Transient Thermal Analysis of the Conical Rotor Motor using LPTN with Accurate Heat Transfer Coefficients

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Abstract—**The conical rotor motor is widely used in crane and other hoisting equipment because of the self-locked ability and that it has an intermittent load (S3-25% operation). This paper presents an investigation on the transient thermal analysis of a conical rotor motor. The transient thermal analysis is conducted based on the lumped parameter thermal network (LPTN). To achieve accurate heat transfer coefficients, the computational fluid dynamics (CFD) is considered to simulate the air flow condition, such as the velocity, pressure, etc. Then, a combination of the two methods is applied to calculate the transient temperature. Finally, the accuracy of the proposed method is verified by the 3D finite element method (FEM) and the temperature test, and good agreements are achieved.**

Key words—**Conical rotor motor, transient thermal characteristic, LPTN, CFD, FEM.**

I. Introduction

THE crane and other hoisting engines often use conical rotor motor for drive. Compared to other motors, the conical rotor has the self-locked ability to avoid sliding or falling when the power is off. However, this motor does not run continuously as it has an intermittent load. Limits to the continuous operating time are set by the allowed maximum operating temperature for insulation. Thermal analysis is therefore important in conical motor to ensure safety. Typically this motor runs with the S3-25% operation as studied in this paper. The motor runs with repeated cycles consisting of a constant output power period followed by a power-off period.

The lumped parameter thermal network (LPTN) is widely used for calculating the temperature rise in electrical machines. In LPTN models, heat transfer process is abstracted from a thermal point of view and can be described via equivalent circuit diagrams. The thermal capacity is modeled by means of a capacitor, as used for describing electric circuits. Compared to the numerical method such as finite element method (FEM) and finite volume method, lumped parameter modeling requires less calculation time and is easy to optimize parameters, especially for 3D modeling and dynamic simulation. Also LPTN can be used in sensitivity analysis to vary the effective thermal conductivity between expected lower and upper bounds and to observe the effect on the temperature rise.

In many publications, the thermal network is strongly simplified to further reduce the setup and computing time. The complete machine is represented with only 10 to 30 nodes [1-4] and the acceptable average temperature of the component is calculated. However, the simplified thermal network does not represent the exact position of the hot-spot temperature in electrical machines because of the limited nodes. Another problem is to estimate surface heat transfer coefficient if the flow condition is uncertain and requires an experienced designer in order to obtain acceptable results. While the CFD model can use conjugate heat transfer method to obtain accuracy temperature distribution and flow condition, but it is limited by the minimal time step. It is not possible to calculate time varying simulation.

For this investigation, a totally enclosed, fan-cooled (TEFC) conical rotor motor with complexity geometry is taken as the example. The air flow between the fins caused by the centrifugal fan embedded at the ending bearing is uncertain, thus the 3D CFD model is built to estimate the flow rate and conditions, as shown in Fig. 1, and then the LPTN model of the conical rotor motor is proposed to calculate the temperature performance in both steady and dynamic states. In addition, the feedback is used to correct temperature dependent losses. Finally, the results calculated by the LPTN model is verified by 3D numerical models and good agreements are achieved.

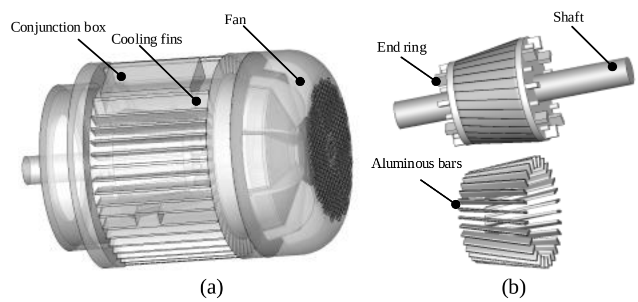


Fig. 1. Structure of the conical rotor motor: (a) Cooling construction of investigated motor, (b) Conical rotor core.

II. Loss Calculation

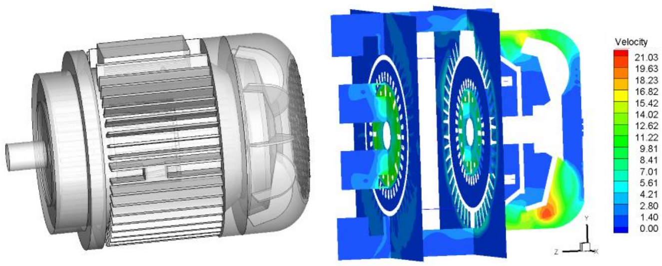
Three iron loss components are considered in the widely used Bertotti's iron loss separation model, namely, hysteresis loss P_h, eddy current loss P_e, and anomalous loss P_a

$$P_{fe}=P_h+P_e+P_a=k_h fB_m^{\alpha}+k_e\left(fB_m\right)^2+k_a\left(fB_m\right)^{1.5} \quad (1)$$

The 2-D time-stepping FEA adopted to calculate the iron loss using ANSYS Maxwell. Copper losses, including the proximity loss, can be easily obtained from analytical expressions. Air friction loss is directly evaluated and included in the CFD thermal model. Detailed description and loss value would be presented in the full paper.

III. Fluid Analysis Model

Based on the computational fluid dynamics (CFD) and the numerical heat transfer theory, a detailed three dimensional fluid flow and heat transfer model was built with several assumptions to reduce the model scale by using the liquid-solid conjugate heat transfer approach. By applying boundary conditions, the steady-state temperature and fluid field of the conical rotor motor is simulated numerically by using the finite volume method. The solution model is shown in Fig. 2(a). Flow velocity around the frame and in the stator and rotor air cave is shown in Fig. 2(b). The key to obtaining an accurate thermal model is to use proven empirical formulations to gain an accurate value for the *h* coefficient for any convection surface in the machine. The following dimensionless numbers, such as Reynolds (Re), Grashof (Gr), Prandtl (Pr) and Nusselt (Nu), are used for nature and forced convections. Based on the previous fluid calculation, the typical surfaces of the electrical machines, i.e., flats plats, cylinders, fin channels, etc., are calculated by using the formulations [5]. Detailed introduction will be presented in the full paper.



(a) (b)

Fig. 2. (a) CFD solution model. (b) Velocity distribution in the motor

IV. LPTN Analysis Model

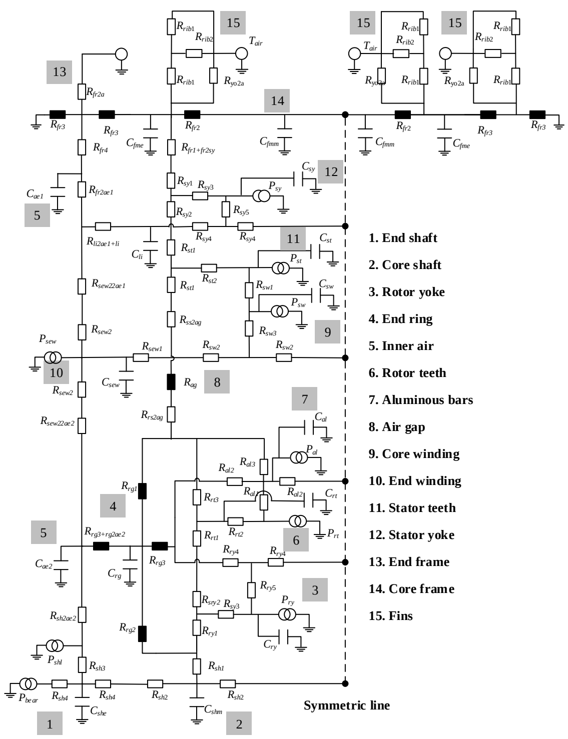


Fig. 3. Equivalent circuit diagram of LPTN .

Fig. 3 shows the thermal network of the conical rotor motor with improved LPTN method. The components of the motor are represented by 4 elements and the capacity is induced to calculate the dynamic state.

For each operating condition, the calculated losses of the electric machines are used as the thermal model input. The parameters of electrical machines have strong interaction between the electromagnetic and thermal analyses, i.e. the losses are critically dependent on the temperature and vice versa. In the LPTN model, the losses are represented by current generator parallel-connected to the thermal components. In order to provide more realistic simulation, feedback is used to correct temperature dependent winding loss in the model with the following formula:

$$P_{c1} = P_{c10} \cdot (234.5 + T) / (243.5 + T_{c10})$$

where P_{c10} is the modeled copper loss at T_{c10}.

The LPTN model is implemented in MATLAB/Simulink by replacing the thermal circuit components with their electric circuit alternatives. Step time is set as 10 s, and the temperature results of windings are presented in Fig. 4.

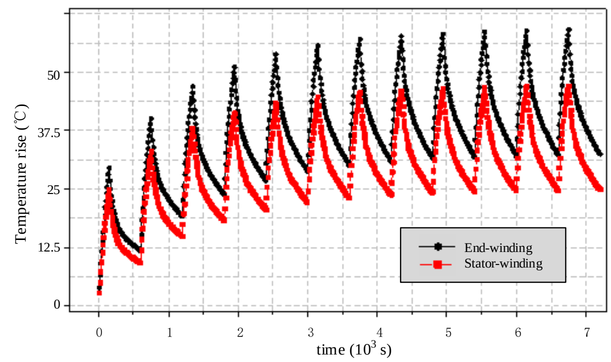


Fig.4. Transient thermal results of winding applied by LPTN.

V. Experiments and Verification

The correctness of the proposed model and the rationality of the solution method were verified by the temperature test of the motor. Also, the the steady-state results calculated by LPTN model is verified by 3D-FEM and good agreements are achieved. Detailed methods, results and discussion will be presented in the full-length paper.

VI. References

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