Advancements In Brushless Motor Technology

Carlton K. Brown
AMETEK
Elgin, IL

ABSTRACT

AMETEK Rotron introduced brushless motor technology into the heavy-duty transportation market in 1989. The last paper presented was at the APTA Rail Conference in June of 1993. Since then, significant motor technology has developed and design concepts have changed to provide improved performance and additional products for the transportation industry.

The advantages of brushless motor technology are well known in our industry. Light weight, high efficiency, and long maintenance free continuous operation are being experienced daily on most North American Transit Properties. As a result of over 10 years of experience, APTA has included brushless motor requirements for all non- cranking motor applications in the new heavy duty transit bus guidelines. This paper will update the industry on the design changes and improvements that have occurred over the last seven years and highlight brushless motor design since that time when our primary offerings used Hall effect electronics.

INTRODUCTION

In January of 1998, AMETEK, a substantial motor manufacturer, purchased the Rotron Division from EG&G. The Rotron Transportation products have been successfully merged into the Technical Products Group of the Electromechanical Group. This Group is primarily engaged in the manufacture of brushless motors for several market segments as well as Transportation. This has resulted in the availability of additional resources and technology to continue to improve our offerings to the industry.

The development of Rotron Transportation Products is based on motor design and experience in Military and Aircraft products. The actual products introduced into transportation have been designed based on surveys and early discussions with transportation experts and equipment manufacturers. The overriding issue from all of the discussions was to develop products that would provide a long service life with a minimum of maintenance.

MOTOR DESIGNS AND CONFIGURATIONS

There are two basic electronically commutated brushless dc motor configurations. In all brushless motors, the elements forming the magnetic circuit are reversed. This means that the coil windings that form the armature of a brush motor are stationary and the permanent magnets form the rotor. This configuration puts the current carrying coils on the motor housing where the heat generated can be readily absorbed into the mass of the motor housing and dissipated to the atmosphere. This provides an excellent path for the removal of heat from the brushless motor. AMETEK manufacturer motors of this configuration at power levels of up to 1.5 horsepower. This is shown in the cutaway in figure number 1.

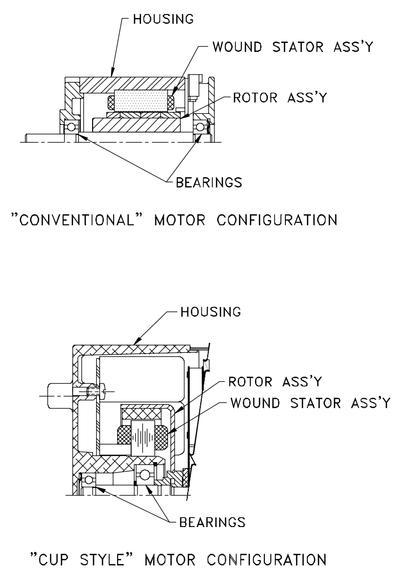


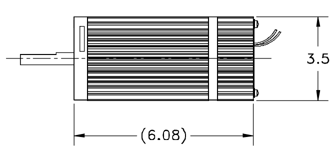
Figure 1.

The second configuration is called a cup or inverted motor and is shown as a cutaway in figure number 1. In this type of brushless motor, the wound stator is located inside of the permanent magnets. The permanent magnets are mounted on the inside diameter of a cup that rotates around the armature. The heat dissipation of this type of design is similar to that of a standard dc brush motor, and normally is used in blower applications where high ambient temperatures are not significant. The advantages of this type of design is that the bulk of the rotating mass is located within the bearing centers. This permits much easier balancing and therefore higher speed capability. AMETEK manufacturer blowers of this configuration at power levels of up to 1200 watts.

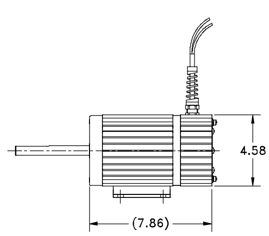
The first transportation motors developed were the 47 frame and 64 frame platforms that are still used in our air conditioning and water circulating pumps as well as other designs. Examples of these designs are shown in figure 2. All of the earlier designs used Hall effect electronics for commutating the motors. The Hall effect designs use a shaft encoder to time the point of powering each stator winding to rotate the motor at its operational speeds. It was also recognized at that time that additional products were needed to meet the lower power requirements of many of the vehicle applications such as defroster, heater and drivers booster blowers. In 1995, we introduced our 3-inch motor design.

The early 3-inch designs shown in figure 3 use the same type of Hall effect electronics for commutation and incorporate all of the same internal mechanical components that are used in the 47 frame motor. One of the primary differences is the elimination of the finned motor housing. Although this reduces the heat dissipation capacity of the motor, it also reduces the cost of the design. The 3-inch motor has been successfully incorporated into many defroster, heater and booster blower applications. In recent years, we have been able to reduce customer product costs by superceding the 47 frame motor with 3 inch motor designs.

Later designs of 3-inch motors use a newer electronic technology that does not require the use of Hall effect switches. This is called a sensorless design. The availability of newer electronic components made it possible to sense the back EMF in the coils of the stator and power the windings in the correct sequence to provide the proper shaft rotational output. The development of the sensorless motor driver permitted more compact designs as axial space was not required to accommodate the hall switches.

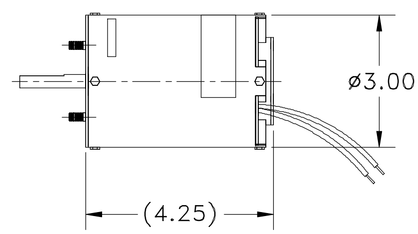


47 FRAME MOTOR CONFIGURATION

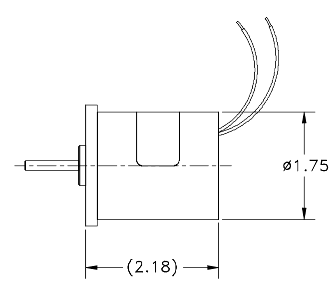


64 FRAME MOTOR CONFIGURATION

Figure 2.



3” MOTOR CONFIGURATION



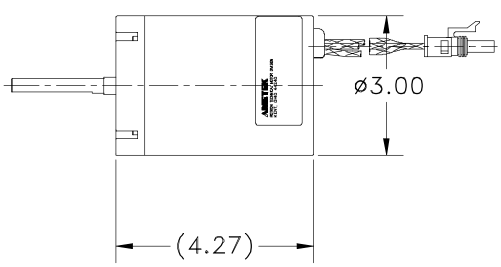
22 FRAME MOTOR CONFIGURATION

Figure 3.

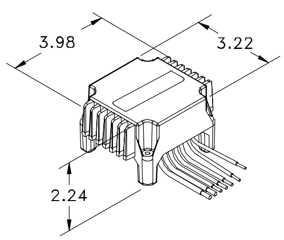
In recent years, we have added a smaller 22 frame (1.7 inch) motor shown in figure 3 to the offerings to round out the product line. The 22 frame motor does not have extensive use in the Heavy Duty Transportation Market.

NEW DEVELOPMENTS - DURATEK 3.0 MOTOR

Our most recent development for the transportation market is the new DurA-tek 3.0 three inch motor platform. This design is currently offered with a sensorless electronics design, and is suitable for heavy-duty transit applications where significant heat loads are not present. The design incorporates new electronics that will provide up to four-speed operation simply by providing signal voltage on specific wires. A variable speed option will be available for the DurA-tek 3.0 later this year. Variable speed control will be accomplished by varying voltage on a signal wire. The DurA-tek 3.0 motors are shown in figure 4.



3" DURA–TEK MOTOR

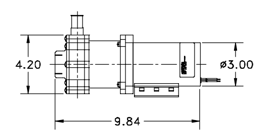


EXTERNAL DRIVE MODULE

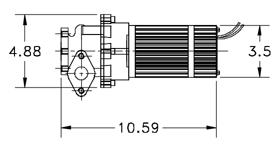
Figure 4.

The primary advantage of the DurA-tek 3,0 is that it is designed for higher production volumes and more automated assembly. This results in lower manufactured cost and therefore lower production prices. The other advantage is that the modern sensorless electronics package developed for DurA-tek 3.0 can be incorporated into existing designs that operate in the same power range (standard 3 inch and 47 Frame). Usage of the DurA-tek 3.0 electronic drive will increase the availability of multiple and variable speed electronic motor drives in existing products.

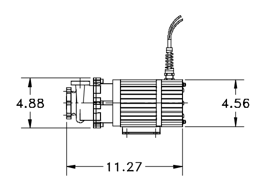
One of the first new product developments using the DurA-tek 3.0 motor is a lower flow brushless sealless water-circulating pump. This pump will complete our transportation water circulating pump offerings. With the availability of this new design, we now offer three pumps as shown in figure 5. This includes our industry standard 47 frame pump that delivers 18 gpm at free flow, our 64 frame pump that delivers 26 gpm at free flow, and the new DurA-tek 3.0 pump that delivers 10 gpm at free flow. Comparative performance curves of all three pumps are shown in figure 6. All three pumps are sealless designs and the pump portion is magnetically coupled to the motor. This provides the longest possible life between maintenance intervals. When motor maintenance is required, the motor can be removed and replaced without disturbing the pump or its piping.



3" DURA–TEK 12GPM SEAL–LESS PUMP

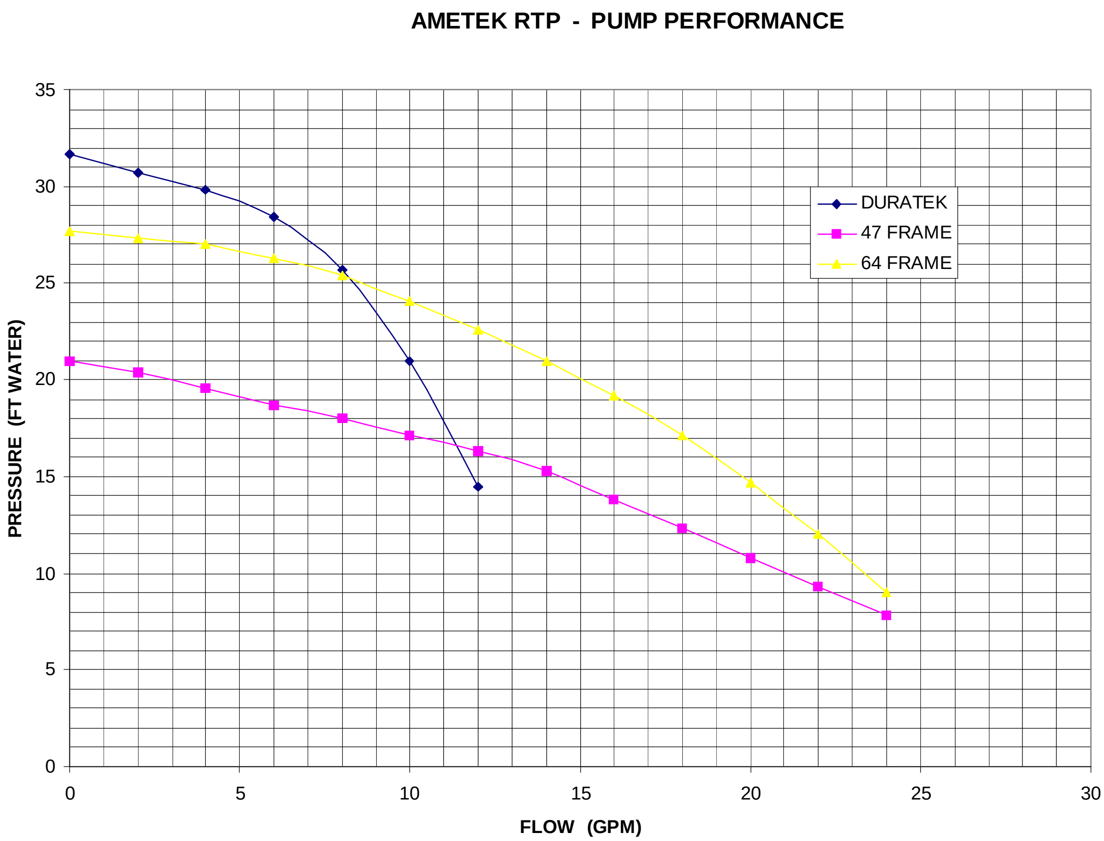


47 FRAME 18GPM SEAL–LESS PUMP



64 FRAME 24GPM SEAL–LESS PUMP

Figure 5.



AMETEK RTP - PUMP PERFORMANCE
PRESSURE (FT WATER)
FLOW (GPM)
0
5
10
15
20
25
30
35
DURATEK
47 FRAME
64 FRAME

Figure 6.

DESIGN STANDARDS

The primary difference between all brush DC motors and brushless DC motors is the maintenance required. The most common reason for brush motor maintenance is brush replacement, which usually is required on an annual basis. The second maintenance item is commutator wear. Brush DC motors require periodic disassembly to machine the commutator to correct for the wear caused by the brushes. This is required every two to three years. Eventually the commutator is worn to the point that it is no longer repairable and the armature must be replaced. This normally is required after about 4 to 6 years of service. The third cause of mechanical failure of a brush motor is bearing failure. This is not considered an issue as the brush DC motor is disassembled several times during its life for more frequent failure modes and bearings can be inspected and replaced at that time.

MOTOR DESIGN LIFE

In brushless DC motors, the only mechanical failure mode is the bearings. For this reason, bearing design is extremely important in the mechanical design of any brushless motor. Bearings normally fail for either mechanical repeated stresses (fatigue) or loss of lubrication (wear). In order to properly design a long life bearing, consideration most be given to the following mechanical issues which include radial, axial and overhung bearing loading, dynamic vehicle loading and equipment balance, rotational speed, operating temperature, and environmental conditions. In long life bearing design, when the body of the motor is a dissimilar metal such as aluminum, the bearing needs to be supported in a stainless steel sleeve. This greatly improves the mechanical life and offsets the difference in thermal expansion.

The bearings used in fractional and low HP motors are either sealed or shielded and packed with grease for their life. There is no simple way to re-lubricate a bearing of this size so that the bearing as installed in the motor carries its lifetime supply of grease. Care is needed in selecting the best grease lubricant for the operating conditions including grease viscosity and ability to withstand the operating temperatures without breaking down and loosing its lubricating properties.

Our experience over the years in determining true motor life has shown that the critical life factor with a properly supported bearing is lubrication. Lubrication life is significantly less than the mechanical life and in order to bring the lubrication life above 40,000 hours it is necessary to significantly oversize the bearing. This provides the bearing with sufficient lubrication storage to allow for normal operation in excess of 40,000 hours. In many cases, this results in a L10 bearing mechanical life that can be measured in millions of hours. It often is not practical to run a motor under full operating conditions to determine its bearing life before introducing the product into production. As a result, bearing manufacturers have developed empirical formulas based on laboratory testing of bearings. The use of these formulas provides a reasonably accurate method of determining the true bearing and motor life. Our own internal life testing of various motor products has verified that our motors do meet the full intent of the APTA specifications. The empirical formula for mechanical or fatigue life can be found in most engineering handbooks. The empirical formulas used for lubrication life are complex, specific, and proprietary to each bearing manufacturer.

Any motor manufacturer that provides only a L10 bearing calculation for their motor is only providing half of the life information. We manufacturer many motors that have L10 bearing life that is in excess of 100,000 hours. We do not bid these products to meet the heavy-duty transit requirements unless the lubrication life will support a 40,000 hour motor life. To meet APTA specifications it is essential to have motor suppliers provide both the mechanical and lubrication life of the motor bearings they supply.

SUMMARY

As the development of our products continue, we expect to see numerous improvements. Programs are underway to engineer a new 64 frame motor platform to increase reliability while reducing manufacturing cost. We are continuing to investigate methods and new materials for increasing bearing life and will continue investigating new lubrications, bearing cages, shields, seals, and bearing metals. Electronics are forever changing and improving. They are under constant review and although there have not been any dramatic breakthroughs in technology there are continuous incremental improvements that are being incorporated into our electronics.

The things to remember when specifying brushless DC motor products are:

1. 40,000 motor design life. The key factors to bearing life is grease type, bearing size and proper bearing support.
2. Heat dissipation capability of brushless motors is greatest when the stator windings are part of the motor case.
3. Construction must be rugged enough to withstand the dynamics of heavy duty transit bus operation.