The NovaTorque Motor Technology

By John Petro   January 9, 2006

Introduction

Today's competitive marketplace demands products that constantly improve in cost and/or performance. Attention to new developments as they appear and application of these new developments to existing products is necessary to maintain a competitive edge. Successful new product developments should emphasize minimizing inherent natural limitations and maximizing the use of production materials and improved processes. This results in better use of source materials and less overall waste. With respect to electric motors, one major natural limitation has been thermal performance, and one area with substantial material waste has been in the production of conventional circular lamination stacks.

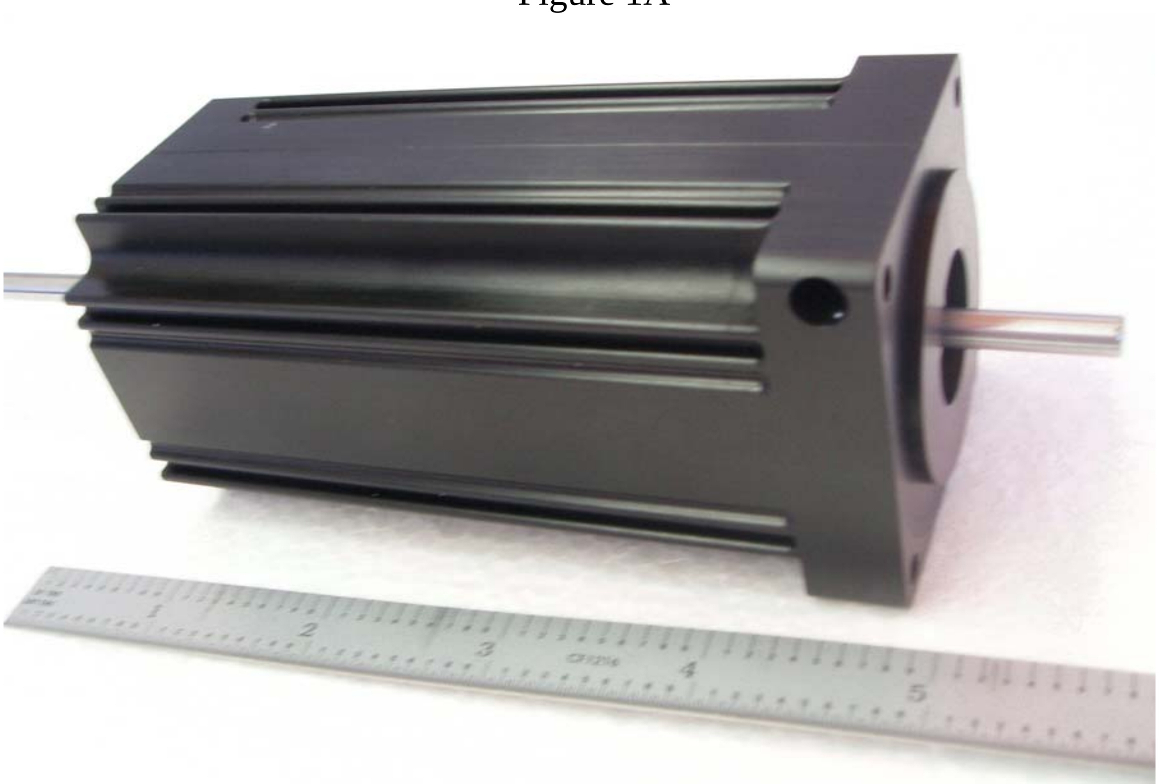
NovaTorque, Inc. has the goal of developing and introducing a new motor technology with improved power efficiency and attractive manufacturing cost. This technology has a wide range of possible applications, including appliances, industrial controls and automotive uses. The new NovaTorque motor technology was first introduced at the SMMA technical conference in October 2005 in Chicago with a paper that outlined some of the performance characteristics of this new motor technology. Since that time, additional progress has been made in a number of areas. This paper will describe some of that progress and will go into some of the details of how the most recent performance results have been achieved.

One area of progress has been in the area of patents. NovaTorque has filed for a number of patents on this technology. We have received a notice of allowance on one of our most basic patents and expect that this US patent will be published shortly. A wide range of foreign fillings for some of our basic patents has also been completed. There will be additional US and foreign patents filings as we move forward with this technology. However, with the patent protection we have already received, we can now disclose more of the motor details which were the subject of a number of questions which we did not answer at the SMMA conference.

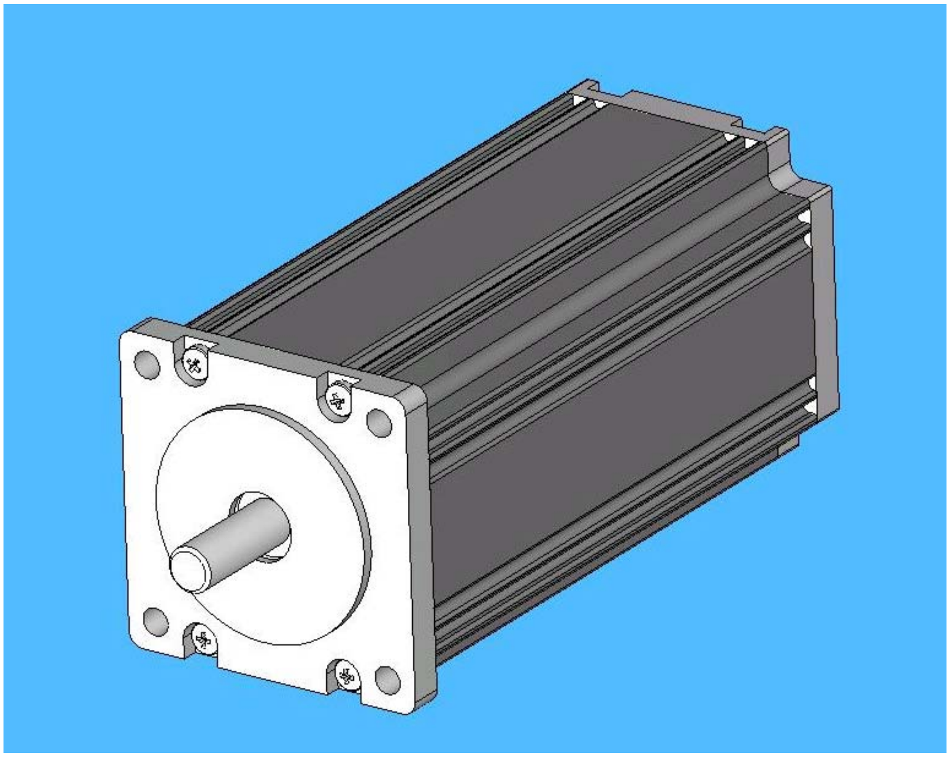
NovaTorque Motor Performance

First, some data regarding motor performance will be presented in order to show the progress we are making in developing this motor technology. NovaTorque has gone through a number of generations of engineering models and motor prototypes during the development of this motor technology. However, to keep things simple we are calling the motors presented at the SMMA show our First Generation motors. Since that show we have enhanced these motors to what we call the Enhanced First Generation motor. We have also designed a new pre-production prototype we call the Second Generation motor. Table 1 presents some relevant data on these three motors. Figures 1A and 1B are pictures of the First Generation and Enhanced First Generation motors, while Figure 1C is a drawing of a Second Generation motor.

First Generation NovaTorque Motor
Figure 1A



Enhanced First Generation NovaTorque Motor
Figure 1B



NovaTorque Second Generation Motor
Figure 1C

First Generation motors have been tested by NovaTorque and found to perform as expected and several Enhanced First Generation motors are currently being tested by well-known motor manufacturers. We currently have Second Generation prototypes ready for testing and are working on the development of the Third Generation motors, which are expected to be available later this spring. This Third Generation will have all the same physical specifications and costs of the Second Generation motor but, will have about 50 percent more torque output. The last column to the comparison chart shows the expected performance for this motor. As you can see, we have been rapidly improving the performance of our motors.

NovaTorque Motor Comparison
Table 1

Description	Units	NovaTorque 1st Generation SMMA paper	NovaTorque Enhanced 1st Generation	NovaTorque 2nd Generation Preliminary	NovaTorque 3rd Generation Estimated
Electrical					
Torque Constant	N-m/Amp	0.18	0.09	0.24	0.36
Motor Constant	N-m/√Watt	0.10	0.06	0.10	0.15
Resistance (Lead to Lead)	Ohms	3.2	2.27	5.4	5.4
Inductance (Lead to Lead)	mH	8.0	7.0	14	14
Continuous Torque (free air)	N-m	0.12	0.28	0.50	0.75
Peak Torque	N-m	0.6	0.9	1.4	2.2
Mechanical					
Diameter	mm	50	50	55	55
Length	mm	125	106	120	120
Weight	Kg	0.9	0.950	1.3	1.3
Rotor Inertia	$kg\text{-}m^2 \times 10^{-6}$	12	11	21	21
Thermal Resistance (motor mounted on 300 mm x 300 mm x 6 mm plate)	Deg C/Watt	2.8	1.3	0.8	0.7

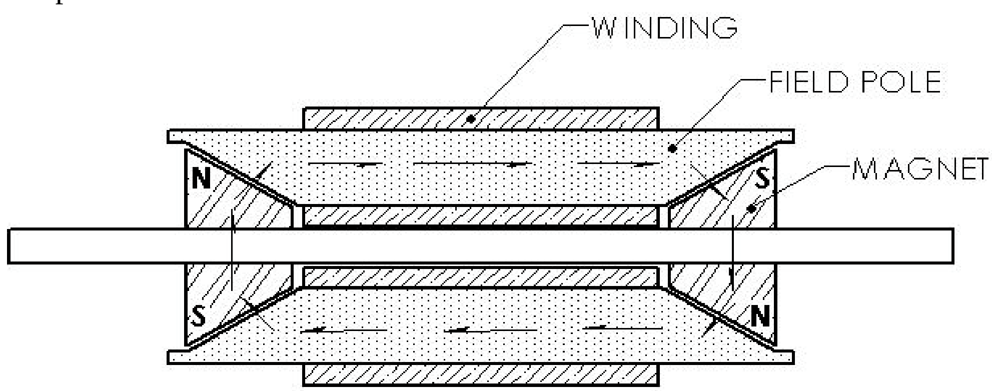
I would also like to present some comparisons with some commercially available motors. These are presented in the following chart and compared with the NovaTorque Second Generation and the estimated performance of the Third Generation motors.

NovaTorque to Commercial Motor Data Comparison
Table 2

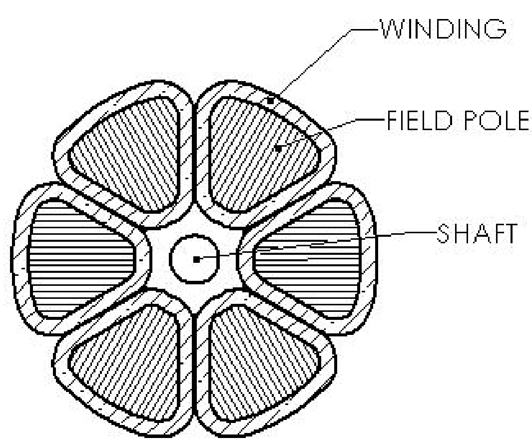
Description	Units	P Motor Frame 23	M Motor	B Motor IEC 55	NovaTorque 2nd Generation Preliminary	NovaTorque 3rd Generation Estimated
Electrical						
Torque Constant	N-m/Amp	0.055	0.043	0.38	0.24	0.36
Motor Constant	N-m/√Watt	0.07	0.071	0.128	0.10	0.15
Resistance (Lead to Lead)	Ohms	0.6	0.366	12.3	5.4	5.4
Inductance (Lead to Lead)	mH	1.4	0.49	19.9	14	14
Continuous Torque (free air)	N-m	0.34	0.29	0.45	0.50	0.75
Peak Torque	N-m	0.53	1.3	1.8	1.4	2.2
Mechanical						
Diameter	mm	57	57	55	55	55
Length	mm	76	74	102	120	120
Weight	Kg	0.84	0.74	1.1	1.3	1.3
Rotor Inertia	$kg\text{-}m^2 \times 10^{-6}$	16	13.4	6.8	21	21
Thermal Resistance	Deg C/Watt	3.1	NA	NA	0.8	0.7

The NovaTorque Motor Design

The basic design of this new motor is shown in Figure 2A and 2B. It is relatively simple in concept based on two oppositely polarized magnets with field poles forming the flux path between the magnets. Several of the benefits are immediately obvious. First, the field pole windings are a simple bobbin winding with the outside of the winding at the outside diameter of the motor. Second, there is no passive flux return path or “back iron” needed in this motor topology. Third, the flux path is mostly straight in the field pole. The flux path is also well contained and relatively uniform throughout the field pole and the coils are in close proximity to the magnets. The magnet shape shown is conical which results in a natural best packing, but this is not the only shape that can be utilized. We have patents filed on this and other similar magnet shapes and variations of this basic motor topology. While this topology is simple, there are many design details that need to be considered when designing a motor with this novel topology. A motor built with this topology exhibits some very unique and desirable characteristics. I will discuss a few of the most important of these features next.



Lengthwise Cross Section View of NovaTorque Motor
Figure 2A

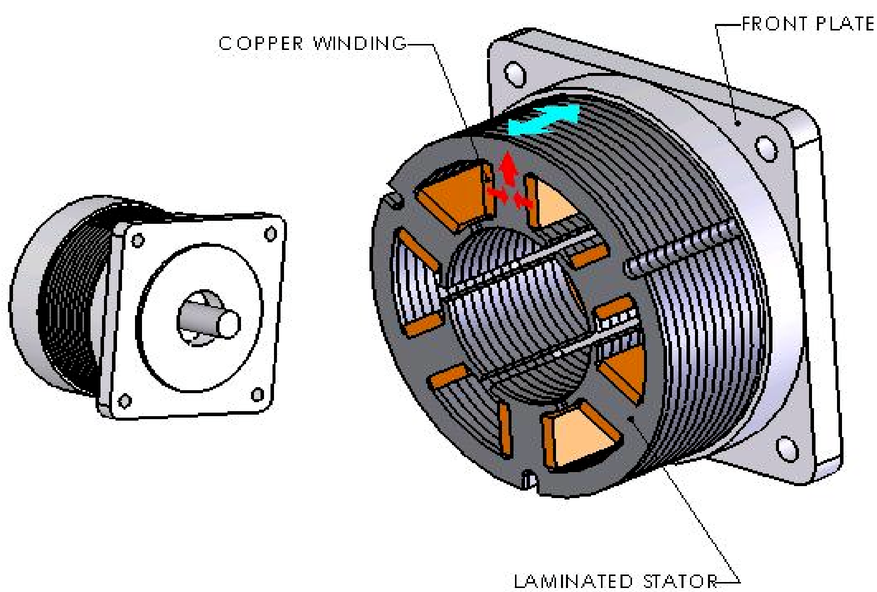


End on Cross Section View of NovaTorque Motor
Figure 2B

Thermal Performance

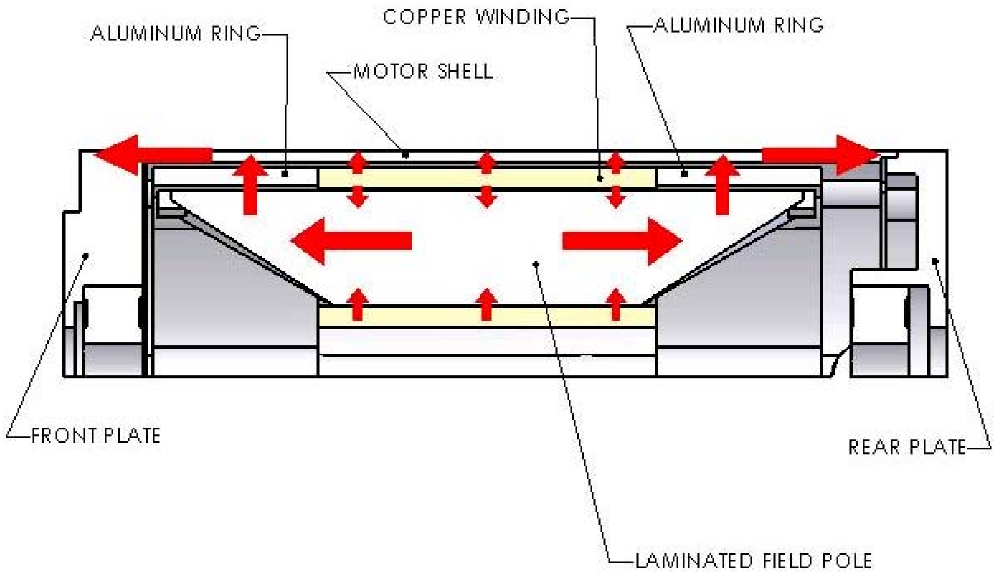
The first design aspect that I will examine is thermal performance. Thermal limitations are often the constraint that limits the maximum output torque and power that a motor can achieve. Taking a look at the thermal path of a traditional motor shown in Figure 3 versus this new motor design, shown in Figure 4, makes clear the advantages this new motor technology has with respect to thermal performance.

In a traditional motor, the winding is located in slots in a laminated field pole assembly. That configuration has some of the winding in air with very limited thermal contact with the laminations. Because of the insulated laminated structure, thermal conductivity across the lamination stack can be less than one-tenth the intrinsic thermal conductivity of the lamination material. This limits the thermal transfer from the center of the motor to the end plates. In addition, it is difficult to wind with a good packing factor when winding in slots. The thermal paths in a conventional motor are shown below in Figure 3.



Thermal Path for a Conventional Motor
Figure 3

One of the most important characteristics of the NovaTorque motor is its excellent thermal conductivity path from the coil to the external case (see Figure 4). Because of the way the coil is wound, a significant portion of the outside of the coil can be directly coupled to the external aluminum case. Because of the high thermal conductivity of aluminum and the fact that the outside case is continuous, heat is readily transferred to the ends of the case. Because the laminations run axially, heat is also easily carried from the insides of the coil and down the field pole to where it can easily be coupled to the outside case and motor end plates. With the simple winding for the coil, coils can be wound with a filler material that enhances thermal conductivity. This simple winding geometry also allows a near perfect wind, which leads to more uniform temperature distribution inside the coil. The aspect ratio of the coil also provides a large surface contact area both on the coil ID and OD and, in general, leads to relatively thin winding depth. In addition, there are no wasted end turns or turns that are not in good thermal contact with the coil structure.

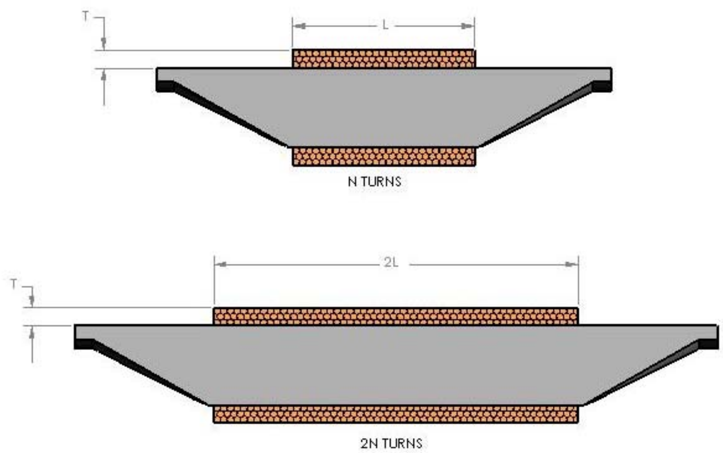


NovaTorque Motor Thermal Paths
Figure 4

We have also taken advantage of thermal modeling to make a number of small changes to the overall case design, which improves both conducted and free air thermal performance. This better thermal performance results in lower coil operating temperatures when running at equivalent power levels. Those lower operating temperatures in turn yield better reliability and allow more design flexibility with respect to material selection which can result in lower manufacturing costs.

The Effects of Varying Coil Length

A second unique characteristic of the NovaTorque motor design is that the thermal performance and overall motor efficiency can be easily varied by changing only the coil length of the motor without modifying any other of the motor components. To better understand this feature, consider the following motor example as shown in Figure 5. If we design a motor to have a coil length of "L", this coil will have "N" turns with resistance of "R" and operate at "I" amperes of current to produce "T" torque. If we now double "L" so that the coil length is "2L", the number of turns will be "2N" with a resistance of "2R" and the current necessary to produce "T" torque will be one-half "I" or "0.5I" since there are "2N" turns. The power in the first case will be "I squared times R" and the power in the second case is "(0.5I) squared times 2R", or equivalently "one-half I squared R".



Coil Length	L
Coil Thickness	t
Resistance	R
Turns	N
Amperes	I
Power	I^2R
Coil Length	2L
Coil Thickness	t
Resistance	2R
Turns	2N
Amperes	0.5I
Power	$0.5I^2R$

Changing Coil Length in the NovaTorque Motor
Figure 5

By doubling the coil length (without changing the coil diameter) the power required to produce the exact same torque has been cut in half! The flux path design of the NovaTorque motor is not materially affected by this increase in field pole length. No changes are necessary to the magnets or pole shoes of the field poles, only the coil and core length needs to be altered. So to improve efficiency, the only costs are the additional copper and steel required to extend the coil length. The only change to the motor is a length change. If the length of the coil is changed to 3L the power drops to $0.3333I^2R$. We have modeled motors where the coil length has been extended 5 to 10 times its original length and the magnetics show very little change in characteristics. With such long extended motors, high performance with respect to torque and speed can be obtained with remarkably reduced currents.

As should be readily apparent, if instead of dropping the current to reduce the power dissipation and increase efficiency, the current is set to keep the same value of power dissipation in the motor with the longer length coils, a higher output torque can be obtained. This approach to producing more torque will continue to work until the magnetic saturation of the field poles is reached.

Other Notable Characteristics

A few of other notable features of this new design include:

First, to the motor drive, this new motor looks like a standard three-phase brushless DC motor. It can be connected either in the "Y" or Delta configurations and will run from any conventional motor drive. It can be operated sensorless, with Hall devices or with an encoder providing commutation tracks. The only difference from the drive standpoint is that with the winding flexibility of the coil in the NovaTorque motor, motors can be wound with very high K_e values and associated inductance values or with very low K_e values with almost no inductance. These extremes are not readily available with conventional motors. The very low K_e values may be an advantage with battery powered devices and very low inductance windings are an excellent fit for generator applications.

The magnets we have used so far are monolithic. This means that they are simple to assemble onto the shaft and that they are capable of very high rotation speeds. This inherent high speed capability is further enhanced by the low magnetic eddy current and hysteresis losses that this motor can be built to achieve.

The magnets can be any of the high coercivity materials such as Neodymium Iron, Samarium Cobalt or Ceramic (ferrite). The choice of magnet material depends on cost objectives, size constraints and performance goals such as operating temperature. An interesting aspect of this design is that only the motor length changes to achieve the same operating performance with different energy product magnet materials. As expected, the higher the energy product of the magnet, the shorter the motor becomes.

Another performance enhancing characteristic is the mostly straight flux path in the field poles. This leads to advantages that can be gained by using grain-oriented steels for the field poles. The power transformer industry has widely adopted the use of grain-oriented steels to improve efficiency. The motor industry has in general been prevented from using grain-oriented steels because of the circular flux path present in conventional motor designs. The NovaTorque topology can use either oriented or non-oriented materials

Manufacturing Cost Advantages

Some of the manufacturing cost issues of this new motor design will be addressed next. From the start we have been looking for a new motor design which could achieve good performance with a low production cost. We feel we have achieved this in our current motor design. The coil is about as simple as can be developed and can be produced in volume at high speeds with low cost machinery. This also allows for easy customization for various customer voltage and current requirements. The high packing factor, excellent material utilization and the elimination of end turns lead to optimum coil costing.

The straight field poles allow for multiple approaches in manufacturing from net shaped pressed metal parts to conventional stamped laminations which are assembled to produce variable cross section geometries. In addition NovaTorque is developing several other novel production techniques which take advantage of certain characteristics of this new motor design. The fact that the field poles are relatively straight and can be manufactured individually can result in less steel waste in the production process. The uniform magnetic loading of the field poles also means that all the steel in the motor can be fully utilized.

The ability of this new design to work well even with large magnetic air gaps reduces the need for holding close tolerances and opens up other manufacturing possibilities that help reduce costs for various components.

The external shell, while not absolutely necessary, is a simple aluminum extruded tube which is cut to length and greatly enhances the thermal characteristics of this motor while adding very little to the overall motor cost. The end plates can be manufactured with the same processes used with conventional motors.

The motor shaft can be constructed out of either magnetic or nonmagnetic materials, such as low cost stainless steels or even lower cost cold rolled steel rod.

The magnets can be any high coercivity magnet and, while sintered Neodymium magnets are preferred, bonded or ceramic magnets can be used. The rotor is simple to construct with the monolithic magnets.

The overall assembly of the motor can utilize either the more conventional circular tube configuration or be split along the lengthwise axis into half shells, as in our First Generation prototypes. This creates options for assembling this motor with different and possibly less costly manufacturing techniques.

Overall, this new motor design should be economical to produce in both large and small volumes. NovaTorque is currently developing a prototype manufacturing line in California.

Improved Motor Efficiency

I will close by examining the NovaTorque motor design with respect to motor efficiency. By now it should be apparent that this new motor design offers a number of advantageous characteristics when it comes to high operating efficiency. To start with, the ability to extend the coil winding length opens up a new design opportunity with respect to the tradeoff of motor cost and efficiency. This factor, in combination with better coil packing, the wide range of wire sizes and shapes that can be utilized, and the elimination of end turns, means that the coil can be operated at its maximum possible efficiency point.

In addition, the straight flux paths and the elimination of back iron means that the magnetic path is highly efficient. The ability to use grain oriented materials and the options available for field pole construction can yield lower eddy current and hysteresis losses. The design of this motor also places the coils in close proximity to the magnets, thus reducing stray magnetic field losses.

The highly optimized thermal path means that the motor can readily transfer the generated heat out to the external world. Efficiency is enhanced because the coil operation temperatures are lower, thereby reducing the coil temperature rise and the resultant rise in coil resistance.

All of the above factors combined with a motor that has good operating torque with respect to size and is fully capable of high rotation speeds results in a motor with very high output power capability.

The methods used in the NovaTorque motor to achieve higher efficiency are very different from the current approach, which is generally to move to a larger motor frame size or, alternatively, to incorporate much more costly materials. We expect to see many applications where the higher efficiency NovaTorque motor is chosen since it will be cost competitive with traditional motors now available.

Conclusion

NovaTorque has developed a new motor technology with significant inherent benefits over conventional designs. The technology has better power efficiency and thermal dissipation characteristics than current motors. It can also offer better material utilization during manufacturing. Our near term goal is to replace existing brushless DC motors in a wide range of applications by offering a motor with higher efficiency, better performance and lower manufacturing costs than currently available motors. A number of additional improvements are currently being worked on or are being planned. We expect to transition this technology to industry in 2006 and see it expanding rapidly in the next few years. NovaTorque expects to be working in conjunction with licensees to further develop this technology as it is commercialized.

NovaTorque will also address the generator, DC brush and line-operated AC motor markets as we further develop this technology. We at NovaTorque are developing this motor technology in hopes that it will see widespread adoption to help improve the energy efficiency of motors in a wide range of applications including appliances, industrial controls and automobiles. We plan to develop and to license this technology widely and we will be protecting our rights and those of our licensees under our patents.