

High Speed Motor Test Rig

Operation Manual

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Team 4

Matthew Ketchum (mrk13g)

Thyeasha Joseph (tlj11f)

Durval Marques (dm15s)

Francisco Barreto (fjb11b)

Leonardo Branco (lc15d)

Sponsor: Danfoss Turbocor

Faculty Advisor: Dr. Patrick Hollis

Table of Content

Table of figures	ii
Abstract	iii
1. Functional Analysis	1
2. Project Specifications	1
2.1 Base frame	1
2.2 Rotating assembly	2
2.3 Alignment system	3
2.4 Safety Shielding	5
3. Project Assembly	6
3.1 Recommended Tooling and Equipment	6
3.2 Frame	6
3.3 Set Screw Bracket	8
3.4 Rotating Assembly	8
3.5 Compressors	8
4. Operating Instructions	9
4.1 System Alignment	9
4.1.2 Vertical Adjustment	9
4.1.3 Horizontal Adjustment	10
5. Trouble Shooting	10
6. Regular Maintenance	11
7. Conclusion	11
8. Appendix	12

Table of Figures

Figure 1: High speed motor test rig assemble with two TT-500 compressors models	1
Figure 2: Upper view of supporting frame without upper cross members [units in mm]	2
Figure 3: Section view of rotating assembly – 2 rigid couplers, 2 shafts and 1 flexible coupler	2
Figure 4: Rigid coupler McMasterr-Carr Re-machinable	3
Figure 5: Bellow couple R&W BK2 150 dimensions	4
Figure 6: Alignment system: set screw brackets for horizontal adjustment and shims for vertical adjustment	5
Figure 7: Horizontal and vertical alignment mechanisms integrated with the test rig base frame	5
Figure 8: Shim upper view	6
Figure 9: High speed motor test rig assembled with the safety shield	11
Figure 10: Exploded view	7
Figure 11: Base frame assembly	12
Figure 12: Upper outer cross member	13
Figure 13: Upper inner cross member	14
Figure 14: Long runner	15
Figure 15: End cover on Upper outer cross member	16
Figure 16: End Cover on Upper Inner Cross Member	17
Figure 17: Set Screw Bracket Assembly	18
Figure 18: Set Screw Bracket Assembly on Long Runner	19
Figure 19: Rotating Assembly	20

Abstract

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.

1. Functional Analysis

As delegated by Danfoss Turbocor, the High Speed Motor Test Rig designed by Senior Design Team 4 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 qualify motor performance, the test rig needs, besides the precision in the alignment process, to be able to deal with high speeds – around 40,000 rpm – and be compatible with the specific features that constitutes Turbocor compressors. One of these main 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, the overall design has to be changed to validate the alignment process first with dial indicators. The following is a breakdown of each subsystem, its components, and their functions.

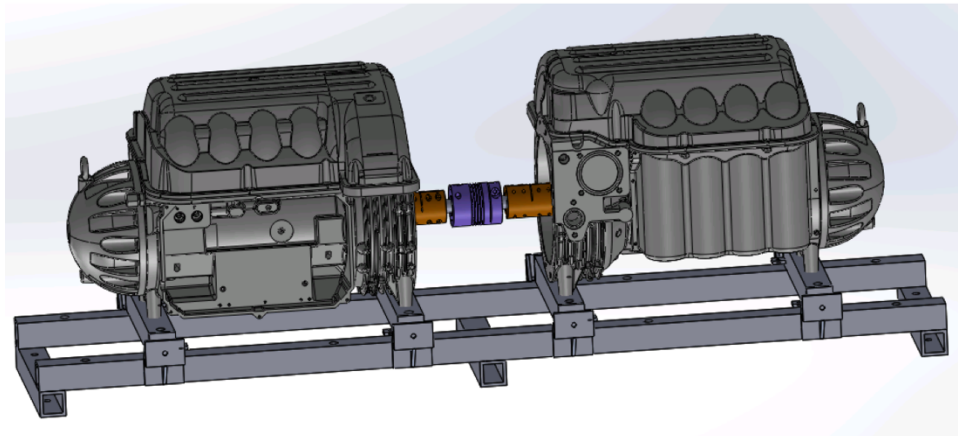


Figure 1: High speed motor test rig assemble with two TT-500 compressors models.

2. Project Specifications

2.1 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.

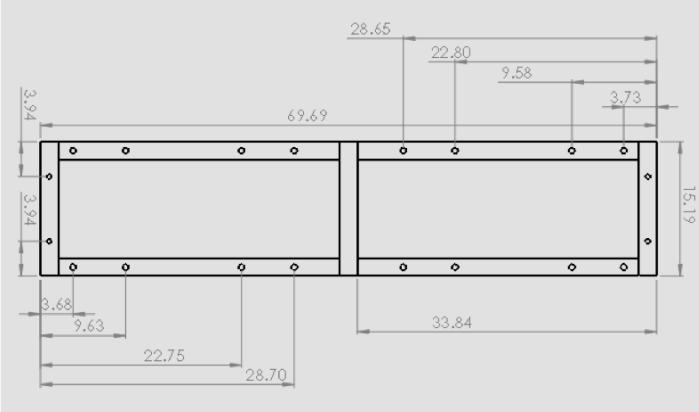


Figure 2: Upper view of supporting frame without upper cross members [units in mm]

2.2 Rotating assembly

Composed of two rigid couplers, one flexible coupler and two shafts, 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 flexible coupler in order to support axial, radial and angular misalignment. As the rotating assembly will be running at speeds around 40,000 rpm, 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.

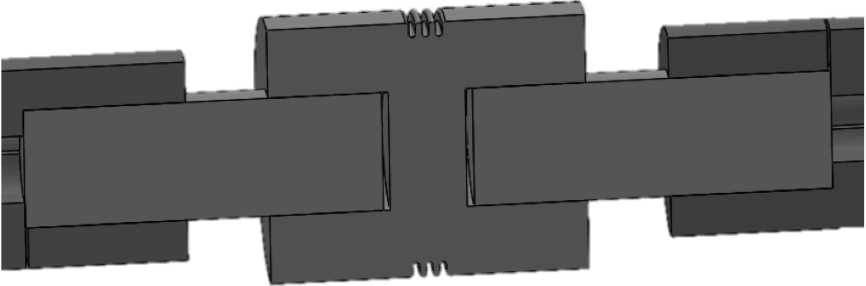


Figure 3: Section view of rotating assembly – 2 rigid couplers, 2 shafts and 1 flexible coupler

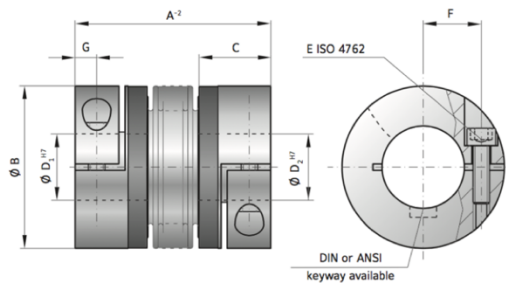
The rigid couplers selected are re-machined to the diameter of the compressor shaft. The flexible coupler is the R&W BK2 150. To conjoin the coupler, two shafts are used to fit into both couplers.. The dimensions of the shaft can be founded on Figure 8, and the couplers specification on Figure 6 and 7.



Figure 4: Rigid coupler McMasterr-Carr Re-machinable

The rigid coupler is initially mounted on the shaft of the compressor after the impellers being removed. The impellers are removed before any type of testing because the validation of the alignment system is the first concern of the test rig and at this point we are not interested yet on verifying the compression capacity of Turbocor compressors.

This coupler will be machined until reach an inner diameter of 22 mm (compressor shaft) and 25.4 mm (connecting shaft). After being machined the coupler will be balanced at Turbocor facilities in order to avoid any problems with misbalanced mass.



Overall length (mm)	A ²	95	107	144
Outside diameter (mm)	B	81		
Fit length (mm)	C	36		
Inside diameter possible from Ø to Ø H7 (mm)	D ₁ / D ₂	19-42		
Fastening screw ISO 4762	E	M10		
Tightening torque of the fastening screw (Nm)		70		
Distance between centerlines (mm)	F	27		
Distance (mm)	G	11		

Figure 5: Bellows couple R&W BK2 150 dimensions

The R&W BK2 150 is composed by aluminum hubs for low inertia and conical bushings for high clamping forces. This coupler is one of the key components because it can deal with the misalignments that the high speed can cause during a test for example.

The precision of the shaft is 50 µm. The shaft diameter and its length was determined mainly due the natural frequency analysis and the values are 25.4 mm and 107.0 mm. The shaft will connect the rigid coupler to the flexible and is made of 1566 hardened steel.

2.3 Alignment system

The method to measure the misalignment is through the use of dial indicators. To measure the misalignment, it is suggested to use a laser alignment tool (SKF TSKA 31) in order to provide more accuracy, precision and also to avoid the possibility of human errors, although at this stage of the project the measure method will be with dial indicators. The decision to use dial indicators instead of a laser aligner was made by the sponsor, because of unforeseen budget limitations.

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.

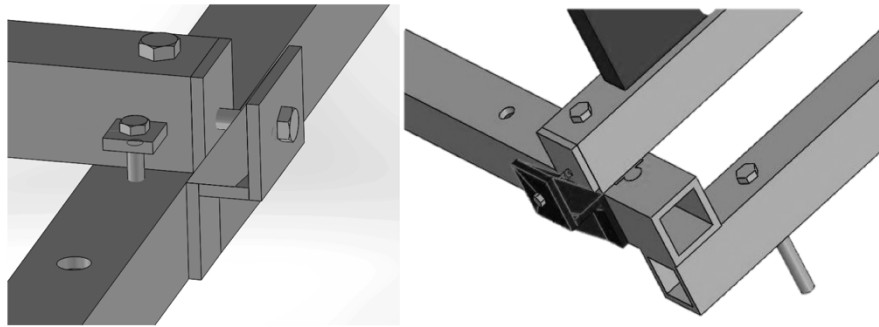


Figure 6: Alignment system: set screw brackets for horizontal adjustment and shims for vertical adjustment

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.

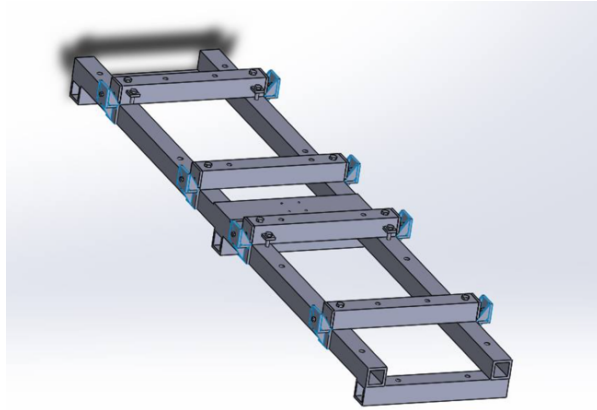


Figure 7: Horizontal and vertical alignment mechanisms integrated with the test rig base frame

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 Figure

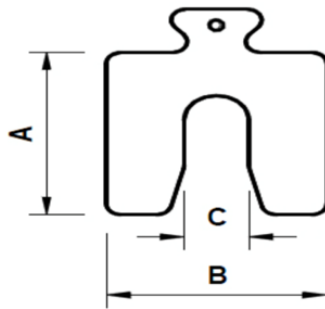


Figure 8: Shim upper view

2.4 Safety Shielding

The safety shielding was designed to prevent accidents due to possible failures and to provide better safety conditions to the operators of the test rig. It is made of steel with a thickness of $3/16''$. This shielding encompasses the rotating assembly and fits between the compressors.

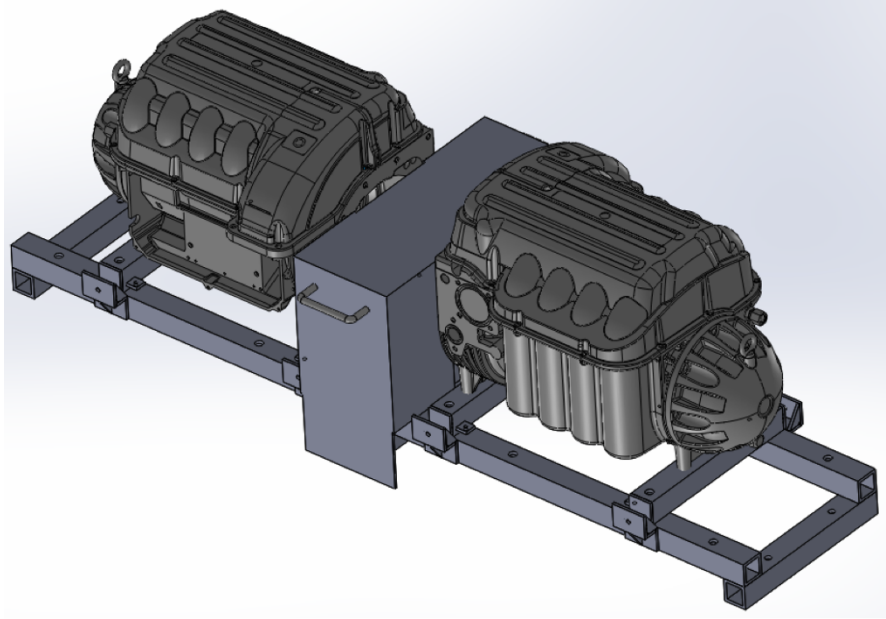


Figure 9: High speed motor test rig assembled with the safety shield

In summary, the high speed motor test rig needs to be able to operate in the following range of torque and speed:

The necessity to validate the alignment process required a proposal of testing and verifying all the alignment process. To do so the test rig was designed and each subsystem had their characteristics analyzed. Those characteristics can be verified as follows.

3. 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.

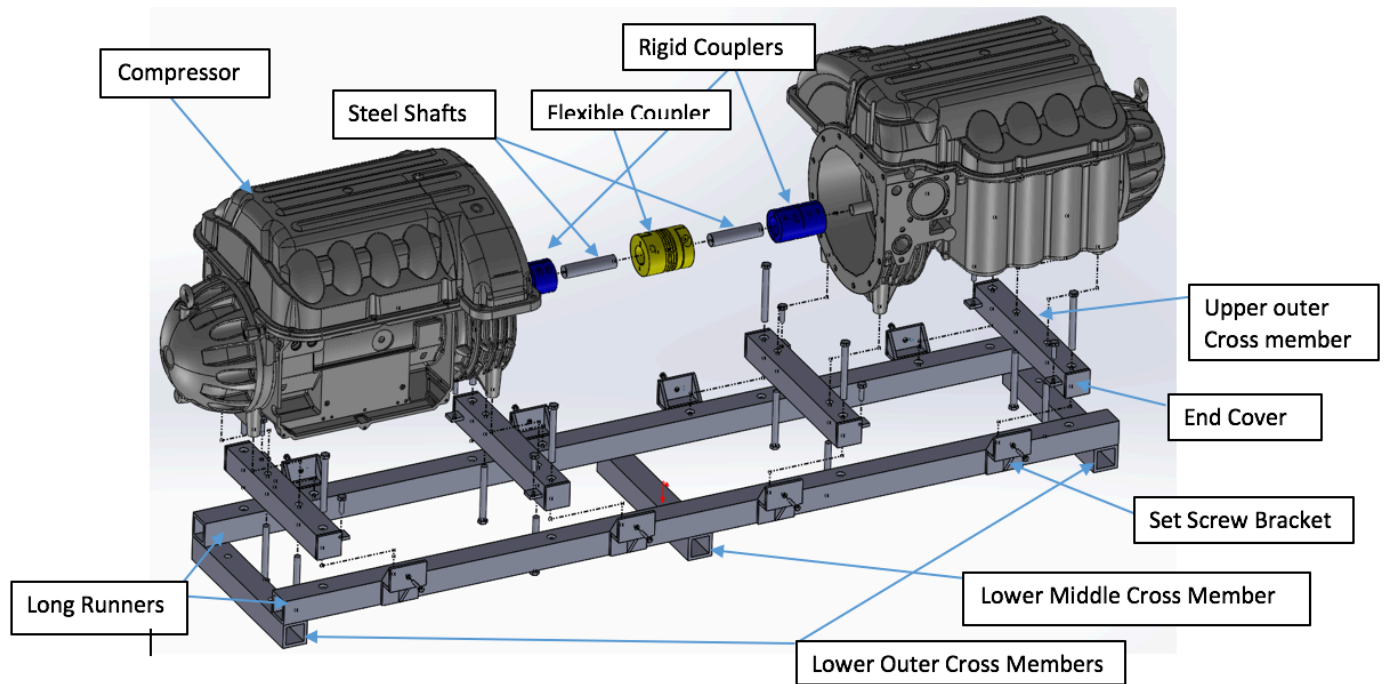


Figure 10. Exploded View.

3.1 Recommended Tooling and Equipment

Those performing 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 ½” 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.

Shaft alignment requires the use of either a SKF TKSA 31 laser aligner, or the use of a dial indicator. The dial indicator will be the assumed method and used in this operation manual. To properly fasten the dial indicator, the tool must have a strong magnetic base or clamp.

3.2 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 outer” and “upper inner” cross members. The “inner” pieces are bolted to the frame with ½”-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 ¼” 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 ½” washers. One washer under the head of the cap screw and one on the ½” 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.

3.3 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.

3.4 Rotating Assembly

Components that comprise the rotating assembly are two steel shafts, two rigid couplers, and one flexible coupler. Starting first with the BK2 flexible coupler, loosen the two clamping screws. Slide each shaft 36mm into each end of the flexible coupler. Tighten the BK2 couplers screw to 70Nm (it may be easier to tighten these after the rotating assembly is connected to the compressors. Next, slide the rigid couplers 38mm onto the exposed ends of the shafts (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.

3.5 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.

4. 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.

4.1 System Alignment

Alignment of compressor shaft requires the use of a dial indicator. The indicator should have an accuracy of 0.0001” and have an attachment that allows it to be rigidly mounted to a surface. To properly function, the indicator attachment arm needs to have multiple pivot points, this allows it to mount to one side of the rotating assembly, and reach around to the other.

The process for alignment begins with using the dial indicator. The indicator must be attached to one side of the rotating assembly and rotate 360 degrees. It is predicted that the user preforming the alignment will need to mount the dial indicator base to a rigid coupler and rest the dial reading arm upon the other rigid couple.

4.1.2 Vertical Adjustment

With the dial base attached to a rigid coupler, reach the arm to a surface on the other side of the rotating assemble (must be somewhere past the opposing side of the flexible coupler). Start with the dial indicator in the 12 o'clock position and zero the reading. By hand, rotate the shafts to the 6 o'clock positon and note the dial reading. During rotation, if the dial reading moves clockwise, the shaft being measured is lower than the shaft that the dial is mounted too. The

value displayed at 6 o'clock is two times the vertical displacement between the shafts. To correct the vertical alignment, insert shims under the compressor that has the lower shaft position.

To select the appropriate shim(s), choose the largest shim width that is still less than the vertical offset value. Next, fine tune by using thinner shims to lessen the offset amount. The sum of the shim thicknesses used should be as close as possible to the measured offset value.

4.1.3 Horizontal Adjustment

Begin with the dial indicator rigidly fixed to one side of the rotating assembly (a rigid coupler is ideal). Reach the dial arm to the other side of the rotating assembly and set it upon a solid surface (the rigid coupler is ideal). Start with the indicator in the 3 o'clock position and zero the reading. Rotate the assembly to the 9 o'clock position and note the final reading. During shaft rotation if the dial rotates in the counter clockwise direction, the compressor opposing the side the dial indicator will need to be shifted towards the side of the 9 o'clock indicator position. If the indicator dial rotated clockwise, the compressor opposite the side of the mounted indicator should be shifted to the 3 o'clock side (starting position of the dial indicator). Half of the dial value is the horizontal offset amount. To correct this offset, use the set screws to shift the lateral position of the compressors. The set screw threads are 3/8"-24, this means that with one full rotation, the screw will thread in 0.0417 inches (1/24"). Use this value to estimate the required amount of rotations to shift the compressor. Be sure to use the same amount of rotation on the other set screw that is on the same side of the frame.

5. 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 (h7 is ideal) is reached. While doing vertical alignment, if the dial indicator mounting position is disturbed after the dial readings have begun, the alignment process must start over. Maintaining the same position of the indicator is imperative to an accurate alignment. While performing 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

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.

6. 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.

7. 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

8. Appendix

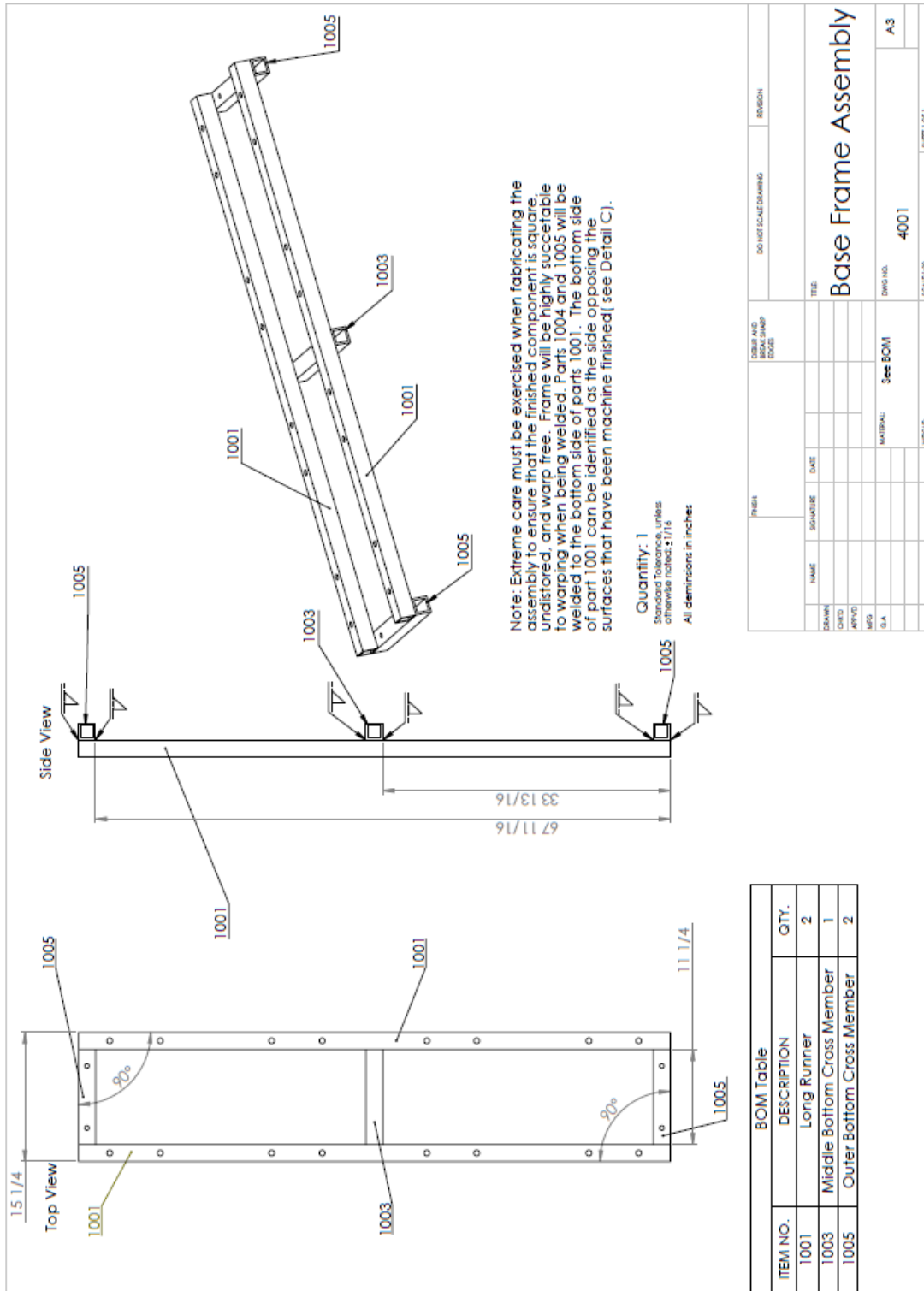


Figure 11. Base Frame Assembly

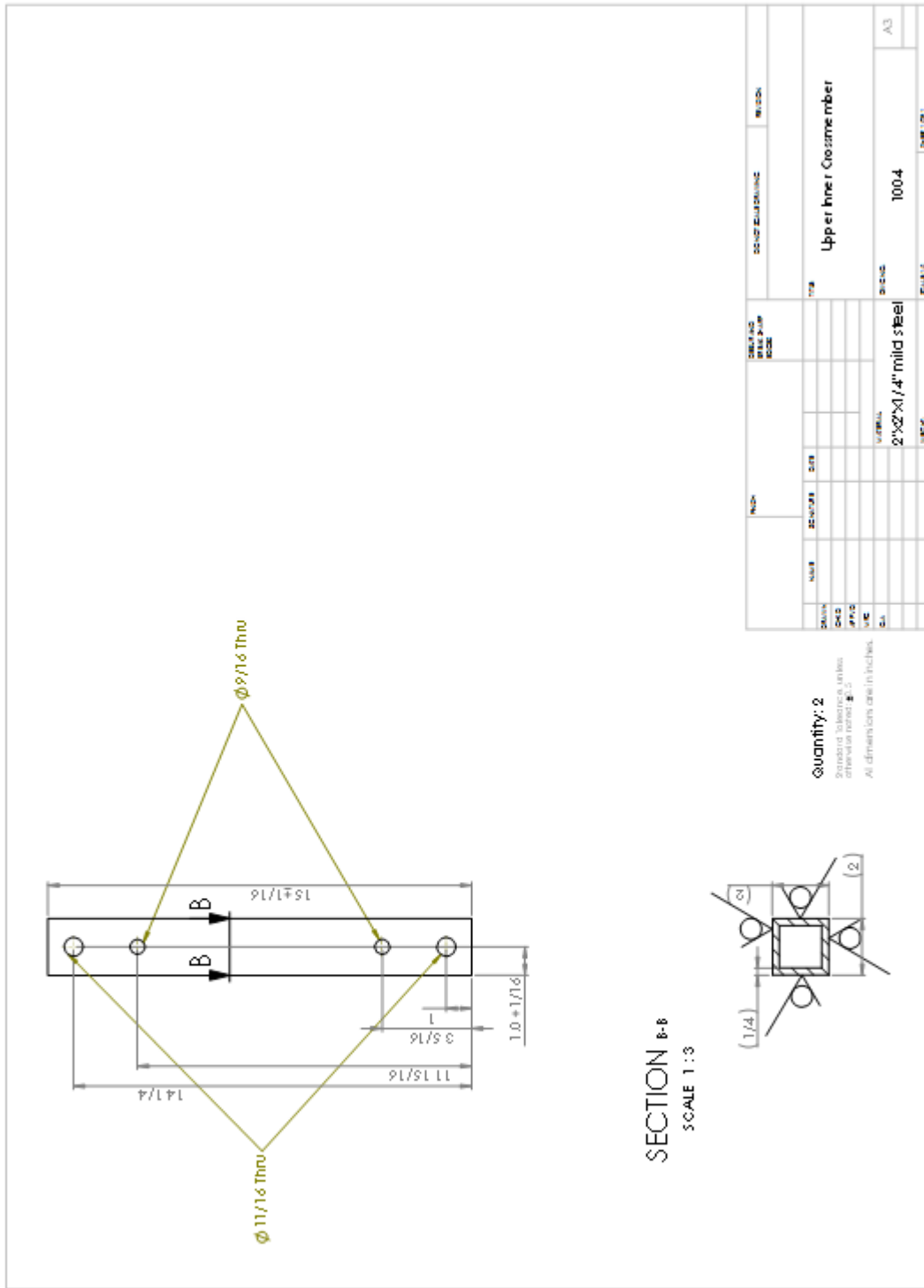


Figure 13. Upper Inner Cross Member

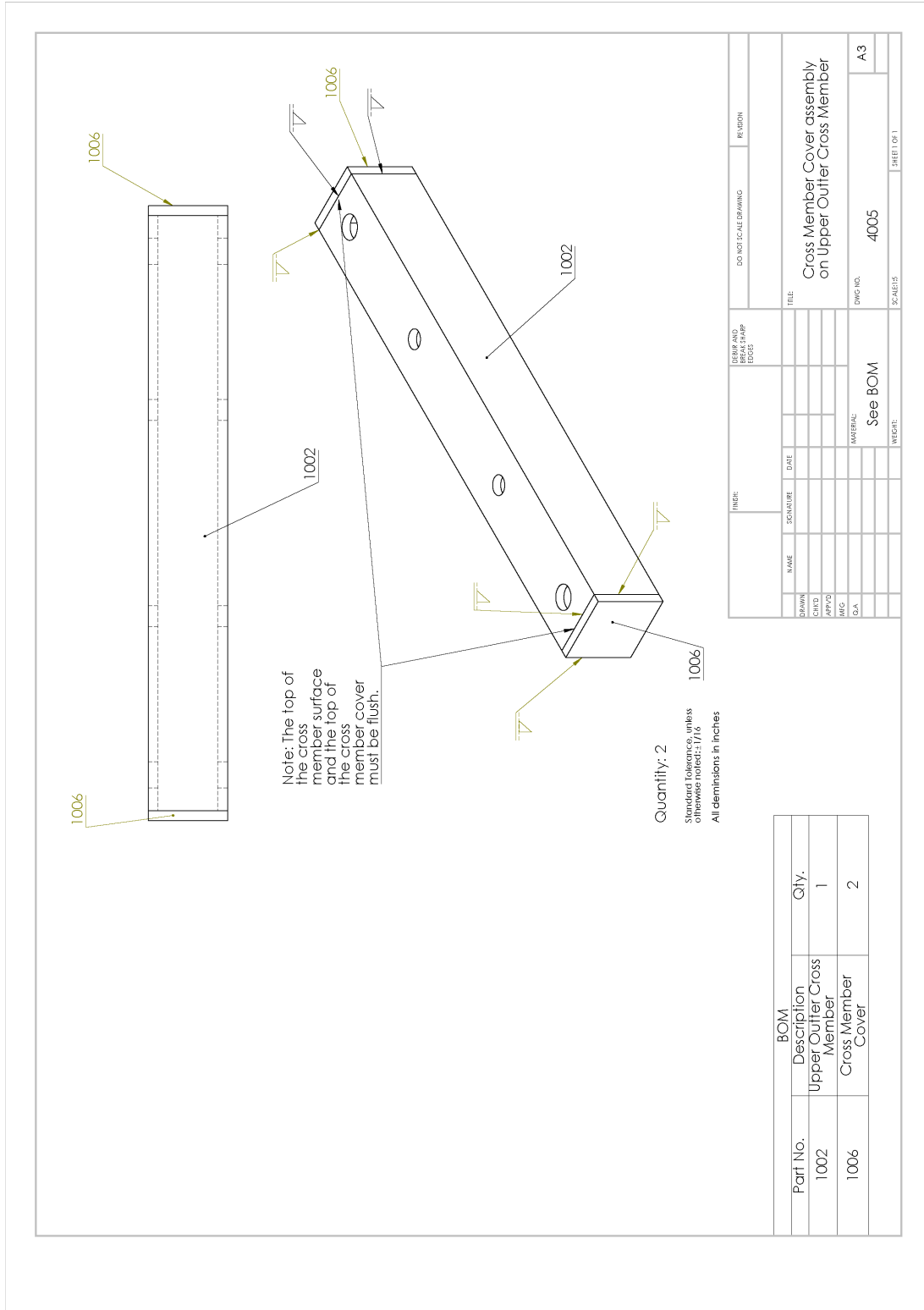


Figure 15. End Cover on Upper Outer Cross Member

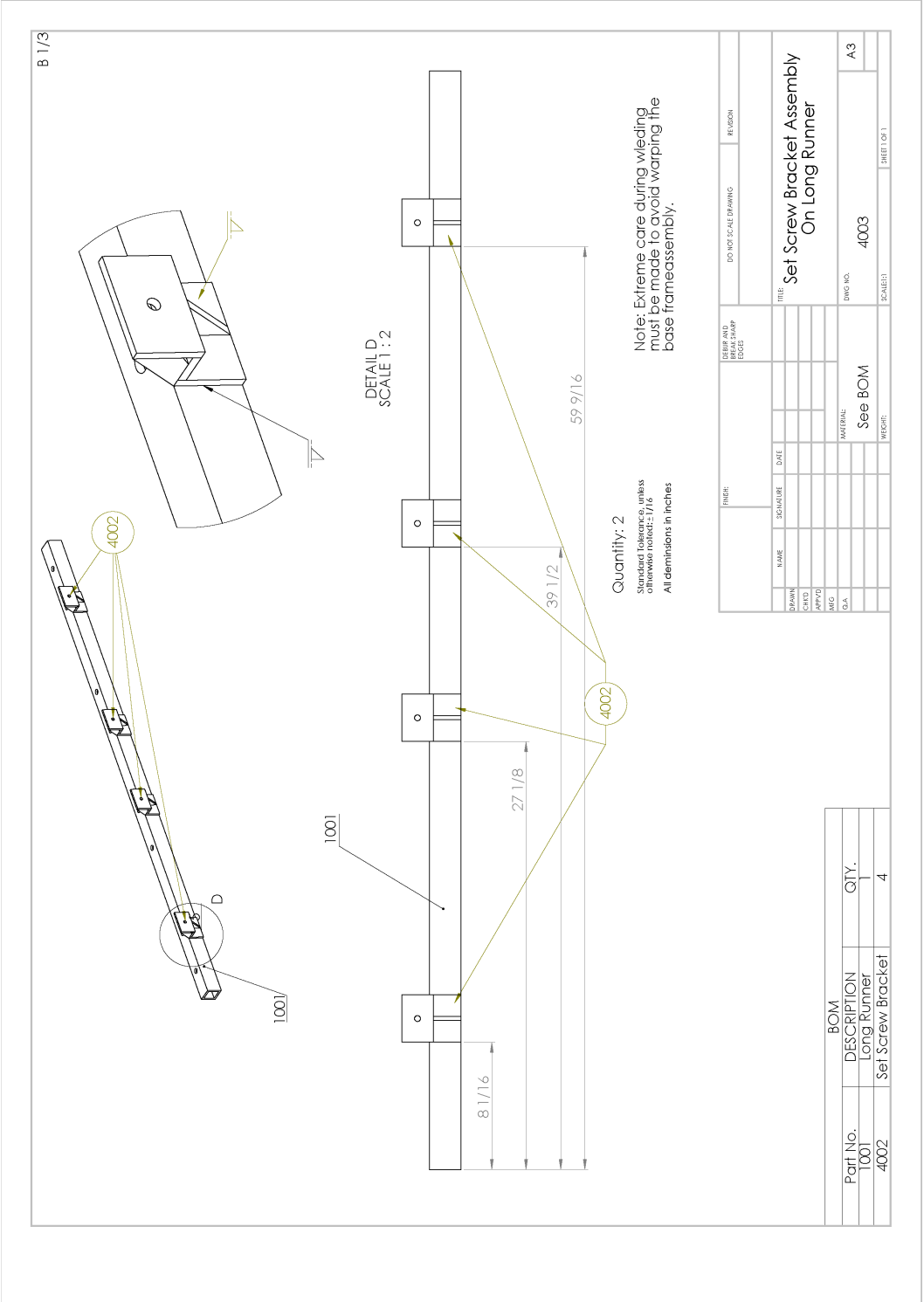


Figure 18. Set Screw Bracket Assembly on Long Runner

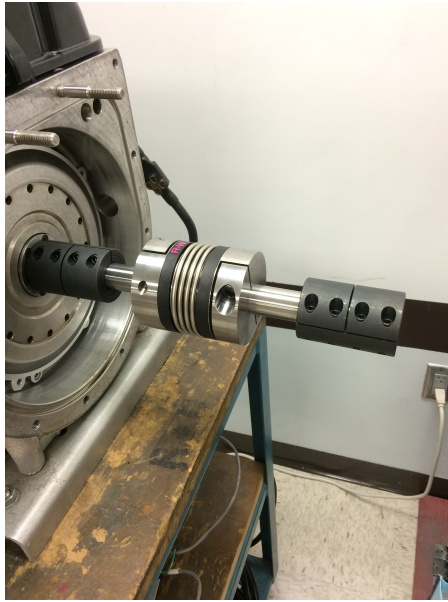
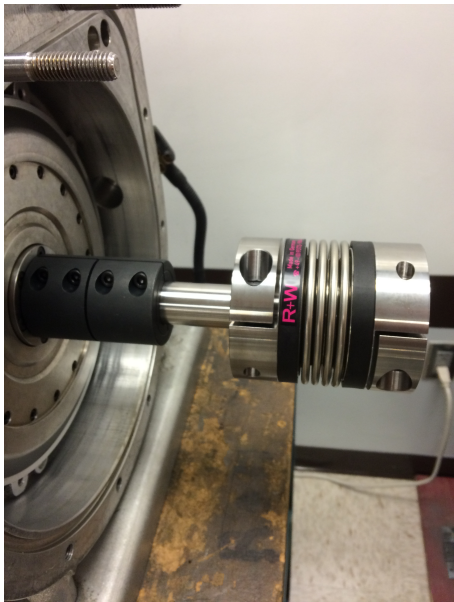
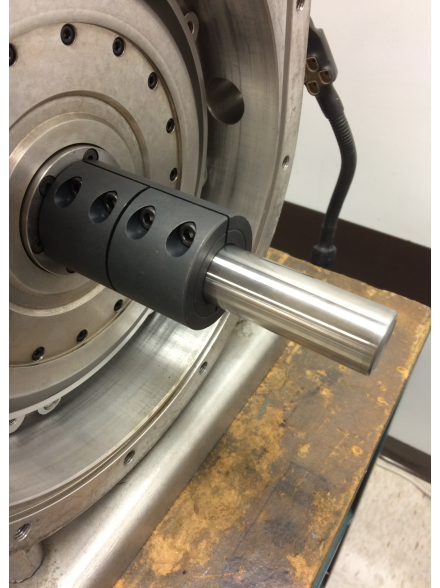
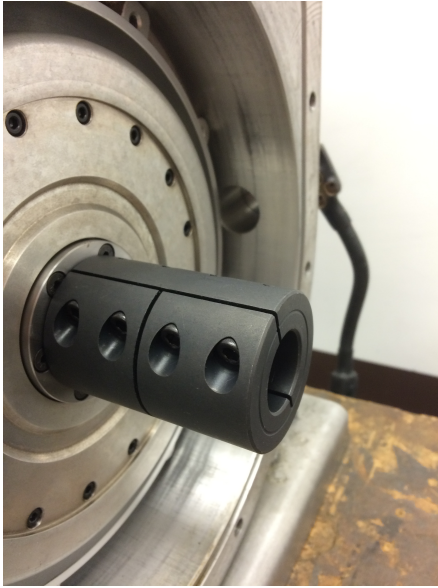
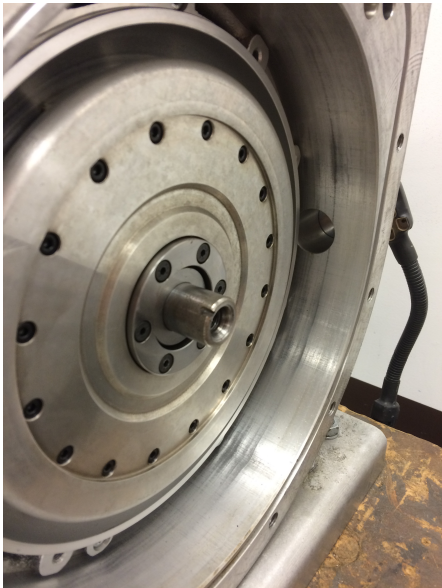


Figure 19. Rotating Assembly