IPRO 348: Techno-Business Study of Water Pump Motor Technologies

Sponsored By: Pentair, Inc.

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Tejash Patel

I. Introduction

The intent of this project was to investigate applying new motor technologies in partnership with Pentair, Inc. We were specifically focusing on direct current (DC) motor technologies for use in their water pumps in residential and commercial applications. This technology can allow for higher efficiency, lower cost, and make their products more useable worldwide.

Our purpose in undertaking this project was to research the available technologies in the market. This included finding a specific motor or motors that could potentially be used by Pentair, Inc. in their water pumps and designing a way to adapt it to their present line of pumps for testing. In addition, we investigated the potential for using alternative energy as a means of powering the motor, and analyzed the cost effect of switching to the new type of motor selected.

II. Objectives and Background

Our sponsor, Pentair, Inc, is a multi-billion dollar corporation that produces water pumps for a wide variety of applications, ranging from small residential pumps to large scale industrial and agricultural products. They attribute their success to their rigorous approach to upholding their high standards in business, morals and ethics. Included in this is a devotion to providing a high quality product that will suit the consumer while falling within an affordable price range. In addition to this, they recognize the need to strive for energy efficiency, to do their part to preserve the environment in light of studies showing vastly increased carbon emissions and energy waste in the past 60 years.

The goal of this endeavor is to select a new motor technology that will not only continue to uphold Pentair's standard of excellence, but also to provide a more universal technology that is “green”. This is where our IPRO team comes in: our objective was to search out this technology, to investigate potential motor technologies that are not only on the market, but also ones that are still under development. We sought to provide Pentair with our recommendation on a motor technology to either use or that merited serious consideration and further investigation.

In searching for a new technology, Pentair was specifically interested in direct current technology, which was a centering point for our research efforts. We were also asked to research the possible role of alternative energy sources for use with pump motors, as well as to do cost analysis to ensure any alternatives were still economically viable.

Today, the most used electric motor used for pumps is the alternating current (AC) motor, which is what Pentair currently uses for their water pumps. Essentially, AC motors work by using magnetic reluctance. This is done by charging stators surrounded by an open cylinder of coils. The coils are charged by an alternating current and cause a revolving magnetic charge on the rotors, which causes a torque on the shaft. This is the oldest form of electric motor technology, due to having a lot of research and a good market to support it. It also is a very simple form of power.

However, the motor technology is still faced with problems. One problem pump manufacturers face is the challenge of controlling the speed of the AC motor. For applications like our one horsepower pump the driver for the AC inverter is very expensive compared to a DC version. The AC motor also fails to handle low speeds. For the use of a pump, various speeds are needed. Letting the motor idle when it could be performing at low speeds is an inefficiency that has a large impact in comparison to a greener, cost-effective technology.

III. Organization and Procedure

In order to accomplish the goals outlined above, we divided our group up into two teams. The first, the technical team, focused on the technological aspect of the project, researching motors, alternative energy, and other technical topics. The other team, the recording team, was responsible for coordinating the research and compiling and organizing information, as well as contributing to the research effort. The team roster along with the budget can be found in Appendices A and B.

Our first step was to research and understand the current motor technology used by Pentair. This included looking up information on the internet, reading textbooks on motors, and visiting one of Pentair's plants in Delavan, Wisconsin. In this meeting, we received more information on what they wanted our team to accomplish. Additionally, we received test data on the motor that they are currently using. This data can be found in Appendix D. From these test results came the guidelines for a new motor – we sought a technology that met or preferably exceeded the standards of the one currently used.

With these guidelines in mind, we began researching various types of motors, specifically direct current motors. The vast majority of this research was done via internet, looking at informational websites as well as looking at product lines of several different companies to see what technologies they offered and for what applications. By looking at the advantages and disadvantages of each choice, we were able to come to a decision of a motor technology to further investigate.

After deciding on which types of motors would be most suited to the application, we narrowed it down to one choice (brushless direct current motors), inasmuch as that was the only technology available that was suited to our products power consumption and torque requirements. Since many of the motor types we looked at were not widely available, this limited our options for a practical technology to choose. Once we had decided, we began looking for a specific motor to be used for testing purposes. This was done classic approaches (internet searching, sales calls, and email contact), in the Chicagoland area, throughout the U.S., and places elsewhere in Europe and Asia.

Eventually, we narrowed the choice down to a few motors and went back up to the Delavan, WI plant to meet with Pentair and discuss the choices. A motor was decided on, but unfortunately would not be able to be shipped on time to do our own testing. The specifications for the selected motor and the controller that operates it as provided by the company can be found in Appendix E. In order to assist in the future testing process, parts were designed to adapt the purchased motor to the current production pump used by Pentair, since the interfaces are not the same dimensions. Drawings of these parts can be found in Appendix F. Additionally, lifetime cost models were developed to determine whether these more expensive motor choices would be cost effective over the course of their lifetimes.

Concurrently, research was done on the possibility of applying alternative energy sources to power the motors. This eventually led to cost modeling concerning using solar panels to assist in powering the motor. Additionally, research was done concerning what type of controller would be used for the motor and what type of power input it took. Energy efficiency was equally important when looking at the controller as it was with the motor. It was decided that we should use the controllers dedicated to the motors as provided by the manufacturers.

Our recommendation and final report to Pentair contains all of the above information. It also includes a defense of the technology that we have selected that we believe is the best for them to consider for their line of water pumps.

IV. Findings and Analysis

This portion of the report will discuss the various types of motor technologies we have researched in the introductory phases of our search for a motor. We knew our sponsor, Pentair, found this to be the most critical part of our search, as did we. We searched through various markets and companies to find up-and-coming electric motor technologies to allow our sponsor to get a step up and leave their primitive Alternating Current motors. The most prominent of the various types of motors in the market are:

- Servo Motors
- Stepper Motors
- Switch Reluctance Motors (SR)
- Permanent Magnet Motors
- Direct Current Brushed Motors (DCB)
- Direct Current Brushless Motors (DCBL)

After each motor type was researched, we found that some of these types of motors would not be helpful for our search for a pump motor. We disregarded servo and DCB due to their limited use and short term durability, respectively.

The first motor researched was the SR motor. This motor works by generating torque through magnetic reluctance. This is done by inducing charge on non permanent magnetic poles. This synchronized process repeats continuously to operate the motor. Advantages we found for this motor were actually very surprising. Despite its simple design, the motor produces large torque values at high speeds (rotations per minute - RPM's). This makes the motor efficient in various ways making it cheap, durable, and effective. Unfortunately, the disadvantages are just as great. The motor is typically very robust. It is also an unpredictable process, causing it to create loud torque pulsations. These prevent any chance for the motor to be used in a residential environment. With more research this motor may become very important in the future, but for now it is not a viable solution.

Another motor we looked at was the stepper motor. Like the SR motor, it is a synchronized process. In place of poles with induced charge, there are stages of electric charge "stations" that move the shaft of the motor. Instead of the traditional cylindrical wiring there are stations of electricity charged gear teeth. Due to the "steps" the motor takes to perform a revolution, the motor has a very smooth operation. It also allows for great control. Although these are both essential for a good motor, the cost of stepper engines to operate at the specifications of a pump is high, especially since most stepper motors will lose torque at high speeds.

The next motor technology we researched was the permanent magnet motor. Like DC brushless and SR, magnetic reluctance is the key to its performance. However, instead of inducing the stators of the motor, permanent magnets are used inside the motor. The advantage of this style is that it allows for the motor to require less current to operate. To its disadvantage though, there is such a limited source for this type of this motor (which is all overseas) that becoming dependent on it would not be advisable for any company to do.

Lastly, we investigated the brushless DC motor (DCBL). It operates like the SR motor in the sense that it uses induction to stimulate torque. Of all DC motors, it is the most widely used and can be utilized for nearly all electric motor needs. It is very easily customizable as well. Unlike the brushed DC motor, it does not need wiring for connections inside the motor. Although it makes the motor a little less efficient, we believe that the general quality is an improvement. Since it has no wiring for the connections, the durability and maintenance of the motor increase significantly, which make for a very important for a dependable motor. It is overall the best motor for use in a pump.

When researching various types of motor technologies we made sure that we not only covered it from an engineering standpoint, but from the business perspective as well. Even if we found the perfect motor based on technical specifications, that doesn't necessarily mean it will meet the standards economically. During our research, we looked at various criteria that we believed the motor and its supplier should have and maintain. Pentair made it clear that they wanted quality products for their clients. We also wanted to make sure that the client was completely satisfied with the motor they purchase and not one that would only bring hassle.

One of the most vital points for us was the cost of running the motor. That includes its operating voltage. If it was higher than necessary, then the clients will be stuck with a higher electricity bill than they should. Another important point was the maintenance of the motor. That includes how durable it is and what we can estimate its lifetime to be. That made finding a relatively inexpensive motor one of our criterion. The doubled lifetime and increased efficiency in comparison to the current production AC motor showed that the savings would indeed be substantial. Another aspect for our consideration was how the motor would act during operation. This includes the size and noise produced by the motor. Having a large, noisy motor would not keep the client happy, so we were pleased by the smaller size and claimed relatively quiet operation of the DC brushless motor.

Every DC motor needs a controller to be able to operate. There are a variety of controllers out on the market that would’ve suited our purposes. One of these technologies is the variable speed controller. This controller would have allowed for the speed of our motor to change when the system demanded more or less power. Extra control does come with a price tag, however, and we determined that the cost of integrating this technology far outweighed that of the energy we would save by having adjustable speed. We decided to simply use the controllers that the manufacturers recommended to use with the motors, which were helpful in that we did not need to obtain a DC power source to be able to use them.

We discovered that the DCBL could perform at least adequately to meet all of our criteria when it came to both business and engineering. It then came down to deciding which motor and supplier to pick. We decided that the supplier of the selected motors should be a respectable company that has been around for a while and was maintaining stability even through hard times. The company had to be one that followed all the environmental procedures required by the respective government. Both Anaheim Automation (based out of California) and MotionKing (based out of China) had these qualities. Specifications for all of these motors can be found in Appendix F. Their motors made it to our final three. Ultimately, we decided on the Anaheim Automation BLZ482S-160V-3500 due to ordering problems with the MotionKing motor.

Once the motor had been selected, obstacles arose in preparing for testing. The first, and most major, was that the lead time on receiving the motor from the distributer was 10-12 weeks. Due to this, we were unable to test the motor. Despite this, we did preparation work so that the motor could be tested.

The first step was to secure a facility and equipment for testing. Illinois Institute of Technology did not have the facilities necessary for specific types of testing where the motor would be attached to the pump. At our request, Pentair agreed to make their facilities available for testing. We did not need to secure a direct current (DC) power supply to power the motor due to the nature of the controller, that is, the controller converts alternating current (AC) power to DC power.

A difficulty that we came across was that the shaft size and face plate dimensions of the DC motor were not the same as the currently produced motor or the same as required for interfacing with the pump. To correct this problem, parts were designed to act as an interface between the DC motor and the pump. Drawings of these parts can be found in Appendix G. The first is an adapter plate, which is mounted on to the DC motor and which has connecting feet that a screw would go through to mount to the pump, as the AC motor would. The second part is a shaft adapter, which corrects the shaft size of the DC motor to match that which is required by the pump.

In considering alternative energies, we felt it prudent to investigate the potential for application for a technology that could be used throughout the world. Therefore, it needed to be relatively cheap and useable, for applications in third world countries as well as developed countries where alternative energies such as wind and solar power can be tapped.

One of the most immediate and lethal problems facing many third world countries is the availability of clean drinking water. India is both densely populated and has high solar insulation, providing an ideal combination for solar power in India. India is already a leader in wind power generation. Africa, as a continent, has tremendous solar energy capabilities due to the proximity of most of its land mass to the equator. At that latitude, most of Africa will have 325 days of strong sunlight. Most electrical systems in many African countries are quite obsolete, as they date from the colonial era. However, the alternative energy resources that these places do have can be used. Since all alternative energy sources provide DC power, having a DC motor becomes an additional advantage.

A solar panel is from $1-$5 per watt and we will need a higher amount of wattage than the motor because it is not 100% efficient and we would also need a battery bank because the motor start up surge is 3 to 7 times what it takes to run. In places near the equator that receive large amounts of sunlight throughout the year, this is very valuable technology and would serve very well to operate the motor.

V. Conclusion and Recommendations

In view of what was discussed above, we believe that direct current brushless (DCBL) motors are the best possible technology to use that are readily available on the market. It is also recommended that further testing be done on the motor selected to determine whether it meets the efficiency and performance standards set forth by Pentair and that the motor claims to have. Some conditions to consider in choosing to use this type of motor is the size difference and the potential need to re-design pumps or custom make adapter parts in the future to accommodate this. With the much longer lifetime and higher efficiency saving the consumer money, we believe that the higher initial cost would be worth it to the consumer, so the pump would still be marketable as well.

Additionally, we believe that it would be advisable to look further into switched reluctance (SR) motors in the future. Since the technology has not yet been perfected, we don't believe that it is currently a good choice. However, there is large interest in this motor in the market, and investments into research to fix the torque pulsations are being made. This type of motor could be the best direct current alternative if its major flaws are correctable.

VI. Appendices

Appendix A: Team Budget

Appendix B: Team Roster

Appendix C: Timeline

Appendix D: Pentair Contacts

Appendix E: Pentair Motor Specifications/Test Results

Appendix F: Selected Motor/Controller Specifications

Appendix G: Adapter Part Drawings

Appendix A: Team Budget

Expenses	**Cost**
Travel To Pentair (200 miles * 2 cars * 3 trips * $.50/mile)	$600.00
Prototype, Hardware, and Software	$200.00
Printing	$50.00
Meals during Pentair trips, (3 meals * 8 people * $7.00/person)	$168.00
TOTAL:	$1018.00

Appendix B: Team Roster

Team Member	Role
Colmenares, Andre **acolmena@iit.edu** [redacted] **Chemical Engineering** **4th year**	Technical Team Researcher
Hannink, Veronica **vhannink@iit.edu** [redacted] **Mechanical Engineering** **3rd year**	Recording Team Minute Taker Researcher
Jackson, Lisa **jackso2@iit.edu** [redacted] **Psychology** **4th year**	Recording Team Pentair Contact Researcher
Lee, Sunho **slee8@iit.edu** [redacted] **Mechanical Engineering** **3rd year**	Technical Team Researcher
Matariyeh, Khalid **kmatariy@iit.edu** [redacted] **Mechanical Engineering** **3rd year**	Technical Team Researcher
Oberg, Jarrett **joberg@iit.edu** [redacted] **Electrical Engineering** **4th year**	Technical Team Team Leader Researcher
Patel, Tejash **tpatel43@iit.edu** [redacted] **Applied Math** **4th year**	Recording Team Researcher

Appendix C: Projected Timeline

Months	August	September				October				November					Dec.
week **Tasks**	08/23 to 08/30	08/30 to 09/06	09/06 to 09/13	09/13 to 09/20	09/20 to 09/27	09/27 to 10/04	10/04 to 10/11	10/11 to 10/18	10/18 to 10/25	10/25 to 11/01	11/01 to 11/08	11/08 to 11/15	11/15 to 11/22	11/22 to 11/29	11/29 to 12/06
1st Visit with Pentair			■												
Initial Project Plan			■												
2nd Visit with Pentair						■									
Testing								■	■	■	■				
Mid Term								■							
IPRO Final Project Report												■	■		
Poster Creation													■	■	
Project Presentation with Pentair (3rd visit)														■	
Practice														■	
IPRO Day															■
Research	■	■	■	■	■	■	■	■	■	■	■	■	■	■	

Appendix D: Pentair Contacts

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Bill Genaw
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Peter Bianco
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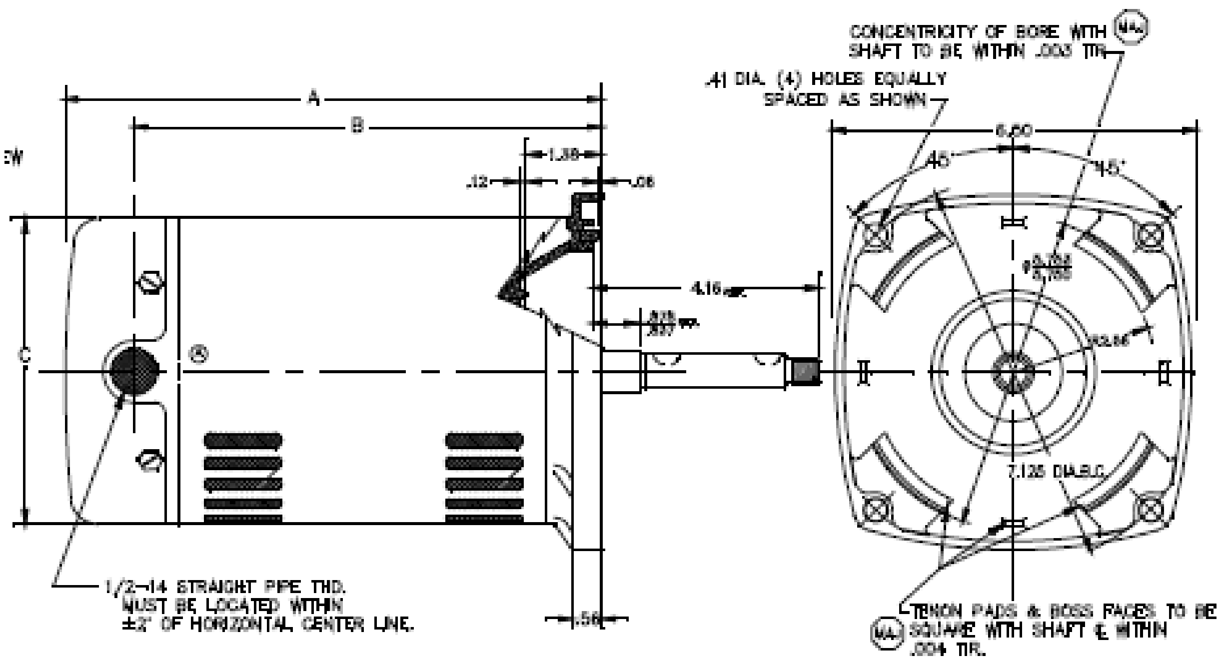
peter.bianco@pentair.com

Appendix E: Pentair Motor Specifications

AOSmith C48K2EC11C3:

Voltage	**230 V**
Current	**8.95 A**
Power	**1549 W**
Rated Speed	**3450 rpm**
Torque	**436 oz-in**
Horsepower	**1.5 hp**
Peak Efficiency	**~74%**
Frequency	**60 Hz**

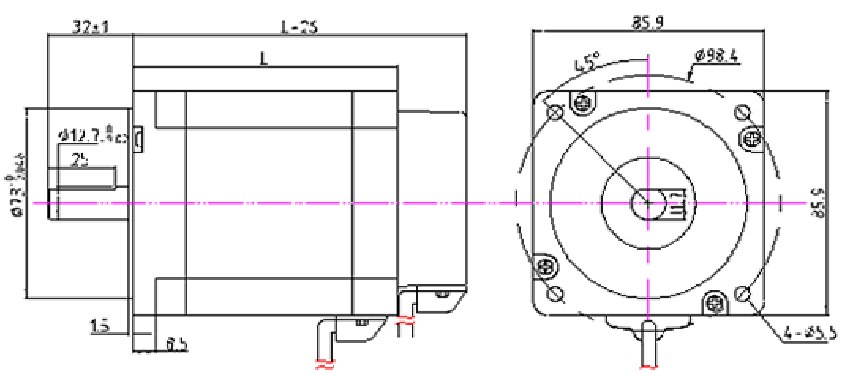


Appendix F: Selected Motor/Controller Specifications

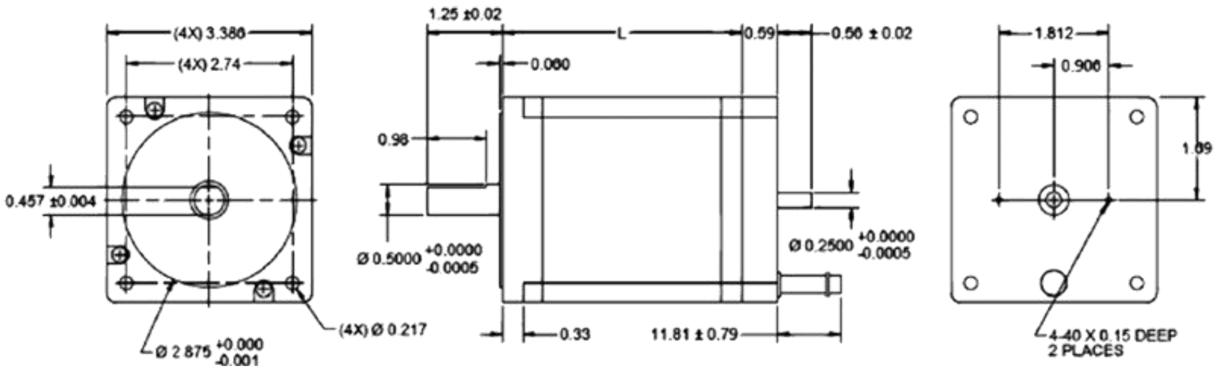
Motor Criteria	Motion King 90BLDC125A-640	Anaheim Automation BLY344D-160V-3000	Anaheim Automation BLZ482S-160V-3500
Voltage	310	160	160
Current (A)	2.83	4.125	9.4
Rated Speed (rpm)	3000	3000	3500
Torque (oz-in)	892 oz-in	297 oz-in	580 oz-in
Power (W)	660	660	1500
Controller	ZKS009C JS	MDC150-120151	MDC150-120151

Controller Criteria	Motion King ZKS009C JS	Anaheim Automation MDC150-120151
Input Voltage	220 VAC	120 VAC
Continuous Output Current	3 A	2.5-7.5 A
Hall Sensor Power Output		6.25 V @ 30 mA
Rated Power Output	750 W	

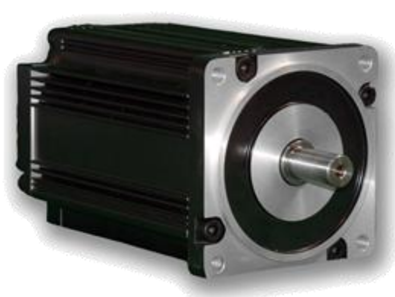
Motion King 90BLDC125A-640:

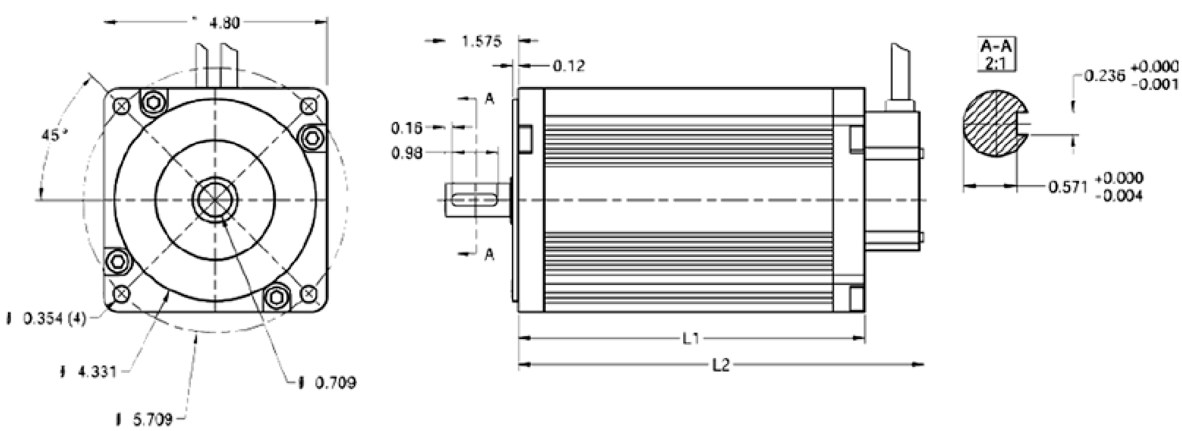


Anaheim Automation BLY344D-160V-3000:



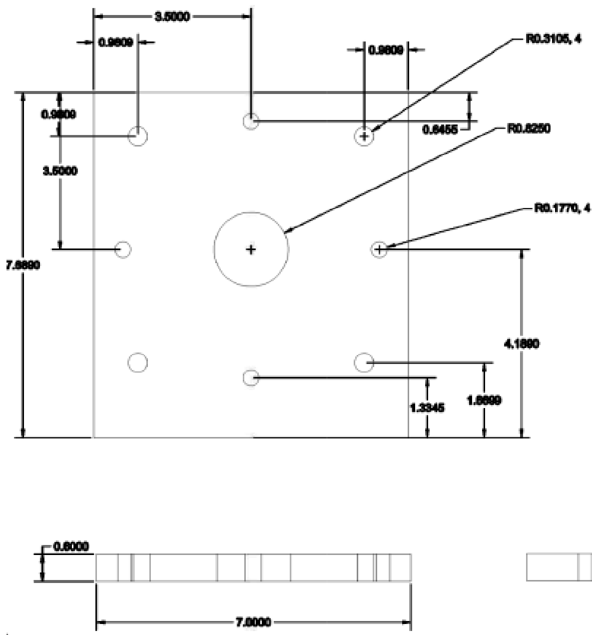
Anaheim Automation BLZ482S-160V-3500:

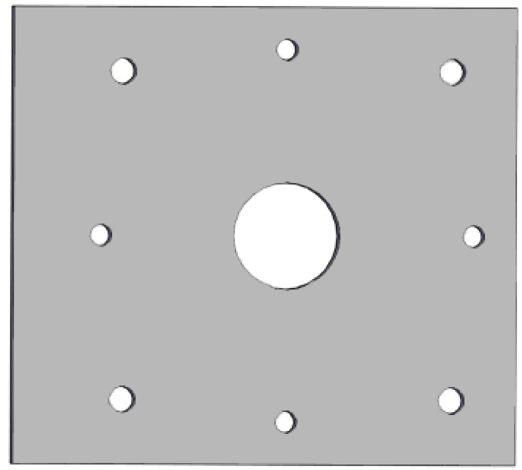




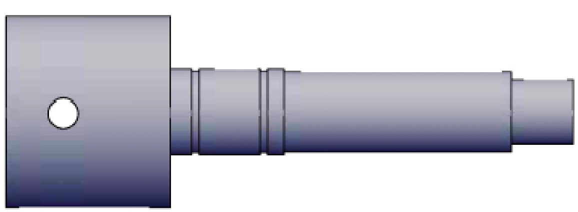
Appendix G: Adapter Part Drawings

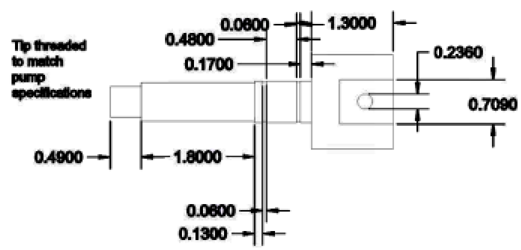
Adapter Plate

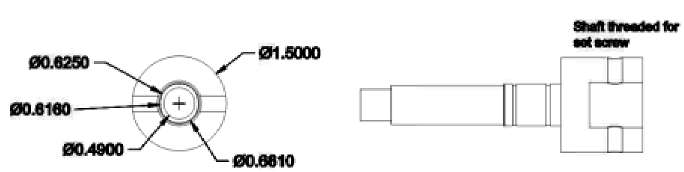




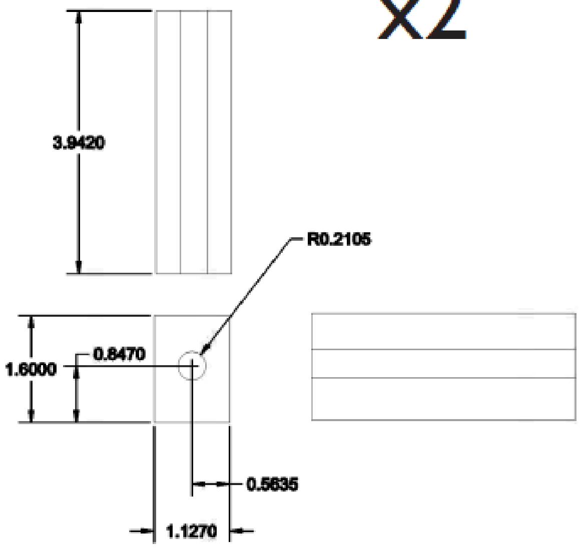
Adapter Shaft







Feet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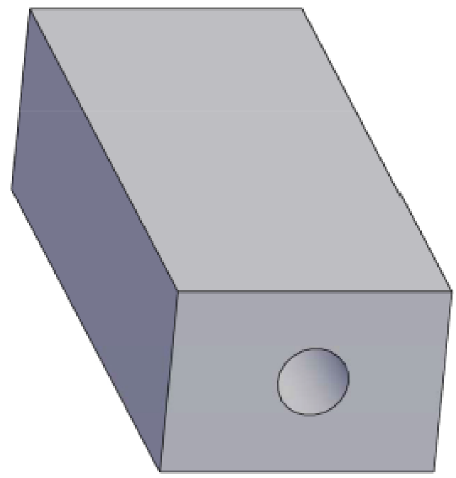

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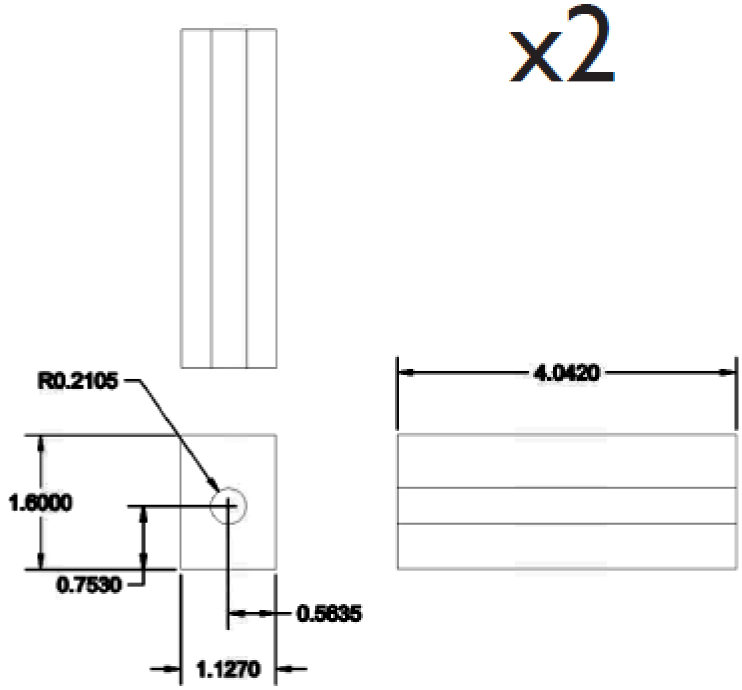
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