Team 24: Magnetically Coupled Pump System for Cryogenic Propellant Tank Destratification

FAMU/FSU College of Engineering
Department of Mechanical Engineering

Design for Manufacturing, Reliability, and Economics Report

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Submitted to:
Dr. Nikhil Gupta

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Team Member Biography's

Matthew Boebinger (Team Leader): Matthew is a senior mechanical engineering student that is specializing in mechanics and materials engineering at Florida State University. After graduating in Spring 2015 with his Bachelors of Science in Mechanical Engineering, he plans on pursuing a Master's degree and then a Doctoral degree in materials engineering.

Kahasim Brown: Kahasim is a senior mechanical engineering student specializing in thermal fluid and aerospace sciences with a minor in Business Administration. After graduating he plans on receiving his professional engineering degree while sharpening his mechanical tools development and starting a business hosted in his hometown.

Anthony Ciciarelli: Anthony is a senior mechanical engineering student with a focus in thermal fluids at Florida State University. He will graduate in the spring 2015 with a Bachelor of Science in Mechanical Engineering. After graduation he plans on pursuing a full time job in the industry, obtaining his MBA, and obtaining a professional engineering license.

Janet Massengale: Janet is a senior mechanical engineering student specializing in thermal fluid sciences at Florida State University. This is her second year as the treasurer of ASME. She is also the webmaster for both the SWE and AIAA. Upon graduation she plans to work in the pulp and paper industry and obtain a professional engineering license.

Acknowledgement

The team would like to acknowledge faculty advisor Dr. Wei Guo, as well as our engineering liaisons Jim Martin and James Smith for their knowledge and assistance in making the project successful. Additional acknowledgements to Dr. Gupta and Dr. Shih for their constructive feedback on the teams project throughout the semester.

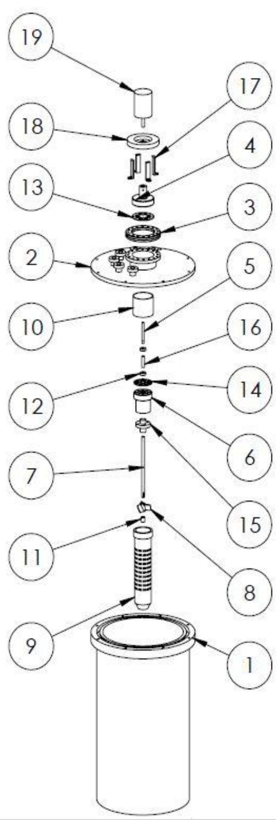
Abstract

National Aeronautical and Space Administration has proposed a project to mix cryogenic fluids by way of magnetic coupling from the motor to the impeller. This was done using the following prototype. In this report the completed prototype of our magnetically coupler cryogenic pump is discussed. The prototype is looked at with respect to the manufacturing stage, how the prototype will reliably preform, and the cost of the prototype itself. In the design for manufacture section the construction of the prototype is discussed in length as the design is examined in exploded sub-assemblies. The design for reliability section discusses the performance of the prototype after different degrees of use. Also discussed in this section are the possible sources for reliability concern or failure of the system. In the design for economics section the cost of the prototype system is compared with current models already in the market. In this economics section the system's component costs are discussed as compared to a total design cost.

1. Design for Manufacturing

In the following section, the assembly and manufacturing of the system is discussed. The total installation time was around 1.5 hours. Much of the assembly time was taken up by the welding process needed for connecting the static shaft and the pump housing anchor to the flange and the pump shaft to the inner coupler pump attachment, as well as the time needed for the epoxy to set on the motor mount legs. This welding assembly can be seen in Figure 3. However the total assembly time after the welding can be done in less than 4 hours. As far as the complexity of our design, our design was kept as simple as possible as per our sponsor's request, but it could be simplified slightly. This can be achieved by making the impeller solidly attached to the pump shaft, but this changes little overall.

The entire prototype can be seen in the Figure 1 below with the components labeled. This design however has many components and can be broken down into several more comprehensive sub-assemblies. These sub-assemblies are the outer coupler motor sub-assembly (Fig 2), the inner coupler sub-assembly (Fig 4), the pump housing sub-assembly (Fig 5), and the previously mentioned welding sub-assembly (Fig 3).



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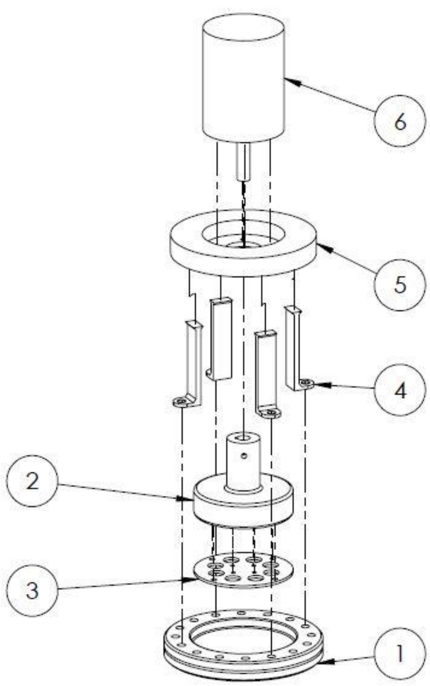
1	CF-1424 Cryostat	1
2	Cryostat Lid	1
3	6inch ConFlat Flange - Milled	1
4	Outer Magnet Coupler	1
5	Static Shaft	1
6	Inner Magnet Coupler	1
7	Axial Pump Shaft	1
8	Sample Propeller	1
9	Pump Housing	1
10	Housing Anchors	1
11	Shaft Cap	1
12	Bearings	2
13	Outer Magnet Coupler Faceplate	1
14	Inner Magnet Coupler Faceplate	1
15	Inner Magnet Coupler Pump Attachment	1
16	Bushing	1
17	Motor Mount Leg	4
18	Motor Mount	1
19	Sample Motor	1

Figure 1: Prototype System Assembly

The first sub-assembly, the outer coupler and motor sub-assembly, consists of the motor, motor mount, the four motor mount legs, the outer coupler, outer coupler faceplate, and the flange. It can be seen in Figure 2. The first step of the assembly consists of inserting the four magnets into the outer magnet coupler. This must be done with the poles alternating to ensure maximum coupling between the two couplers. The method for the easiest insertion of the magnets is as follows.

1. Attach the outer coupler faceplate with one of the outer screws.
2. Insert one magnet into its appropriate hole.
3. Rotate the faceplate so that it holds the inserted magnet in place.
4. Insert the next magnet with the opposite poles facing outwards.
5. Rotate the faceplate so that it now holds both magnets in place.
6. Repeat steps 4 and 5 until all the magnets are in place and the faceplate lines up with its screw holes.
7. Screw the faceplate in securely.

Now that the outer magnet coupler is fully assembled the next step is to make epoxy the motor mount legs to the motor mount. This was done using a guide part indicating where the legs needed to be located and the flange itself. After attaching the legs to the flange they are the put into the indicator spots on the motor mount plate with epoxy. The motor mount system then needed to set for 24 hours.



ITEM NO.	PART NUMBER	QTY.
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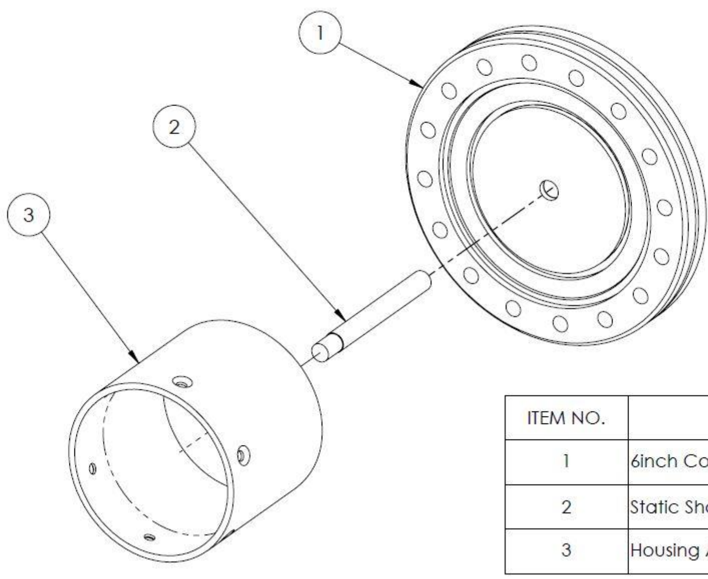
2	Outer Magnet Coupler	1
3	Outer Magnet Coupler Faceplate	1
4	Motor Mount Leg	4
5	Motor Mount	1
6	Sample Motor	1

Figure 2: Outer Coupler and Motor Sub-Assembly

With the coupler and motor mount fully assembled the two components can then be attached to the motor. Using the provided screws the motor can be attached to the motor mount. The outer coupler is then put over the motor shaft with the key in place. The coupler is the offset about 3/16 inches from the motor to ensure that the outer coupler does not scrape against the flange, and set in place using the two set screws. Finally the motor mount is then attached to the flange. With this the outer coupler motor mount sub-assembly is complete.

The next sub-assembly to be constructed would be the welding sub-assembly (Fig 3). The welding was done in the machine shop by the machinist working there. The parts that needed welding were the static shaft and the pump housing anchor. They were welded into the appropriate grooves cut into the milled down flange. With the shaft and pump housing anchor welded in place the other two internal sub-assemblies can be placed over the static shaft. In addition to the required flange welding, the pump shaft had to be welded to the inner coupler pump attachment to ensure that the shaft remains perfectly straight.

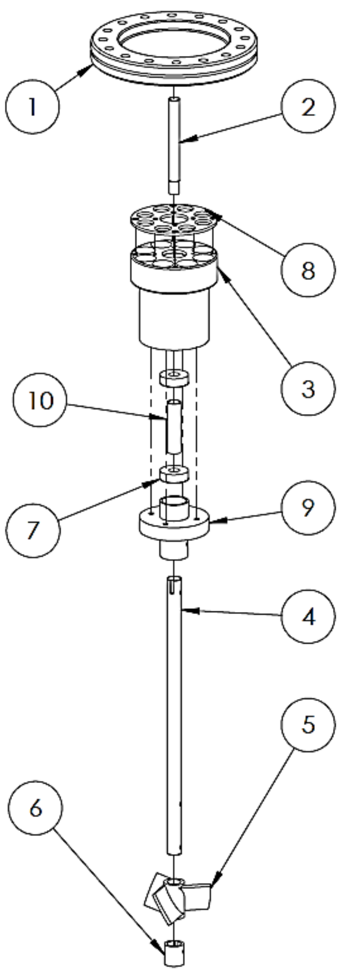


ITEM NO.	PART NUMBER	QTY.
1	6inch ConFlat Flange - Milled	1
2	Static Shaft	1
3	Housing Anchors	1

Figure 3: Welding Sub-Assembly with the pump housing anchor and static shaft

The next sub-assembly to be made would be the inner coupler sub-assembly (Fig 4). This assembly is composed of the flange, static shaft, inner coupler, inner coupler faceplate, bearings, bushings, inner coupler pump attachment, pump shaft, and the impeller. The first step of the assembly consists of inserting the four magnets into the inner magnet coupler. This must be done with the poles alternating to ensure maximum coupling between the two couplers. The method for the easiest insertion of the magnets is the same as it was stated earlier.

The rest of the inner magnet coupler assembly is the most complex of the assembly of the prototype. Once the inner coupler is fully assembled with the magnets, the coupler is placed over the static shaft. The first bearing is then press fitted all the way down until it makes contact with the lip of the inner coupler. Place the spacing bushing over the shaft. Then place the other bearing onto the static shaft. Screw the locking nut onto the static shaft along with a washer to hold the bearings in place. Finally install the inner coupler pump attachment with the pump shaft welded onto it using the provided four screws. The cylinder extending from this part will brace against the second bearing and through installation will guarantee spacing between the inner coupler and the flange. Finally the impeller provided by to us by NASA, shown in Figure 4, is attached over the pump shaft using two more 3/16" pins and the shaft cap. This completes the inner coupler sub-assembly as seen in Figure 4.



ITEM NO.	PART NUMBER	QTY.
1	6inch ConFlat Flange - Milled	1
2	Static Shaft	1
3	Inner Magnet Coupler	1
4	Axial Pump Shaft	1
5	Sample Propeller	1
6	Shaft Cap	1
7	Bearings	2
8	Inner Magnet Coupler Faceplate	1
9	Inner Magnet Coupler Pump Attachment	1
10	Bushing	1

Figure 4: Inner Coupler Sub-Assembly and the impeller that was provided by NASA

The final sub-assembly to be made would be the pump housing sub-assembly (Fig 5). This sub-assembly only consists of the flange, pump housing anchor and pump housing. Once the pump housing anchor is welded onto the flange, the inner coupler sub-assembly is placed onto the static shaft as described above. Then insert the pump housing over the inner coupler sub-assembly and attach it to the pump housing anchor using the six provided countersink screws.

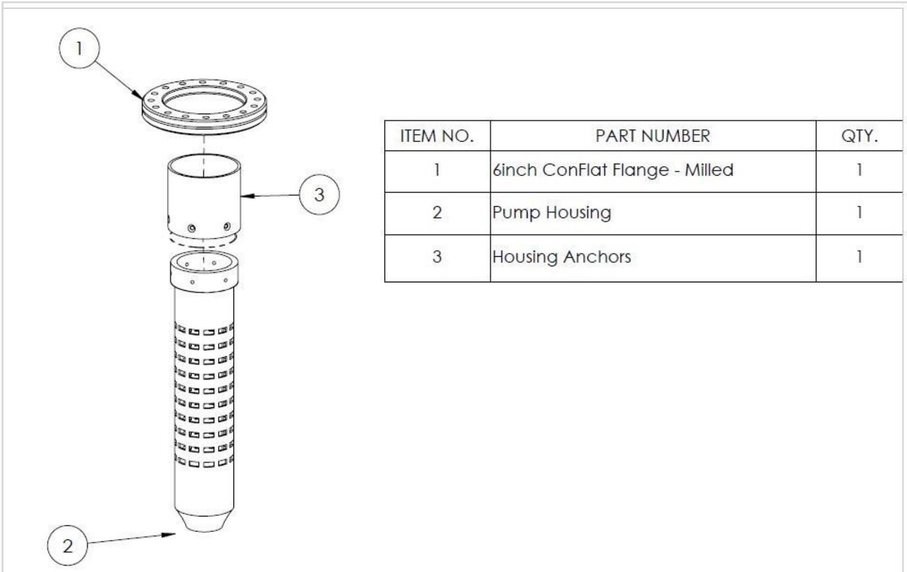
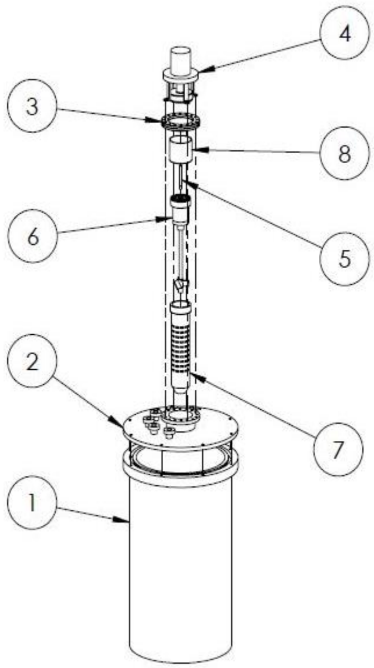


Figure 5: Pump Housing Sub-Assembly

This final assembly shows how each sub-assembly fits together to fully assembly the prototype and can be seen in Figure 6. With the Outer Coupler Motor Sub-Assembly, Inner Coupler Sub-Assembly, and the Pump Housing Sub-Assembly all attached to the flange through the welded static shaft, pump housing anchor and the motor mount the prototype pump mixer system is complete. For testing the prototype system must then be installed into the NASA provided testing cryostat. This final step consists of attaching the flange to the cryostat top using the 16 proved bolts. The cryostat top is then firmly attached to the provided cryostat. With this complete the prototype has been fully assembled into the testing cryostat.



ITEM NO.	PART NUMBER
1	CF-1424 Cryostat
2	Cryostat Lid
3	6inch ConFlat Flange - Milled
4	Outer Coupler Motor Sub-Assembly
5	Static Shaft
6	Inner Magnet Coupler Sub-Assembly
7	Pump Housing
8	Housing Anchors

Figure 6: Complete System Assembly for Manufacturing

2. Design for Reliability

Sustainability

Although this project was proposed to show proof of concept of magnetic coupling technology, great care was taken when considering the life span of the design. Due to the nature of this project we were very judicious when selecting materials and components of the design. Many of the components were designed to outlast the electrical components such as the motor and motor controller that were purchased. Additionally the materials used to make each component of the design were selected to ensure they were non-magnetic and their strength would not be compromised when submerged in the cryogenic fluids. The main components that were considered for reliability include: bearings, magnets, and materials.

Bearing

The bearings used for this design were carefully selected to consider the life span as well as the nature of the project. Calculations were performed in order to select a suitable bearing that would withstand the forces applied to each bearing. These calculations considered a life span of 8000hrs with a factor of safety of four. A sample calculation for the bearings can be viewed in the Appendix B-1. Great consideration was also used when selecting the material the bearings were made of. This is due to the fact that the bearings were significantly close to the magnets. Additionally the bearings would be subjected to extremely cold conditions (77K). Due to these concerns stainless steel was used because it is non-magnetic and does not display the phenomenon of ductile to brittle transition when introduced to extreme colds. In addition to these concerns, the bearings were cleaned of all lubricants to ensure that when exposed to cryogenic temperature, the prototype will run. Since the bearings used in the design were selected so carefully it is not unreasonable for the bearing to last in excess of 16000hrs.

Magnets

Due to the fact that the coupling magnets are the essence of our project special attention was taken when selecting them. The magnets the team selected are made of the rare earth metal neodymium. This type of magnet was selected due to its exceptional magnetic strength. Additionally neodymium magnets are known to lose less than 1% of their magnetic strength over a time span of 10 years. Another reason why these magnets were selected is because they do not lose strength when subject to extreme colds, as is the case in this application. For the reasons stated above the team believes that the magnets will be one of the longest lasting components of the design.

Materials

The materials used in the design were another component that needed to be selected with great thoughtfulness. This is because of the magnetic forces as well as the extreme colds the materials are exposed to. In order for the materials to have a respectable life span in the extreme colds a metal that did not display the phenomenon of ductile to brittle transition was needed. For this reason aluminum was the first material of choice. Unfortunately due to the eddy currents introduced by the magnetic forces aluminum could not be used in areas that moved relative to the magnets. This lead us to choose stainless steel as the material used in these situations. Both of the metals used will outlast any other component in the design due to their high strength and the minimal stresses felt in this application.

Failure

Although many of the components were designed to last a great deal longer then what is needed for this project some failure can still occur. Failure Mode Effects Analysis (F.M.E.A) was performed for all the major components of the design to account for these possible mishaps. The F.M.E.A for this design can be viewed in Appendix C-1. After performing the F.M.E.A three main concerns of failure were found Bearing wear, tolerancing of the pump, and the cryogenic behavior of the project. These possible mishaps were corrected for and the appropriate action was taken to avoid these issues.

3. Design for Economics

When selecting components for the design of this project the economics were of utmost importance. A $600 budget was proposed for this project in order to ensure the design was competitive in the market. Many of the materials procured for this design were extensively researched in order to find the best market price while still producing a reliable product. Figure 7 shows a breakdown of all the materials and components purchased for the design. Evident in this picture the design stayed well within the given budget. However some materials were donated in order to assist in the project's success such as a 6" flange, an inducer, bearings, raw materials, and a cryostat used for testing the design. Additionally all of the machining of the design was done at the FAMU-FSU College of Engineering free of charge. Even though some materials were donated and all the machining was done for free it is not unreasonable for the design to stay well within the budget if it was mass-produced. This is because many parts can be bought in bulk at a severely reduced price and machining can be done at large manufacturing plant for pennies on the dollar. Moreover the amount of magnets needed to produce the required amount of torque was unknown. After testing the couplers for the optimal amount of magnets it was found that only half of the magnets were needed for the prototype. This discovery would reduce the price of the magnets and further reduce the overall price of the design.

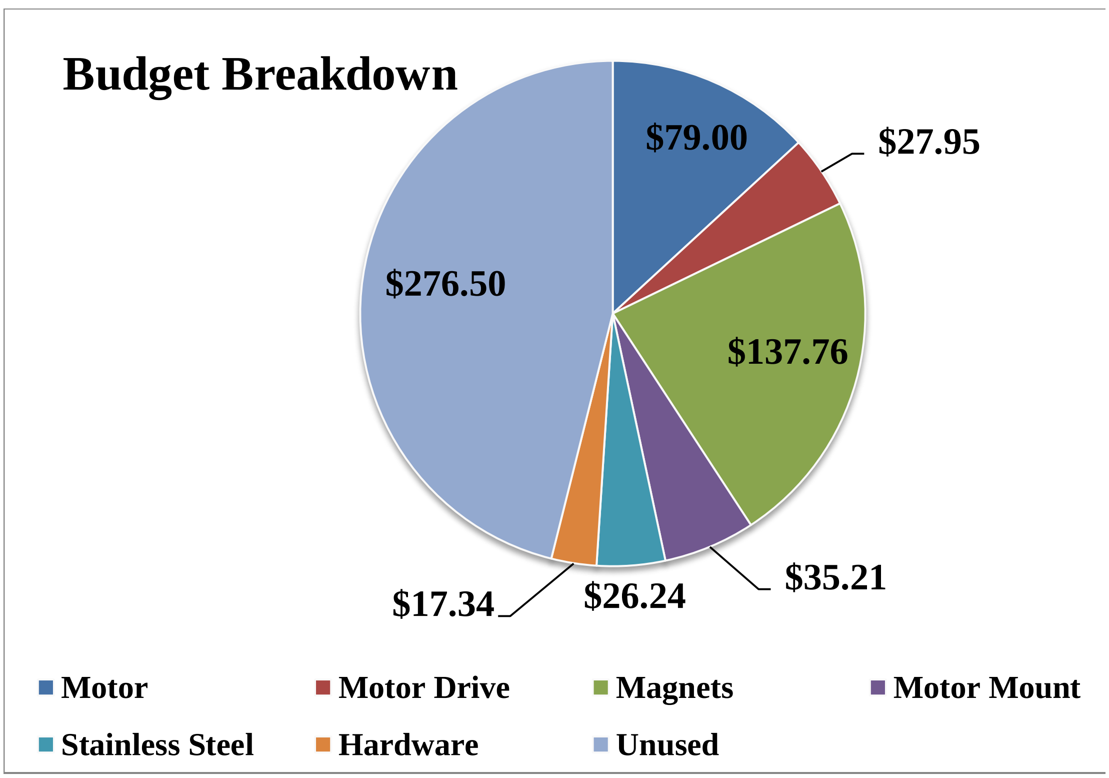


Figure 7: Breakdown of the materials used for the prototype

Market Comparison

The prototype the team designed is extremely competitive compared to the products in the market. Looking at Figure 8 it is evident the overall cost of the prototype is significantly lower than the products currently on the market. Granted many of these products account for a generous profit margin, if manufactured the proposed design would definitely leave room for a respectable profit. Also some of these designs do not include a motor, which would significantly increase the price of the product. The prototype designed by the team comes fully functional with a motor and motor driver for a fraction of the price. Additionally many of these products are not designed to withstand the extreme colds, as our application requires thus requiring some adjustments. Furthermore many of these designs do not have a 1:1 coupling ratio instead they rely on the eddy currents to rotate a ferromagnetic plate. This reduces the efficiency of the pump requiring more power for the same amount of volumetric flow rate. Although it is difficult to predict the profitability of the team's design due to the donated components, free labor, and lack of mass production it is not out of the question to believe that this design can be a successful product.

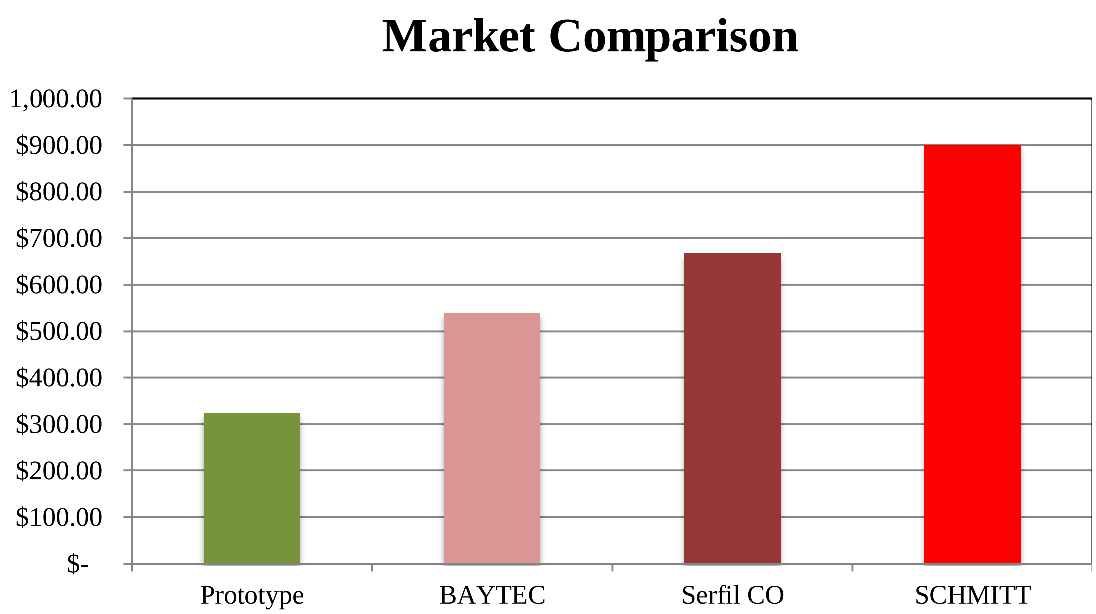


Figure 8: The senior design group's prototype compared to products on the market.

4. Conclusion

In summary, the process in which the prototype is manufactured has been determined and discussed in detail using sub-assemblies. The total time it takes to assemble the prototype is about one and a half hours of assembling after about three hours of welding and letting the epoxy on the motor mount set for a day. Assembly is then done in three different steps. First the outer magnet coupler sub-assembly, then the next sub-assembly consists of the inner magnet coupler and the bearing system, the final sub-assembly consists of the pump housing. The reliability of the design is then discussed detailing the lifetime of the system before failure, being 8,000 hours conservatively, as well as discussing the major reliability concerns with the prototype using failure modes and effects analysis. Finally the economics of the prototype are discussed. The total cost for the prototype ended up being $325. The percentage of each individual component cost with respect to the total system cost is shown in the pie charts above. The prototype is then compared to existing products on the market and was determined to be much cheaper than other available systems available and one of the only that uses direct magnet coupling and can function in cryogenic applications.

5. References

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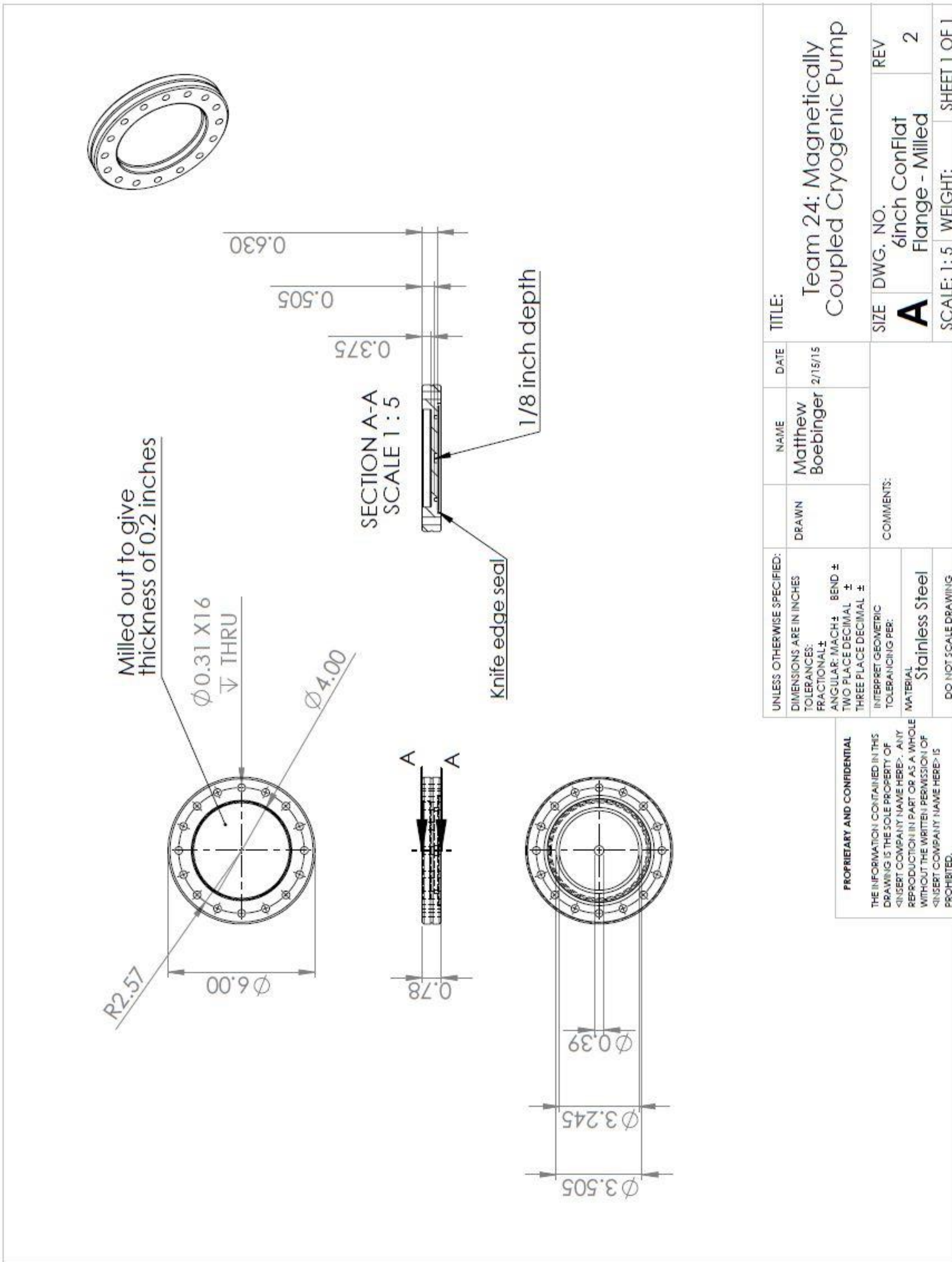
Appendix A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2/15/15
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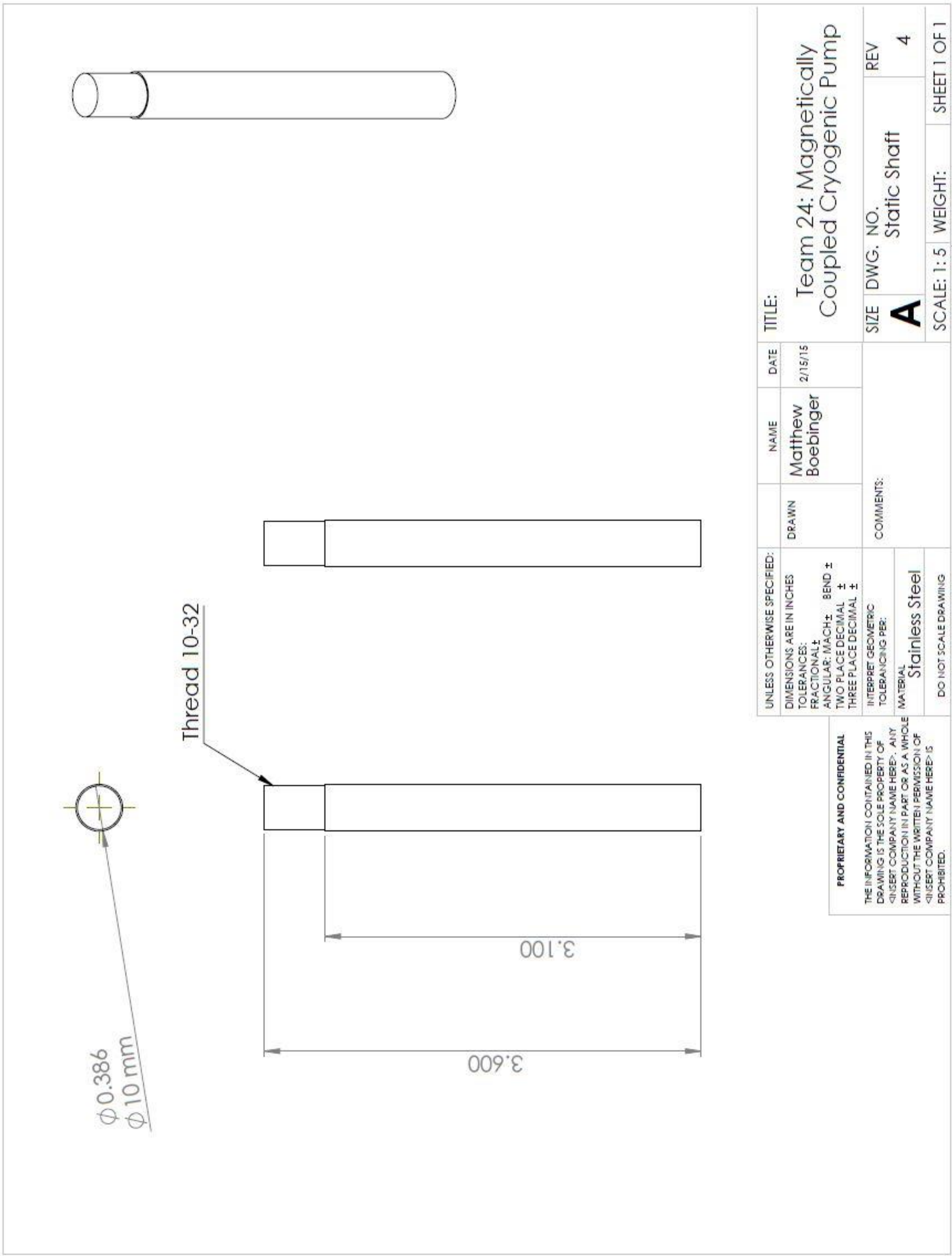
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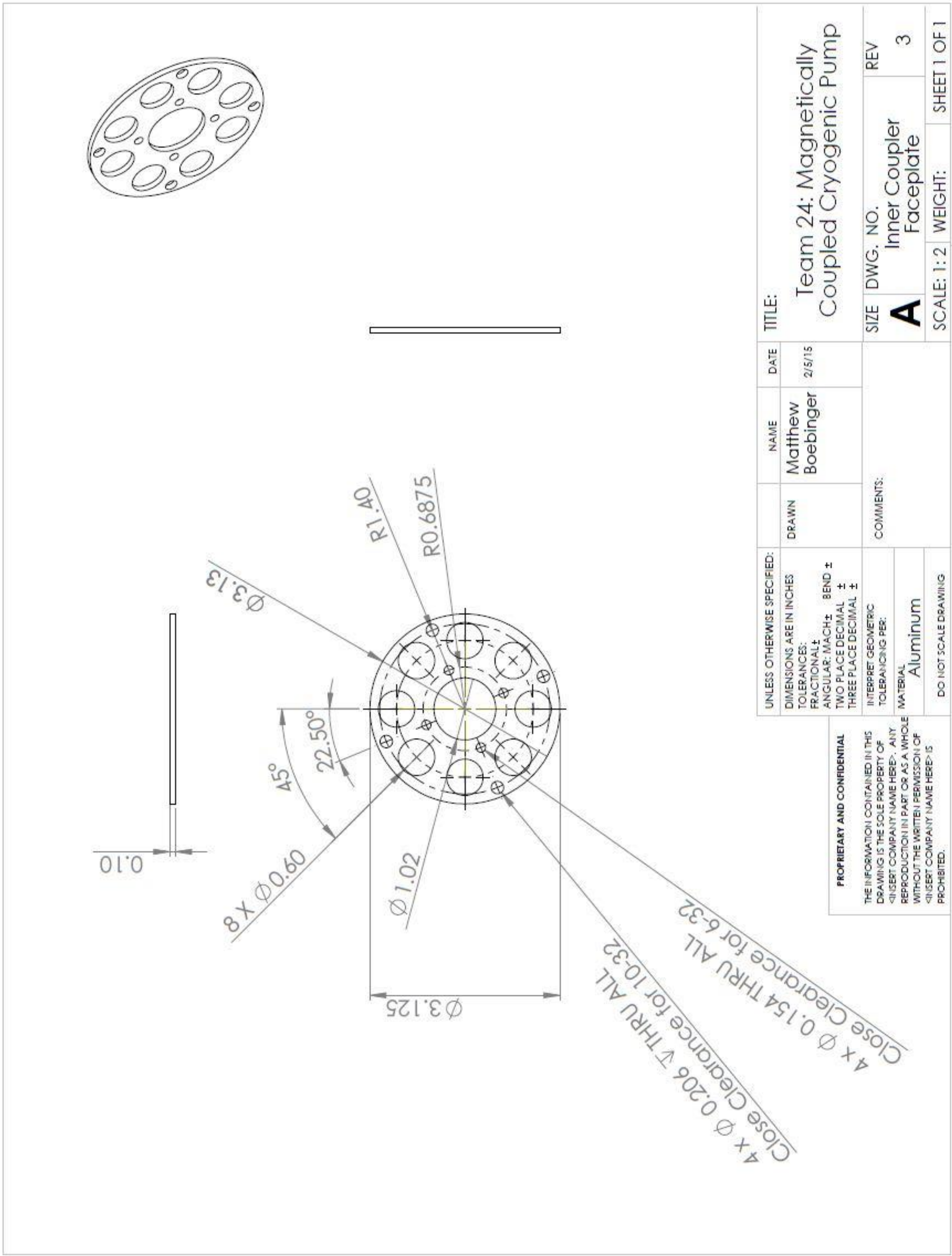

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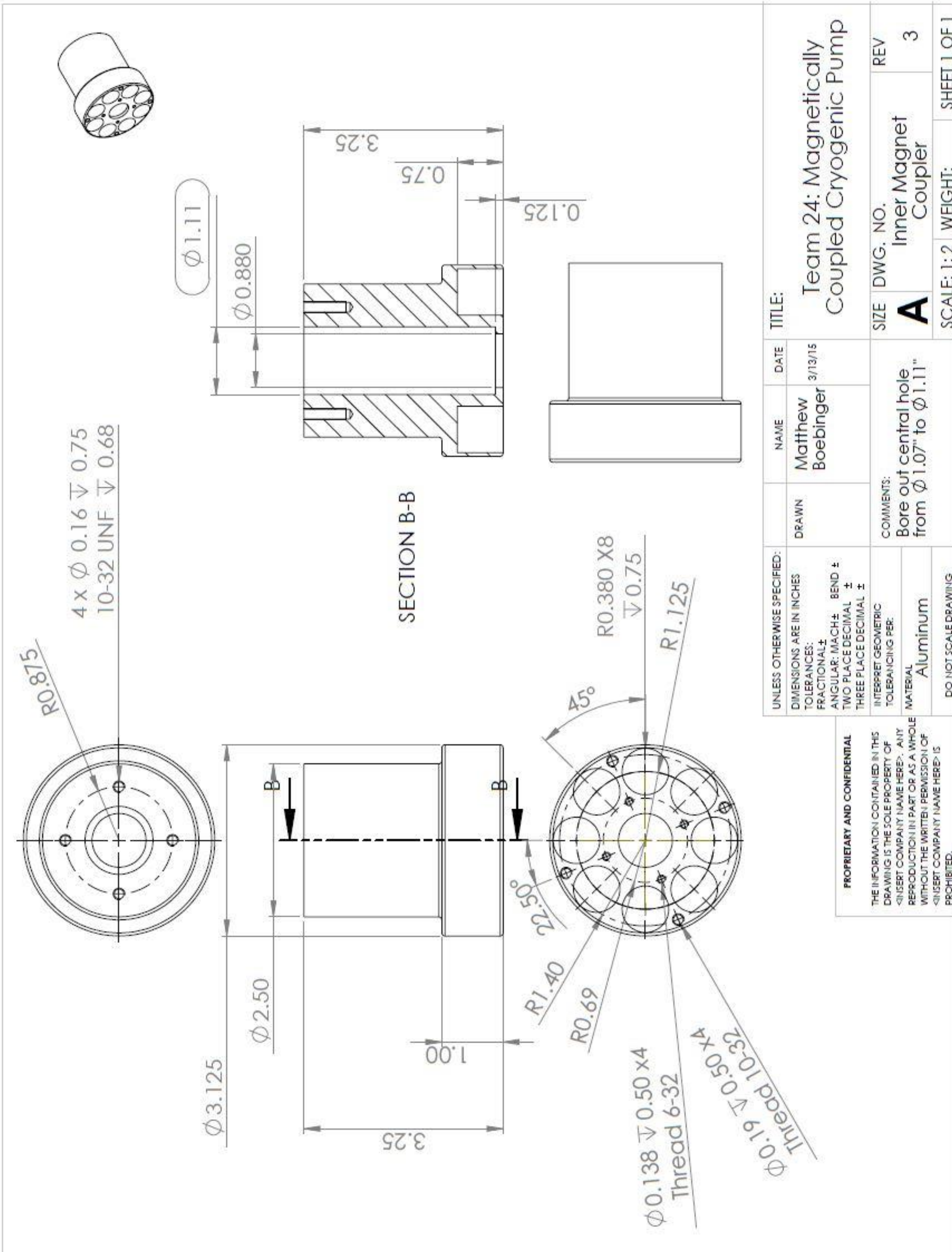
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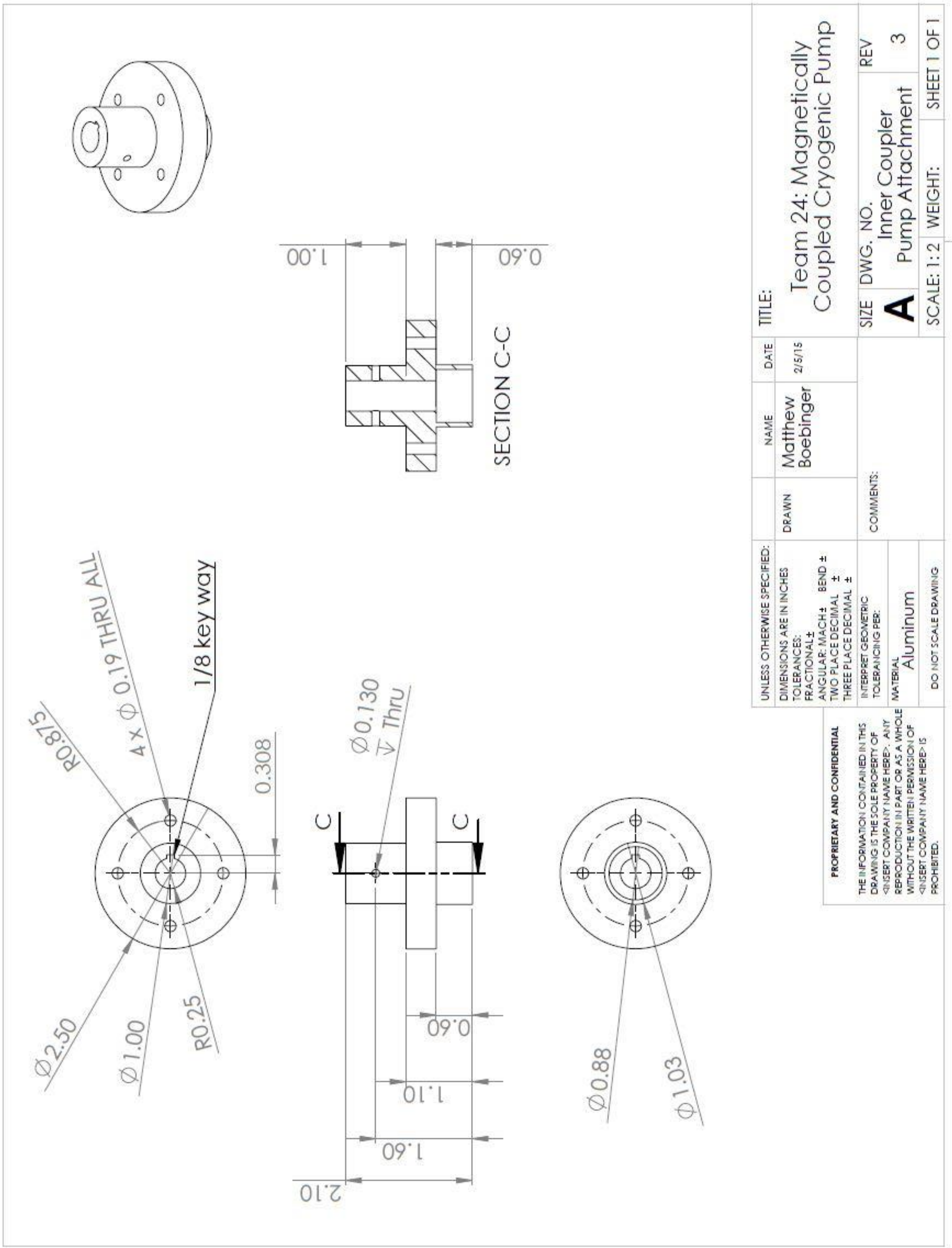
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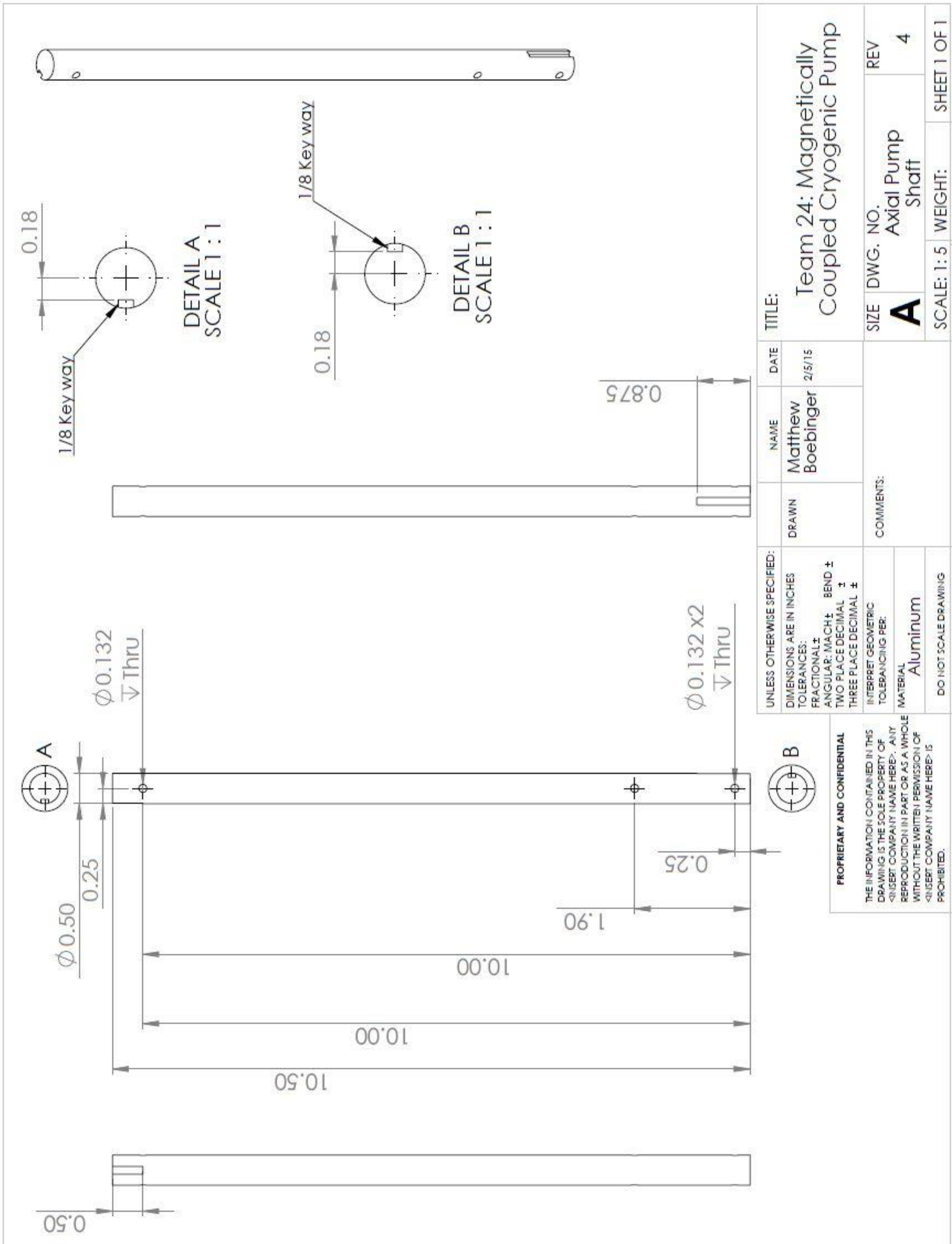

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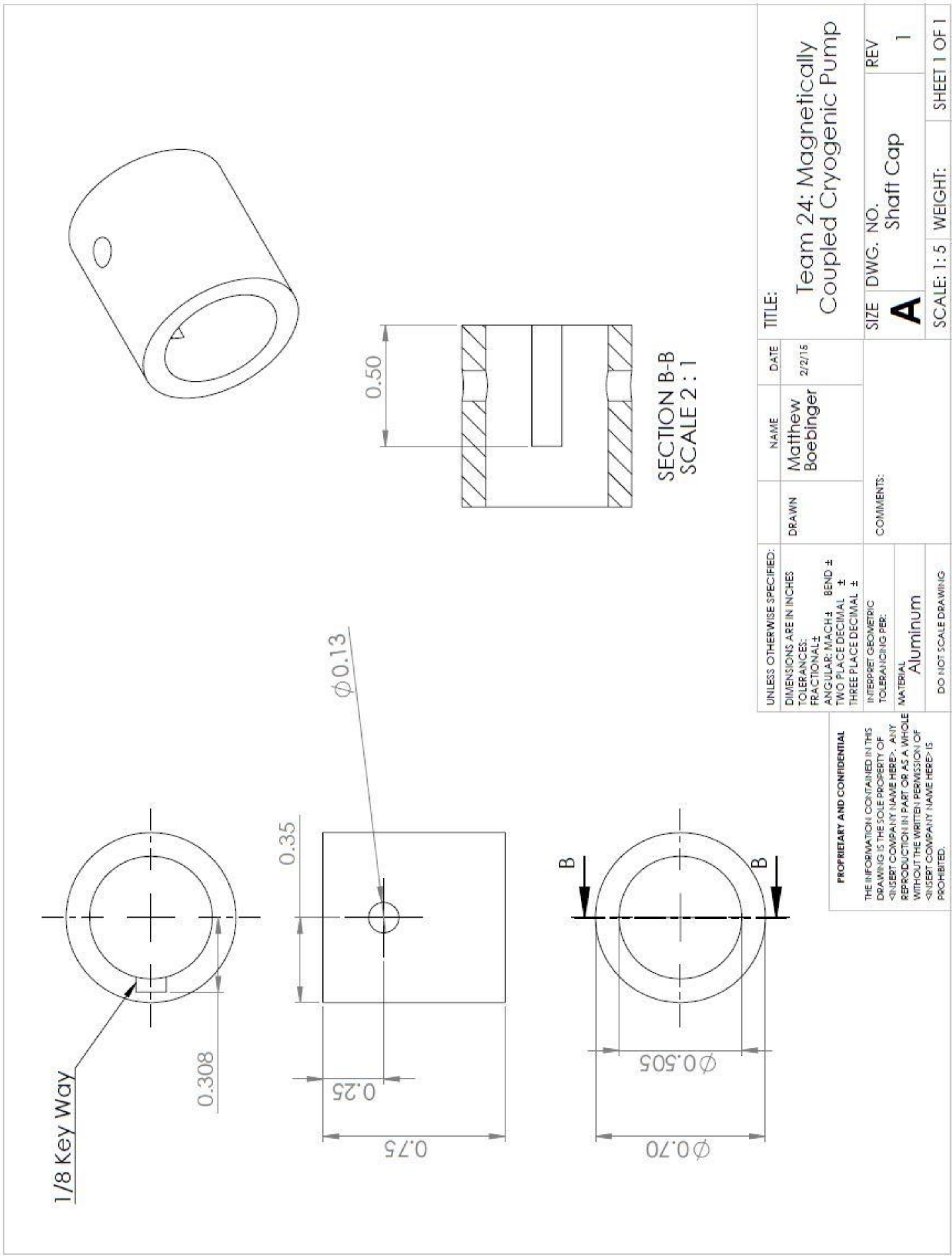

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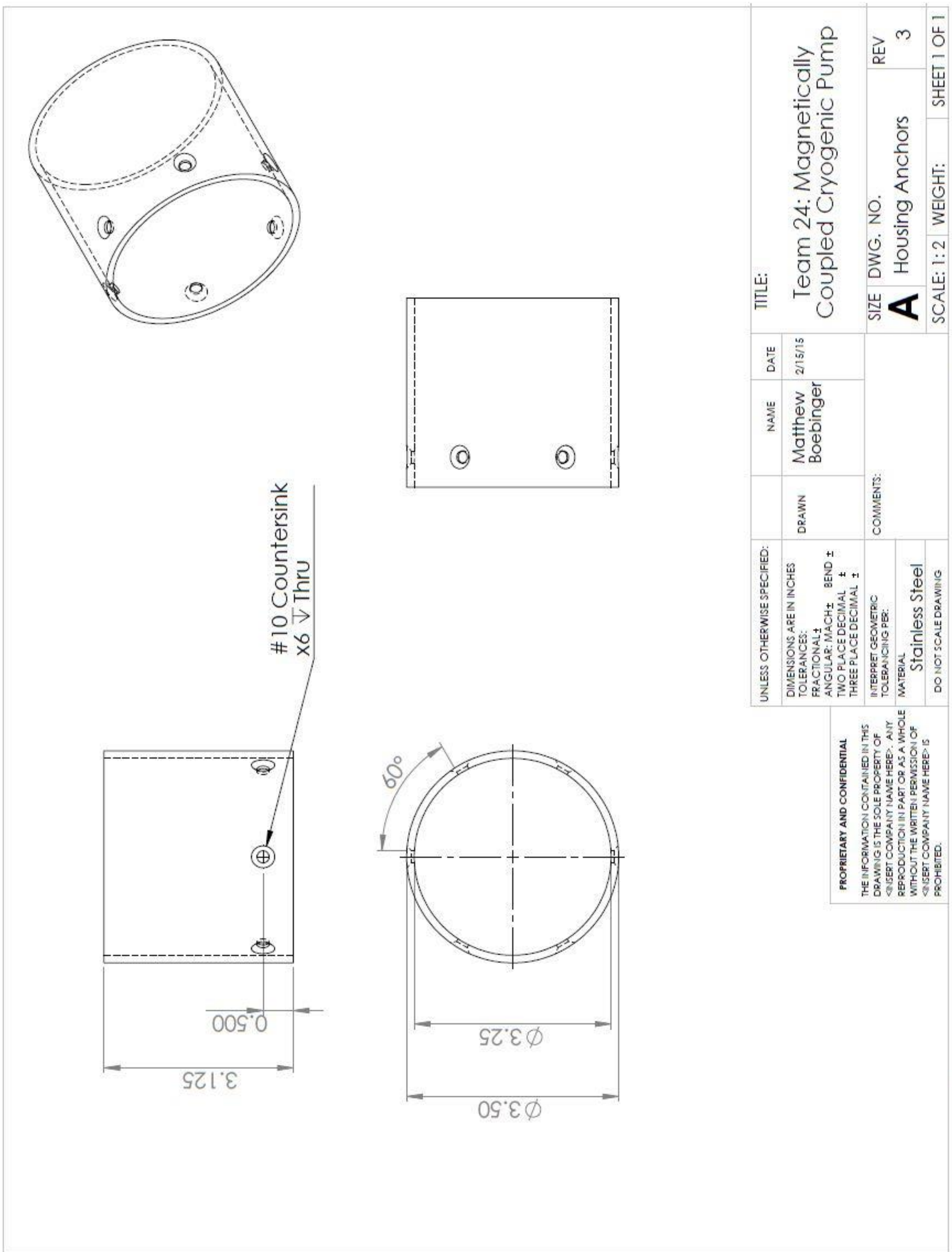
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
COMMENTS:
MATERIAL
Aluminum
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
Shaft Cap
REV
1
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1


#10 Countersink
x6 Thru
60°
0.500
3.125
Ø3.25
Ø3.50
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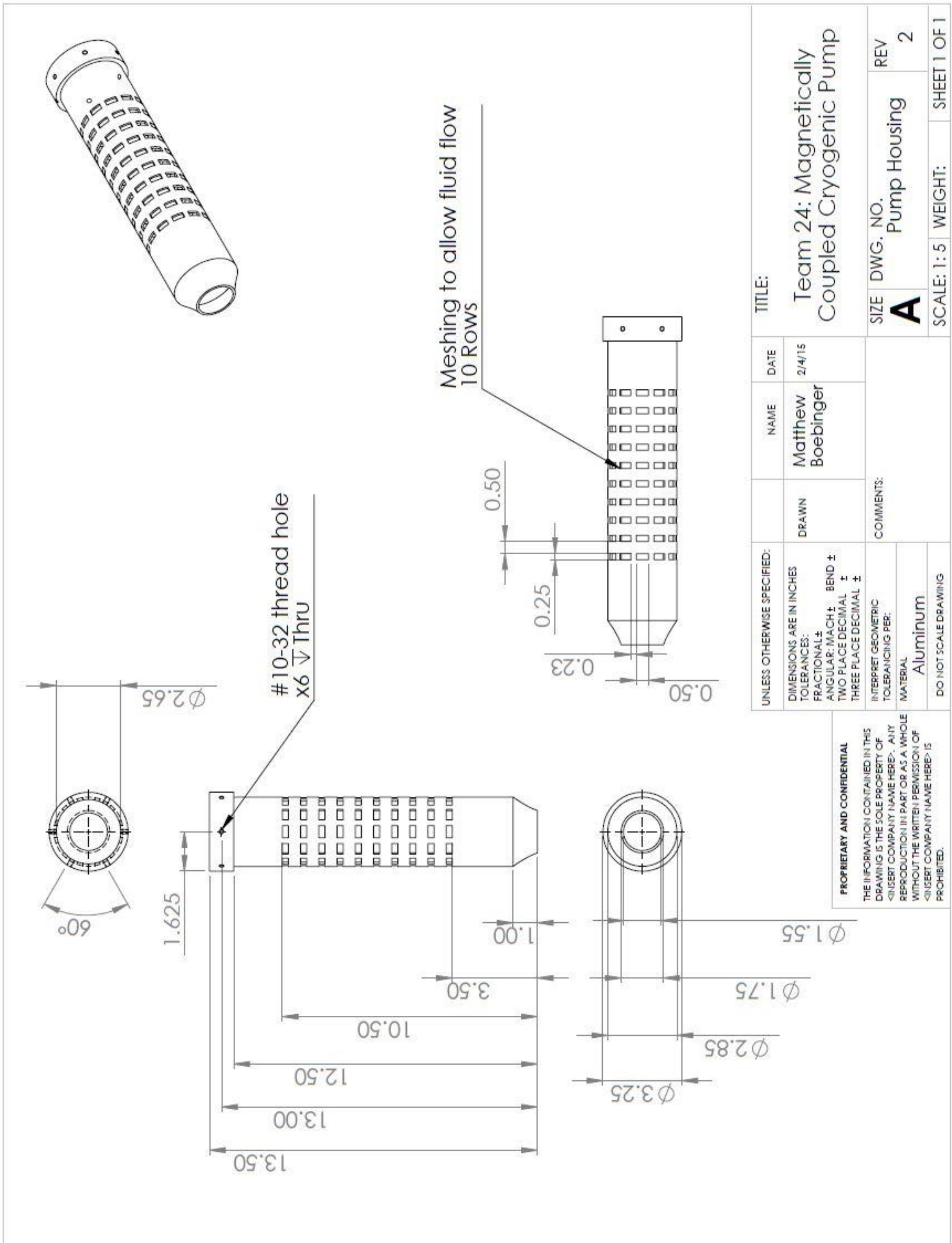
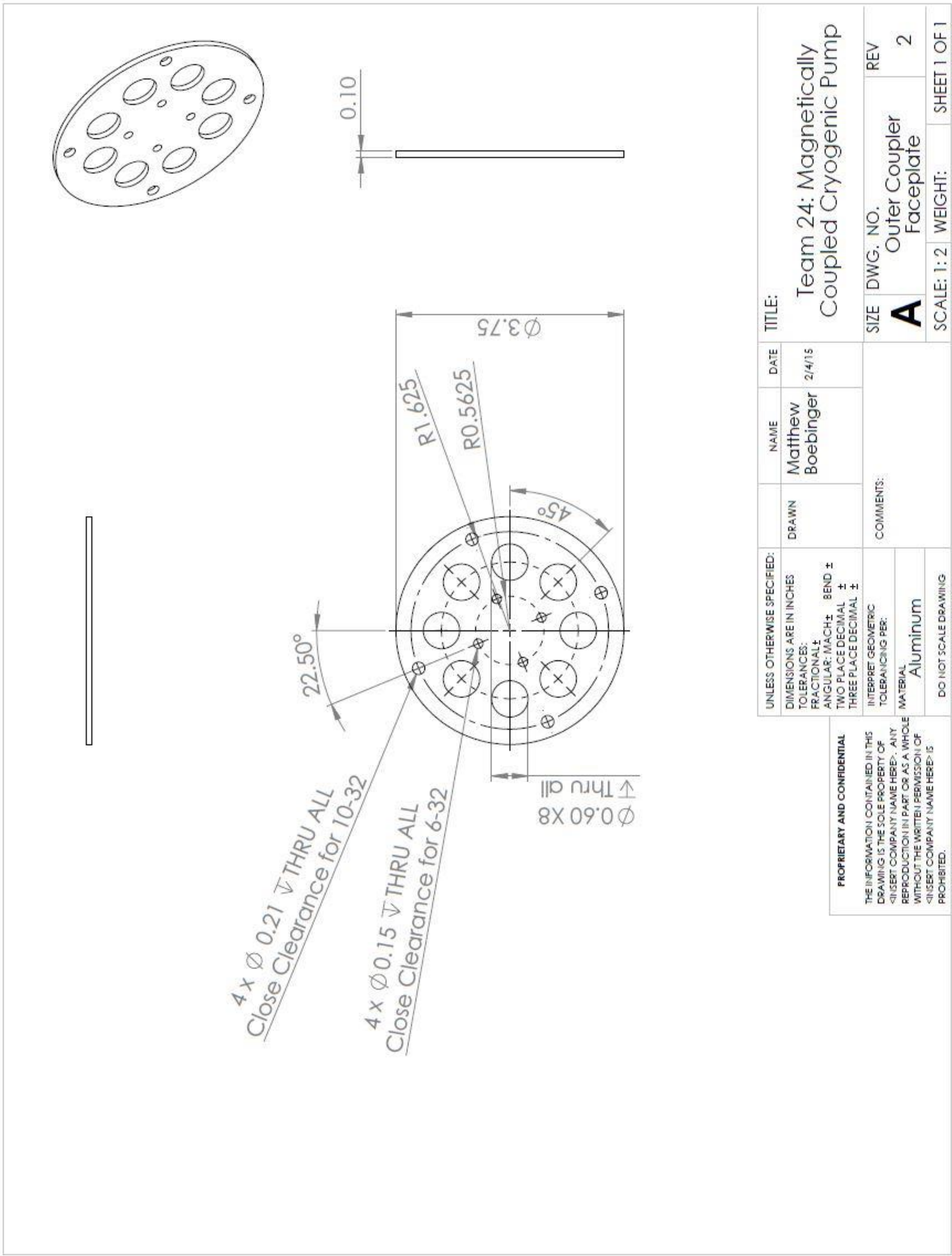
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Stainless Steel
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Matthew Boebinger
2/15/15
COMMENTS:
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
SIZE
A
DWG. NO.
Housing Anchors
REV
3
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
1
2
3
4
5


Meshing to allow fluid flow
10 Rows
#10-32 thread hole
x6 ⊽ Thru
0.50
0.25
0.23
0.50
Ø2.65
60°
1.625
1.00
3.50
10.50
12.50
13.00
13.50
Ø1.55
Ø1.75
Ø2.85
Ø3.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NAME
DATE
DRAWN
Matthew Boebinger
2/4/15
COMMENTS:
MATERIAL
Aluminum
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
SIZE
A
DWG. NO.
Pump Housing
REV
2
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1


0.10
Ø3.75
R1.625
R0.5625
45°
22.50°
Ø0.60 X8
Thru all
4 x Ø 0.21 THRU ALL
Close Clearance for 10-32
4 x Ø0.15 THRU ALL
Close Clearance for 6-32
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Aluminum
DO NOT SCALE DRAWING
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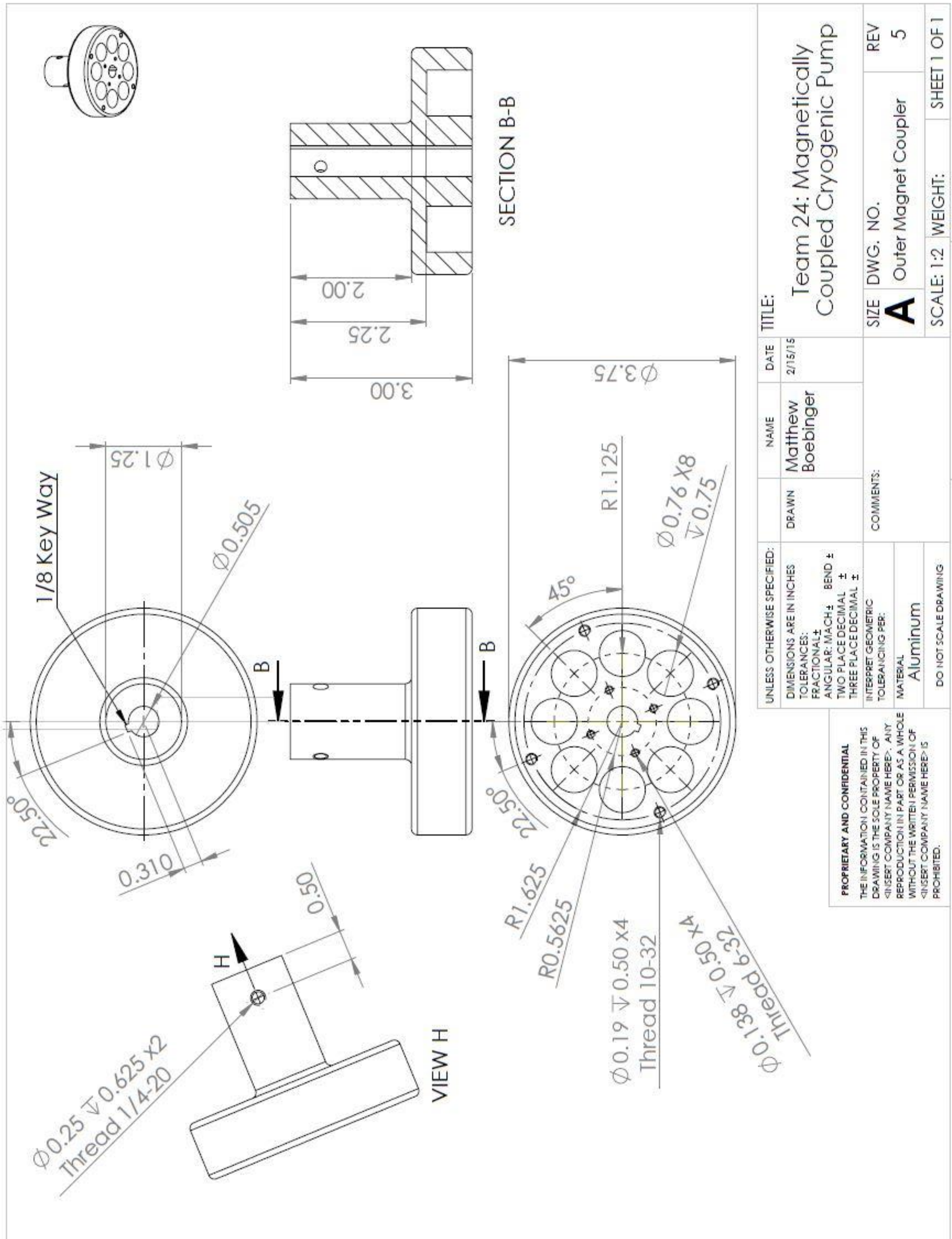
DRAWN
NAME
Matthew Boebinger
DATE
2/4/15
COMMENTS:
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
SIZE
A
DWG. NO.
Outer Coupler Faceplate
REV
2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


SECTION B-B
2.00
2.25
3.00
Ø3.75
Ø1.25
1/8 Key Way
Ø0.505
R1.125
Ø0.76 X8
↧0.75
45°
B
B
22.50°
22.50°
0.310
0.50
H
VIEW H
Ø0.25 ↧0.625 x2
Thread 1/4-20
R1.625
R0.5625
Ø0.19 ↧0.50 x4
Thread 10-32
Ø0.138 ↧0.50 x4
Thread 6-32
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
DO NOT SCALE DRAWING
DRAWN
NAME
Matthew Boebinger
DATE
2/15/15
COMMENTS:
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
SIZE
A
DWG. NO.
Outer Magnet Coupler
REV
5
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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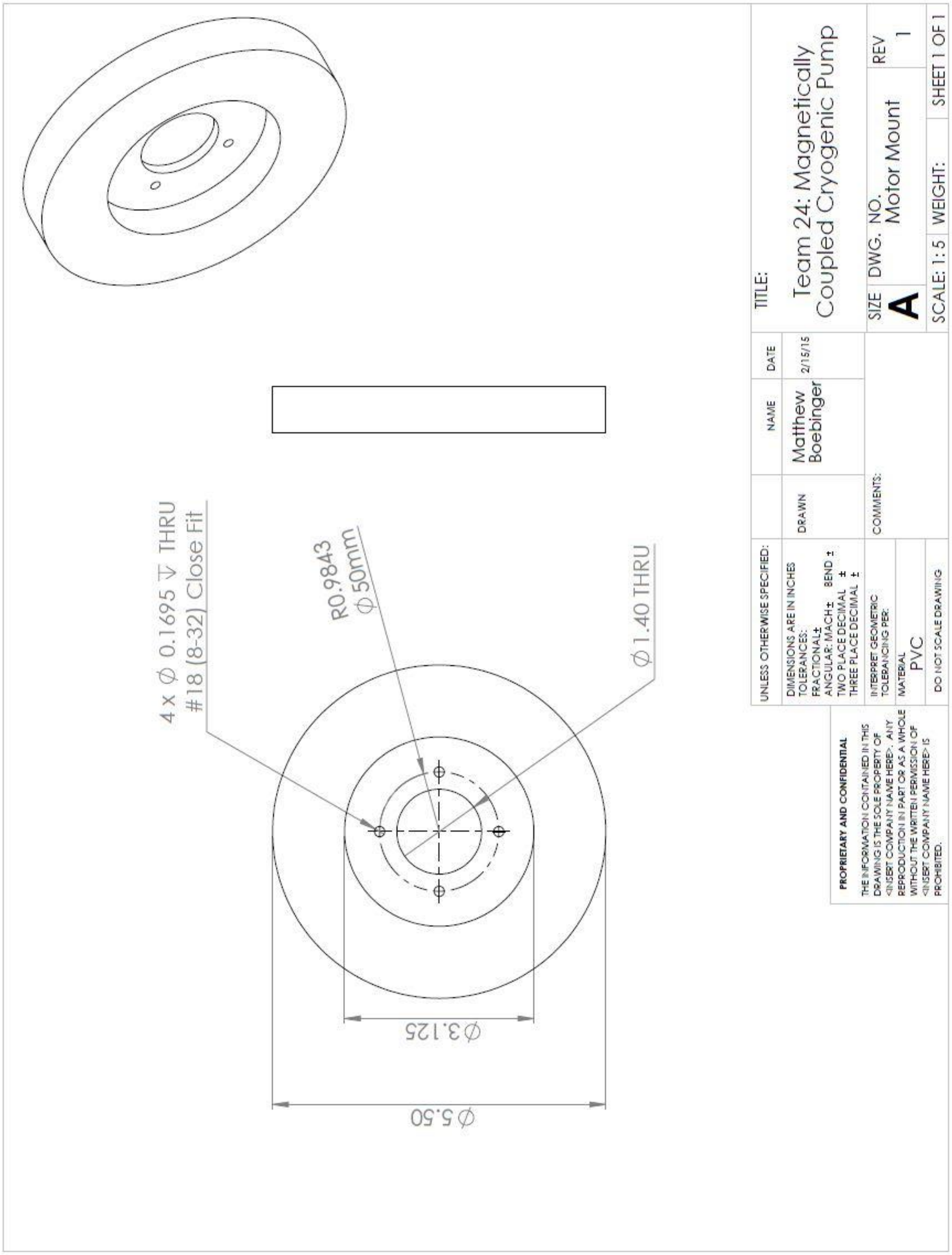
4 x ∅ 0.1695 ↧ THRU
#18 (8-32) Close Fit
R0.9843
∅ 50mm
∅ 1.40 THRU
∅3.125
∅5.50
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
NAME
DATE
DRAWN
Matthew Boebinger
2/15/15
SIZE
A
DWG. NO.
Motor Mount
REV
1
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PVC
DO NOT SCALE DRAWING
COMMENTS:
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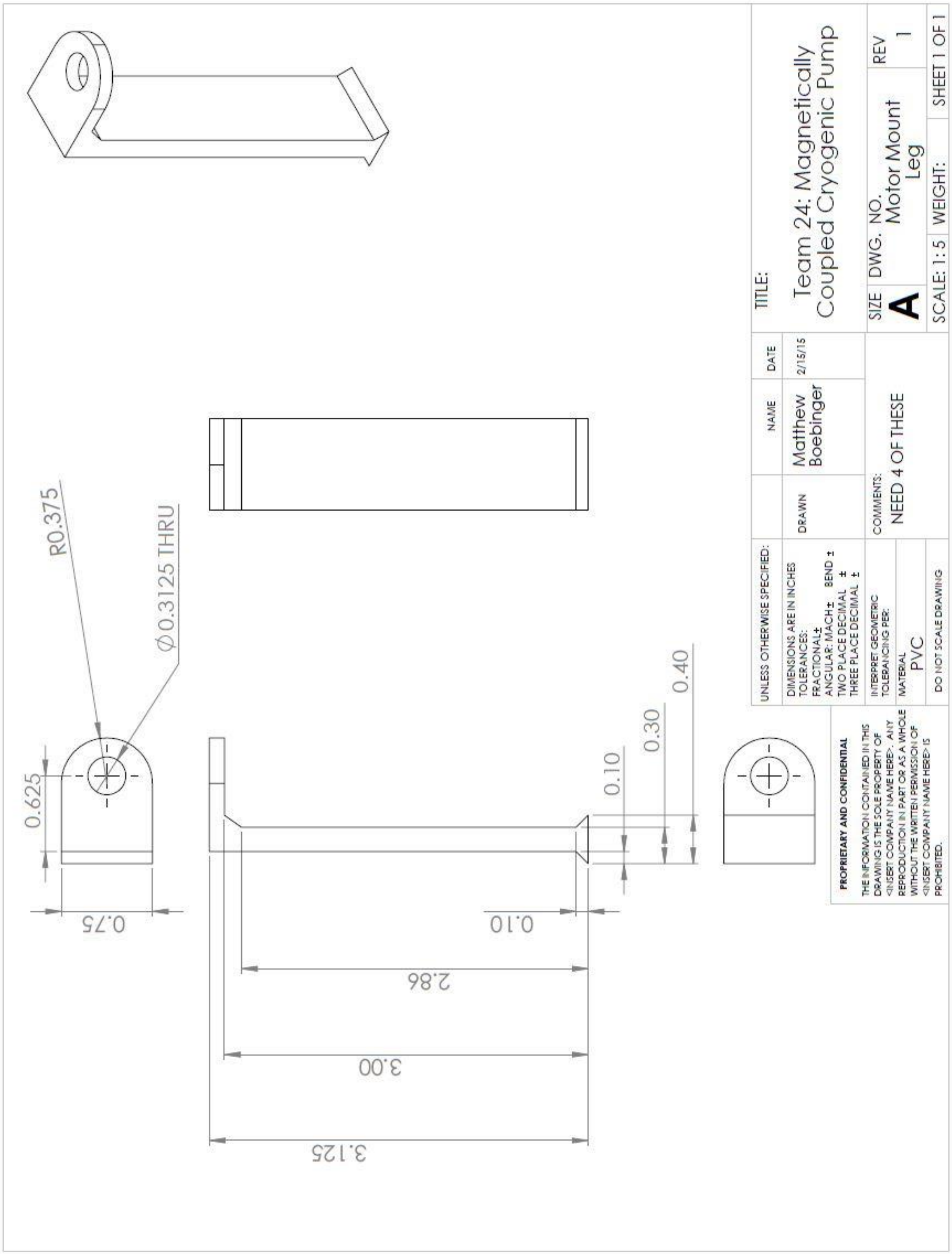
R0.375
Ø0.3125 THRU
0.625
0.75
0.10
0.30
0.40
0.10
2.86
3.00
3.125
TITLE:
Team 24: Magnetically Coupled Cryogenic Pump
DRAWN
NAME
DATE
Matthew Boebinger
2/15/15
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PVC
DO NOT SCALE DRAWING
COMMENTS:
NEED 4 OF THESE
SIZE
A
DWG. NO.
Motor Mount Leg
REV
1
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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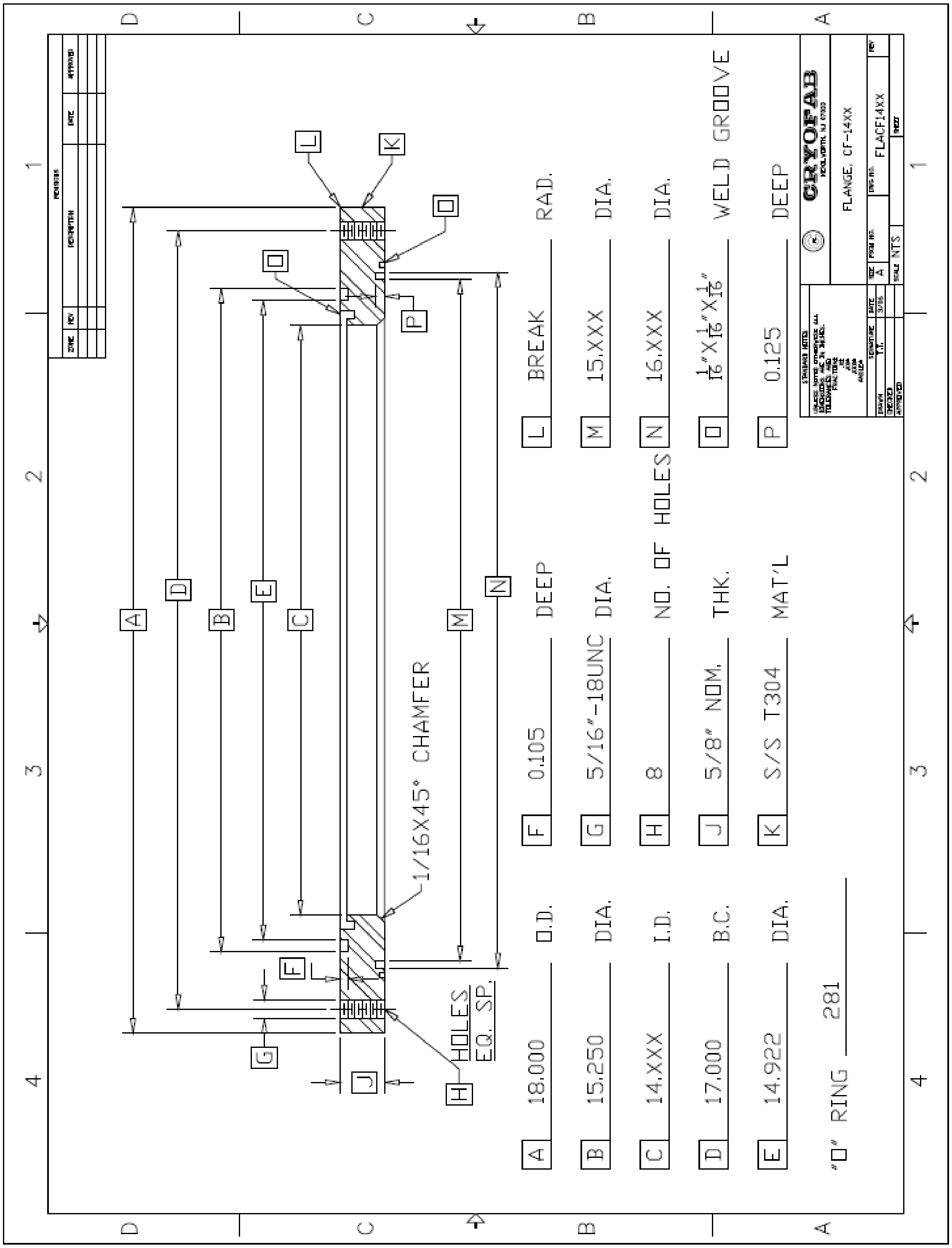
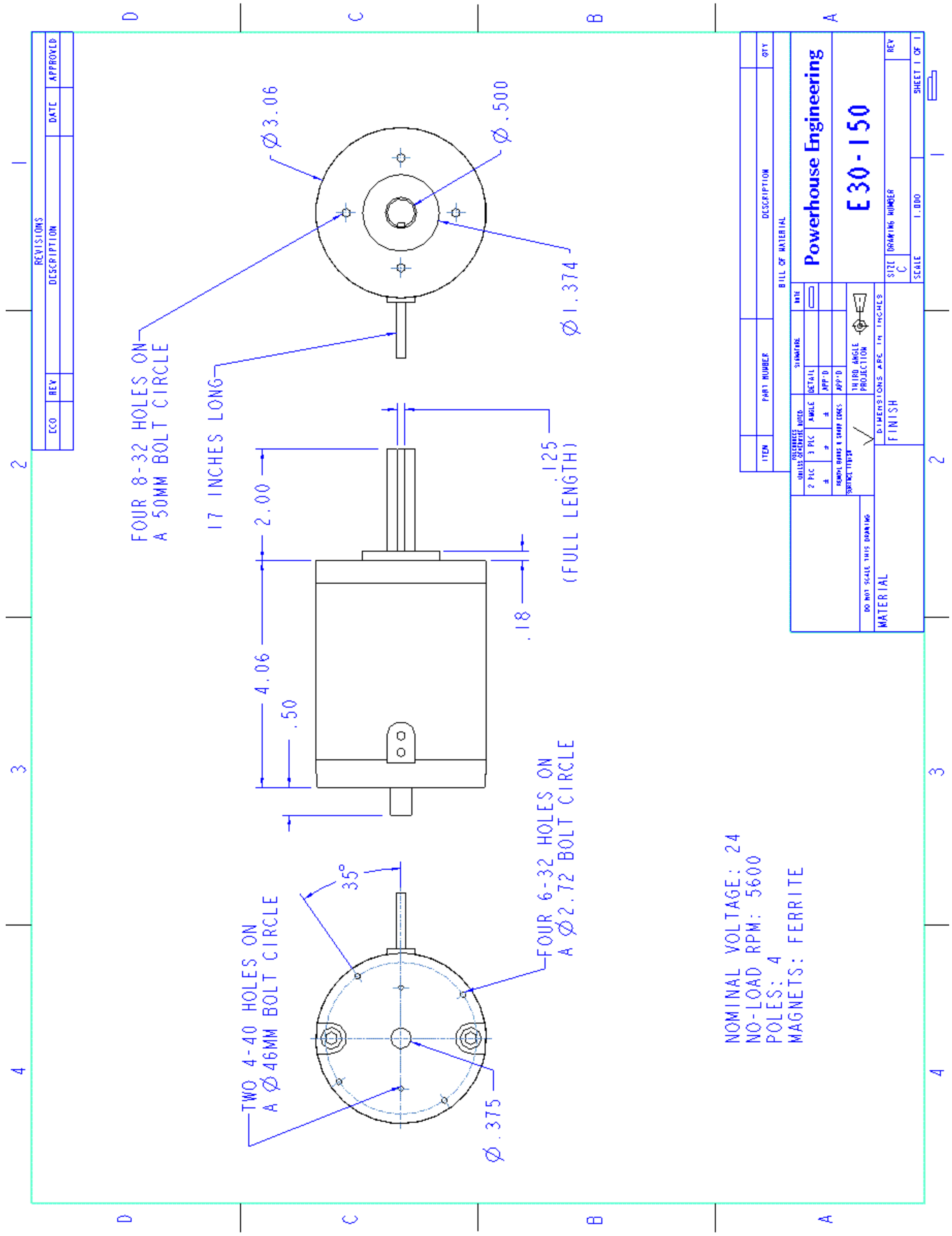

A 18.000 O.D.
B 15.250 DIA.
C 14.XXX I.D.
D 17.000 B.C.
E 14.922 DIA.
"O" RING 281
F 0.105 DEEP
G 5/16"-18UNC DIA.
H 8 NO. OF HOLES
J 5/8" NOM. THK.
K S/S T304 MAT'L
L BREAK RAD.
M 15.XXX DIA.
N 16.XXX DIA.
O 1/16"X1/16"X1/16" WELD GROOVE
P 0.125 DEEP
1/16X45° CHAMFER
HOLES EQ. SP.
CRYOFAB
FLANGE, CF-14XX
FLACF14XX
NTS


Ø3.06
Ø.500
Ø1.374
FOUR 8-32 HOLES ON A 50MM BOLT CIRCLE
17 INCHES LONG
2.00
.125 (FULL LENGTH)
.18
4.06
.50
35°
TWO 4-40 HOLES ON A Ø46MM BOLT CIRCLE
FOUR 6-32 HOLES ON A Ø2.72 BOLT CIRCLE
Ø.375
NOMINAL VOLTAGE: 24
NO-LOAD RPM: 5600
POLES: 4
MAGNETS: FERRITE
Powerhouse Engineering
E30-150
REVISIONS
BILL OF MATERIAL
THIRD ANGLE PROJECTION
DIMENSIONS ARE IN INCHES
FINISH
MATERIAL
SIZE C
SCALE 1.000
SHEET 1 OF 1

Appendix B

$Fr := 6\,lbf$

$Fa := 10.5\,lbf$

$L_h := 8000\,hr$

$\omega := 1500\,rpm$

$$Fe := \left(Fr^2 + Fa^2\right)^{\frac{1}{2}} = 53.794\,N$$

$$C\_ := Fe \cdot L_{10}^{\frac{1}{3}} = 482.146\,N$$

From SKF bearing catalog

$C_0 := 193N = 43.388\,lbf$

From Table 11-24

$$\frac{Fa}{C_0} = 0.242$$

Linear Interpolation

$$e := .34 + (.38 - .34) \cdot \frac{.242 - .17}{.28 - .17} = 0.366$$

$V := 1.2$

$$\frac{Fa}{V \cdot Fr} = 1.458$$

$$Y := 1.15 + (1.31 - 1.15) \cdot \frac{.242 - .17}{.28 - .17} = 1.255$$

$X := .56$

$F_e := X \cdot V \cdot Fr + Y \cdot Fa = 76.539\,N$

$$C\_\_ := F_e \cdot L_{10}^{\frac{1}{3}} = 686.004\,N$$

Repeat process Until C does not change

Appendix C

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur?**	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.
Bearing Wear	Bearings have more friction or wobble	Will require more power from the motor, or cause more heat from friction	5	Extended use without replacement	3	Monitor use. Bi-monthly maintenance	9	135	Maintain system. Keep log of use to determine when system requires maintance	User	bearing calculations were performed to ensure a life of 8000 hr of use with a factor of safety of 4. 11/2/14
Magnet Seperation	Magnets in respective couplers are too far apart to couple	Pump will no longer work/pump fluid	4	improper assembly	2	Following proper instructions for assembly and measuring the correct operating distance	2	16	Monitor the system when srating it up to ensure a 1:1 coupling if slippage occurs move the couplers closer together	Manufacturer	Tested the couplers in torsion machine to find the maximum operating distance 3/20/15
Number of Magnets	sufficient torsional strength for coupling is not achieved	Pump will no longer work/pump fluid	5	To many magnets close together causes the magnetic fields to smear together therfore no torque is generated	1	Following the instucions for proper amount of magnets for a given coupler	2	10	Follow instruction manuel and monitor system when first starting up to ensure the coupling is 1:1	Manufacturer	Tested the couplers for the optimized amount of magnets for a 3.5" coupler 3/20/15
Magnetic Materials	Coupling may fail if torque exceeds the rated amount	Increased tourque on motor and couplers. The rtequired volumetric flow rate is not met	3	Pump housing anchor material magnetic.	1	Procuring the proper non magnetic material	1	3	Checking the material for magnetic properties using a high strength magnet	manufacturer	Checked materials for magnetic properties. Returned the magnetic material and recived proper material. 2/10/15
Motor Connection	motor overheats or shorts out. Insufficient power	Motor will stop working as well as pump. Volumetric flow rate not achieved	4	Incorrect electrical assembly/ short circuit	4	Following the instruction manuel on proper connection of motor to driver and driver to battery	1	16	Follow the operaation manuel step by step or hire certified electrician to install motor	user	discussed proper connection with electrical engineers and seeked help from faculty. 3/1/15
Motor Drive Failure	Overheats	Motor will stop working as well as pump	5	Incorrect electrical assembly, short circuit, and exsessive voltage	2	Following instruction manuel on proper connection and voltage input	2	20	Follow operation manuel test output voltage of battery or outlet hire electrician to install	user	discussed proper connection with electrical engineers and seeked help from faculty. 3/1/15
Cryrogenic Behavior	Bearing lubricant freezes/stiffens	Increase torque on motor possibly seize the pump	6	lubricant not fully removed from bearing or incorrect bearing assembly	4	Ensure all lubricant is stripped from the bearing or buy non lubricated bearings	4	96	start the system slowly to ensure the bearings run smoothely without seizure	Manufacturer	ordered non lubricated bearings from the store to ensure no lubrication was applied to the bearings. 12/10/14
Tolerancing of Pump	Coupler screws/ impeller scrapes against pump housing	Increase friction and damage parts	6	improper assembly. Machine tolerance not tight enough	4	Follow the operation manuel exactly for assembly and ensure machines have high tolreances	1	24	use looser tolerances.	Manufacturer	tolerances of machine shop was checked and proper assembly was ensured. 3/31/15