

Overload Capability Analysis of the Shaft-less Propulsion Motor Based on LPTN

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The propulsion motor of Autonomous Underwater Vehicle (AUV) needs overload capability for short-term acceleration, which is influenced by thermal boundary conditions. This article employs an lumped parameter thermal network (LPTN) coupled with electromagnetic and thermal field to model a 40kW shaft-less motor for AUV propulsion. An empirical method utilizing experimental training data and a particle swarm algorithm identifies the LPTN parameters. Then, the LPTN is used to predict the temperature rise under different overload conditions and analyze the runtime within the thermal boundary conditions of the shaft-less propulsion motor. The experimental results show that the error between the simulated runtime and the experimental value is within 15%. Further, this method not only reduces the calculation time but can also be used for overload capability analysis of other propulsion motors.

Index Terms—Overload capability, lumped parameter thermal network (LPTN), parameter identification, Shaft-less propulsion.

I. INTRODUCTION

As the primary power source of the Autonomous Underwater Vehicle (AUV), the propulsion motor must contend with significantly increased resistance when encountering varying flow velocities or executing emergency maneuvers to avoid hazards. These operational demands require the motor to deliver higher power output over short durations, leveraging its overload capability to ensure sufficient power delivery for rapid navigation. However, motor operation under overload conditions leads to a substantial current surge, generating excessive heat. Elevated temperatures not only accelerate insulation failure but also induce permanent magnet demagnetization, compromising motor integrity. Consequently, accurately predicting the thermal field dynamics is critical to evaluating the propulsion motor's overload capability and ensuring operational reliability.

Numerical methods such as finite element analysis (FEA) and computational fluid dynamics (CFD) are widely used to analyze motor temperature fields. However, these methods are computationally expensive when modeling dynamic thermal transients during motor temperature rise [1]. In contrast, the lumped parameter thermal network (LPTN) methodology offers distinct advantages in computational efficiency and model simplicity. While prior work [1] successfully applied LPTN to coupled electromagnetic-thermal analysis of permanent magnet rectifier generators, achieving steady-state thermal predictions with <5% error, its application has been limited to equilibrium conditions. This method reduces computation time and has sufficient accuracy. However, reference [1] does not analyze the transient temperature rise of the motor.

To address the above problems, this paper proposes a method to analyze the overload capability of motors based on LPTN coupled with electromagnetic field and thermal field. The LPTN parameters are identified by experimental data and

particle swarm optimization (PSO) to improve the accuracy. This method was validated through the shaft-less propulsion motor of the AUV (as shown in Fig. 1).

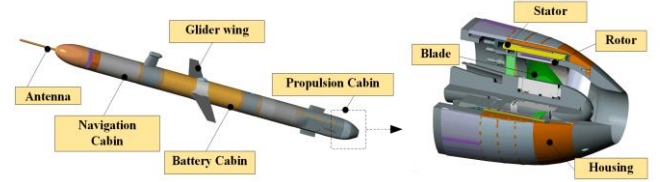


Fig. 1. The structure of the AUV and its propulsion cabin.

II. THERMAL MODEL OF THE PROPULSION MOTOR

A. Structure and Parameters of Studied Machine

A 96-slot 8-pole Surface mounted permanent magnet (SMPM) machine with 45° Halbach array PMs for AUV propulsion is studied in this article. The stator and rotor are each fully enclosed by sleeves, as shown in Fig. 1. When the propulsion motor is operating, water flows through the air gap. The basic parameters of the motor are shown in TABLE I.

B. Thermal Model

The thermal resistance of conduction in motors can be obtained through analytical formulas, but not all thermal resistances can be accurately calculated; the thermal resistance of windings is represented by equivalent thermal conductivity with a specific range. The detailed LPTN is shown in Fig. 2. To reduce the order of the model and the parameters to be identified later, the stator yoke and teeth are equivalent to one node.

The proposed LPTN model can be described by the state-space equation as follows [2]

$$\dot{\Theta} = \mathbf{A}(n)\Theta + \mathbf{B}(n)\mathbf{u}(T_w, n, I) \quad (1)$$

where Θ is the temperature vector; $\mathbf{u}$ is the input vector, including the water temperature and the losses of the motor under specific operating conditions (Water temperature T_w , Rotation speed n and Current I); $\mathbf{A}$ is the system matrix; $\mathbf{B}$ is the

input matrix. Both **A** and **B** are related to changes in rotation speed n .

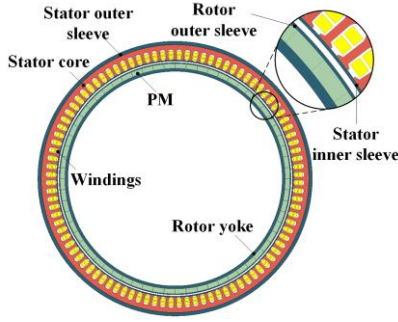


Fig. 1. The structure of the studied machine.

TABLE I
BASIC PARAMETERS OF PROTOTYPE

Parameters	Value
Rated Input power	40 kW
Stator outer diameter	240 mm
Stator inner diameter(without sleeve)	205 mm
Rotor outer diameter (without sleeve)	202 mm
Rotor inner diameter	188.5 mm
Thickness of stator inner/rotor outer sleeve	0.8 mm

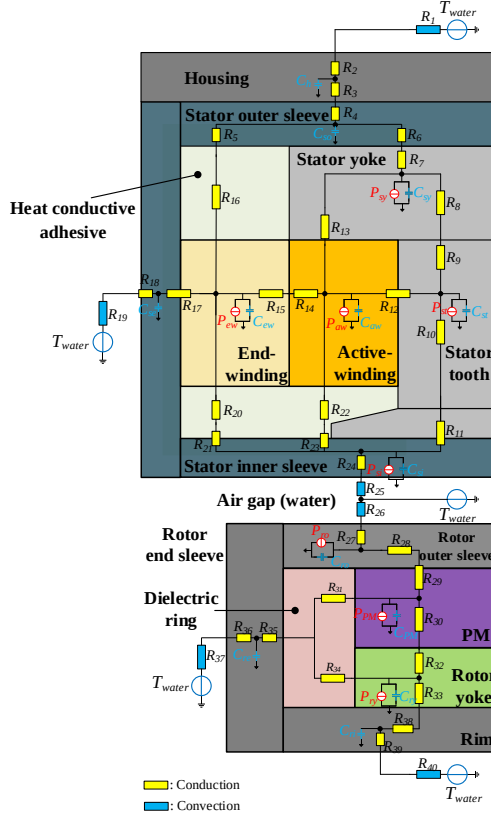


Fig. 2. Detailed LPTN of the studied machine

III. PARAMETER IDENTIFICATION AND VALIDATION

A. Parameter identification

To generate the training data and validate the temperature simulation method, an experimental platform is established, as shown in Fig. 3. Due to the size of the motor, PT1000 were placed only on the end winding to measure the temperature. PSO based on MATLAB is used for offline identification. The

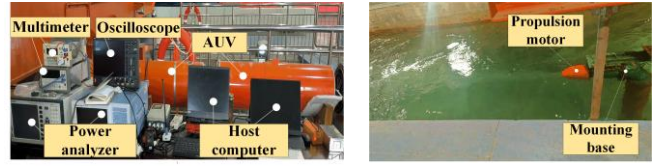


Fig. 3. Experimental platform.

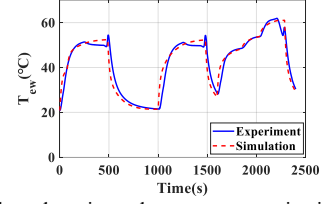


Fig. 4. Measured and estimated temperatures in intermittent operating conditions.

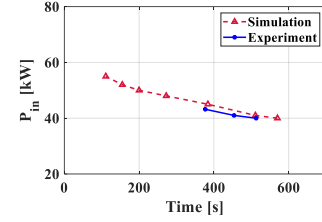


Fig. 5. Simulation and experimental values of runtime under overload conditions.

search domain for each parameter can be limited to an appropriate range to reduce the identification time.

B. Model validation

Verify the identified parameters using temperature data under intermittent operating conditions. The error between simulated and measured values is within 8 °C, as shown in Fig. 4.

IV. OVERLOAD CAPABILITY ANALYSIS

Through the identified LPTN model, the losses under different overload conditions are taken as input to predict the temperature rise of the end winding. When the temperature reaches the maximum allowable temperature of the insulation material, the runtime at this time is recorded, which is the simulated overload runtime. Due to the limitations of the experiment conditions, only part of the overload capability could be verified. The simulation and experimental results of overload capability are shown in Fig. 5.

V. CONCLUSION

In this paper, an LPTN model of an AUV propulsion motor is developed to analyze the transient temperature rise of the motor, and the error of the model is within 8°C. The error value of the overload capability analysis is within 15%. This overload capability analysis method not only reduces calculation time but can also be applied to other propulsion motors, including other overload motors.

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