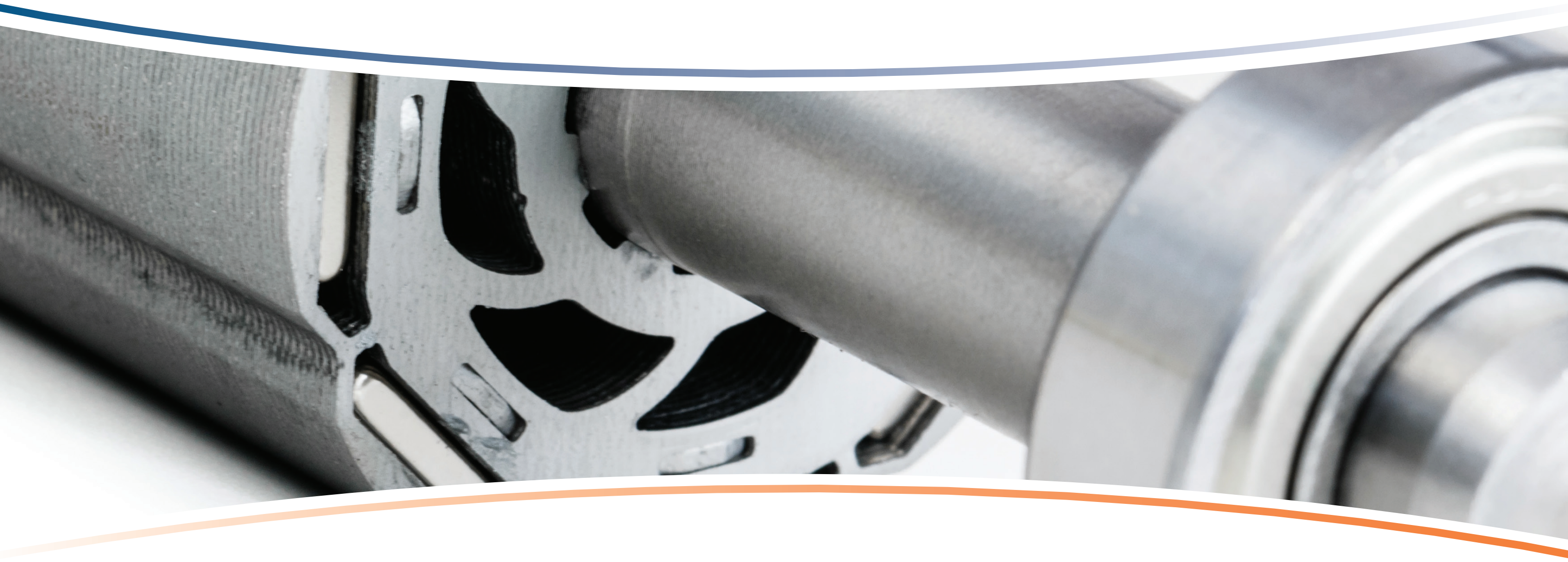

Magnet Retention in Permanent Magnet DC Motors – Part II

Configuration and Material Selection

For more than 50 years, Windings has provided engineered electromagnetic solutions for critical applications across a wide variety of industries. As a full-service provider, Windings is a leader in the engineering, optimization and manufacturing of custom electric motors, generators and related components including rotors, stators, lamination stacks and insulation systems.

High Performance Electric Motors

Permanent magnet synchronous motors (PMSMs) provide excellent performance in torque density, energy efficiency, and controllability. Mounting permanent magnets to the rotor of a brushless DC (BLDC) motor reduces rotor inertia and allows higher acceleration. This topology is well suited for high speed applications but is limited by how well the magnets can be kept secured in place on the rotor.

Rare Earth Magnets

Rare earth magnets, first developed in the 1960s, have a misleading name. The elements used, such as neodymium, samarium, and cobalt, are relatively common around the world. But their distribution is diffuse; no large deposits offer easy access. That makes mining time-consuming and labor-intensive, and therefore expensive.

Because materials lose their magnetic properties at extremely high temperatures, rare earth magnets are formed by sintering—applying moderate heat and pressure to force materials into a shape. The results have stronger magnetic properties than alnico alloys, ceramic ferrites, or magnetite, but are relatively brittle. This creates additional challenges for keeping the magnets intact and in place at high rotational speeds.

Motors used in energy recovery systems and electric turbochargers can reach top rotational speeds in excess of 100,000 rpm. Any permanent magnet rotor with a rated top speed of more than 10,000 rpm should incorporate a secondary, redundant magnet retention system.

Retention Methods and Materials

PMSM motor manufacturers quickly learned that simple adhesives were insufficient in securing the magnets to the rotor at high speeds or high temperatures; a backup system on the magnet OD was necessary as a precaution against failure of the primary magnet-to-rotor adhesive bond failure. Some designs feature reverse keystone slots in the outer surface of the rotor. Flanged magnets slide into these slots and are contained at either end. These interior magnet designs solve the retention problem, but increased manufacturing complexity drives up cost and negatively impacts performance. Consequently, very few designs incorporate a keystone magnet retention system.

The distance between the rotor and stator, referred to as the air gap, has a significant impact on performance and presents a design engineering challenge for manufacturers. The closer the magnets are located to the windings, the higher torque output produced by the motor. Any material added between the rotor magnets and the stator windings increases that distance and thus decreases power output of the motor.

To minimize the air gap and still secure the magnets, a retention method must be extremely thin, strong, and inflexible. It must withstand sudden torque spikes incurred during rapid acceleration and deceleration, as well as sustained centrifugal forces at higher speeds, while maintaining its properties across a broad range of temperatures.

Material Properties and Priorities

In concept, manufacturers could use virtually any material to hold the magnets in place at high rotational speeds. In practice, only a few materials have the properties necessary to meet the strenuous requirements of a PMSM motor: metal alloy sleeves and synthetic fiber roving. Both share the benefits of material stability and machine safety, but they vary in performance characteristics and differ significantly in manufacturing processes. Engineers measure these differences through theoretical and numerical analyses. As with every other design engineering factor, choosing between the two involves trade-offs.

For each material considered, design engineers evaluate the following properties:

- Yield Strength
- Density
- Thermal Conductivity
- Resistivity
- Maximum Operating Temperature

To offer PMSMs with confidence in their reliability and safety, manufacturers expect the finished product to exhibit all these properties at 120 percent of their rated top speed in all specified applications and environmental conditions.

Metal Alloy Sleeves

For manufacturers, metals are known quantities. Their characteristics are well documented, and the means of forming them are long-established practices. This familiarity makes metal alloy sleeves a practical choice for magnet retention—although size is a limiting factor. The most common metal alloys used in retention sleeves are ANSI 361L stainless steel, Ti6A14V titanium alloy, and Inconel 718.

Yield strength and material density determine how well a sleeve material will perform under stress. Stainless steel grades similar to 361L are the lowest-cost option but have low yield strength and high conductivity compared to the other alloys. This can also be expressed in terms of specific strength (yield strength divided by material density). Materials with higher yield strength and higher material density allow higher rotational speeds.

Thermal conductivity becomes a concern at high rotational speeds in demanding environments, such as aerospace applications. If a sleeve material traps heat generated by the rotor, it can affect machine performance and safety. **Thermal expansion** during use also creates operational risks.

Resistivity is the degree to which a material resists electric current. Because electric motors are based on the relationship between rotor and stator, any material between them may affect its output. This is further complicated by the effect of a conductive material in motion; eddy currents losses generated within the air gap can reduce efficiency and increase internal heat.

Maximum operating temperature is specified by design engineers for a given application. In turn, electric motors must provide the desired power output at the specified environmental temperature, accounting for heat gains resulting from thermal conductivity and resistivity.

Manufacturability is one additional factor that determines material selection. The most common method of fitting metal alloy sleeves over permanent magnet rotors is to machine the inner diameter of the sleeve to closely match the outer diameter of the rotor, create a heat differential between the two parts (heating the sleeve, cooling the rotor, or both), and assembling them while the sleeve is slightly expanded. Once the assembled unit reaches a stable temperature, the outer surface of the sleeve may require further machining to meet specifications of the stator.

Metal alloy sleeves can be made separately from the rotors before assembly. This provides two advantages for manufacturers. One is that sleeves and rotors are both machined parts; the manufacturer doesn't need to create separate capabilities to use them; the other is that sleeves can be made elsewhere, allowing the maker to outsource one part of production if necessary.

Unfortunately manufacturing and machining difficulties limit the practical size of metal alloy sleeves. As rotor diameter or length increase, maintaining the necessary tight tolerances using the metal sleeve method becomes extremely difficult for even the most advanced manufacturers. Also, some metal alloys are very expensive, have limited availability based on size, or are very difficult to grind to final dimensions.

Synthetic Fiber Roving

Another method of magnet retention is roving—the use of high-tension fibers wrapped around the magnet circumference. Several types of synthetic fibers have been used for roving, including fiberglass reinforced plastic, Kevlar® and carbon fiber, which is being used increasingly in high performance applications.

Roving material properties are similar but not identical. Design engineers select one over another based on the requirements of the project at hand. Factors that inform a buying decision can include technical specifications, previous experience, cost, or availability.

Yield strength and density depend on the size and number of fiber tows (strands) applied. Synthetic roving involves the winding of multi-filament tows directly over the rotor. This takes place under conditions in which temperature, tension, and time are tightly controlled.

Thermal conductivity is lower for synthetic materials than for metal alloy sleeves; it dissipates heat poorly. The greater the rotor coverage by roving, the higher the potential for heat retention. Once cured, roving has a very low coefficient of **thermal expansion**.

Resistivity, measured by finite element analysis, is much lower for roving than metal sleeves. It therefore has low eddy current losses.

Maximum operating temperature is determined by application requirements, not the properties of the electric motor or its parts. But where metal alloy sleeves may trap or generate heat, roving does not.

Manufacturability may be the most important difference between these two magnet retention methods. Carbon fiber roving must be heated to its glass–liquid transition temperature but not reach its melting temperature. The material itself can be very expensive—and, because it must be applied in-situ, carbon fiber roving requires additional manufacturing capabilities.

Summary

Surface mounted rare earth magnets help BLDC motors deliver high performance in specialized applications. Design engineers use magnet retention systems to ensure reliable and safe operation at rotational speeds above 10,000 rpm. Metal alloy sleeves can be made with the same methods as rotors and stators—that is, primarily by machining. But their use is limited by size. Carbon fiber roving requires costly materials and additional manufacturing capabilities but provides effective magnet retention at a greater range of rotor sizes.

The team at Windings views carbon fiber roving as the more versatile technology and is committed to continued leadership in magnet retention research and manufacturing.

For further information, please contact us!

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