griding the technician would remove a small amount of material at a time while using the computer screen on the right of the picture above as his reference to where the material needed to be removed from, in our case this process needed to be repeated about 15 times on the front and the rear of the shaft. A process that took nearly four hours to complete.

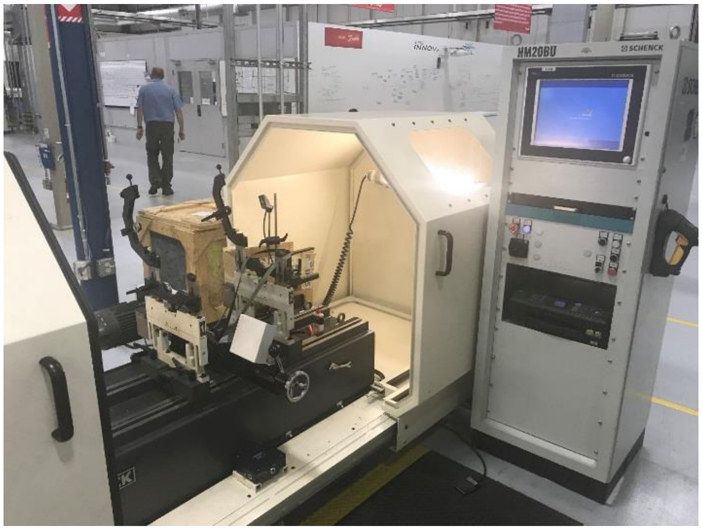

Figure 16: Balance Machine

Torque Fixture

A torqueing fixture is required to put the shaft together for balancing. The shaft is put on those V-blocks seen in the picture above, and the butt of the shaft has three holes that fit into the dowel pins on the fixture. Then an operator can torque the shaft bolt to its required 50Nm of torque.

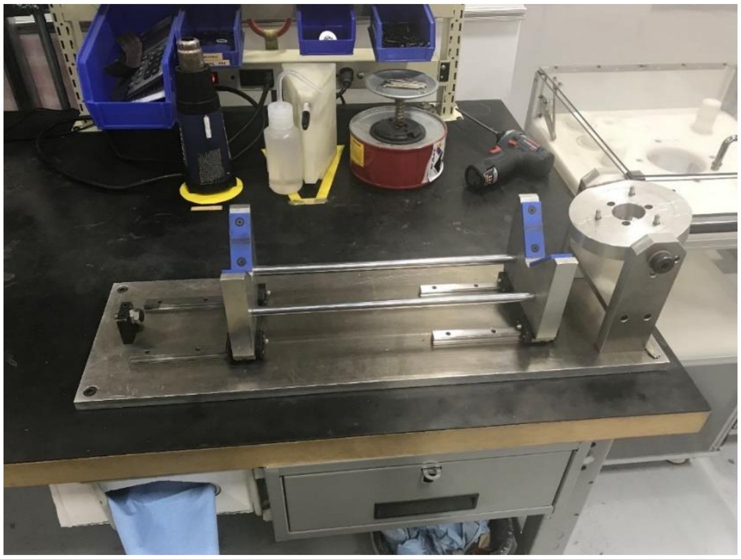

Figure 17: Torque Fixture for Shaft

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. The TKSA 31 will guide the user through any misalignment corrections. The TKSA 31 must be properly installed otherwise measurements taken can be very inaccurate.

Figure 18 displays the dimension input box. This screen allows the two custom tolerances to be created and modified. This is done by inputting parameters into the angular and parallel misalignment boxes. The TKSA 31 is calibrated for both English and Metric units which can be selected in the setting menu before the alignment process has begun.

Figure 18: Laser Alignment Dimension Screen

The next phase in the alignment process is to take the sensor measurements. This process is initialized by selecting the measurement type via the Settings menu then Measurement Settings. Three shaft positions are measured, at -90 degrees, 0 degrees, and +90 degrees. This is also known as the 9 o'clock position, the 12 o'clock position and 3 o'clock position. When using the sensor, a blue triangular wedge will indicate the required position for each step. The first position that will be measured will be in 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 this has been completed, the same process will be done for the 12 o'clock position and the 3 o'clock position. While these measurements are being taking it is important that the laser alignment tool remains completely stationary. It is also important to not use the laser alignment tool as a handle to rotate the shaft. This could cause unnecessary damage to the device. While aligning the shafts, the angle difference between the two sensors should be no more than 2 degrees to get an accurate measurement. This process can be seen in Figure 19 below.

Figure 19: Laser Alignment Process Page

The results page will appear after all the measurements are taken. This page will show the coupling and feet adjustment values. The tolerance range status and motor alignment specifications can be seen on the results page. The desired motor location is represented by the black line, while the blue line represents the motor's current location. This can be seen from Figure 20 below.

Figure 20: Horizontal Motor Alignment Live Feed

The user is prompted by the system to correct measurements that are out of tolerance. Once this is complete, the screen will go into the vertical correction screen which can be seen in Figure 21. 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 or the 6 o'clock. This can be seen in Figure 21 below. Then once the wedge turns green, the next arrow is selected to validate the position in which the sensors are located.

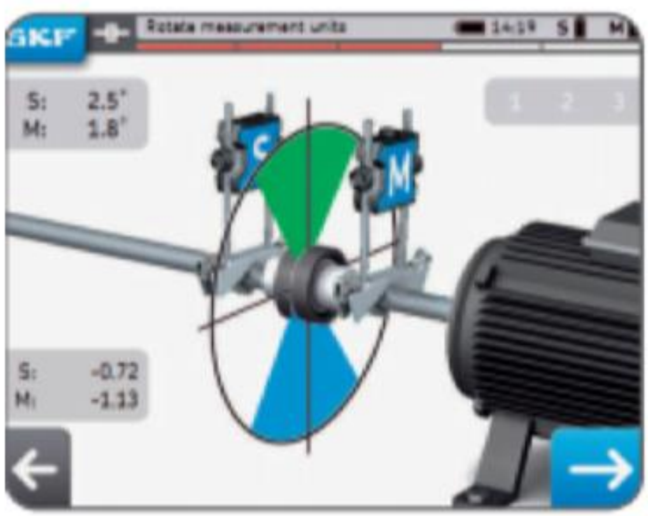

Figure 21: Vertical Laser Alignment Live Feed

The next display that is shown is the live feed of the vertical misalignment of the motor. The arrows that on the display are used to indicate the distance and direction the motor must be moved. The distance and direction are based on the parameters that were input earlier in the measurements. The distance values update instantly. Once the tolerance is given, then a green checkmark will appear next the misalignment and offset as shown below in Figure 22.

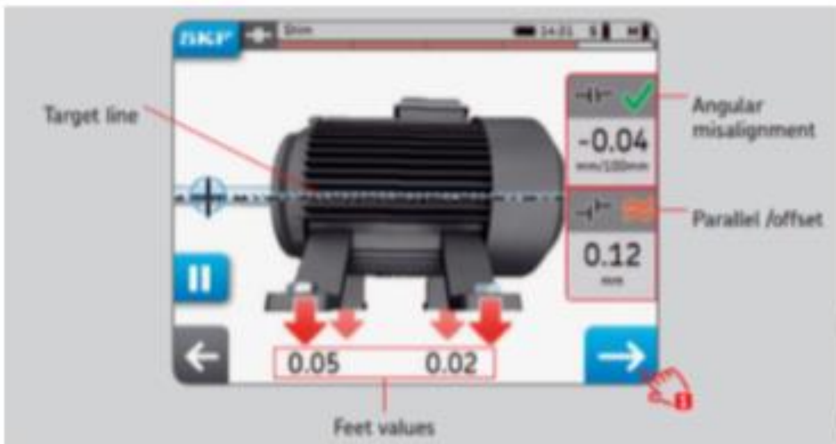

Figure 22: Vertical Motor Alignment Live Feed

Horizontal corrections then need to be calibrated. The sensors in this case will be placed in either the 3 o'clock or the 9 o'clock position. Once that position is confirmed by adjusting the position of the motor, it will be validated by hitting the next arrow button that will move on to the next display.

The live feed of the misalignment in the horizontal direction is shown in Figure 23 below. The image shown is an aerial view of the compressor with the arrows indicating where an adjustment needs to be made. When the values of the misalignment and offset are within range of the tolerance, the screen will display a green check mark and the user will be allowed to continue.

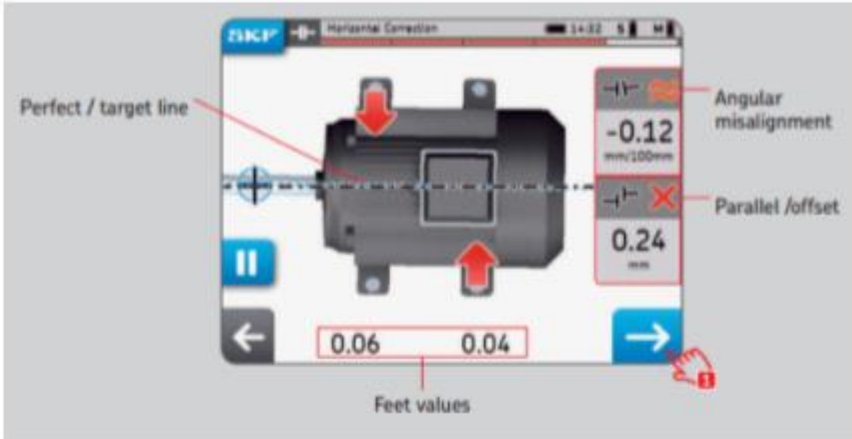

Figure 23: Horizontal Laser Alignment Live Feed

Start Up Operation

Once the compressors are properly coupled and aligned, the safety shield is placed into position. The power levers to both compressors are moved to the "on" position. The system is operated by a Danfoss technician who oversees all the software adjustments. This involves ensuring that the shafts are properly levitated and concentric. The technician will connect each motor individually to the software to levitate the shaft of each motor and calibrate it with the mock torque transducer as the center point.

Operation Instructions

To test the motors power output, the technician will slowly increase the compressors rpm until the required target is reached. The torque transducer will output the torque measured between the compressors. Due to the load, the motor is experiencing, coolant temperatures must be kept under standard operating temperatures. Once the testing is done the compressors are gradually ramped down until they reach a halt.

Note: Special attention must be placed on any vibration that may arise. Due to the nature of the high rpms that are reached, any vibration may be catastrophic and may cause injury. This could potentially cause damage the compressors.

Clean Up & Storage

Once testing is done the compressors must be shut off and left to cool down to safe handling temperatures. The laser aligning tool is then stored in its own case. Once cool, the power supply cables must be disconnected before continuing. The couplers are loosened from the coupler adapter and the mock torque transducer shaft. The motors are then unbolted from the stand and pulled apart. These motors will be stored with the shaft extender still fixed on its position. The coupler adapters are stored in a secure place as well. The couplers are also removed from the mock torque transducer shaft to prevent any unnecessary wear to the couplers flexible components.

Every part must be inspected after each run. Any damage or impact on the rotating parts could impact the precision balancing that the parts received. This should be immediately reported for damage report, rebalancing, or if severely damaged, machining of a new part.

References

[1] Pullo, Jack, et al. "High Speed Motor Test Rig." *Operations Manual*, 7 Apr. 2017, ww2.eng.famu.fsu.edu/me/senior_design/2017/team05/deliverables/Operation%20Manual%20Spring%202017.pdf.

Appendices:

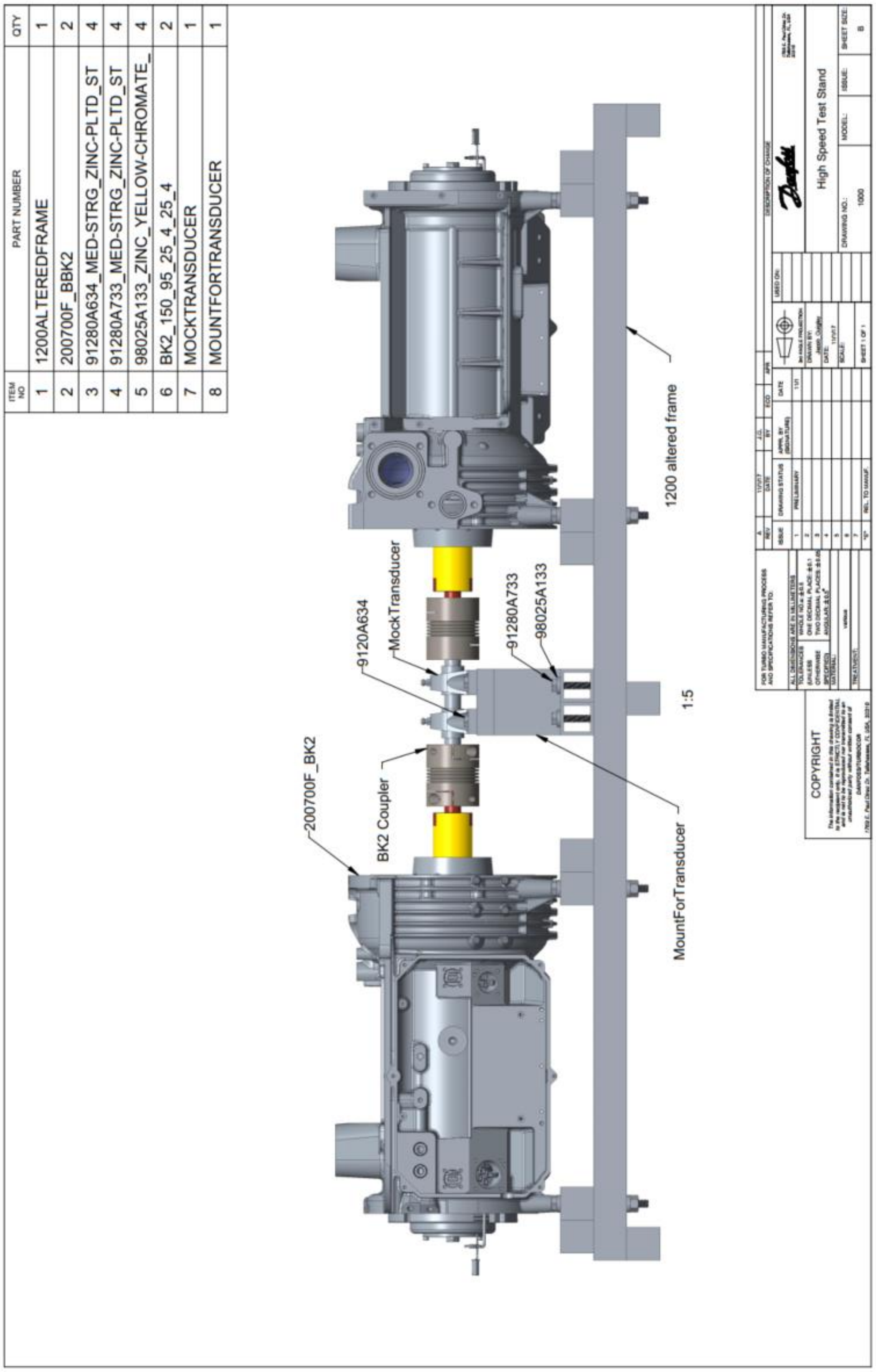

Figure 24: BK2 Compressor Assembly

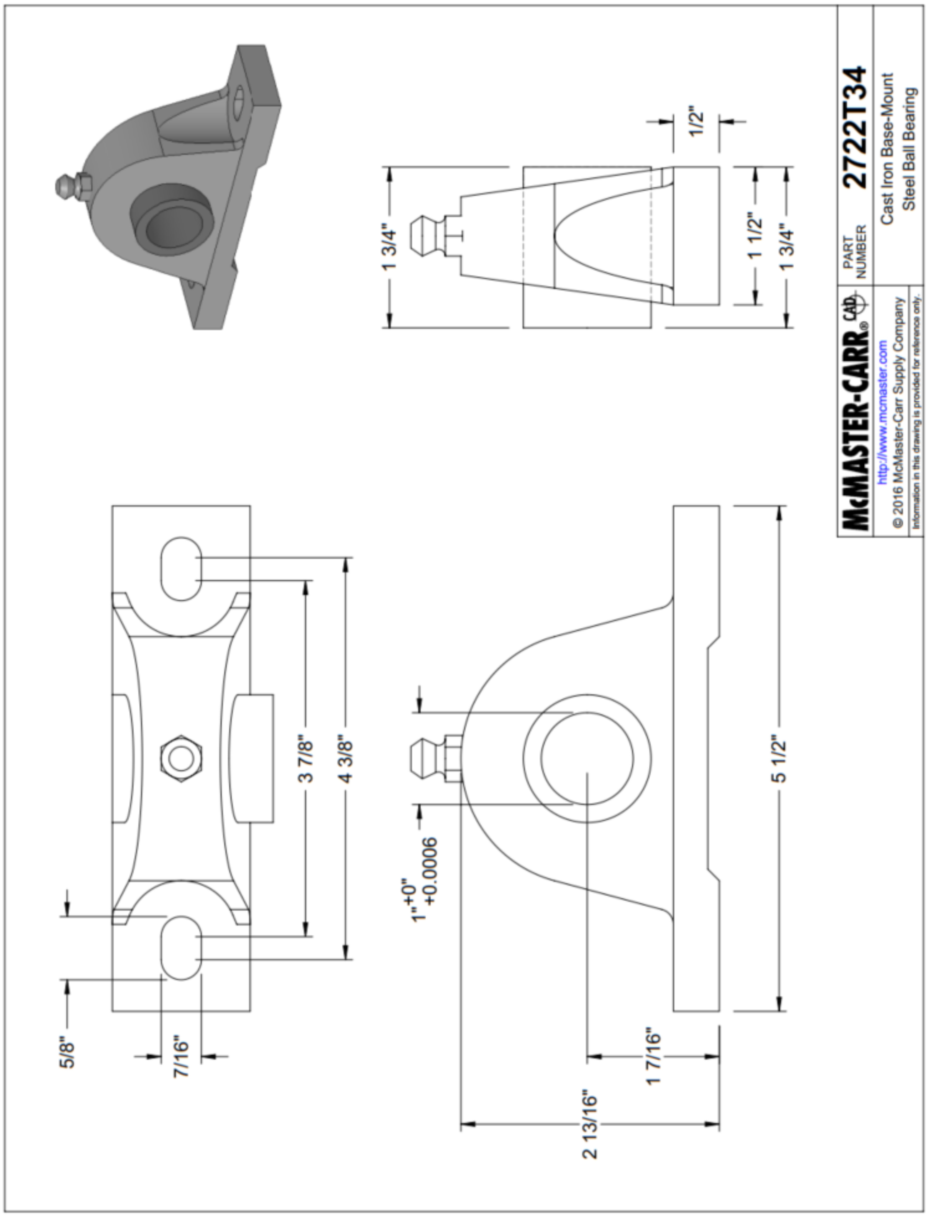

Figure 25: Bearing Mount Drawing

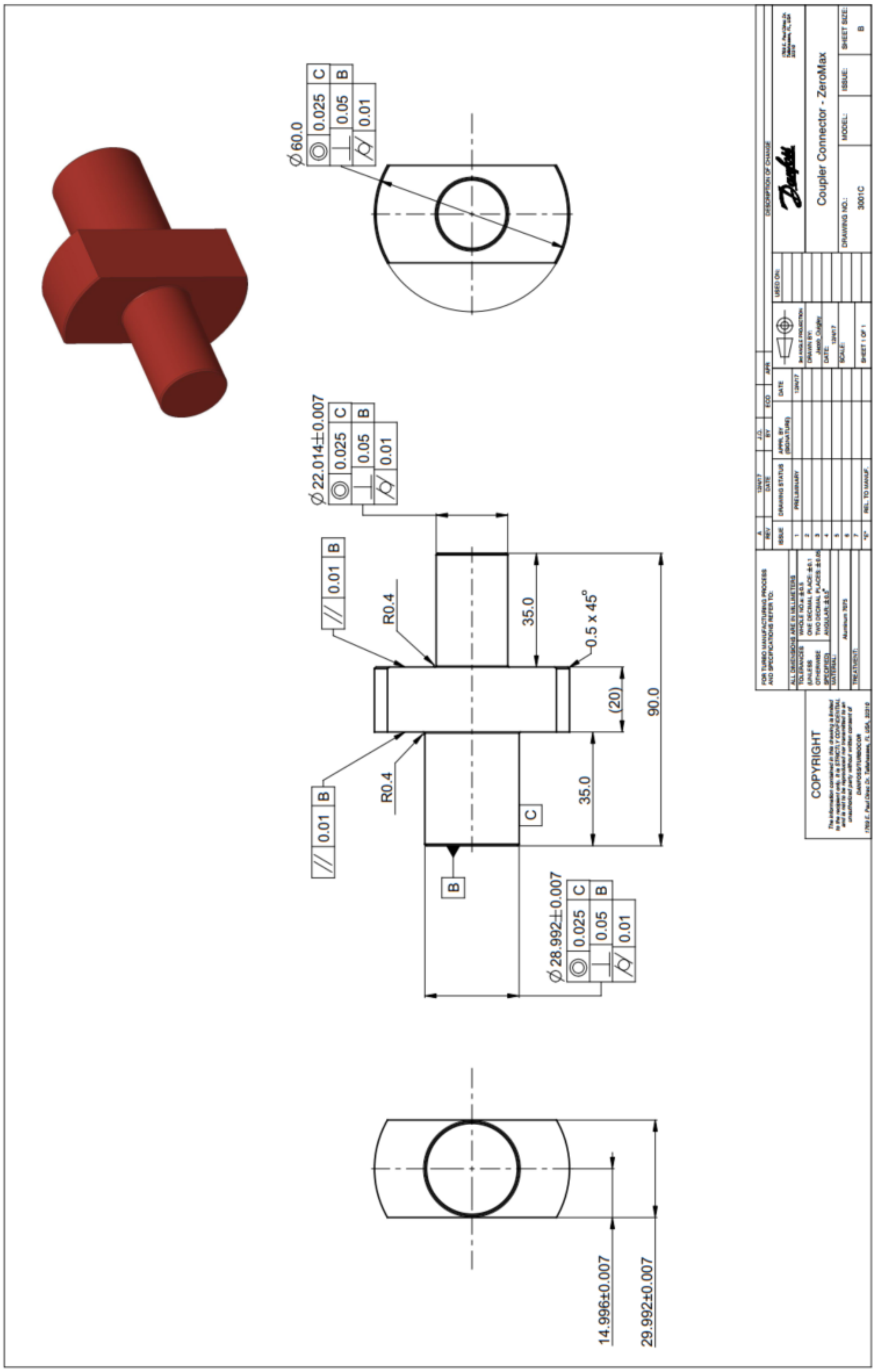

Figure 26: Zero-Max Coupler Connector Drawing

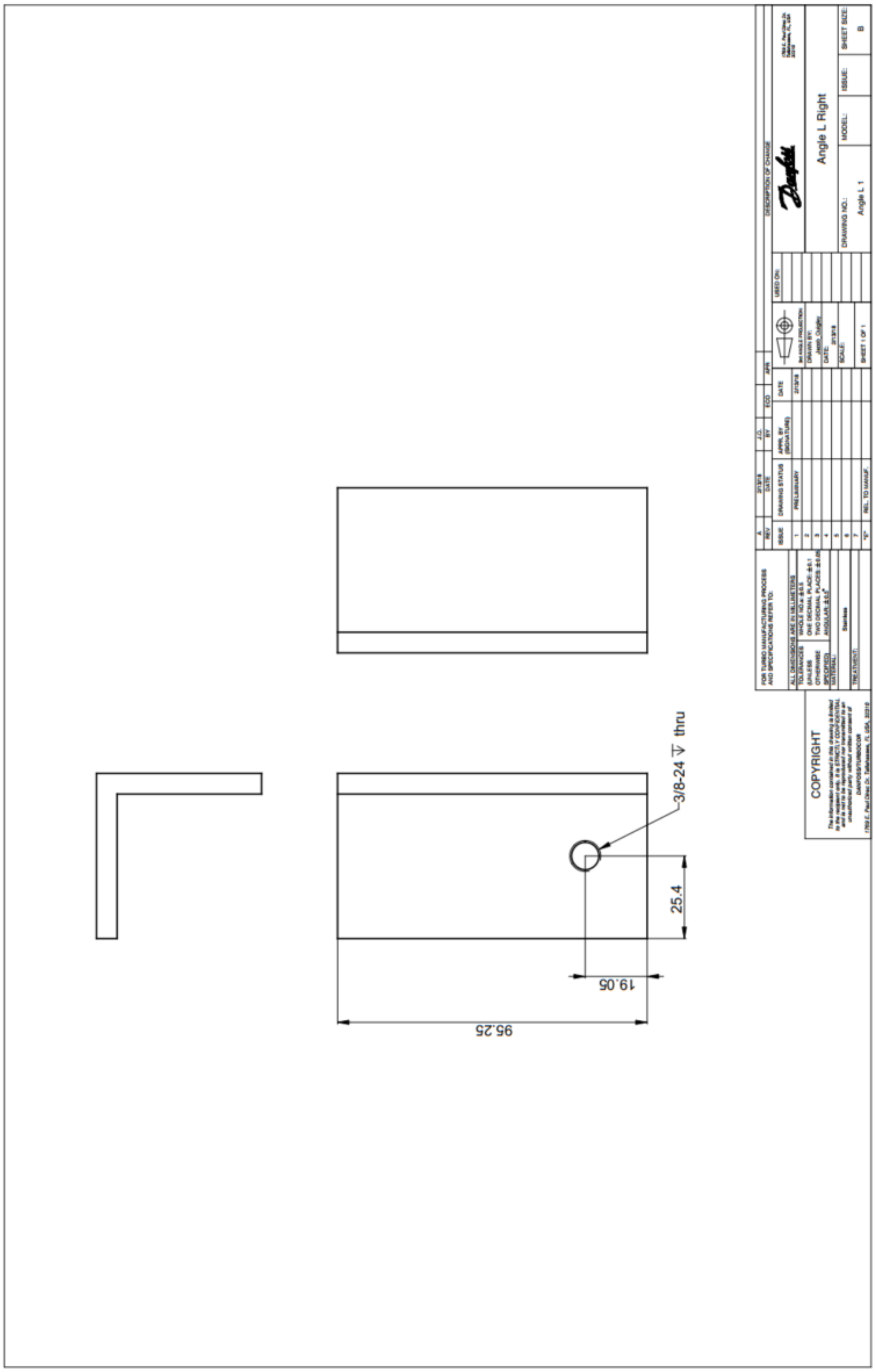

Figure 27: Right Angle L Drawing

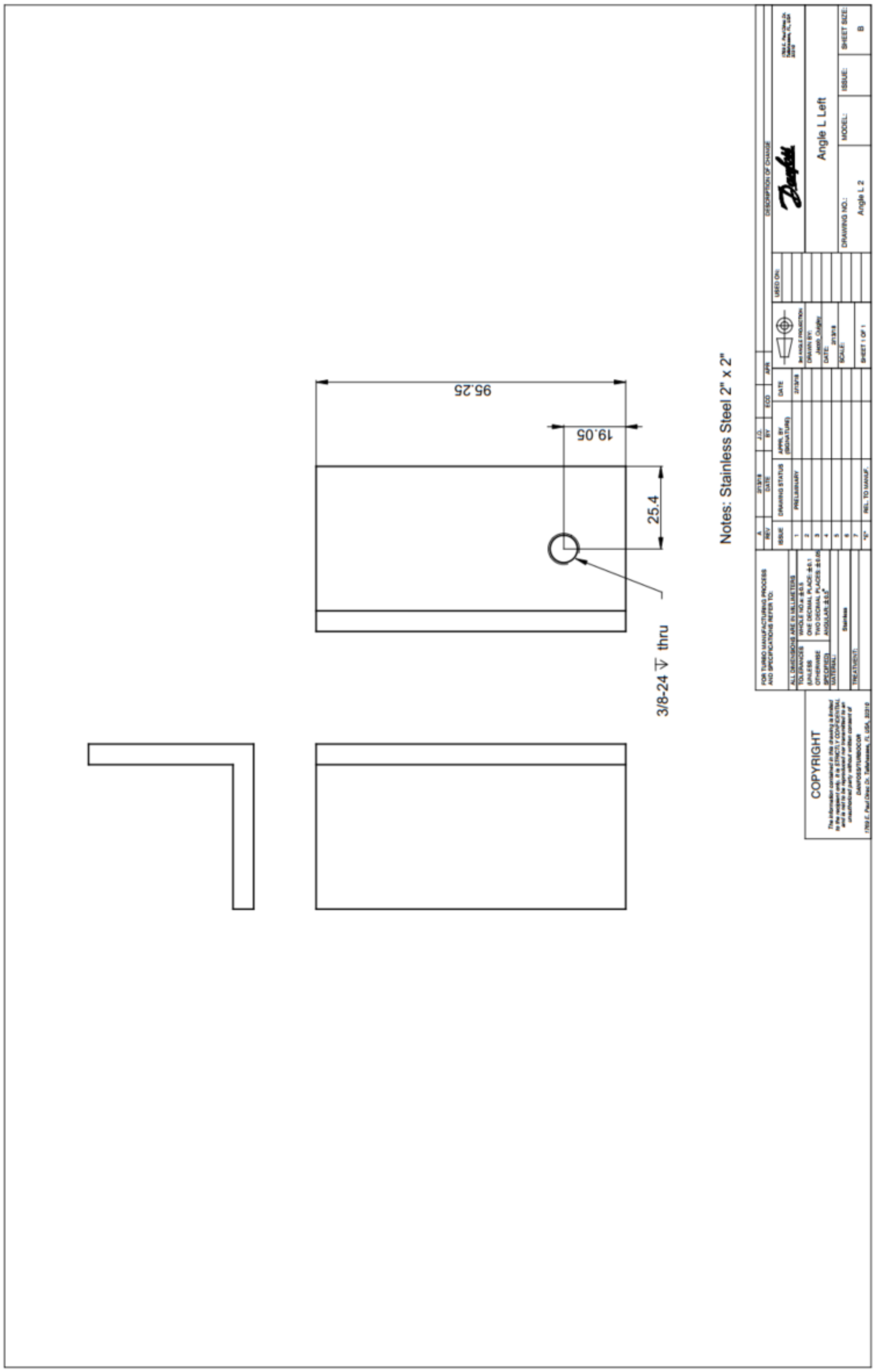

Figure 28: Left Angle L Drawing

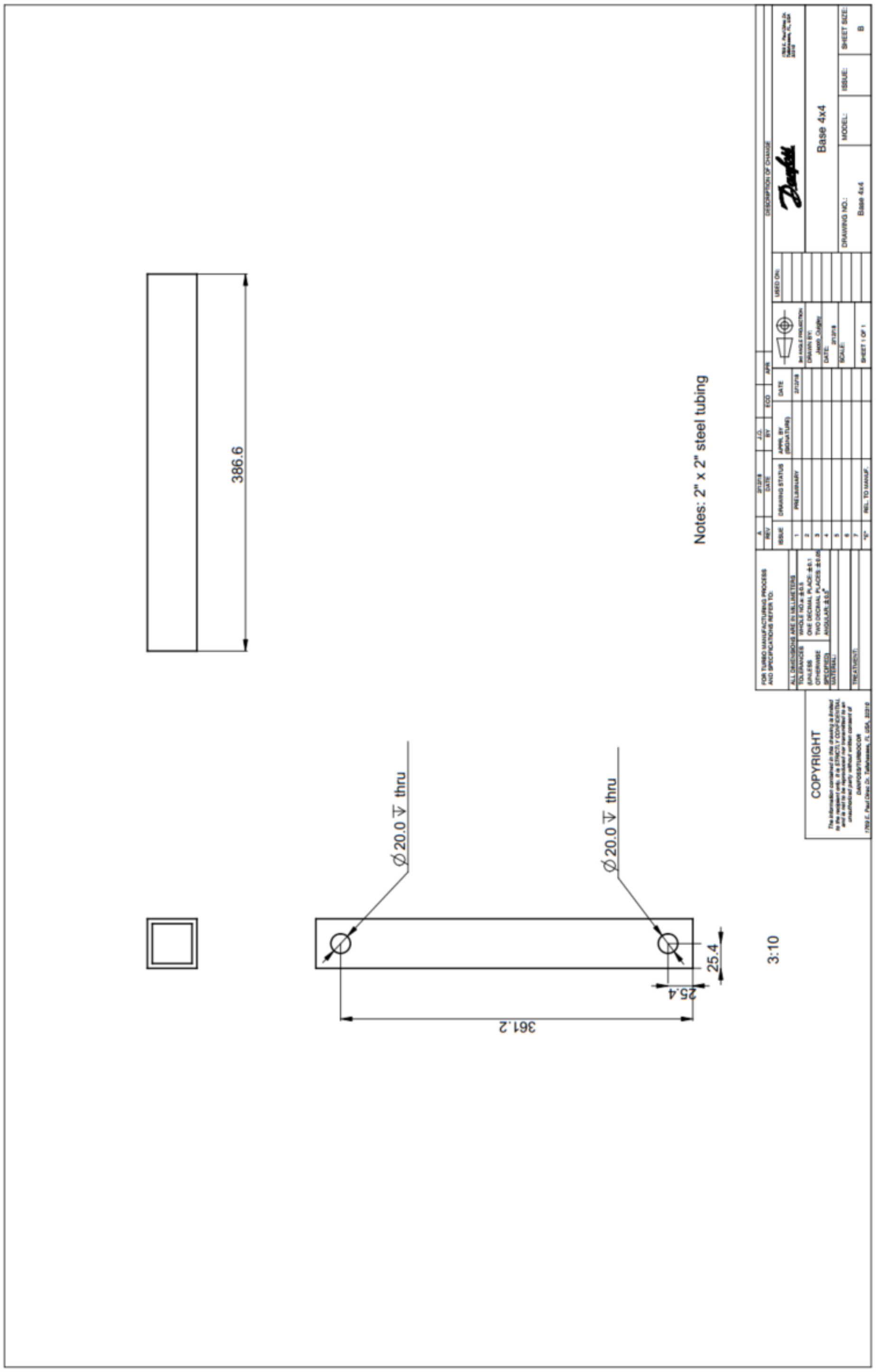

Figure 29: Base 4x4 Drawing

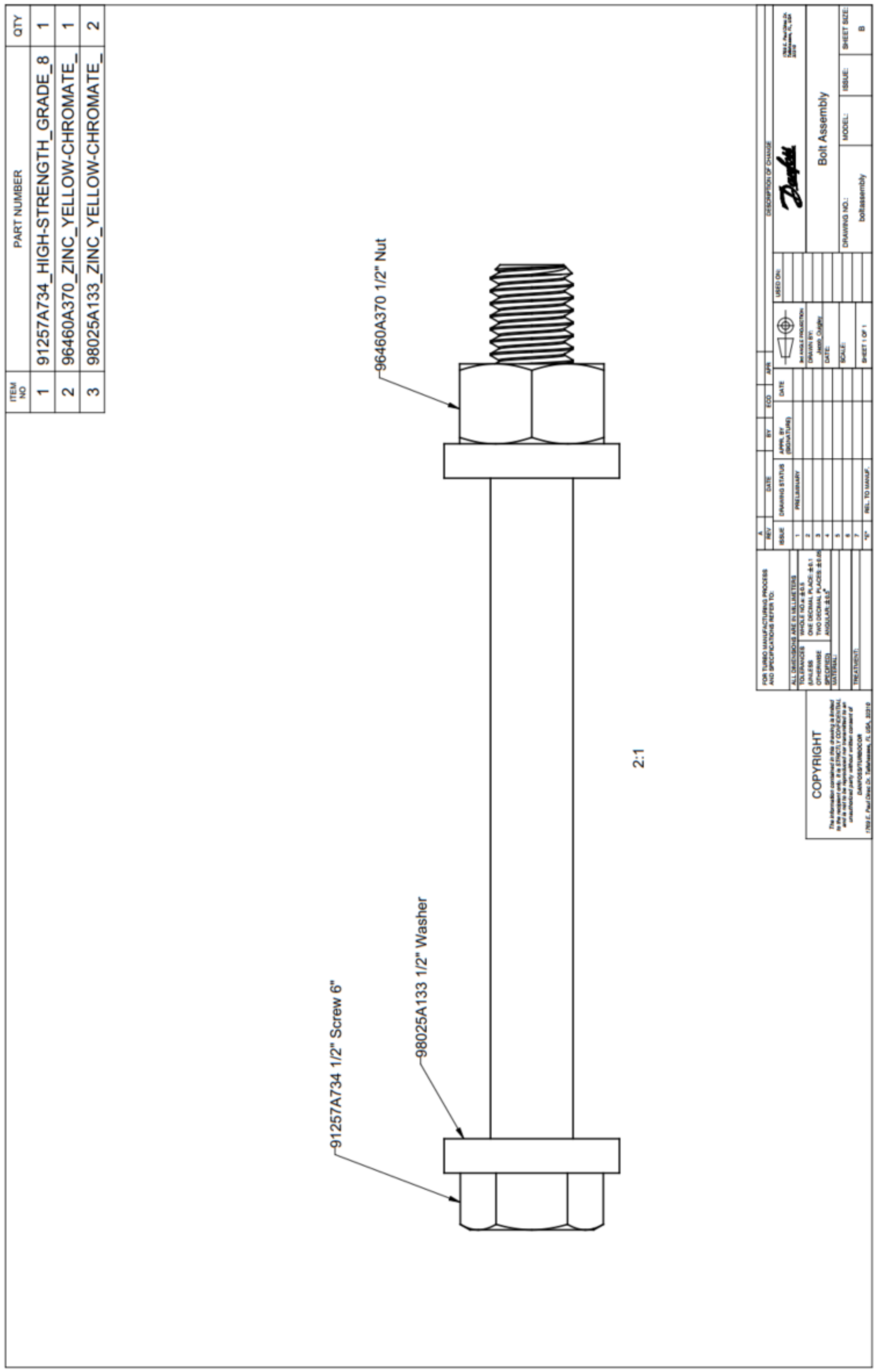

Figure 30: Bolt Assembly Drawing

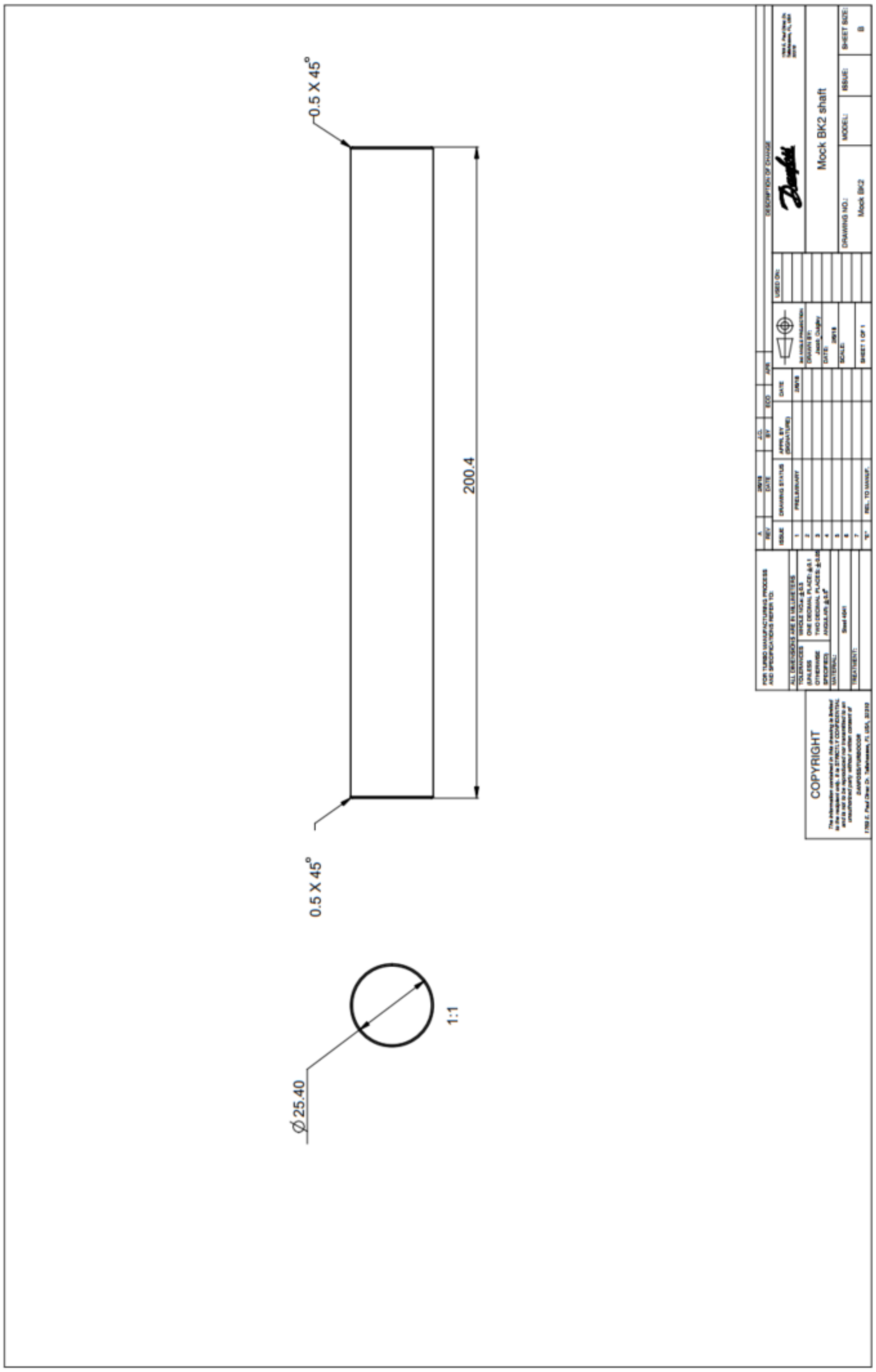

Figure 31: Mock BK2 Shaft Drawing

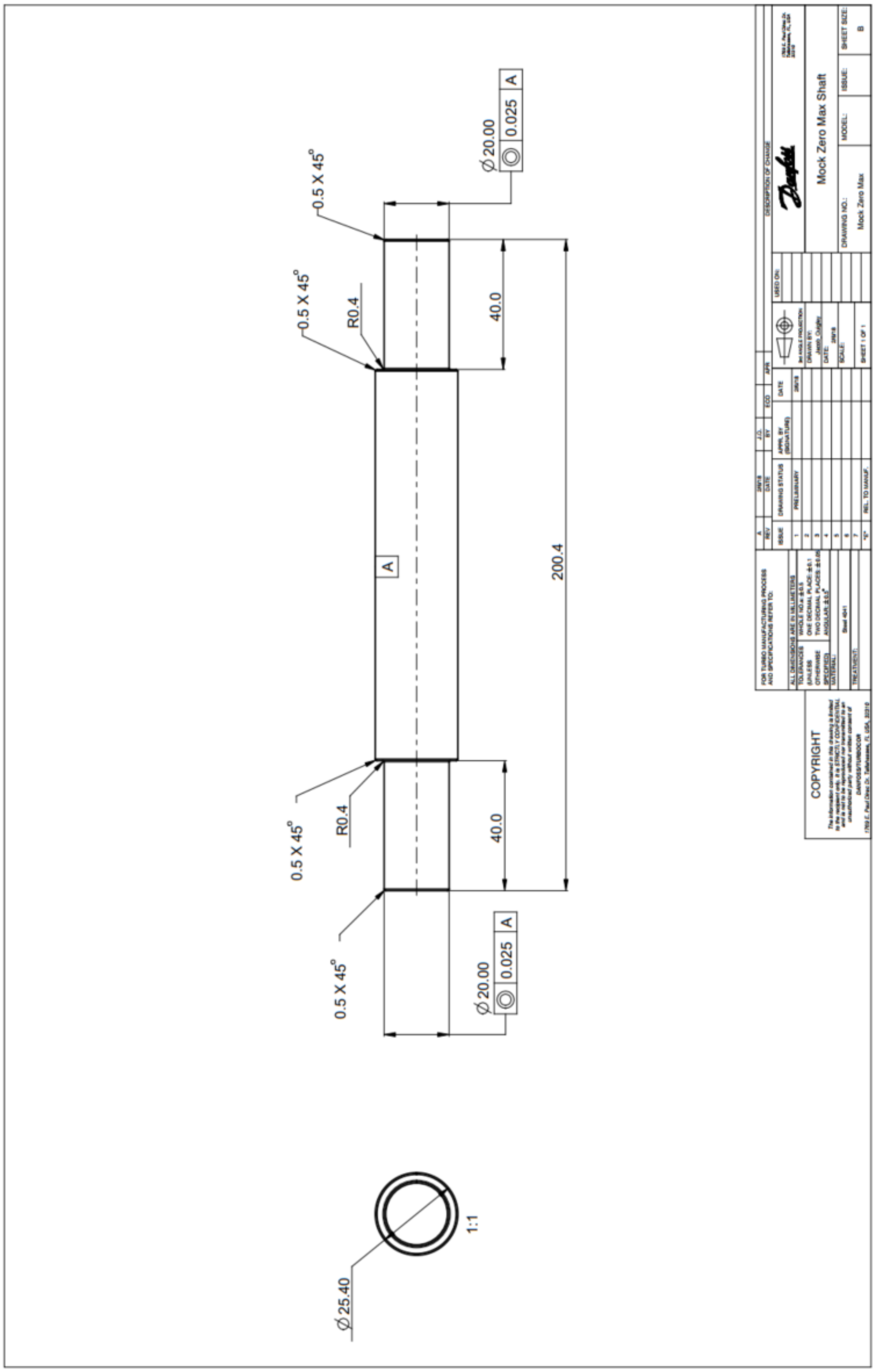

Figure 32: Mock Zero-Max Shaft Drawing

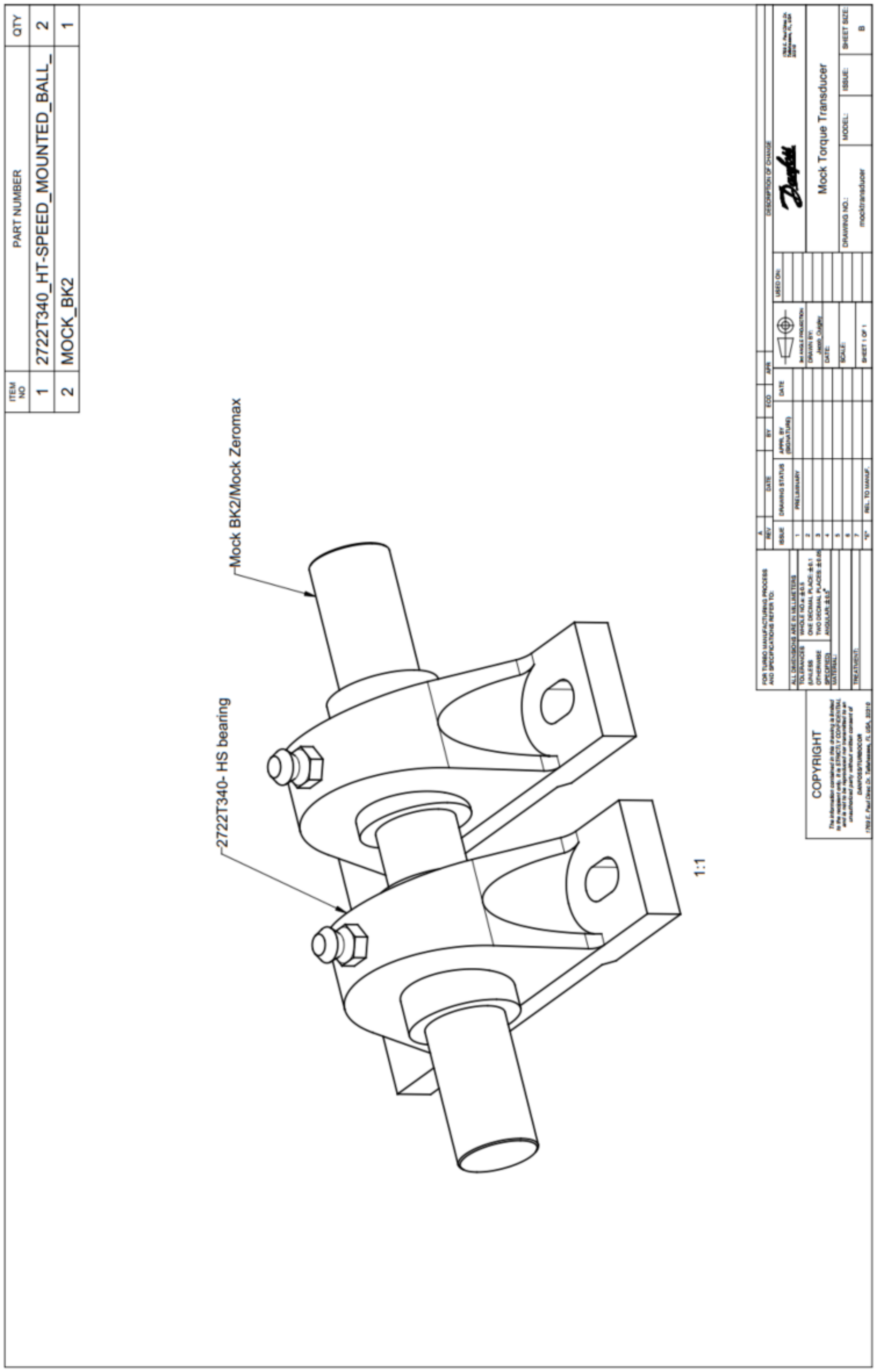

Figure 33: Mock Torque Transducer Assembly

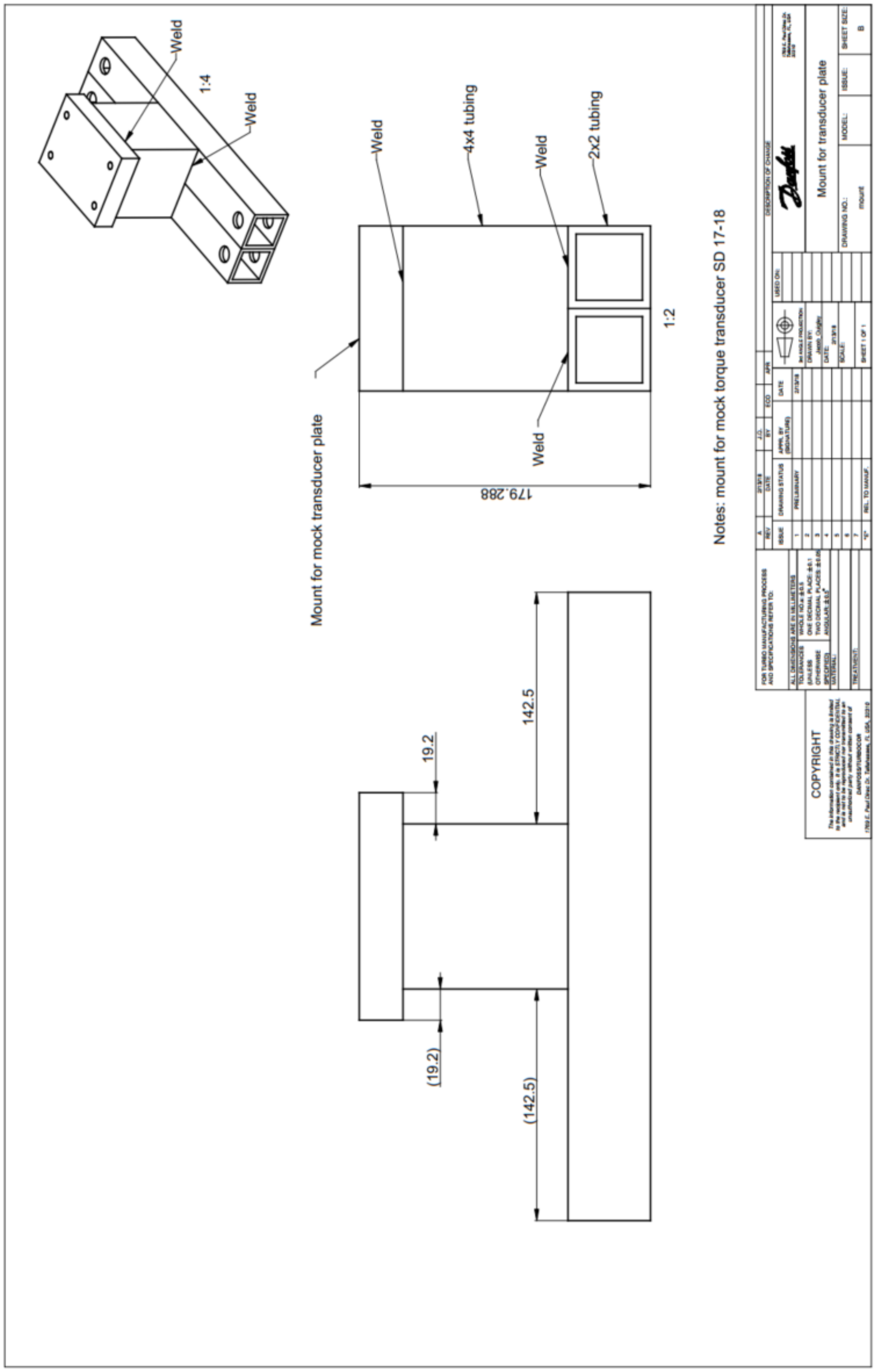

Figure 34: Mock Torque Transducer Mount Assembly

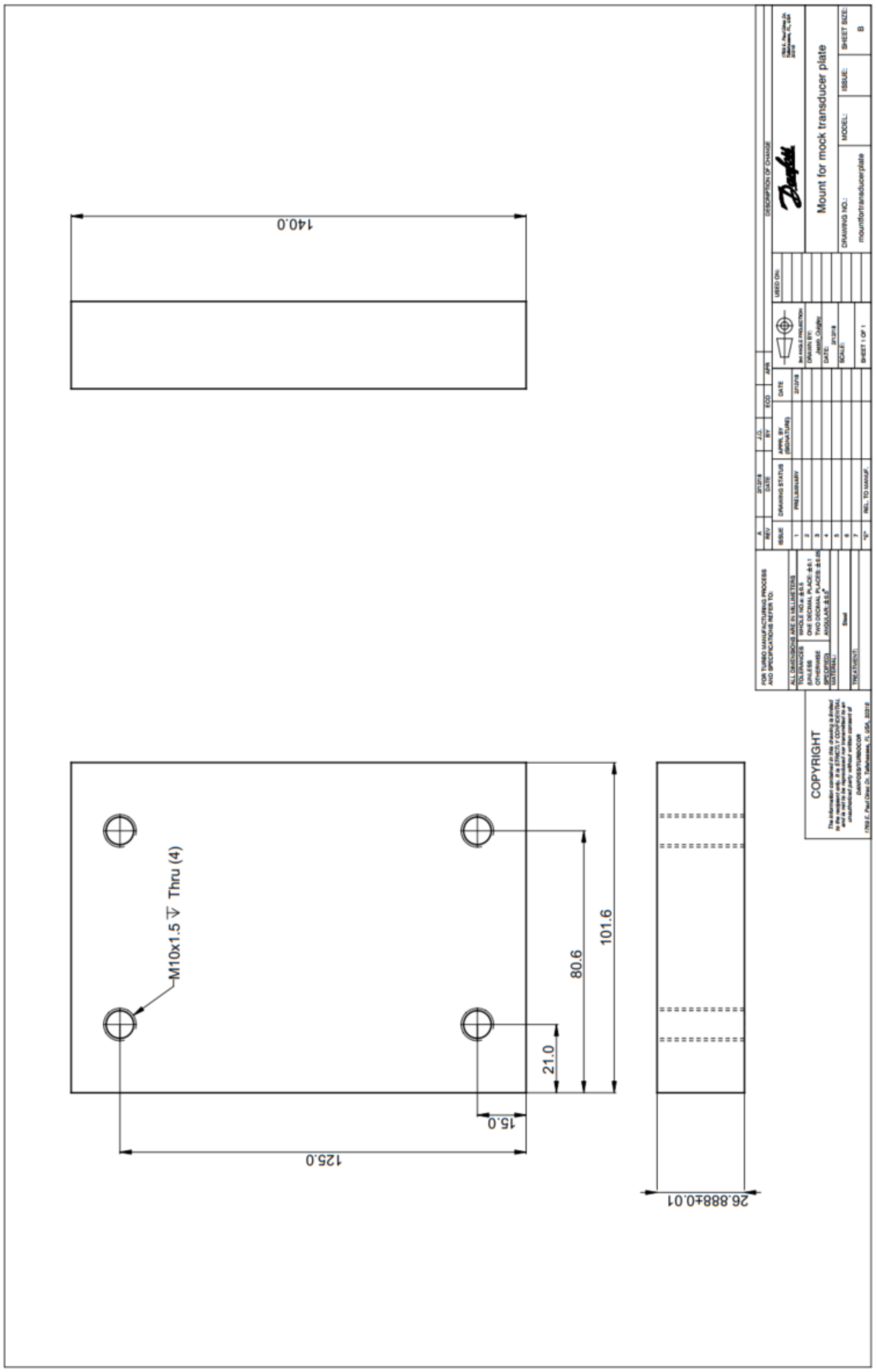

Figure 35: Mount for Torque Transducer Plate Drawing

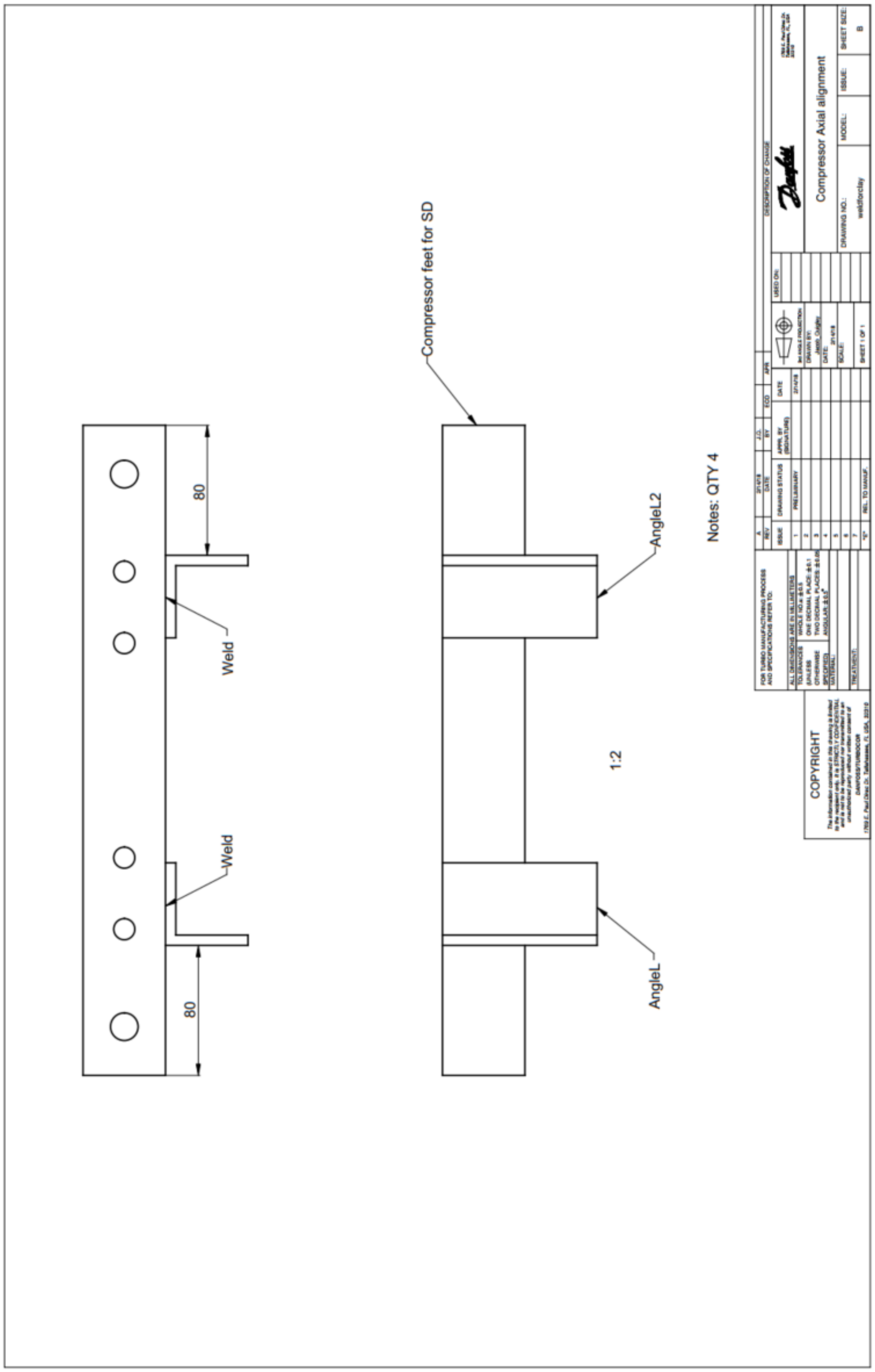

Figure 36: Compressor Axial Alignment