Brushless PM-Motors Speed Ahead

Dan Jones

There are more brushless PM motors being made every day. These brushless PM motors are smaller in size — i.e., less than 50 watts in power output found in hard-disk drives, CD and DVD players and many portable medical devices. Servo systems with brushless PM motors ranging from 50 watts to 50 kilowatts are now challenging the larger electric motor applications. A few manufacturers have pushed brushless PM motors above 200 Kw.

History

The development of this motor type was initially driven by the U.S. government and the military. Brushed DC motors suffered from extreme wear at altitudes above 30,000 feet during World War Two. As the U.S. was launched into the Space Age in 1958, there was a critical need for an electric motor that ran on DC batteries and eliminated carbon brushes. From 1963 through 1968, the brushless PM motor developed rapidly, driven by space aircraft needs. Concurrently, two other technology developments enhanced the brushless PM motor's major improvements: the development of electronic drives with reliable electronic commutation, followed by the creation of the first rare earth magnet — Samarium cobalt — spurred the use of these brushless PM motors in the Apollo Lunar Module. By 1965 space-qualified motors from 1 watt to 370 watts were in use.

In 1968 Siemens used a brushless PM motor with an electronic drive system to be used in battery powered tape recorders. They sold the brushless system to U.S. Tape Recorders for the incredible unheard of price of $25. The Japanese motor suppliers joined the Europeans (plus some emerging U.S. motor manufacturers). By 1982 the direct drive brushless PM motor had replaced a belt driven AC induction motor in IBM's first major electric hard disk drive machine. It stored an incredibly high 50 megawatts (at that time). A few years before a number of machine tools began using much larger brushless PM motors with transistor drives. The last 30 years has seen the brushless PM motor evolve into a major player in thousands of applications.

Measuring Up

The brushless PM motor measures up to other motor types quite well. It is a synchronous motor with linear-torque-speed-current performance (Fig. 1) voltage drive's torque vs. speed profile. Its peak torque capability exceeds any other motor type. Raising the input voltage proportionately increases motor speed. The rotor inertia is low in conventional inner rotor brushless motor types, thereby accelerating and decelerating application loads faster than other motor types. It possesses a higher torque and power density capability. It also possesses a higher intrinsic power efficiency. If it wasn't for its higher unit cost and the need for electronic commutation it would be in many more applications today. While the brushless PM motor will instantly draw more current, it rapidly settles down to its rated levels. Motor life is long usually limited by bearing problems. Induction motors must limit their peak or inrush current by using a soft starting circuit

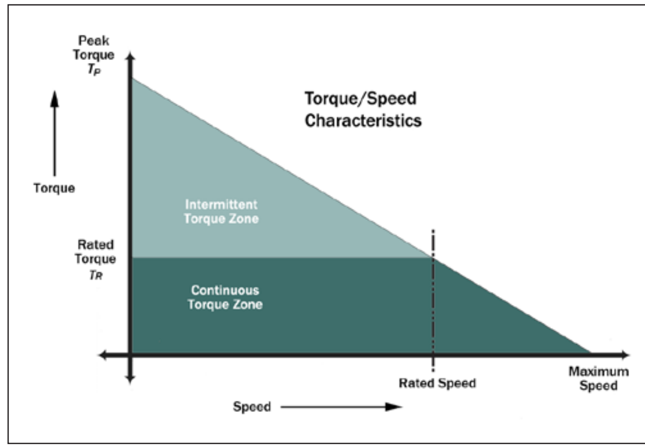

Figure 1 Typical BLPM motor torque-speed curve with rated and peak torque zones.

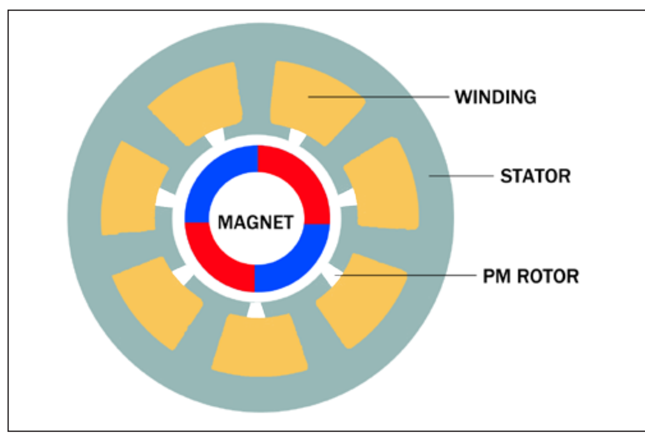

Figure 2 Traditional inner rotor slotted BLPM motor.

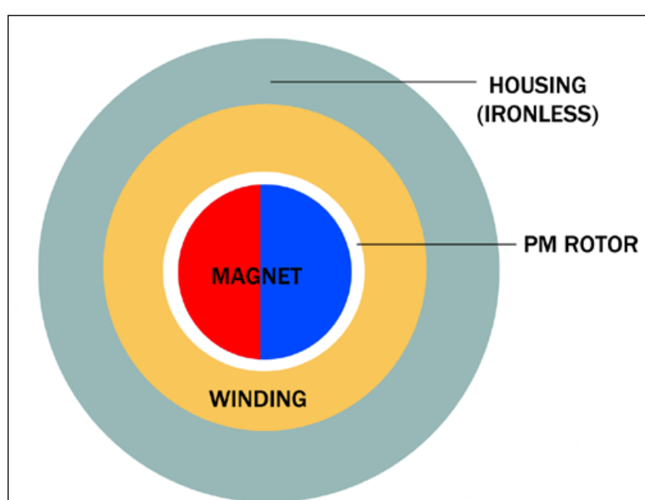

Figure 3 Slotless or ironless BLPM motor.

that slows, and limits current build up. The brush dc motor will experience higher current arcing with repeated application starts and stops. The brushless PM motor makes an excellent long-life-position servo with proper feedback devices.

Motor Shapes Match Customer Needs

Brushless PM motors have morphed into a myriad of configurations; they are also known by many names: brushless dc motors; brushless PMAC motors; brushless PM motors; permanent magnet synchronous motors (PMSM); and electronically controlled (or commutated) motors.

The initial motor configuration developed was the radial surface magnet PM motor type (Fig. 2)—still the most popular type used today. The availability of the strong, rare earth magnets (samarium cobalt and later, neodymium-iron-boron) led to the development of the ironless or slotless/brushless PM motors (Fig. 3). This motor type eliminated the stator magnetic steel tooth structure and utilized the rare earth's higher air gap flux to produce lower sufficient torque. Eddy current and hysteresis losses within the ironless motor were virtually eliminated. Applications requiring smooth torque and speed in many medical and instrumentation applications use the ironless type.

A more recent development was the buried magnet—or internal permanent magnet (IPM)—motor (Fig. 4). It was developed to provide more shaft torque in the same package size as its surface magnet counterpart. Two torques (a permanent magnet torque and a reluctance torque) are created and are added vectorially to achieve the higher torques. This motor type has been utilized as a next-generation replacement in most recent brushless PM servo motor products.

Another motor with magnets located radially on the rotor surface is the large pancake-shaped, direct drive rotary (DDR) brushless PM motor (Fig. 5). They use the principle of large outside motor diameters to significantly increase the motor's torque capability. Most DDR motors have large rotor IDs to reduce the motor's overall weight. They can grow as large as 39" OD and develop peak torques approaching 12,000 Nm (8,850 lb-ft). Applications range from large machine tool table drives to telescope positioners where position accuracy is critical. The DDR motor can be supplied as a housed or frameless motor.

The frameless DDR motor can be assembled directly on the machine application's major shaft, thereby eliminating any coupling losses. Ignoring some new IPM designs, the DDR motor has load or rated speeds below 1,000 rpm. Some larger DDR motors operate at speeds below 100 rpm.

The axial flux, brushless PM motor has located its magnets on the motor face; it has a number of shapes with the more popular single- and dual-stator windings facing the rotating magnet structure. This configuration is being used in automotive and other traction applications. It typically provides both a high-peak torque and a high-speed capability.

The various brushless PM motor configurations described are currently used in today's applications. Other new motor types just moving into production include the transverse flux and hybrid motor types that use permanent magnets in combination with other motor technologies.

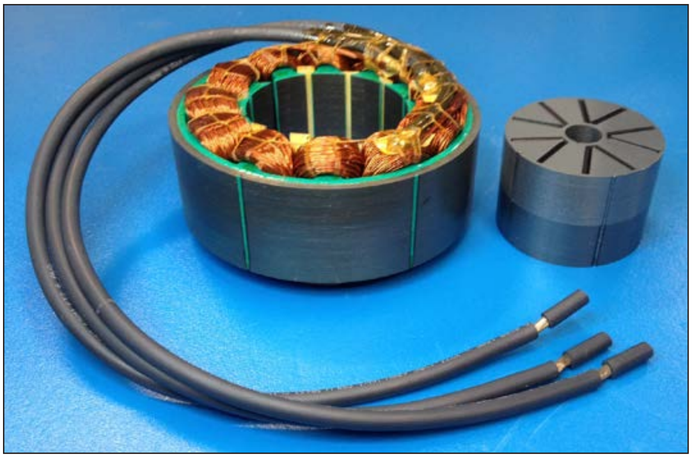

Figure 4 Buried magnet or internal PM (IPM) BLPM motor. (courtesy Applimotion)

Figure 5 Direct Drive Rotary (DDR) BLPM Motor (frameless type). (courtesy Applimotion)

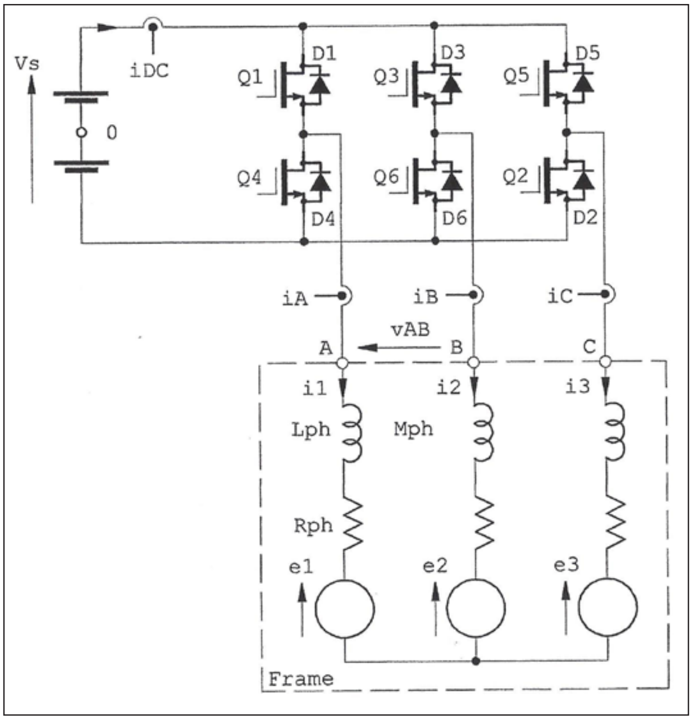

Figure 6 Three-phase BLPM motor and driver in 6-step H ridge configuration (Courtesy of SPEED, CD-adapco).

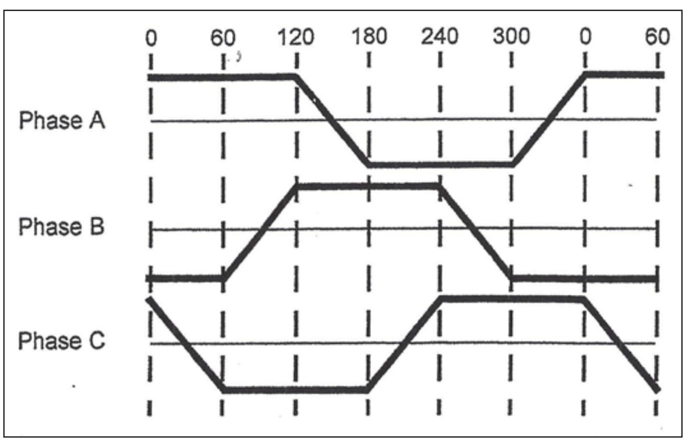

Figure 7 BLPM motor trapezoidal back EMF. (Used in fans, blowers, pumps, toys, lawn mowers, etc.)

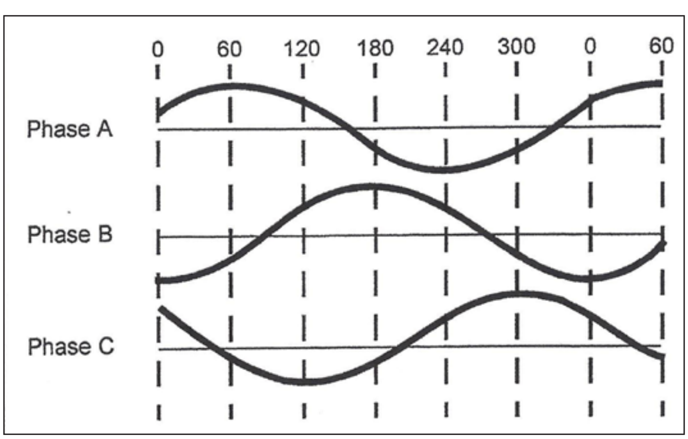

Figure 8 BLPM motor sine wave back EMF. (Used in machine tools, grinders, and many other position servo motor applications.)

Electronic Control

The brushless PM motor requires some means of switching or commutating the motor's stator windings at the correct position to ensure continuous motion. Hall devices or commutating encoders are typical devices used to locate the rotor position to ensure smooth commutation. For variable speed applications the motor's internal back emf signals can be utilized. With the exception of smaller motor types, an overwhelming number of larger brushless PM motors are 3-phase wye or delta-connected inverter drives. For four-quadrant operation, six power FETs or IBGTs in an inverter configuration are used to ensure servo-like operation (Fig. 6).

There are two major drive strategies used to control a brushless PM motor: they are designated square wave current, and trapezoidal torque vs. sine wave current and sine wave torque profiles. The square wave current drives are used in ticket printers, fans and blowers. The sine wave current drives are utilized in more demanding machine tool grinding and machines where torque ripple is minimized.

But the brushless PM motor's back emf wave forms must be designed in a trapezoidal (Fig. 7) or sine wave (Fig. 8) configuration. The brushless PM motor's back emf must be shaped by various motor design choices to achieve the trapezoidal wave form or the sinusoidal wave form and then matched to the inverter drive's appropriate wave forms to achieve the application's required performance.

Double-Digit Growth

Two major-market needs continue to propel brushless PM motor growth in both current and new applications:

- The first is the continued evolution of power and control electronics in the form of ICs and power modules. Drive and control costs for brushless PM motors under one Kilowatt (1.37 hp) have dropped dramatically over the past decade. The brushless PM motor and associated drive are moving into the cost-sensitive heating, ventilation and air conditioning (HVAC) market.
- The second need is the establishment of new power efficiency requirements by the U.S. government that fosters the use of brushless PM motors. The only dark cloud looming over brushless PM motor growth is the availability of rare earth magnets for the higher-performance brushless PM motors at "reasonable" prices. **PTE**

Dan Jones has since 1962 worked as chief and staff engineer with numerous companies. Whether as direct employee or consultant—he has applied his technical skills and experience working with and writing about DC, step, AC, brush and brushless motors; electronic drives, and on control systems in applications for the military, industrial and commercial markets. Jones is a former president of the Association of International Motion Engineers (AIME), and has served on the board of directors of the Small Motor Manufacturers Association (SMMA). Jones is president of Incremotion Associates, a firm combining the capabilities of engineering and marketing with a direct focus upon the motion control and power conversion industries.