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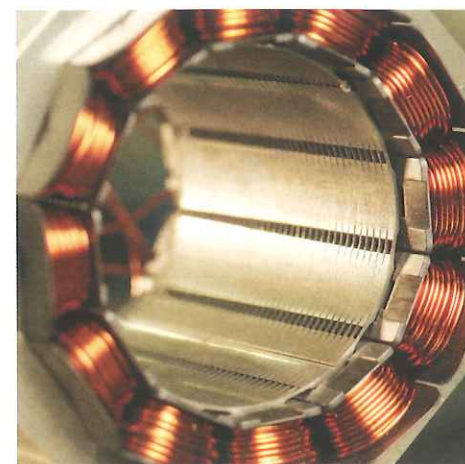
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DRIVES, CONTROLS & AUTOMATION: **HIGH-SPEED MACHINES**

High-speed machines drive technology forward

There is a demand for high-speed advanced electrical machines and drives for wide-ranging applications in all market sectors. Eureka reports on this technology.



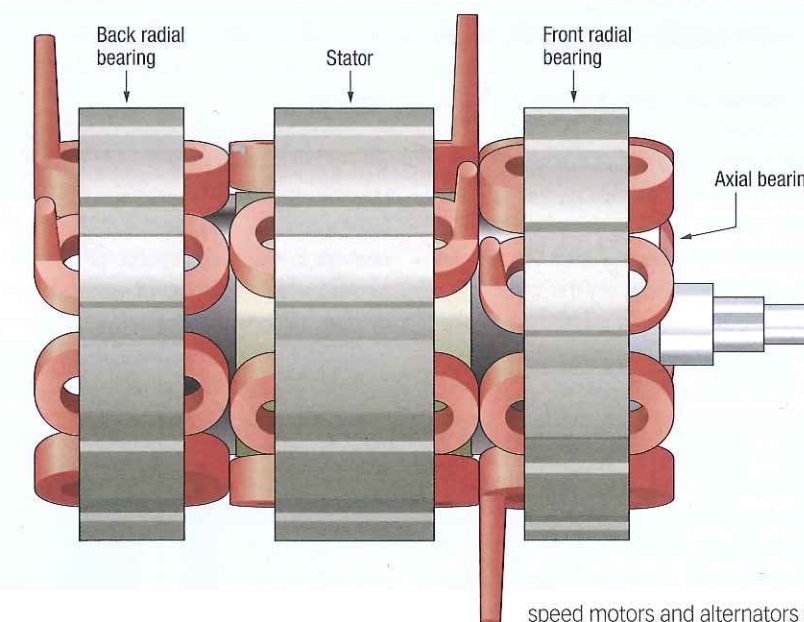
There is currently significant attention being paid to the development of high-speed machine technology such as motors and generators. In particular, permanent magnet machines are gaining traction due to their outstanding efficiency, high power density, small size, low weight, simple mechanical construction, easy maintenance and good reliability.

The motivation for their development varies considerably. However, common objectives are to improve efficiency, conserve energy, reduce environmental pollution, increase power density, enhance functionality and improve reliability and maintainability and is also being driven by legislation, consumer expectations regarding performance and more fierce competition in the market place.

Many of the applications for these machines pose particularly severe challenges in terms of the rotational speed and/or space envelope constraints (eg the thermal operating environment) for example, while others are particularly challenging in terms of being highly cost-sensitive or safety critical.

In the past, many industrial applications have used existing technology to achieve high rotational shaft speeds. Direct-drive high-speed machines or a slow-speed electric motor coupled with a speed increasing gearbox have typically generated the necessary shaft speeds. But advances in high-speed motor technology, along with improvements in the cost and performance of power electronic drives, materials, non-conventional bearings and more efficient cooling methods, permit an alternative approach.

This uses high-speed machines that can directly drive, or be driven by a high-speed



system such as turbine, compressor or other turbomachinery. This results in significant performance benefits, such as reduction in motor generator size, as well as reduced cost and simplified integration. Integration of these small, highly efficient machines into the coupled equipment further reduces cost and complexity. Recently, researchers have focused on the design of high-speed, super high-speed, or even ultra-high-speed machines for applications such as turbochargers/superchargers, compressors, spindles, blowers, pumps, flywheel energy storage systems and machine tools that require higher speed drives. Such high-speed machinery includes gas compressors, pumps, centrifuges, distributed generation units (microturbines), spindles and flywheel energy storage, and high-

speed motors and alternators as examples of electric machines.

The increasing interest in these types of machines is partially due to the very small size and weight achievable in comparison to machines using conventional design strategies. The higher the motor speed, the smaller the electric machine volume for the same power output. The volume of the machine is proportional to the output power and inversely proportional to phase current density, airgap flux density and the angular velocity.

Although current density can be increased considerably by using super conducting materials, it is still very expensive and not suitable for low-power machines. The large number of additional components required to provide cryogenic temperature for super

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conducting will reduce the power density greatly for low-power machines. Therefore, increasing rotor speed is desirable to increase power density of the machine.

The advent of cost effective frequency converters has allowed the speed range of larger electric machines of 100 to 1,000 kW to be increased to 4,000-6,000 rpm. The prospect of a permanent magnet motor of 20MW operating at higher speed offers the possibility of low mass, very compact geared or direct-drive, which have been used at these higher speeds for decades, i.e. in combination with both steam and gas turbines.

Operating speeds cover a broad range, from 10 to 200k rpm. Increasing speed is one of the most powerful elements for improving if the application can stand it. The design of high speed machines is known to be very challenging because materials are operated closer to their mechanical limits.

The high speed capability of machine is constrained by several parameters, such as rotor mechanical, thermal, and electromagnetic limits. Additionally, one can enlist the limits of the power electronic converters, especially the switching frequency.

From an electromagnetic point of view, higher speeds mean higher induced voltage, with extra stress on the insulation. The skin effect due to high frequencies increases the AC resistance.

Increasing speed also presents mechanical integration complications, however. Among these complications are rotor-dynamic behaviours related to the phenomenon of critical speed. Part of the structure comes to close to the elasticity/plasticity limit, which makes material choice difficult, since most strong materials are non-magnetic and reverse. The centrifugal force wants to radially push out any component in the rotor. This may cause difficulties for rotors with windings or permanent magnets, close to the air gap. It is possible to use a thin non-magnetic bandage (e.g. fibre-glass) or high-strength metal sleeve or a proprietary advanced graphite-composite sleeve can be used that offer unique advantages to machine performance.

The magnitude of the air gap also plays an important role. The bearing needs to be able to sustain, in a stable way, the envisaged speed. Transition to non-touching air bearings/ foil or magnetic bearings has created excellent



opportunities for increasing speed and improving reliability.

Speeds within the range of 20-50k rpm are well within conventional bearing capabilities. However, for improved reliability, foil bearings are highly desirable, although the size of the foil bearings is inversely proportional to speed.

Also, a higher number of machine poles can be selected for improving performance. The fundamental of the machine current is a multiple of mechanical frequency. However, machine current should be low enough for easy integration with the power electronics.

Fundamental electrical frequencies above 1.5 kHz should be avoided to prevent distorted stator currents, which result in increased machine losses and electromagnetic interference (EMI). In this speed range, 4-, 6- and 8-pole machines may be selected.

For speeds below 20k rpm, foil bearings are not feasible due to increased size. Rotor-dynamic behaviour usually does not create problems since the first critical speed is far above the operating speed range. An increased number of poles can be used for reduced machine sizes.

The size of the magnetic bearings is not very sensitive to the operating speed ranges. Implementations at high speeds are more challenging since higher frequency bandwidth is required. This is due to the fact that the critical speeds are within the operating speed range.

SDT has developed a high-speed permanent magnet motor that can deliver between 2 kW-5kW and integrated control system, which is designed to run at up to 50,000 rpm and have

integrated controllers.

To further increase the capabilities of proprietary high speed motor systems, As a specialist in high-speed electric drives, UK-based SDT uses a technique called phase advance control that allows the delivery of high output torque at high speeds. This method allows phase current to build up in a motor winding before back EMF reaches any significant level.

In this development, the following materials have been used have properties that greatly influence motor performance: the permanent magnet, core ferromagnetic materials, magnet wires, winding insulation. However, since SmCo magnets have a much higher temperature stability it was decided to use them for the magnet poles. The two important characteristics of the ferromagnetic materials that have influence on the motor performance are the maximum saturation flux density and the specific core loss. The high saturation cobalt iron alloys have high maximum saturation flux density and a relatively low specific core loss.

This high speed machine solution is highly scalable and provides a solution for where consideration is being given to a variable speed drive to better match the drive to varying load requirements to reduce energy consumption. Suitable applications are currently being found in automotive, commercial vehicles, spindle, aerospace, industrial pumping and many other industries where compact, high performance machines and flexible transmission technology are demanded.

Given the challenging requirements of high-speed, high power motors in a small package, reliability is best ensured using a comprehensive engineering approach such as thermal, structural, dynamic as well drive electronics, and high performance bearings.

An electric motor is a complex piece of equipment, covering many engineering disciplines. Careful consideration must be given to all aspects of motor design when evaluating the impact of high rotational speeds and increased frequencies. Ultimately, the final design will be a tradeoff between multiple aspects of machine design, including rotor tip speed, rotordynamics, and cooling.

www.sdt drivetechnology.co.uk



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