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Novel windings elevate brushless dc motor efficiency

Greg Graham, Gerry Yankie and Dan Jones report on a recent development in brushless permanent magnet dc motor technology that is claimed to take these high-efficiency motors to even higher levels of performance

Brushless permanent magnet (PM) motors lead all electric motor types in terms of efficiency and power per motor volume. The ironless family of small brushless PM motors is the best example today of high performance, high efficiency electric motors. However, with the development of a new 'thick coil' armature technology by the US company, ThinGap, an even higher level of performance can be achieved.

Thick coil technology can be utilised equally in PM ironless brushed and brushless motors. Electric motor manufacturers have traditionally employed round insulated copper wire in armatures for both iron core and ironless brushed dc motors. While ironless dc motors with round insulated copper wire overcome many of the weaknesses of conventional iron core motors, they are limited by the copper packing density and the larger magnetic air gaps. A thick coil ironless armature is mechanically more rugged due to its dense and rigid structure. The lower winding resistance results in higher motor efficiency, and the smaller air gap leads to increased flux density and hence to an increase in the torque developed by the motor.

The ironless core family of dc brushless motors divides into fixed and rotating return path configurations (Figure 1). Only the construction that possesses a fixed magnetic field via a rotating return path is a complete brushless dc motor equivalent to the ironless brushed motor configuration. All other brushless dc motor types (iron core and ironless) have a rotating magnetic field, because the PM rotor rotates and the magnetic return path does not. This condition of changing magnetic flux linkages creates hysteresis, contributing to the motor's internal losses. ThinGap's construction has no relative motion between rotor and housing return path. The overall structure is shaped like a double rotating cup, the thick coil stator providing a rugged mechanical structure, with low electrical resistance and very low inductance.

The new rotating return path brushless dc ironless motor configuration is focused on applications with larger inertia and on applications that will benefit from the elimination of gearboxes or gear trains. The ThinGap family possesses rotor inertias five to ten times higher than today's iron core versions. The much higher continuous torque capabilities are also important in direct drive applications or those that use lower ratio gear trains. The best planetary gear trains offer 95 to 97% transmission efficiency per gear train pass or stage. Using them subtracts from the high system efficiencies established by the ThinGap motor-driver package. Higher peak torque and power values can be obtained in ironless brushed and brushless dc motors. There is no magnetic saturation of the stator and rotor soft iron and steel materials due to high peak currents.

In a typical application, a ThinGap ironless rotating return path brushless dc motor with thick coil technology has been installed in an electric discharge machining (EDM) system. The 11kg spindle head and onboard cutting tool needs to move very smoothly and slowly during the cutting phase and then rapidly retract when cutting is completed. There is no gearbox; the motor is directly connected to the spindle drive lead screw. The servo system is completed by an Agile Systems three-axis driver/controller package and MicroE laser optical encoder, which achieves a resolution of approximately 40 nanometres. The combination has proved very successful, increasing machine performance and productivity, and improving operator safety.

Appendix:

Higher efficiency means lower losses

A perfect motor would convert all its electric power input to power output. Unfortunately, there is no motor today that achieves 100% electric input to mechanical output conversion. There are always losses inside the motor that reduce overall motor efficiency, and the design engineer's task is to reduce these losses significantly. Motor internal losses can be listed as follows:

- Copper winding (function of conductivity of copper and the resistance of the stator coils)
- Coulomb friction (brushes, bearings, shaft seals, etc)
- Viscous friction (bearing lubrication, certain material damping characteristics as a function of speed)
- Hysteresis (magnetic memory in motor's soft iron parts)
- Eddy currents (primarily soft iron losses caused by material type and thickness of laminations, material induction levels and commutation frequencies. Losses are proportional to the square of the speed)
- Windage (aerodynamic effects due to motor geometry and speed)

In most applications the copper winding losses are the largest. They are calculated by multiplying the square of the input current by the stator's winding resistance. Only when the motor shaft speeds exceed 10,000rpm do eddy current losses begin to become significant.

For a brushless permanent magnet dc motor, copper losses are minimal thanks to the very low winding resistance. Ball bearings overcome coulomb friction losses, while viscous friction is generally low. There are no hysteresis losses and no eddy currents, as there are no moving iron or steel structures. Windage is also low, thanks to the homogeneous structure within a smaller air gap.

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