Electric Motor Design of an Integrated Motor Propulsor for Unmanned Underwater Vehicles : The Effect of Waterproofing Can

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This paper deals with the effect of waterproofing can in the electric motor, which is a major part of an integrated motor propulsor for unmanned underwater vehicles. To achieve the design goal of the electric motor, the variable thickness and materials of waterproofing can are examined with 2-dimensional finite element analysis considering its eddy current loss. The selected waterproofing can is applied to the electric motor, and tested to verify the analytical expectation.

Index Terms— **Eddy current loss, finite element analysis, integrated motor propulsor, waterproofing can.**

I. Introduction

THE INTEGRATED MOTOR PROPULSOR (IMP) offers several advantages over ordinary propulsors or thrusters [1]. The IMP can be divided into two, rim-bearing type and hub-bearing type, according to bearing position [1]-[3]. The authors in this paper have developed an electric motor of a rim bearing type IMP for unmanned underwater vehicle, and written some papers about the motor design [4]-[6]. The previous papers are related to a basic design process or the first prototype of IMP motor which is not considered about waterproof.

In this paper, a welded can is considered and designed as a part of the electro-magnetic design process for waterproof of the electric motor stator. The welded can is called as waterproofing can in here. To achieve the design goal of the IMP motor, the variable thickness and materials of waterproofing can are examined. In order to predict the eddy current loss of the waterproofing can, 2-dimensional (2-D) finite element analysis (FEA) was performed. The selected waterproofing can is applied to the IMP motor, and tested to verify the analytical expectation.

II. Configurations and Specifications of IMP motor

A. Configurations

The considered IMP is composed of rim-driven motor (IMP motor), a fluid hydrodynamic bearing, and a propeller, as shown in Fig. 1. The rotor of the IMP motor is part of the propeller rim, and the stator is embedded in the duct [6].

Fig. 2 shows the configuration of the second prototype for the IMP motor test considering waterproof. Instead of the fluid hydrodynamic bearing and the propeller in IMP, ceramic ball bearing and fixed spokes are used, respectively.

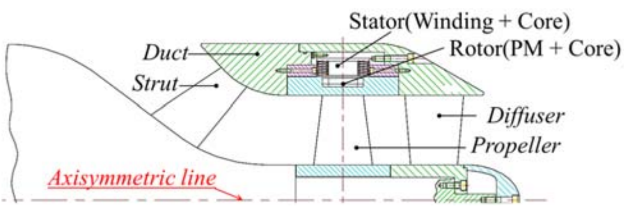

Fig. 1. Conceptual configuration of the proposed IMP system.

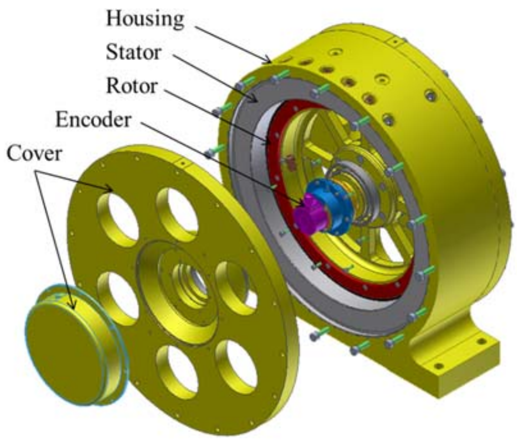

Fig. 2. Configuration of the experimental prototype of the IMP motor.

The rotor is sealed by carbon fiber-reinforced plastics (CFRP). The stator is totally enclosed and sealed by a welded can (waterproof can), and polymer fill a vacuum in the can.

B. Specifications

Table 1 shows the specifications of the IMP motor. The output characteristics of the first prototype satisfy this conditions. In the load test, the first prototype has 46.4kW at 80A input current. When considering the requirement output power, there is about 20% power reserve. Within this amount of power reserve, the eddy current loss is permitted. In other words, the waterproof can is designed and selected when its eddy current loss is under 20% of the output power. Considering both low conductivity and rust prevention, 316L grade-stainless steel (SUS316) and 718grade-inconel (Inconerl718) are examined as can material.

TABLE I
Specifications of the IMP motor

Motor	Output power	37.3	kW
	Max speed	1000	rpm
	Max torque	356.2	Nm
	Outer diameter	500	mm
	Inner diameter	381	mm
Driver	Input voltage	600	Vdc
	Max current	100	Arms

TABLE II
EDDY CURRENT LOSS ANALYSIS RESULTS (SPEED 1000RPM, INPUT CURRENT 80ARMS)

Can Material	Unit	Without Can	SUS316L	Inconel 718	SUS316L	Inconel718	SUS316L	Inconel718
Waterproofing can thickness	mm	0.0	0.6		0.8		1.0	
Torque	N.m	396.6	332.4	358.6	311.8	346.5	291.1	334.2
Percentage torque	%	100.0	83.8	90.4	78.6	87.4	73.4	84.3
Power	kW	41.5	34.8	37.6	32.7	36.3	30.5	35.0
Core loss	W	393.8	387.0	390.5	384.3	389.2	381.7	387.7
Eddy current loss	kW	0.0	7.4	4.5	9.6	5.8	11.9	7.1
Copper loss	W	3552.0	3552.0	3552.0	3552.0	3552.0	3552.0	3552.0
Efficiency	%	91.3	75.4	81.6	70.7	78.8	65.9	76.0

III. ANALYSIS AND EXPERIMENT RESULTS

A. Analysis results

Fig. 3 shows the 2-D FEA model for electro-magnetic field analysis of IMP motor. To calculate the eddy current loss in the waterproofing can, full model is used instead of periodic model. Depending on variation of the waterproof can thickness and its materials, the several eddy current loss analysis were performed and the results are listed in table 2. Considering the loss limit and fabrication cost, 0.6mm thickness SUS316L is selected.

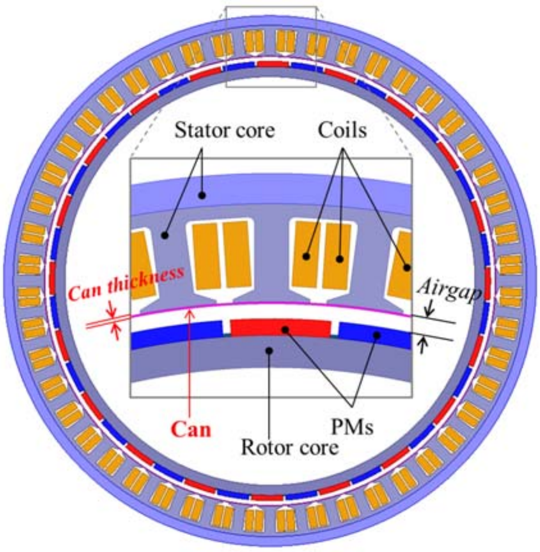

Fig. 3. 2-D FEA model for eddy current loss calculation in waterproofing can.

B. Experiment results

Fig. 4 shows the fabricated second prototype in the water tank and the test set, and Fig. 5 shows the test results according to speed. The measured EMF, loss torque, and loss power are compared in Table 3. More detail explanation for analysis and experiment results will be presented in the extended paper.

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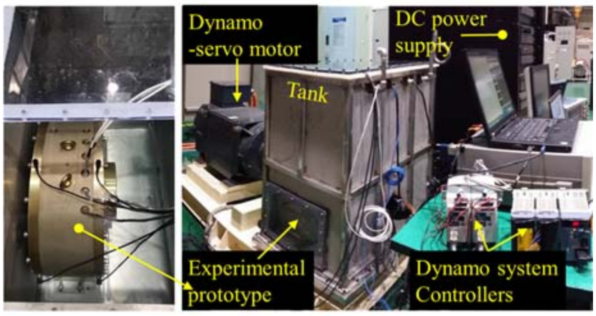

Fig. 4. The experimental prototype in tank and the test set.

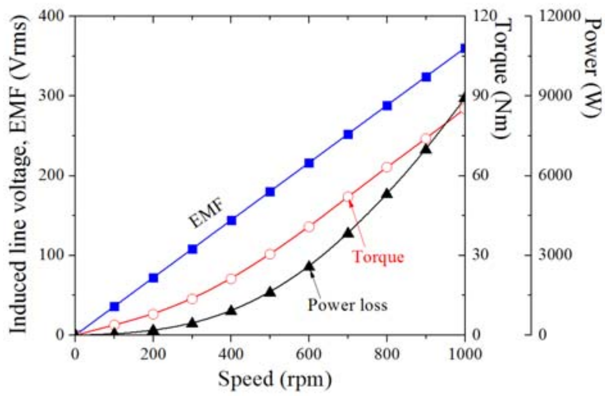

Fig. 5. Test results according to speed variation.

TABLE III
EMF, LOSS TORQUE, AND LOSS POWERS (SPEED 1000RPM)

Conditions	without waterproofing can		with waterproofing can	
	Air	Water	Air	Water
EMF (Vrms)	363.4	360.2	359.3	364.6
Loss torque (Nm)	6.9	85.2	65.3	153.5
Loss power (kW)	0.7	8.9	6.8	16.1