Research on Thermal Characteristics of Submersible Motor Used for Electromagnetic Propeller in Deep-sea Human Occupied Vehicle

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Abstract —With the rigorous requirements of high power density for propulsion system, an 8kw BLDC motor used for electromagnetic propeller in deep-sea Human Occupied Vehicle was investigated in this paper. Compared with traditional design, submersible motor is usually oil-filled and submerged in seawater. Power loss of submersible motor was calculated and the heat transfer coefficients in two parts of the motor including housing surface and the gap filled with oil were presented on the basis of flow field diagnosis in and out of the motor. The temperature distribution of the investigated motor was determined and the influences of environmental temperature and moving speed on motor temperature rise were also discussed in this paper.

I. Introduction

An 8kw electromagnetic propeller used for deep-sea Human Occupied Vehicle was investigated in this paper. Fig. 1 shows the inner structure of submersible motor with a pressure compensator. When the vehicle submerges deeper, the pressure of seawater becomes higher, and the piston of the pressure compensator would shift inward to increase the pressure of the oil to balance the higher pressure of the outer seawater.

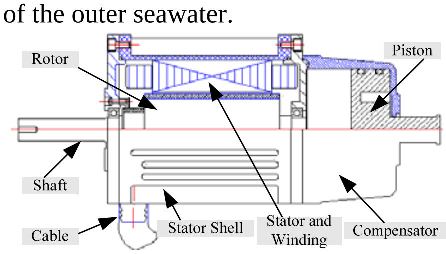

Fig. 1. Inner structure of the BLDC motor with a pressure compensator.

Compared with the air cooling for electrical machines in traditional application, being submerged in seawater and filled with oil, the thermal characteristics of deep-sea submersible motors are quite different from that of traditional applications.

II. Heat Sources of Submersible BLDC Motor

Because of the high viscosity, the oil in the gap could flow with the rotating rotor and this flow would produce viscous power loss which would converse into internal heat in the oil. This loss is not only related to the rotor speed, parameters of the motor and the physical characteristics of the oil, but also related to the flow type of the oil in the gap.

Operating with rated load, the copper loss, core loss and viscous power loss in different environment are given in table I. The calculated results show that core loss and viscous power loss are in the minority, but the copper loss is in the majority [1, 2].

TABLE I
Power Loss in Different Operation With Full Rated Load

	0.1Mpa,25℃	70Mpa,25℃	70Mpa,100℃
Copper Loss (W)	554	554	1150
Core Loss (W)	77	104	104
Viscous Loss (W)	90	124	98

III. Heat Transfer Coefficient in Thermal Analysis

Due to the high viscosity, hydraulic oil could flow with the rotating rotor. Besides, the motor was immerged into the sea. The water on the housing surface could also flow with the moving vehicles. So forced heat convection existed in these two areas, and the environment of heat transfer was improved. The convection heat transfer coefficients are determined as followings.

A. Convection Heat Transfer in the Gap

On one hand, the flowing oil in the gap could produce additional viscous power loss that could deteriorate the thermal transfer environment in the motor and increase motor temperature. On the other hand, the flowing oil would dissipate power loss easily and accelerate the heat transmission, resulting in temperature decrease in motor. The convection heat transfer coefficient is considered according to [3, 4].

B. Convection Heat Transfer on the Housing surface

The corresponding value of heat transfer coefficient versus the moving speed is established in Fig. 2. The analyzed model operates at the temperature of 10℃. As shown in Fig. 6, when the moving speed is smaller than 4m/s, the flow on the surface is laminar, so that heat transfer coefficient increase slowly with the increasing moving speed; as the moving speed surpasses 4m/s, the flow is transition or turbulent, and thus the heat transfer coefficient increases rapidly.

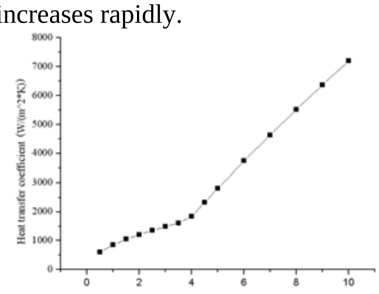

Fig. 2. Heat transfer coefficient versus the moving speed.

IV. THERMAL ANALYSIS OF THE INVESTIGATED MOTOR

A. Test and Calculated Results of Thermal Analysis

In experiment, the motor was immerged in a tank filled with water at the temperature of 10℃, and operated under rated full load at the normal atmosphere. The calculated result of steady temperature distribution is shown in Fig. 3 [5, 6], and Fig. 4 is the test and calculated transient data. The experimental results meet well with the calculated results.

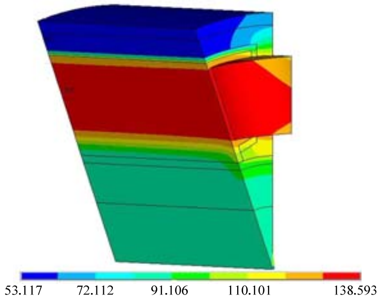

Fig. 3. Steady temperature distribution of investigated motor.

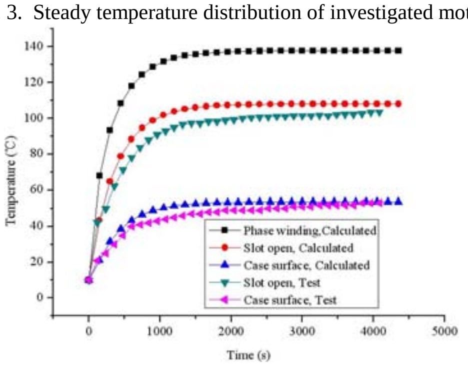

Fig. 4. Test and calculated transient temperature results.

B. Influence of Motor Moving Speed

The investigated motor operates with rated load and the water temperature is set to 10℃. The calculated maximum winding temperatures at different moving speeds are shown in Fig. 5. From Fig.5, we can clearly see that maximum temperatures of phase winding decrease obviously with the increment of moving speed before 6 m/s. However, after the speed of 6 m/s, even if the moving speed continues to increase and the convection heat transfer coefficient increases notably in turbulent flow, it can hardly reduce the winding temperatures any more. The motor temperature tends to reach a saturation value, lower than 100℃.

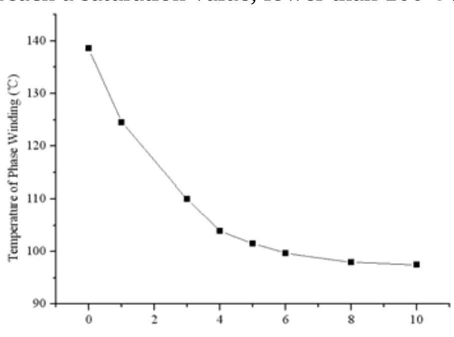

Fig. 5. Maximum winding temperatures at different moving speeds.

C. Influence of Water Temperature

The effect of water temperature on winding maximum temperatures is shown in Fig.6. The calculated results are carried out with the motor moving speed of 1 m/s and with rated load according to previous discussion. As shown in Fig. 6, the winding maximum temperatures increase approximately linearly with the increase of the sea water temperature. The influence of the water temperature on the winding temperature is notable. Thus, the influence of water temperature should be emphasized in analyzing thermal characteristic which is important to design submersible motor.

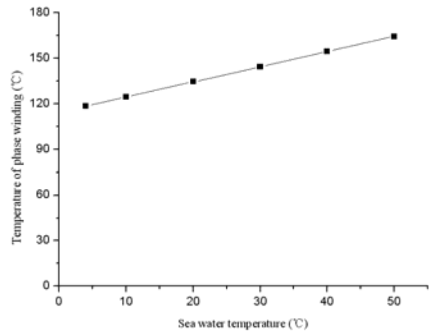

Fig.6. Effect of water temperature on maximum winding temperatures.

V. CONCLUSION

1) Heat transfer coefficient on housing surface would increase with the increment of motor moving speed. In laminar flow convection heat transfer coefficient increases slowly with moving speed, while in turbulent flow, the coefficient increases notably.

2) When the vehicle is moving, the speed is an important influence factor on motor temperature, although the influence becomes weak after a certain speed of moving.

3) Maximum temperatures of submersible motor rises directly with the increment of water temperature.

VI. REFERENCES

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