MSD MOTION SYSTEM DESIGN
Solution snapshot
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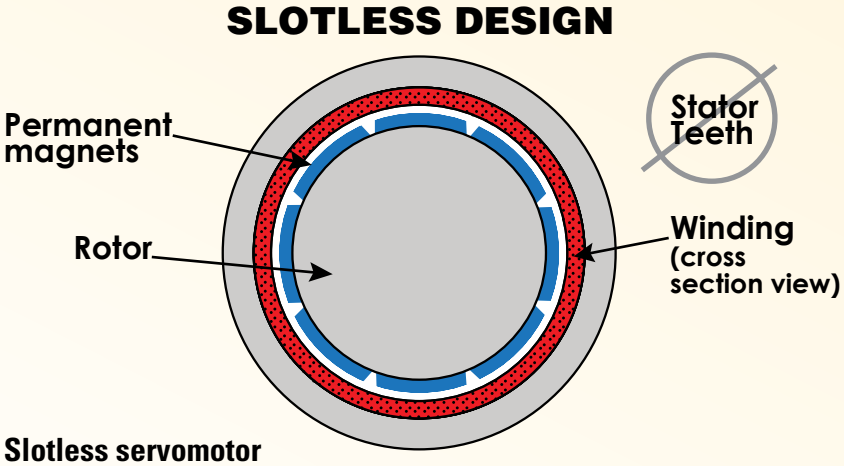
Improve machine performance with slotless motors

Many design engineers working in the field of motion control are familiar with slotless motor designs, but may wonder if these specialized motors significantly improve machine performance. In many cases, they can. Here's why: Slotless motors offer more torque per frame size, produce more power, run smoother, and achieve higher speeds than their slotted counterparts. Following is a closer look at the technology, plus realistic tips on evaluating whether or not your next application could benefit from a slotless motor.

Slotted servomotor construction

A traditional slotted brushless servomotor has a stator made of stamped metal sections called laminations that are stacked to form teeth. Wire is wrapped around these teeth; when current flows in the wire, an electromagnet is created in the stator. Permanent magnets are fixed to the rotor.



Slotless servomotor construction

As in slotted motors, the permanent magnets in slotless servomotors are fixed to the rotor. However, a slotless motor's stator is built without teeth. Motor windings are wrapped around a temporary mold and then encapsulated to hold them in place. Eliminating the teeth yields many benefits.

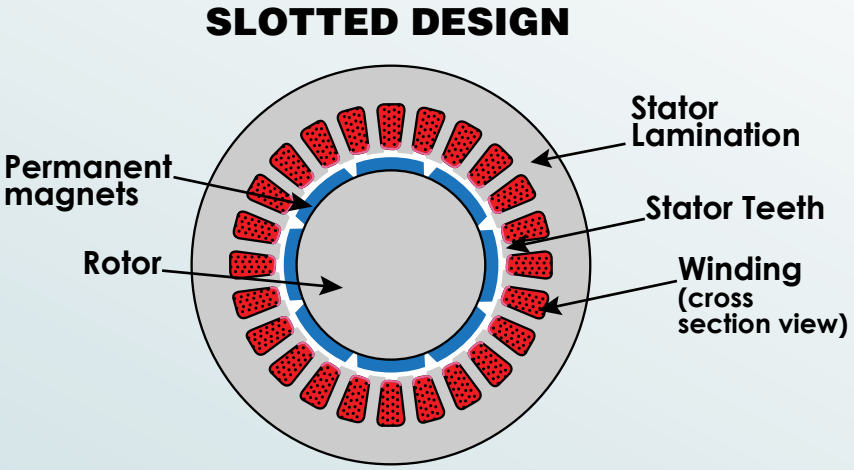
Benefits of slotless motors

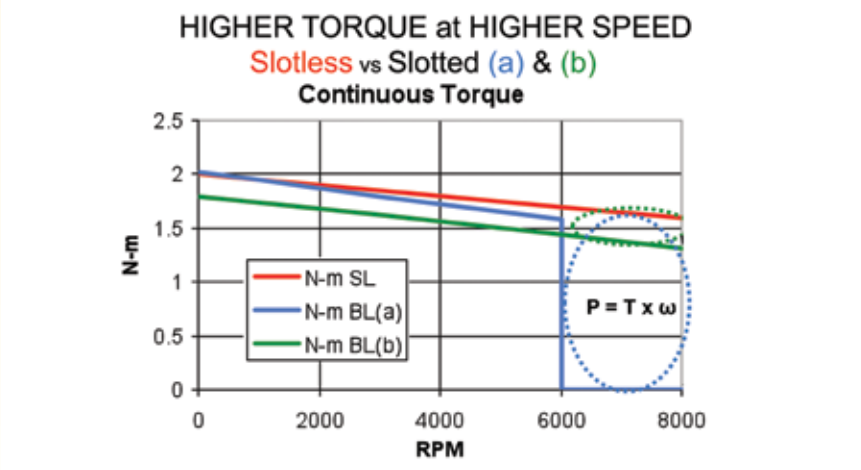
Higher torque: A slotless motor's redesigned stator allows the rotor to be significantly larger. Because torque increases proportionally to rotor diameter, torque from a given slotless motor is significantly higher than that from a similarly sized traditional slotted motor. Due to the absence of teeth, the area available for windings is also greater — which further increases torque. More specifically, torque at a given speed can be increased by 10 to 25% compared to a slotted motor.

Higher speed: As the magnets pass by the teeth in a slotted motor, a change or modulation in the magnetic flux is created, which in turn induces voltage in the surface of the magnets per Faraday's Law — $e = d\phi/dt$. These magnets are conductive, so a current flows in them. These *Eddy currents*, as they're called, increase exponentially with speed and create heat in the magnets, which in turn diminishes their strength. Because slotless motors have no teeth, they can achieve speeds in excess of 32,000 rpm.

Higher power: Power is calculated by multiplying torque by speed. Because a slotless motor outputs both higher speeds and torques, it can produce more than twice (2x) the power of a slotted motor.

Smoother motion: As the magnets on a slotted motor's rotor move past the stator's iron teeth, they are magnetically attracted to the teeth. This





This torque vs. speed curve compares a standard slotless motor (in red) with two standard brushless (slotted) motors from two different premium suppliers. The curve for the BL(a) motor (in blue) achieves 8% less torque and power at 6,000 rpm, and has 0 torque and power at 8,000 rpm. It is also 47% larger because a bigger frame size is required to produce this performance. The curve for the BL(b) motor (in green) achieves 18% less torque and power at 6,000 rpm and roughly 21% less at 8,000 rpm. This motor is approximately the same size as the slotless motor.

creates a torque disturbance known as *cogging*. Because there are no teeth in a slotless motor, cogging is eliminated — yielding smoother motion.

Easier tuning: Motors with larger rotor inertias can be easier and simpler to tune. If the load becomes momentarily decoupled from the motor (a common phenomenon), the servo loop is less likely to become unstable if motor inertia is high relative to the load. In fact, precise servo tuning and filtering, which can be difficult to achieve, may not be required with a slotless motor.

Better stiffness: A rotor with a larger diameter has greater stiffness because torque increases with rotor diameter and a higher-torque motor responds faster to any displacement from the commanded position. The torque displacement curve is steeper.

Higher efficiency: All of the above traits boost motor efficiency by 5 to 25% over slotted motors.

Drawbacks of slotless motors

Despite their benefits, slotless motors are not without drawbacks and are therefore not suited to every application. For any given size, slotless motors generally have larger diameter rotors, and because rotor inertia increases exponentially with the rotor's diameter, inertia can increase significantly. Consider an application in which *load inertia* is very low compared to *motor inertia*, and high acceleration is required. Here, a slotted motor may be able to accelerate faster than a slotless one — if the slotless motor's additional torque cannot compensate for the higher torque required to accelerate the system.

A slotless motor may also be more difficult to manufacture: The motor manufacturer might need to develop custom winding equipment because standard equipment does not do the job. If the choice is made to encapsulate the motor windings in a resin to enhance performance and create a more rugged motor, the motor manufacturer must have significant experience with resin materials and the potting process itself. These manufacturing challenges could increase costs for both the motor manufacturer and end user.

Application benefits of slotless motors

Higher torque is beneficial for most applications and is often the first thing an engineer seeks when choosing a motor. More torque usually means higher acceleration and greater machine output. Additional torque also means that a smaller motor may be used, which can save money; if the motor is part of a moving component, a smaller motor also weighs less and requires less energy to move.

A motor that can run faster may be an obvious choice for high-speed applications such as centrifuges, but faster speed can also help reduce overall machine cost and increase machine output. If the machine's mechanics can handle higher speeds, a faster move time is possible. If a gear reduction can be selected to optimize torque at higher speed, a smaller motor can be used, thereby saving money and weight. Additional power may also eliminate costly secondary mechanics that can shorten machine life and escalate maintenance.

Two specific applications illustrate indispensible slotless-motor benefits. The first is grinding: Here, smooth motor motion (generated by slotless motors) is imperative, as the cogging effect often associated with slotted motors can produce an undesirable finish on final parts. Another example is battery-powered designs. Here, the higher efficiency and potentially smaller size of slotless motors extends operation.

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