Integrated Motor Propulsor Magnet Design with Hybrid Halbach Array for Torque Ripple Reduction

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Background

This paper presents a magnet design using a Halbach array to reduce torque ripple based on the width ratio, and deals with the influence of the material of a radial array permanent magnet (PM) for a 22.5-kW 1500-rpm-class unmanned submarine. This paper is divided into two main parts: a comparison of the characteristics of a hybrid Halbach array integrated motor/propulsor (IMP) with x-axis magnets replaced by ferrite magnets, and an analysis of PM optimization of the Halbach array in terms of torque ripple reduction based on the width ratio of the x-axis array magnet. Results show that the size of the rare-earth magnet, volume of the IMP, and torque ripple were reduced by 25%, 25%, and 75%, respectively, when a ferrite magnet was substituted for the x-axis array magnet and the PM width was optimized for magnetization in the x-axis direction of the Halbach array.

Objectives

- This paper presents a comparison of the characteristics of a hybrid Halbach array IMP with x-axis magnets replaced by ferrite magnets, and considers the PM optimization of the Halbach array in terms of torque ripple reduction based on the width ratio of the x-axis array magnet.
- This paper presents the design and analysis of an IMP for a 22.5-kW 1500-rpm-class unmanned submarine.
- First, the replacement of the rare-earth magnet for magnetization in the x-axis direction is discussed.
- Second, the focus shifts to the PM width ratio; a downscaled PM was used to compensate for the torque pulsation.

Substitution of rare-earth magnet

- The magnetic flux line distribution for the rare-earth magnet; much of the magnetic flux flowed through the PM. However, the flow of the magnetic flux was confirmed to be small in the PM when a ferrite magnet was used for the x-axis array magnet, and much of the magnetic flux flowed through the rotor.
- If a rare-earth magnet is used, the x-axis array magnet is saturated; the x-axis magnet is not saturated when a ferrite magnet is used.

Comparison of no-load induced voltage

- The peak back-EMF value of the ferrite model decreased because of the reduced concentration of the magnetic flux.
- However, despite the volume of rare-earth magnets being reduced by half, the back-EMF shows similar values, and both models exhibited comparable waveforms.
- The ferrite model represents the sinusoidal of the maximum values, but the original model shows a non-sinusoidal shape near the maximum value because of the saturation of the x-axis array magnet.

Results & conclusion

- The volume of rare-earth magnets was reduced by 25%; by changing the width of the magnet, the torque ripple was reduced by 75%.