PM MACHINES FOR PROPULSION

Superior efficiency, reliability and compactness are the core competitive advantages of permanent magnet (PM) machines for direct-drive electrical propulsion

PM machines are used in electrical drive trains to generate the mechanical power that turns a propeller shaft or thruster. In contrast, PM shaft generators convert the rotational mechanical energy of the propulsion shaft back into electricity for use onboard, reducing the need for diesel gensets.

In both types of machines, 'permanent' refers to the use of permanent magnets to create the magnetic field. Where electromagnets require an external power source to generate a magnetic field, the magnets on the PM rotor generate a constant magnetic field with no need for an external power supply.

Magnetic fields interact

"However, in a PM propulsion machine, two magnetic fields need to interact to produce the torque required to turn the rotor. This is achieved by feeding an external current into the stator winding to create a second, rotating magnetic field. This field locks into the constant magnetic field of the rotor magnets, 'dragging' the rotor around. The speed of the rotor can be precisely controlled by adjusting the frequency of the supplied current," says Jussi Puranen, Product Line Director, Electric Machines at The Switch, a BEMAC Group company.

All megawatt (MW)-class PM machines use magnets made of an alloy of neodymium, iron and boron. With magnetic flux, they are designed to last the entire 20- to 30-year lifetime of a vessel. "This longevity dispels a common market misunderstanding about the need for magnet replacement," Puranen adds.

Unmatched performance

Unlike traditional electric motors such as electrically excited synchronous machines (EESMs) and induction machines (IMs) that rely on electromagnets, PM machines generate their magnetic field without consuming additional power. "At the rated operation point, PM machines are typically around 2–4% more efficient than EESMs and 3–6% more efficient than IMs. The difference becomes even greater at partial loads, where these machines primarily operate. This increased efficiency can lead to millions of dollars in fuel cost savings and a reduction of several thousand tons of CO_2 emissions over a vessel's lifetime," says Puranen.

PM machines are also more compact, up to 50% lighter than IMs, and require less maintenance due to fewer wearing parts and components that can fail. EESMs need an automatic voltage regulator for rotor current control, whereas PM machines do not. "PM machines also occupy 30–40% less space in the engine room, making them ideal for vessels where space and weight are at a premium, allowing for more cargo and contributing to overall operational efficiency," Puranen says.

Durability and reliability

PMs are not new and have been commonly used for the past two decades in MW-class applications, including large wind turbines and some azimuthing thrusters. "Operating conditions are actually much harsher for wind turbines than the engine room of a vessel. In an engine room, it never freezes, there's no salt in the air. This background ensures their durability and reliability in maritime applications," says Puranen.

In terms of environmental impact beyond CO_2 emissions, PM machines are comparatively quiet and produce minimal vibration compared to conventional systems, thereby reducing noise pollution. "In one fishing vessel case, our PM system received the DNV silent notation, which puts strict limits on underwater radiated noise (URN), highlighting its minimal noise levels," Puranen adds.

Jussi Puranen, Product Line Director, Electric Machines at The Switch, a BEMAC Group company

Redundancy and safety

Class requirements for PM machines were formalized over the last decade, and the solution is now standard. "However, if the vessel has only one shaft line, then electric propulsion is not fully accepted by class. To overcome this issue, we have developed a tandem concept comprising two motors on a common bedframe. Should one machine fail, the second machine can continue operation, providing at least 50% of the full power. Due to the cubical power-speed dependence of the propeller, this is sufficient to move the vessel at around 80% of full speed," says Puranen.

Because the magnetic field in PM machines cannot be switched off, another class requirement is having a decoupling mechanism inside the machine to lock the rotor in place when the motor is not in operation. "This is necessary because the PM's constant magnetic field can induce voltage even when the motor is turned off – if the rotor continues to rotate. The decoupling mechanism holds the rotor secure and prevents unwanted voltage induction at the machine terminals," Puranen says. "Often, we also use a star-point circuit breaker in PM machines to isolate the windings and manage risks associated with the magnetic field, especially in shaft generator applications. It ensures that maintenance can be performed safely and helps protect the machine and crew from potential electrical hazards."

Cost benefit

Compared to diesel-mechanical propulsion, the initial capital cost of electric propulsion is usually higher. However, it is significantly more cost-effective because of the fuel savings. "Fuel typically accounts for roughly 95% of lifetime costs, and this is where PMs can make a big dent. For example, we have

supplied more than 100 PM shaft generators for LNG carriers, with an estimated operating saving of USD 2 million per vessel," says Puranen.

"PM motors cost about the same as conventional electric motors, but, again, their better efficiency helps reduce lifetime costs and contributes to lower carbon taxes. This is particularly significant for vessels that operate mostly at less than full speed. The lower maintenance requirement further reduces OPEX," he adds.

The Switch's PM machines are standalone, making them straightforward to assemble into a new-build vessel. "When it comes to retrofitting, there are no limitations from the PM machine perspective. However, the procedure for large vessels is complex as you need to drydock the ship and cut a hole in the side to install the machine, which can take several months," says Puranen.

Market trend

PM motors are now very common in smaller vessels and in MW-class propulsion systems used by cruise ships. "For instance, we supplied the 3 MW PM motors for the CSL bulk carrier M/S Nukumi, which won Vessel of the Year at the 2023 Marine Propulsion Decarbonisation Awards," says Puranen.

The major challenge is that larger deep-sea vessels are still using diesel-mechanical systems, but there is a shift afoot due to tightening regulations. "The IMO's target of significantly reducing greenhouse gas emissions is forcing shipowners to adopt cleaner technologies, and PM propulsion is one of the most effective solutions. We were the first in the market to supply PM shaft generators, which took a lot of convincing. Then, it was mostly about fuel savings, but now it's more about emissions reduction," Puranen says.

He doesn't see any issues with market acceptance. "Since 2015, we have sold roughly 400 PM shaft generators for large ships. Together, they have several millions of cumulative running hours, so the basic technology is proven. Our power electronics products also make it very straightforward to connect various kinds of energy sources into the vessel's power system, such as batteries, fuel cells and wind/solar," he adds.

Modular design

The Switch's focus is on direct-drive systems with no gearbox, leading to fewer components, which Puranen believes is the most reliable solution for slow-speed applications. "Our biggest differentiator is our flexibility in offering tailor-made designs optimized for customer requirements. We precisely match PM machine capacity to the vessel's operational speed and power without over-dimensioning. Our modular design approach minimizes engineering costs from project to project. We can adapt interfaces and move things around. For example, we can adjust the cooling system and modify the shaft diameter," says Puranen.

PM machines offer a versatile solution for future electrical propulsion needs as the industry adopts more sustainable solutions. "Certainly, their efficiency, compactness and reliability make them a superior choice versus conventional EESMs and IMs. We've definitely entered the PM era, and the rate of inquiries we are receiving is growing rapidly, particularly for propulsion applications," he concludes.