HEAT TRANSFER IN ELECTRICAL MACHINE: A CASE STUDY

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Abstract: Future design of Aircraft and Automotive needs innovation in propulsion mechanism which are based on electrical mode of operation. More Electric mobility needs a compact high performance electric motor which will assure long operating life with maximum efficiency. Electric motor design needs a multidisciplinary approach including efficient mechanism for heat transfer. The present study reports a Combined Computational fluid dynamics and network approach (CCFDN), applied to the problem of cooling a 1200kW traction alternator. In this combined approach, analysis is first performed using equivalent, lumped thermal network with a simplified circuit aimed at delivering fast, design class results. CFD calculations are next performed to estimate thermal resistances, which are used as input to the thermal networks. Iterative procedure is adopted for solving the network. Results are presented in terms of temperatures at different locations of the device for three cases: one without forced cooling (fan), and second with a fan. The maximum temperature values obtained in the second case is found to be 2.1 times lower than the values obtained in the first case. Results are compared with pure network approach using empirical correlations and with pure conjugate analysis using CFD. The present CCFDN approach avoids using empirical relations, yet much faster than the full conjugate CFD analysis.

I. INTRODUCTION

The prediction of the temperature distribution inside an operating electric motor is one of the most important issues during its design. This prediction allows the engineer to evaluate if the machine will reach the thermal class for which it is being designed, establishing the bearing lubrication intervals as well as checking if the supplied air flow of the cooling system is sufficient for ensuring normal motor operation at rated conditions. The high power densities and the varying operating conditions make the cooling of heavy duty rotating electrical machines a challenging task. The loss distribution of a rotating electric machine changes when its rotational speed is varied. Accordingly, the cooling requirement also changes with speed. The designs of the cooling fan and coolant passages have to be carried out with care by considering the wide range of rotational speeds. The thermal models of the rotating electrical machines ought, therefore, to include the losses and convection heat-transfer coefficients which both vary with the rotational speed of electrical machines and that of the fan supply the coolant flow. The objective of the present work is to develop a thermal model for finding the temperature distribution of different components of the rotating electrical machine. Several works have been done for the electric motor modelling. Most of these works are based on thermal circuit modelling [7]. These works allow predicting the overall motor temperature variation and distribution can be used for determining the effects of different designs, duties and cooling mechanisms of the motor temperature during its operation. Detailed analysis of fluid flow and heat transfer with finite volumes and finite elements are also available [4]. Some works also couple the temperature field determination with the electric and magnetic fields inside electric motors [6]. This paper presents a thermal circuit model of an electric motor aiming to simulate its thermal behaviour during the transient duty towards steady-state operation at rated load. The model is applied to a specific induction electric motor and the predictions are compared to measurements. The purpose of the model is to become an integral part of the motor design process aiming to optimize components and manufacturing processes. In view of the following emerging trends in the industry thermal network analogy will find its extensive application as design decision support platform.

- More Electric Aircrafts & Automotives
- Heat in Electrical Motors
- Miniaturization
- Technology
- High performance
- Low power consumption

II. PROBLEM IDENTIFICATION

The rotating electrical machines convert electrical energy into mechanical energy vice versa using magnetic forces. An alternator is an electromechanical device that converts mechanical energy to alternating current electrical energy. The main mechanisms of heat generation in alternator/induction electric motors are generally divided in four groups, related mainly to the places where they occur. These are Joule losses, iron losses, stray load losses and mechanical losses. Each one of these kinds of energy conversion from electric to thermal energy is detailed below.

Joule Losses: This mechanism corresponds to the conversion of electric energy into thermal energy in electrical conducting media. This type of losses is directly related to the electric resistance of the conductor and changes proportionally to the square of
the current, i.e., \( P_J = R \cdot I^2 \). Energy conversion by Joule effect in squirrel cage induction electric motors occurs in the stator (copper windings) and in the squirrel cage (aluminium bars). Construction details of generic electrical machine is shown in Fig. 1.

Electrical machine efficiency significantly depends on various losses that need to be minimized by design and selection of right materials. Among the other losses heat loss forms a major part which can be minimized by computational fluid dynamics approach while designing. Component wise losses are indicated in Fig. 2.

### III. METHODOLOGY

The thermal modelling of the machine is investigated using a Combined CFD and Thermal network approach. This CCFD approach enables us to evaluate the thermal behaviour of the machine in normal operating mode.

Physical model of rotating machine considered for the thermal analysis is shown in Fig. 3. Thermal analysis is carried out to find temperature distribution of different components of rotating machine using thermal network approach. The lumped resistance network was developed based heat flow paths for the machine. The thermal resistance network for alternator is shown in Fig. 4. Thermal conduction and convective resistances were calculated from the literature. Temperature distributions were investigated using computer program MATLAB. Thermal analysis is also carried out for the machine using commercial CFD package FLUENT. Segregated, steady, implicit solution method RNG k-\( \varepsilon \) model used for the analysis. Extracts the heat transfer coefficient from CFD analysis, incorporated in CCFDN approach, the temperature distribution in alternator is calculated.
IV. RESULTS AND DISCUSSION

The present work main objective of to determine temperature distribution of all the components of present model for varies loading conditions. It is evident from the Fig. 5 that high temperature occur at the stator core and end winding due to iron losses are completely concentrated at stator core. The high temperature at stator has to be cooled by some external agency i.e. like fan etc. this fan is simulated in present work using the pressure jump boundary condition. The maximum temperature is around 407.6 K when there is a pressure jump of 3800 Pa, the minimum pressure jump is given based on the calculation of pressure drop using CFD. Results are presented in terms of temperatures at different locations of the device for three cases: one without forced cooling (fan), and second with a fan. The maximum temperature values obtained in the second case is found to be 2.1 times lower than the values obtained in the first case. Results are compared with pure network approach using empirical correlations and with pure conjugate analysis using CFD.

Fig 5 Temperature contour with pressure jump condition
Fig 6 Temperature contours with stand still air condition

Fig 6 shows the temperature distribution of the alternator when there is stand still air condition. The stand still air is simulated using a Natural convection boundary condition. Maximum temperature is 938.84K in this condition .The forced convection simulation is carried out for different loads like full load, minimum load, and 60% load condition. The maximum temperature in each simulation respectively 448.4 K (maximum load), 340.2 K (minimum load), 395.2 K (60% load condition) at 0.58kg/s mass flow condition.

The temperature distribution of an alternator like stator, rotor, end winding is a crucial necessity high density high speed motors. Thermal network approach will enable designers’ gain an insight on proposed design paving a way for Innovation Thermal network model helps to design cooling mechanism using suitable mode of heat transfer. The present study a combined CFD and network approach is proposed to find the temperature distribution in an alternator. This approach is found to be effective in simulation of temperature distribution in alternator. The solution of thermal network with thermal resistance computed from CFD resulted in the values of temperatures of different components in alternator like stator, rotor, bearing and end winding. The maximum temperatures obtained in the free convection model is 948K in forced convection is 448K and in forced convection with fan is 408K from the maximum load condition. There is a 31% raise in the maximum temperature from minimum load condition to maximum load condition.

CONCLUSION

In the light of developments in more electric Aircraft and Automotive especially the autonomous cars design of compact high performance electric motors is need of the hour Heat transfer in the electric motors is a crucial necessity high density high speed motors. Thermal network approach will enable designers’ gain an insight on proposed design paving a way for Innovation Thermal network model helps to design cooling mechanism using suitable mode of heat transfer.
network is found to be an optimized way of finding the distribution of temperatures.

REFERENCES


