Capability improvement design method considering eddy current loss reduction of axial-flux permanent magnet coupling with Halbach array structure using 3-D FEM

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I. Abstract

This paper deals with torque parametric analysis of axial-flux magnetic coupling with Halbach array magnetized permanent magnet using the 3D finite element method (FEM). We have proposed a design method for the axial flux permanent magnet coupling (AFPMC). AFPMC is manufactured on the basis of parametric analysis result. Finally, this paper presents some methods to reduce eddy current loss. The results are compared with those obtained from 3D FEM.

II. Coupling Applications, Structure of AFPMC ,and Torque fluctuation

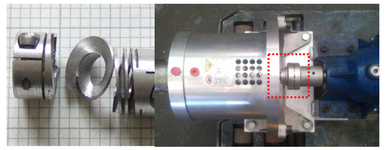


FIG. 1. (a) Broken mechanical coupling, (b) permanent magnet coupling in operation for transmit torque

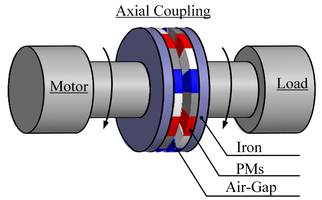


FIG. 2. Conceptual diagram of permanent magnet coupling system

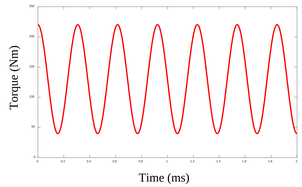


FIG. 3. Example of torque fluctuation in variation caused by inertial force due to load rotation.

- ✓ The permanent magnet couplings (PMCs) transmit torque without any mechanical contact.
- ✓ In particular, the axial flux magnet coupling (AFPMC) has the advantage of a compact and flat construction.

III. Parametric Analysis for Optimal Design of AFPMC

- ✓ The maximum torque is determined by parametric analysis using several variables: PM thickness, radius of magnets, and the number of PM poles.
- ✓ The optimal design of the AFPMC was carried out on the basis of several parametric results

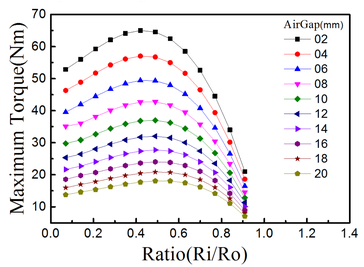


FIG. 4. Parametric analysis results according to inner radius and airgap length.

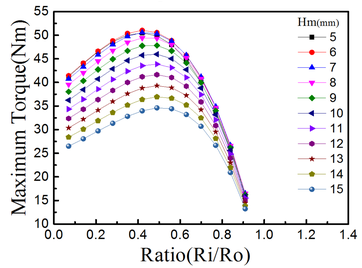


FIG. 5. Parametric analysis results according to inner radius and PM thickness.

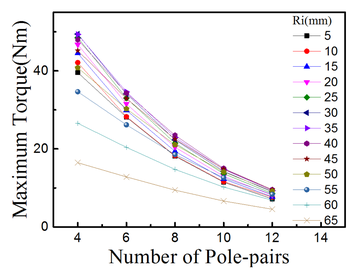
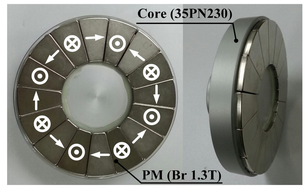


FIG. 6. Parametric analysis results according to number of pole-pairs and inner radius of PM.

- ✓ Analyzing AFPMCs with a Halbach array magnetized PM magnetic torque is very important because this torque provides overload protection in the machines.
- ✓ By anticipating the maximum allowable torque, the product can be minimized.

IV. Manufactured model ,Design Specification, and Experimental Results



AFPMC with Halbach array

FIG. 7. Actual manufactured axial-flux permanent magnet coupling with Halbach Array using parametric analysis results

TABLE I. Axial Flux Permanent Magnet Coupling Specifications

Parameter	Value
Number of Poles	4
Inner radius	32 mm
Outer radius	71.5 mm
PM thickness	6.5 mm
Core thickness(35PN230)	8.8 mm
PM remanence(N42SH)	1.3 T
Air-gap length	Variable

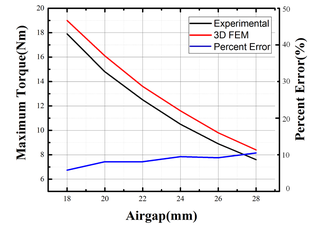
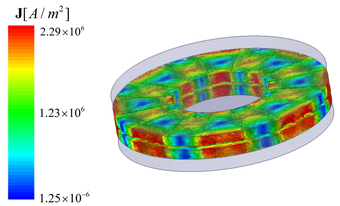


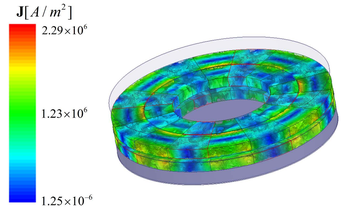
FIG. 8. Comparison of measured results of the maximum torque with 3D FEM and experiment according to air gap length.

V. Eddy Current Loss Analysis according to design methods



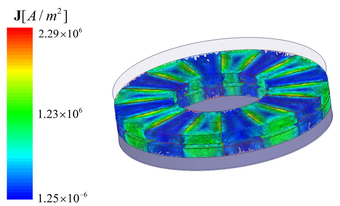
- ✓ Manufactured model
- ✓ Total number of PM = 32
- ✓ Eddy current loss = 512W
- ✓ Pull out torque = 81.7 Nm

FIG. 9. Eddy current distribution of manufactured model



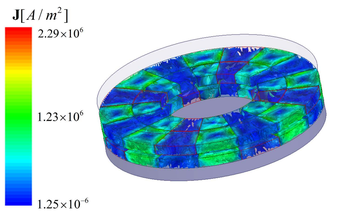
- ✓ Separated magnet in radial direction
- ✓ Total number of PM = 64
- ✓ Eddy current loss = 180W
- ✓ Pull out torque = 76.6 Nm

FIG. 10. The first proposal for reducing eddy current loss.



- ✓ Separated magnet in tangential direction
- ✓ Total number of PM = 32
- ✓ Eddy current loss = 158W
- ✓ Pull out torque = 75.6 Nm

FIG. 11. The second proposal for reducing eddy current loss



- ✓ Separated magnet in radial and tangential direction
- ✓ Total number of PM = 64
- ✓ Eddy current loss = 87.6W
- ✓ Pull out torque = 73.2 Nm

FIG. 12. The third proposal for reducing eddy current loss

VI. Comparison of Specification and Analysis Results

TABLE II. The comparison of analysis results according to design method

Parameter	Manufactured Model	Model 1	Model 2	Model 3
Number of Poles	8	8	8	8
Half pole angle	22.5 degree	22.5 degree	22 degree	22 degree
Inner PM outer radius	71.5	50 mm	71.5 mm	50 mm
Outer PM inner radius	32 mm	50.5 mm	32 mm	50.5 mm
Permanent Magnet Volume	166,944 mm^3	164,864 mm^3	163,255 mm^3	161,216 mm^3
Eddy current loss	512W	180W (64% reduce)	158W (69% reduce)	87.6W (82% reduce)
Maximum torque (Nm)	81.7	76.6 (6.24% decrease)	75.6 (7.46% decrease)	73.2 (10.4 % decrease)

VII. Conclusion

- ✓ In this study, we proposed a design method of Axial-Flux Permanent Magnet Coupling considering reduction of eddy current loss.
- ✓ Designed AFPMC capable of generating maximum torque using parametric analysis under limited conditions by 3D FEM.
- ✓ By using the divided permanent magnets in radial direction or tangential direction, the maximum torque value was slightly reduced, and much of eddy current loss generated in the permanent magnet could be reduced.

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