

Operation Manual

Team 4

VTT Rotor: Back EMF Test Fixture



Members:

Russell Hamerski – rh10g

Thomas Razabdouski – trs09

Tim Romano – tr10j

Andre Steimer – as10f

Andrew Panek – ajp11k

Faculty Advisor: Dr. Louis Cattafesta

Sponsor: Danfoss Turbocor - Brandon Pritchard

Instructors: Dr. Nikhil Gupta, Dr. Chiang Shih

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ABSTRACT

Team 4, sponsored by Danfoss Turbocor, has designed a test fixture that can perform quality control on magnetized rotors by measuring the back electromotive-force (EMF) generated when the rotor is spin within a magnetized stator. The design includes a ball screw that is used to overcome an 80 pound magnetic force when the rotor is inserted into the stator, linear guides designed to reduce friction and aid in alignment and an AC motor that is used to rotate the rotor within the stator. This paper is an operation manual for this test fixture. A functional analysis description has been provided which covers the basic roles of all the various components that make up the test fixture. Some of the components such as the motor and variable frequency drive used to control the motor have specification sheets and operation manuals of their own which are also provided in this manual. A description of the assembly process is also included in this manual should re-creation of another test fixture be necessary. Finally, a section on preventative maintenance has been included which including troubleshooting procedures, regular maintenance and a spare part inventory. This operation manual should be kept with the test fixture for use by the operator.

ACKNOWLEDGMENTS

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1. Introduction

Danfoss Turbocor is planning to launch a new compressor model during 2015. Current production plans call for the use of a rotor that is to be manufactured by a third party company. Turbocor requires a way to quality check these rotors and ensure they are up to their standards. To do this, Turbocor must measure the back electromotive force delivered when the rotor is spun inside a stator. Electromotive force, or EMF, typically refers to the voltage generated when a rotor is spun due to the relative motion of the magnetic fields of the rotor and the stator.¹ To implement this testing procedure successfully and efficiently, a test fixture must be created that can be integrated into Turbocor's existing product manufacturing line. This test fixture will be used to perform the back EMF measurements on each rotor prior to assembling it into the new compressors. Turbocor developed an existing test fixture approximately 10 years ago for use on one of their smaller compressor models. The setup and operation of the previously developed test fixture does give this senior design group an opportunity to view the essential features and operation of the test fixture. A more in depth view of this previous test fixture can be found in Team 4's Design for Manufacturing, Reliability, and Economics Report.

The test fixture for the larger rotor has been fully designed and manufactured. This report serves as an operation manual for the test fixture. A functional analysis will be presented that includes a functional diagram and explanation of the essential design components. There is also a longer explanation of certain components such as the ball screw and Variable Frequency Drive (VFD) that is used to control the motor speed. This longer section is used to note some of the important characteristics of these components such as a data sheet and explanation of use. After this a project assembly and operation instruction is included that can serve as a basis guide to the test fixture operator.

In addition to these sections which go over the design components and use of the test fixture, there are several subsequent sections which cover issues that may come up over the life of the test fixture. There are potential problems that may come up during operation and a troubleshooting section is presented on how to approach these. Additionally, regular maintenance must be performed on the test fixture to ensure that operation runs smoothly, which can include replacement of certain design components. Finally, there will be a discussion of needed spare parts.

2. Functional Analysis

This section covers the basic functional analysis of the VTT Rotor Back EMF Test Fixture and a more detailed description is given in the Operational Instructions section. A diagram showing the main components is shown in Figure 1 below. The most important components of the design are the extruded aluminum baseplate, linear guide system, ball screw assembly, motor, live center assembly and stator housing.

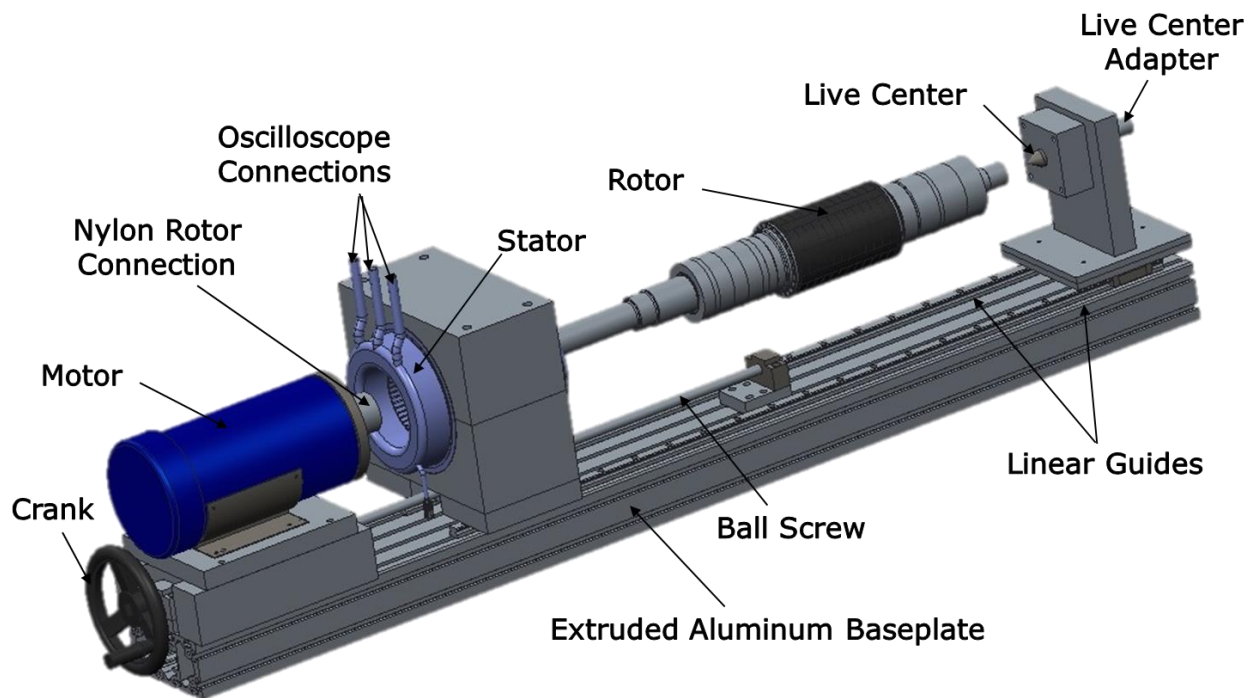


Figure 1: Functional diagram of test fixture (Note: Extruded aluminum 1750 mm long)

The rotor is constrained by the live center and the nylon rotor connection which connects the rotor to the motor shank. Both the live center assembly and the stator housing ride along the linear guides which aids in alignment of the rotor. The live center assembly can be locked into place with linear guide clamps (not seen in diagram), while the stator housing's position is dictated by movement of the crank and ball screw. The motor is used to rotate the rotor, and an external bearing is used to support the motor shank. The speed of the motor is controlled by a VFD. All of these design components are connected to a 1750 mm piece of extruded aluminum that has a 90 mm x 180 mm cross section.

3. Component Specifications

The specifications of various components in the test fixture design are outlined in this section. This include both dimensions of these components as well as specifications such as load limits. Part numbers for all of the relevant components are also mentioned so that reordering of parts for replacement or creation of a new test fixture is possible.

3.1 Extruded Aluminum Baseplate

The extruded aluminum baseplate is supplied by Misumi with the part number HFS8-90180-1750. The overall length of the baseplate is 1750 mm and the cross section is 90 mm by 180 mm. There are four extrusion slots on the 180 mm side and two extrusion slots on the 90 mm. A drawing of the cross section can be seen in Appendix A. The components are connected to the extruded aluminum with extruded aluminum fasteners which are also supplied by Misumi with part numbers PACK-HNTTSN8-6 and PACK-HNTTSN8-5. These correspond to packs of 100 fasteners made for M6 and M5 screws.

3.2 Linear Guide System

The linear guides are heavy load linear guides also supplied by Misumi with the part number SX2R28-1240. Each linear guide is 1240 mm in length and contains 2 connecting blocks, one for the live center assembly and one for the stator housing. The rail width is 20 mm and the unit height is 28 mm. They are lubricated with standard lithium base grease. The linear guides are rated for an allowable static moment of 155 N-m about the length of the rail and have a 12,500 N basic dynamic load rating and 21,300 N basic static load rating.² A three dimensional view and a detailed drawing of the linear guides is provided in Appendix A. The live center assembly is not constrained by the magnetic force as the stator housing is. Therefore, the position of the live center assembly is constrained by linear guide clamps provided by Misumi, part number SVCK28. These linear guide clamps are specifically made for the heavy load linear guides and are made of 4137 alloy steel with a black oxide coating.

3.3 Ball Screw Assembly

The ball screw assembly consists of the ball screw, two bearing blocks and the crank, all of which are supplied by Misumi. The part numbers are BSBR1510-1100 for the ball screw, BSWE12 for the fixed side bearing block, BTN12 for the support side bearing block and PHLW200-17 for the crank. The ball screw is 150 mm in length and 15 mm in diameter with a 10 mm lead. The ball screw has a 5,100 N basic dynamic load rating and a 10,500 basic static load rating.³ The fixed side support unit, or bearing block, has a shaft height of 25 mm, a thickness of 27 mm and a width of 70 mm. The support side bearing block also has a shaft height of 25 mm, a thickness of 20 mm and a width of 70 mm. The crank is a three-spoked offset handwheel made of phenol. The crank has an outer diameter of 200 mm with a 17 mm square hole. Drawings for all parts in the ball screw assembly can be seen in Appendix A.

3.4 Live Center

The live center is supplied by Z Live Center with the part number ZLC 07018-MT2. It has a tapered end with Morse Taper #2, a maximum RPM of 5,500 and a max work piece load of 800 pounds.⁴ It has an overall length of 4.94 inches. A detailed drawing and table of dimensions for the live center is found in Appendix A. The live center adapter is configured for a Morse Taper #2 fit and is supplied by MSC Industrial Supply with the part number 185041.

3.5 Motor System and Variable Frequency Drive

The motor is supplied by Automation Direct with part number E2007A. It is connected to the motor base with part number MTA-BASE-W145T. The motor is 2 HP, 3-phase, 208-230 V, 1800 RPM with a 7/8 inch diameter shaft and a 145TC Frame. The motor is rated to NEMA Premium Efficiency, has Class F insulation, F3 mounting and is made of rolled steel.⁵ A detailed drawing of the motor and motor base and motor specification sheet is in Appendix A. The motor is controlled by a Variable Frequency Drive also supplied by Automation Direct with the part number GS2-22P0. This is a 2 HP, 230 V, 3-phase AC Drive.⁶ It has a rated input current of 19.6 A and a rated output current of 17 A. The dimensions of the VFD are 220 mm x 125 mm x 189.6 mm. A full specification sheet for the VFD can be found in Appendix A. Detailed installation and operation instructions can be found on the [Automation Direct website](#).

4. Project Assembly

The exploded view of the 3D model of test fixture can be seen below in Figure 2. This section goes over the assembly instructions of the mechanical portion of the test fixture.

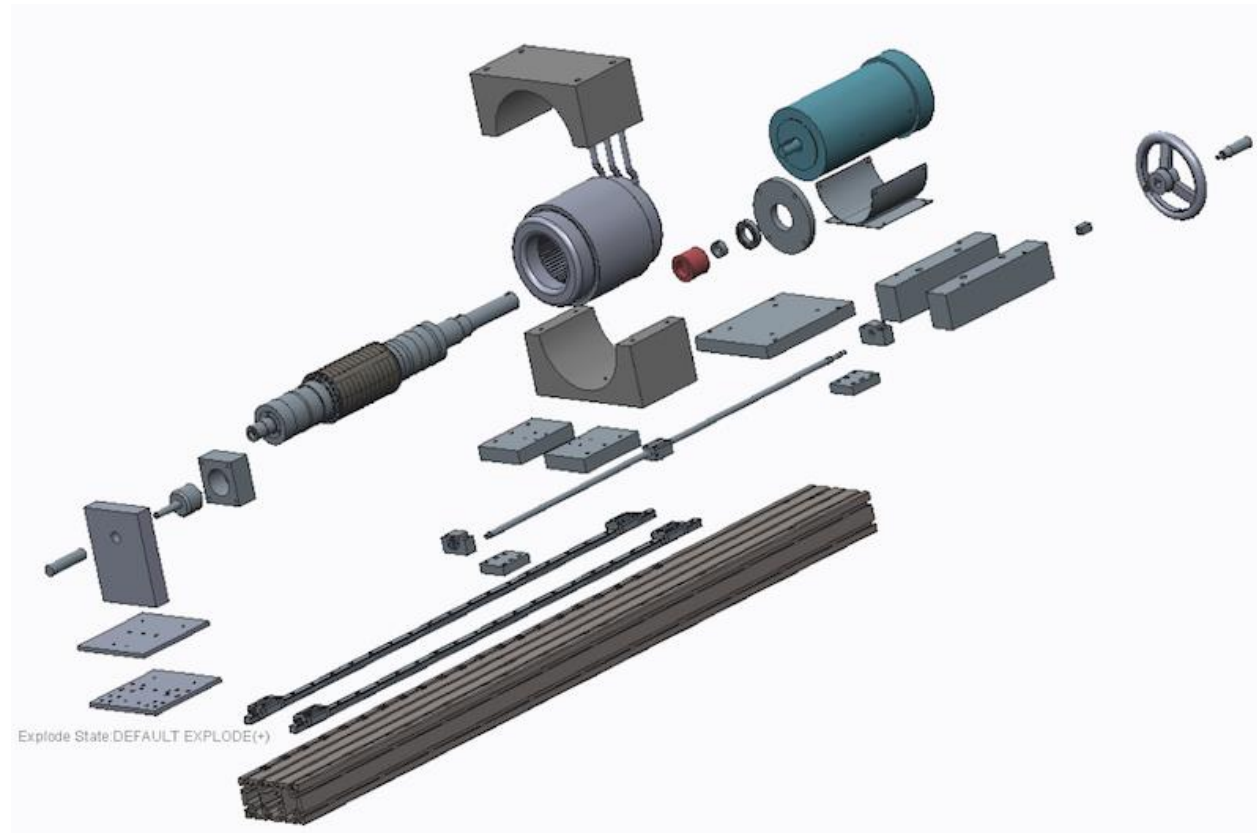


Figure 2: Exploded view of assembly

The first component of the assembly is the extruded aluminum baseplate and all subassemblies are connected to this baseplate. The subassemblies are divided into the motor, stator, ball screw, linear guides and live center subassemblies. The motor has an external bearing used to support to shank. This bearing can be press fit into the bearing support using an arbor press. The bearing support can then be press fit onto the motor shank and slide along and connected to the motor. After this, the motor supports can be connected to the base. A M6 screw with a washer can be dropped into each of the motor support holes and connected to an extruded aluminum fastener which can then be slid into the extruded aluminum baseplate. The motor support base can then be connected to the motor supports with M6 screws and washers. The support base comes with nuts that can be used to connect to the motor frame. The motor needs to be lifted and placed

on the bolts sticking out from the motor base after the nuts are removed. The nuts can then be tightened down and the motor is then secured. The adjustment on the motor base allows for the position of the motor to be altered in the lateral direction.

The ball screw assembly can be constructed next. The support side bearing block has a bearing which needs to be press fit using an arbor press. Once this is done, the ends of the ball screw can be inserted into each bearing block. The bearing block supports can be installed on the extruded aluminum baseplate using M6 screws in the same manner as the motor supports. Each bearing block can then be connected to the bearing block supports using M6 screws and washers. The bearing block supports should not be fully tightened until the linear guides are also installed.

The live center subassembly consists of several custom made components. The live center can be inserted into the live center adapter and the adapter can then be press fit into the upright support. The live center front plate then goes over the portion of the live center that is still exposed and secured with 4 screws. This completes the assembly of the top portion of the live center, and the rest of the live center subassembly needs to be completed after the linear guides are assembled. The stator housing consists of the top and bottom stator housing and two spacers. The top of the stator housing is removable and can be added after the rest of the test fixture is assembled. The spacers can be attached to the bottom stator housing by screwing four screws upwards through the spacers into the bottom stator housing.

At this point, the linear guides can be assembled. The bottom portion of the live center baseplate and the spacers must have screws drilled up through them and then they can be attached to the linear guides. Once connected, the linear guides can have M5 screws with washers inserted into them and connected to the extruded aluminum fasteners. Once this is done, the linear guides, with fasteners connected, may be inserted into the extruded aluminum baseplate. At this point the bottom of the stator housing and live center assembly should be connected to the protruding screws that were previously installed. Once this is done, screws should be inserted into the bottom of the stator housing and into the ball screw block. Now, the stator housing and live center is connected, and the ball screw should be used to make sure everything is aligned. Once alignment is confirmed, the ball screw and linear guides should be fully tightened. The next step is to insert the stator. Once the stator is in the bottom stator housing, the top stator housing can be tightened down. If a table is selected, the baseplate may be connected to the table and assembly is complete.

5. Operation Instructions

Step 1:

- Ensure the entire test fixture has been reset.
 - Motor is off
 - Stator is as close as possible to the motor, live center assembly is at far end of test fixture

Step 2:

- Wrap the nylon straps around the rotor.
 - From here, the rotor can be moved to the test fixture
 - Ensure that the longest end is facing the motor.

Step 3:

- Move the nonmagnetic section of the rotor through the stator

Step 4:

- Attach the stator to the motor coupling.
 - If it does not fit, try rotating the motor shank or the rotor.

Step 5:

- With the nylon straps still connected, slide the live center assembly to the rotor.
 - Ensure that the live center is in contact with the rotor as much as possible.
 - Once done, lock the live center stopper(s).

Step 6:

- Remove the nylon straps from the rotor.
 - Move the gantry away from the test fixture during the testing process.

Step 7:

- Using the crank, center the stator over the magnetic section of the rotor.
 - Resistance will be felt as the stator initially slides over the rotor.
 - After the stator is halfway over the rotor, the rotor will want to center itself.
 - Once resistance is felt again, cranking can be stopped, to ensure the stator is centered.
 - Be cautious, as the wheel may spin if not centered properly.

Step 8:

- Ensure that the oscilloscope is properly connected.

Step 9:

- Turn on the VFD and slowly ramp up the speed of the motor.
 - Once the recommended angular velocity is achieved, record the oscilloscope reading.

Step 10:

- Using the VFD, slowly ramp down the speed of the motor.

Step 11:

- Using the crank, move the stator housing back to its original position next to the motor.

Step 12:

- Move the gantry over the test fixture and connect the nylon straps to the rotor.

Step 13:

- Release the linear guide stops and push the live center away from rotor to its original position.

Step 14:

- Disconnect the rotor from the motor connection, and move the rotor out from the stator.

Step 15:

- Lift the rotor out of the test fixture and onto the next step in the assembly process.

6. Preventative Measures

This section of the Operation Manual outlines measures that must be taken to keep the test fixture operating smoothly without error. This includes troubleshooting of common problems, regular maintenance that must be performed and spare parts needed for extended operation.

6.1 Troubleshooting

This section is intended to help reduce problems with the design that may infringe on its productive working time. The troubleshooting guide should be used by observing the symptom of the problem, and attempting the possible fixes or solutions. A full troubleshooting guide is given in Appendix B.

6.2 Regular Maintenance

This test fixture has been designed to require little maintenance which is important for the longevity and repeatability of the device. One of the few parts that need upkeep is the bearing supporting the motor shank. This part is integral to the design in that it will support the motor shank without damaging the motor. This bearing will need to be replaced over time. This can be done by removing the external bearing assembly from the motor, removing the bearing from the bearing assembly, and then replacing the entire assembly. The live center is another part that can wear over time and require replacement. Live centers are commonly used on lathes and are easily replaceable by design. It is as simple as removing the bolts on the front plate and sliding it out of the taper adapter it rests in during operation. This part was ordered from Z Live Center and they warrantee their products and will refurbish a broken one for 50% of the original price. Though this part will last for many test cycles, it is a cost effective solution to replace this important part as needed over time.

The linear guides and ball screw are also relatively maintenance free as well. They only require lubrication occasionally. These are not sealed systems as that was not required for the test fixture because it will be operated in clean facility. The lubrication will ensure that the components move smoothly and with little friction.

On top of all of this, the test fixture will need to have an infrequent alignment check. All of the connections on the fixture have lock washers on them and are torqued properly and should not move. Though this should be a redundant test, it is necessary to ensure that the results from the test fixture are true and conclusive.

6.3 Spare Parts

Table 1 below highlights the spare parts that are included with the test fixture. These parts will allow extended operation and minimal downtime, both of which are critical on the manufacturing line the test fixture will be implemented on. As many of the components are custom and required specific machining, not many spare parts specific to the test fixture are available beyond hardware required for assembly. In addition, the components ordered from manufacturers, such as the live center, have been determined to be too expensive to have spares and will be ordered as needed. It is important to note that all component orders were done through order requisitions at Turbocor, and so the company can easily reorder the components if the need arises. It is also important to make note of the fact that that M5 and M6 screws are always available on the Danfoss Turbocor manufacturing line and do not have a part number.

Table 1: Spare parts inventory

Part	Vendor Part Number	Quantity
M5 Extruded Aluminum Fasteners	PACK-HNTTSN8-5 (for pack of 100)	64
M6 Extruded Aluminum Fasteners	PACK-HNTTSN8-6 (for pack of 100)	60
Fuse 25A 300 VAC Class T	TJN25 (for pack of 10)	6
Fuse 0.1A 250 VAC Class A	AGC-1 (for pack of 5)	3
M5 Screws	Supplied by Turbocor	-
M6 Screws	Supplied by Turbocor	-

References

- [1] Acroname. "Back-EMF Motion Feedback." Acroname. Brainstem, 2014. Web. 23 Sept. 2014. <<http://www.acroname.com/articles/emf-motion-feedback.html>>.
- [2] "Linear Guides - Heavy Load." MISUMI Product Specifications. Misumi, n.d. Web. 06 Apr. 2015.
- [3] "Rolled Ball Screw -Block Nut/Thread Diameter - Precision Grade C10." MISUMI Product Specifications. Misumi, n.d. Web. 06 Apr. 2015.
- [4] "Super Rolling Live Center ZLC 07018-MT2." Live Center. Z Live Center, n.d. Web. 06 Apr. 2015.
- [5] "E2007A AC MOTOR 2HP 1800RPM." E2007A. Automation Direct, n.d. Web. 06 Apr. 2015.
- [6] "GS2-22P0GS2 2.0 HP AC DRIVE." GS2-22P0 Motor Drive. Automation Direct, n.d. Web. 06 Apr. 2015.

Appendix A

Appendix A contains product specifications for the different components of the test fixture.

HFS (Standard Type)

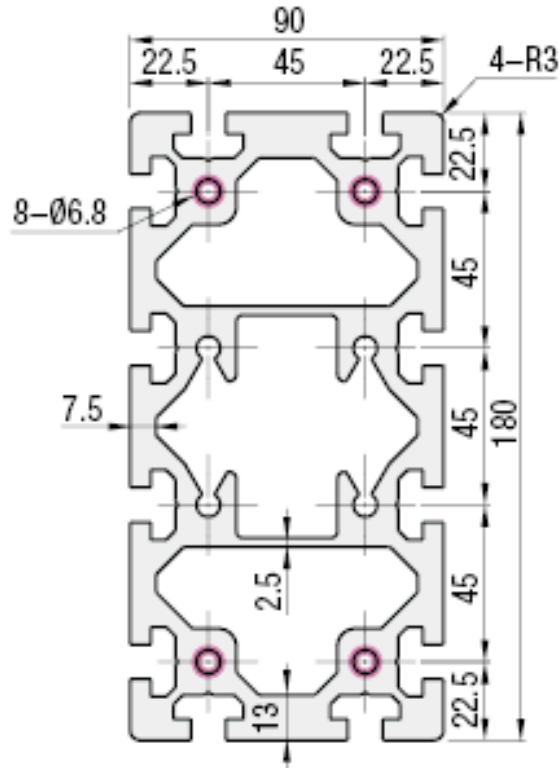


Figure 3: Cross section of extruded aluminum

Medium/Heavy Load Type

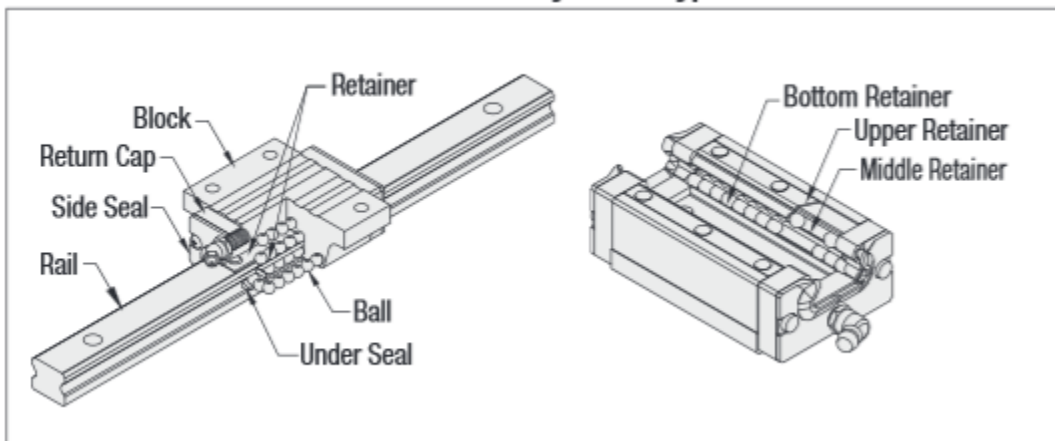


Figure 4: Three-dimensional view of the linear guide and block

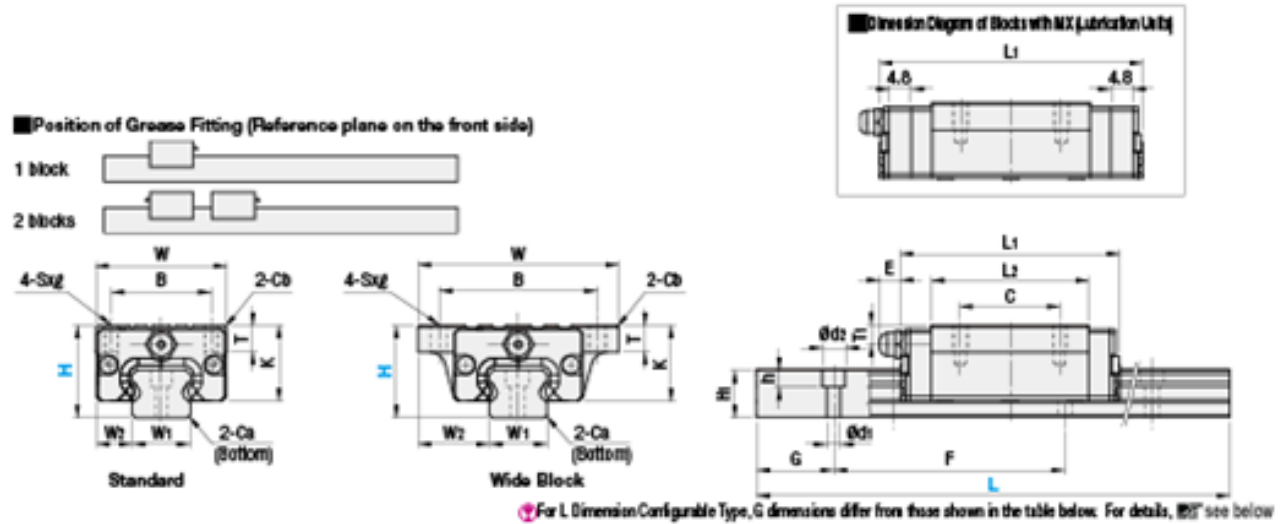


Figure 5: Drawing of the linear guide and linear guide blocks

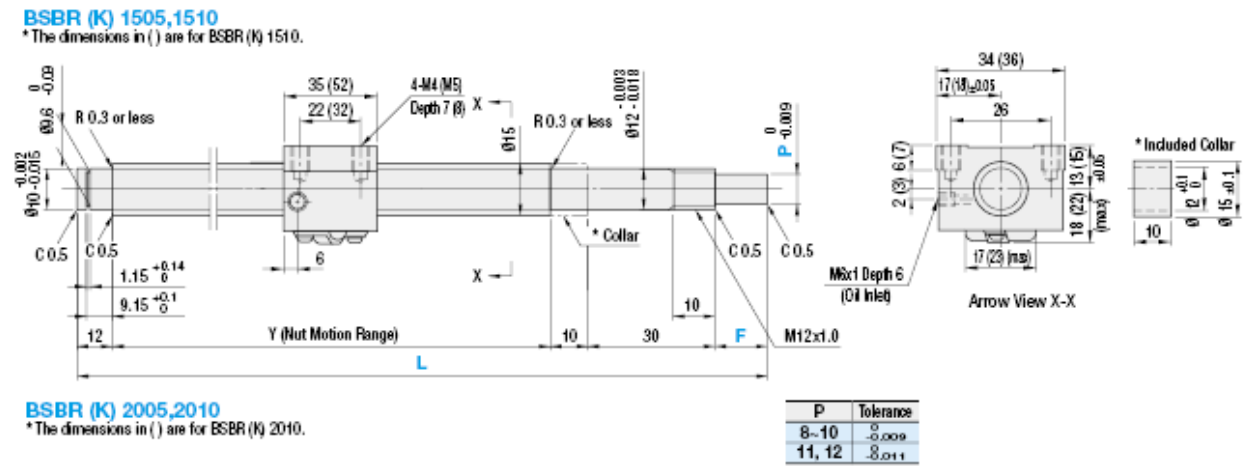


Figure 6: Drawing of the ball screw

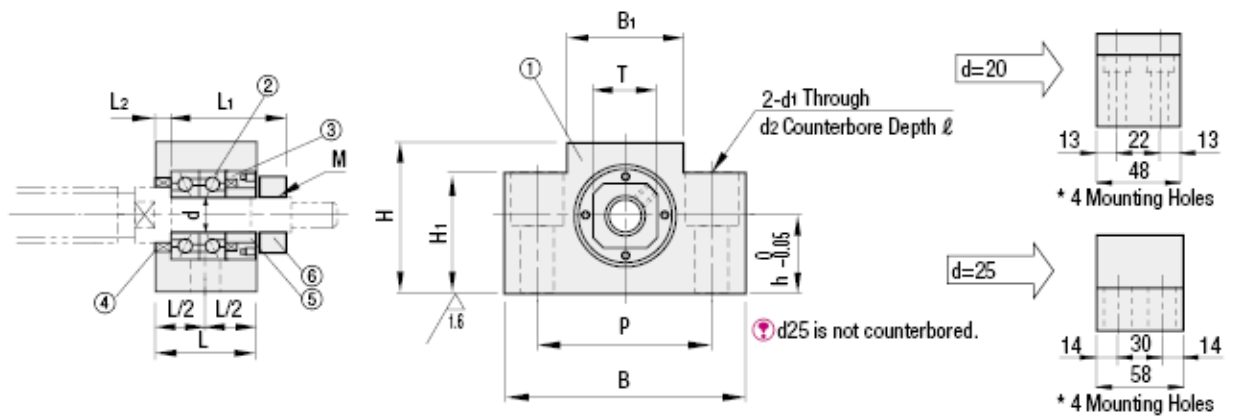


Figure 7: Drawing of the fixed side support unit

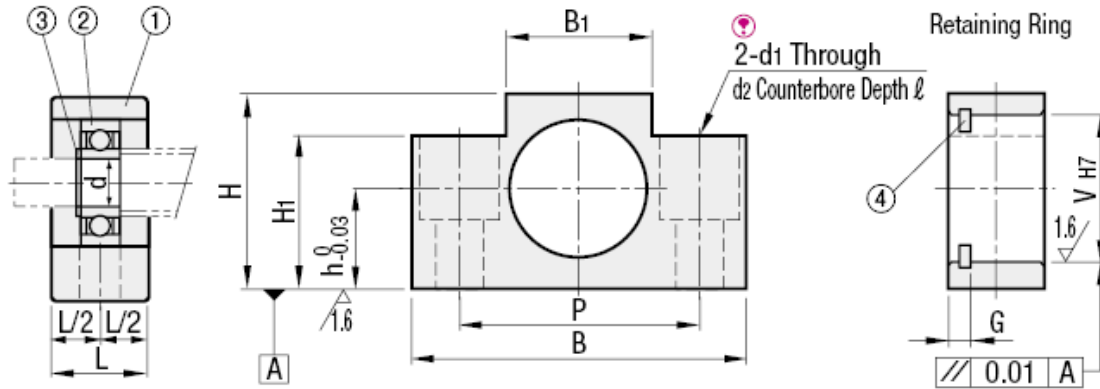


Figure 8: Drawing of the support side support unit

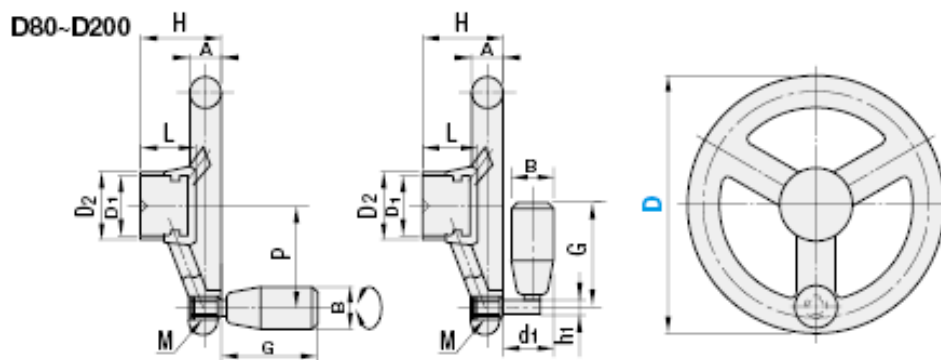


Figure 9: Drawing of the handwheel

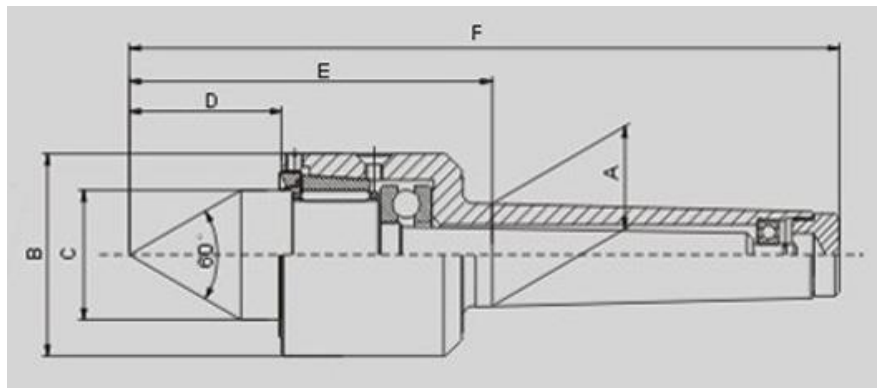


Figure 10: Drawing of the live center

Table 2: Dimensions of live center

Model	A	B	C	D	E	F	Max Load	Max Speed	Accuracy
	inch	inch	inch	inch	inch	inch	lbs	rpm	inch
MT2	0.70	1.42	0.87	1.02	2.70	4.94	800	5,500	0.000197

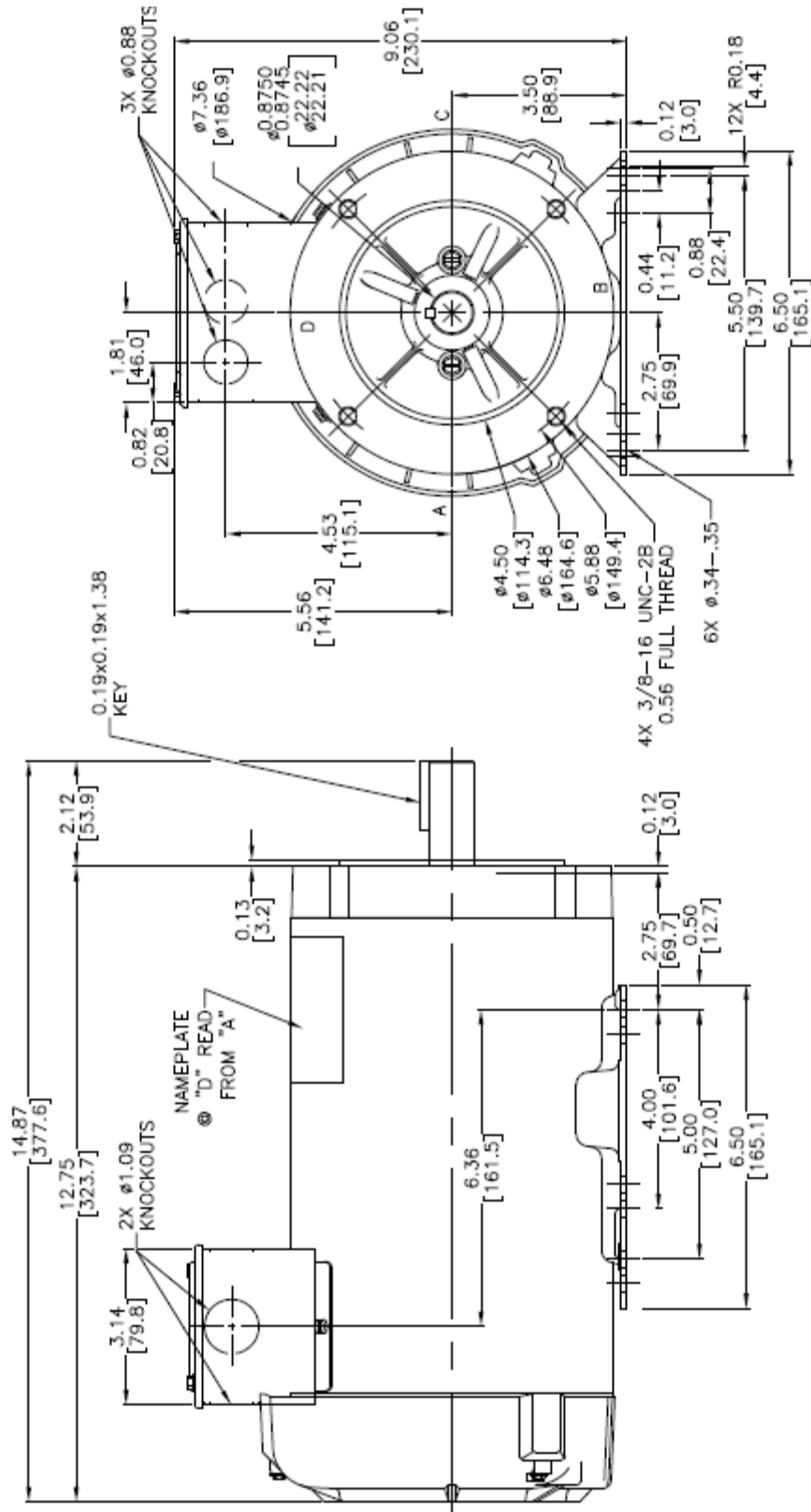


Figure 11: Drawing of AC Motor

Performance Data

Performance Data (460 Volt)															
Part Number	HP	NEMA Design	F.L. RPM	Min RPM	Current (Amps)			Torque (lb-ft)			Max CHP RPM*	Max Safe RPM	F.L. Effic. (%)	F.L. Power Factor	Rotor Inertia (lb-ft ²)
					No Load	Full Load	Locked Rotor	Full Load	Locked Rotor	Break-down					
E2000	1	B	3490	349	0.7	1.4	10	1.5	3.6	5.1	5235	7200	80.0	84	0.04
E2001A		A	1765	177	1.2	1.7	17	3.0	13.7	16.8	1765	4000	85.5	68	0.12
E2002			1170	117	1.3	1.9	10	4.5	13.5	15.8	1755	5400	82.5	60	0.14
E2003	1-1/2		3490	349	1.0	2.0	21	2.3	8.5	11.2	5235	7200	84.0	82	0.06
E2004A			1755	176	1.5	2.3	24	4.5	21.2	26.0	1755	4000	86.5	71	0.14
E2005 †			1175	118	1.3	2.6	17	6.8	13.4	24.4	1762.5	5400	87.5	71.5	0.38
E2006	2		3490	349	1.0	2.4	26	3.0	10.8	13.0	5235	7200	85.5	88	0.08
E2007A			1760	176	1.9	3.0	30.5	6.0	24.5	33.2	1760	4000	86.5	71	0.14
E2008 †			1170	117	1.9	3.2	20.5	9.0	16.8	30.2	1755	4000	88.5	67	0.162
E2009 †	3		3510	351	1.8	3.9	33	4.5	11.0	18.2	5265	7200	86.5	83	0.23
E2010 †		B	1760	176	1.9	3.9	33.5	8.9	22.5	36.0	2640	4000	89.5	80.5	0.38
E2011			1170	117	2.5	4.4	32	13.5	34.0	47.5	1755	4200	89.5	70	0.80
E2012 †	5		3495	350	1.7	6.0	46	7.5	16.0	26.0	5243	5400	88.5	89.5	0.30
E2013 †			1760	176	2.4	6.3	49	15.0	30.1	50.2	2640	4000	89.5	83	0.49
E2014			1170	117	3.7	7.0	46	22.5	47.0	79.0	1755	4200	90.2	75	1.00
E2015	7-1/2		3540	354	3.0	8.9	64	11.1	24.0	38.0	5310	5400	90.2	87	0.55
E2016A			1765	177	4.7	9.7	63.5	22.0	52.0	72.0	1765	4000	91.7	80	0.85
E2018	10		3535	354	3.5	11.8	80	14.9	30.0	46.0	5302.5	5400	91.7	87	0.65
E2019A			1760	176	5.5	12.8	80	29.8	65.0	90.0	1760	4000	91.7	80	1.10

* Maximum Constant HP RPM is for direct coupled loads.

† These specifications are for the Marathon motor currently being sold. Marathon manufactured a previous version of this Part Number (that had a different model #), and that version had some different specifications. For detailed information on the previous motor, please refer to the "Previous Marathon Model Numbers" table below, or click on the previous motor's specification at www.AutomationDirect.com/Retired-Products.

Figure 12: Specification sheet for motor

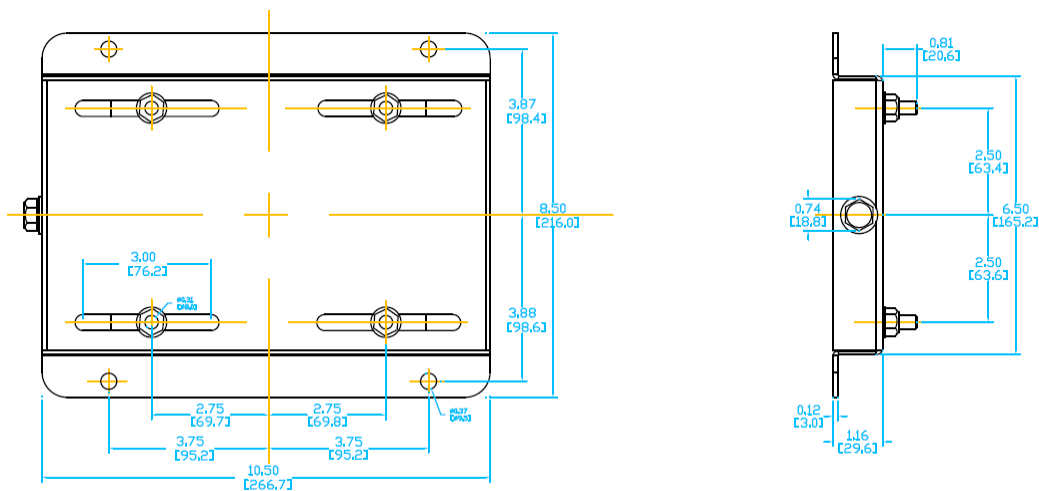


Figure 13: Motor base drawing

230V CLASS GS2 SERIES							
Model		GS2-20P5	GS2-21P0	GS2-22P0	GS2-23P0	GS2-25P0	GS2-27P5
Price		\$158.00	\$177.00	\$251.00	\$309.00	\$363.00	\$465.00
Motor Rating	HP	1/2hp	1hp	2hp	3hp	5hp	7.5hp
	kW	0.4kW	0.75kW	1.5kW	2.2kW	3.7kW	5.5kW
Rated Output Capacity (kVA)		1.0	1.9	2.7	3.8	6.5	9.5
Rated Input Voltage		Single/Three-phase : 200/208/220/230/240 VAC ±10%; 50/60Hz ±5%				Three-phase : 200/208/220/230/240 VAC ±10%; 50/60 Hz ±5%	
Rated Output Voltage		Three-phase : Corresponds to input voltage					
Rated Input Current (A)		6.3/2.9	11.5/6.3	15.7/8.8	27.0/12.5	19.6	28
Rated Output Current (A)		2.5	5.0	7.0	10	17	25
DC Braking		Frequency 60–0 Hz, 0–100% rated current, start time 0.0–5.0 seconds, Stop Time 0.0–25.0 seconds					
Watt Loss @ 100% I (W)		34	57	77	111	185	255
Weight (lb)		3.5	3.6	3.7	8.5	8.5	8.5
Dimensions* (HxWxD) (mm [in])		151.0 x 100.0 x 140.5 [5.94 x 3.94 x 5.53]			220.0 x 125.0 x 189.5 [8.66 x 4.92 x 7.46]		

Figure 14: Specifications over motor drive

Appendix B

This section covers various symptoms that may arise with operation of the test fixture. Possible problems are presented and the solution to remediate these problems are given.

Symptom: Ball Screw will not rotate

Problem:

- Ball screw is binding or not rotating
- Bearing Block is Binding or not rotating
- Ball Screw Blocks are binding or not rotating

Solution:

- Look for deviance in straightness of ball screw
- Look for binding with linear guides
- Replace Ball Screw Block
- Replace Ball screw
- Replace bearing block
- Replace linear guides

Symptom: Live Center will not rotate

Problem:

- Live center internal bearings are binding
- Live center has seized
- Live center is being restricted by foreign object

Solution

- Inspect live center for smooth operation, replace if nose cone does not spin freely
- Remove foreign object obstructing live center

Symptom: Live Center does not remain locked in place

Problem:

- Linear Guide brake not applied
- Linear guide brake not working
- Linear guide brake not fully latched

Solution:

- Apply live center brake
- Replace linear guide brake
- Check for fitment of linear guide brake

Symptom: Motor will not operate

Problem:

- VFD not powered on
- VFD not receiving power
- VFD not wired correctly
- VFD wiring loose or exposed
- Motor not receiving power
- Motor is shorted out
- Motor is binding or will not rotate but has power
- Motor wiring loose or exposed, causing short circuit

Solution:

- Check voltage at VFD for correct voltage
- Check Voltage at Motor for correct voltage
- Check that VFD is powered on, and motor speed is turned up
- Check for loose or exposed wires, leading to short circuit
- Spin motor shank by hand, checking for binding or noise, if shank binds replace motor
- Internal bearing failure, replace motor

Symptom: Stator housing fails to move

Problem:

- Linear guides binding or will not slide
- Ball screw binding or will not rotate
- Hand crank not being rotated
- Foreign object in path of linear guides
- Internal bearing failure with ball screw or linear guide

Solution:

- Check for foreign objects in path of stator housing
- Check for binding in linear guides
- Check for binding in ball screw
- Listen for bearing failure with ball screw or linear guides
- Rotate hand crank

Symptom: Oscilloscope readings are uncharacteristic

Problem:

- Rotor is not correctly aligned within stator
- Rotor is bad

Solution:

- Recheck alignment
- Retest rotor
- If results are still off, rotor may fail quality check