

# Liquid Cooled Induction Motor: Computational Design, Heat Transfer Analysis, Parametric Study, and Performance Testing

Jenwit Soparat and Chi-na Benyajati  
 National Metal and Materials Tech. Center

## ABSTRACT

In order to use an electric induction motor to power an automotive vehicle, heat occurred in a motor is an important issue. Generally, an induction motor could be operating at a high load for many extensive periods. The generated heat in motor could cause damage on motor parts subsequently decreasing their useful service life. The objective of this study was to develop a cooling system of the induction motor by introducing liquid coolant passages on a housing part to obtain higher cooling efficiency than that of conventional Totally Enclosed Fan Cooled system (TEFC).

Principally, conventional TEFC finned housing and rear fan would be replaced by a cylindrical aluminum housing. Special heat transfer oil was chosen as a coolant mainly due to its dielectric property. The liquid cooling housing geometry was defined by series of cooling passages to guide the liquid coolant through and around the housing. The design of liquid cooling system was performed via computational simulation. In the main simulation work, the boundary conditions of heat generation in motor were obtained from previous experimental and computational work on existing TEFC motor. Using resulting temperature distribution in the motor as a design criteria, the effect of two operational variables were investigated i.e. coolant flow pattern and coolant flow rate. Simulation results in each design case were compared and discussed to determine the finalized concept of the liquid cooling system prior to a prototype fabrication and actual performance testing.

**KEYWORDS:** induction motor, liquid cooling, heat transfer, CAE, Computational Fluid Dynamics

**CITATION:** Soparat, J. and Benyajati, C., "Liquid Cooled Induction Motor: Computational Design, Heat Transfer Analysis, Parametric Study, and Performance Testing," *SAE Int. J. Alt. Power.* 2(1):2013, doi:10.4271/2013-01-0005.

## INTRODUCTION

Due to a demanding nature of various applications, modern classes of induction motors need to come in a compact size while performing with high efficiency and capable of running at high speed. All these demands indicate a higher working temperature of a stator wiring [1]. As a result, a thermal analysis becomes an important tool in enhancing the working performance of existing motor models. In a current study, a thermal analysis was carried out by means of a computational method. The calculated results were then compared with those obtained experimentally from an actual induction motor.

Previously, there have been various studies on thermal performance of an electrical motor by using a thermal network method [2, 3, 4]. Majority of proposed models showed that a highest temperature would occur on the wiring on the stator. However, one of limitations for such method was that no detail of temperature contribution on motor parts was provided. Also, part geometries were not taken into the account either.

These issues become apparent when the convection effect needed to be determined on motor with finned housing or other configurations. This was shown experimentally by Farsane et al. [5] who employed a Laser Doppler Anemometry technique to measure air velocity around the motor housing. It was reported that the shape of motor housing had a significant effect on both air velocity and a flow pattern along the housing. Thus, a performance of a motor cooling system could be directly affected by the design of housing and other parts.

**Table 1. Insulator classes of motor [6, 7]**

| Insulator class | Operation Temperature (°C) |
|-----------------|----------------------------|
| A               | 105                        |
| B               | 130                        |
| F               | 155                        |
| H               | 180                        |

The thermal properties of an insulation of copper winding were an important factor on the capacity of an induction motor. Table 1 shows the operation temperature limit of

motor with several electrical insulator classes. A temperature higher than insulator's temperature limit would cause an insulator melt down which could lead to an electrical short circuit in a motor. Even if an operating temperature was lower than the temperature limit, a high temperature could effectively reduce lifetime of induction motor dramatically as shown in Fig. 1.

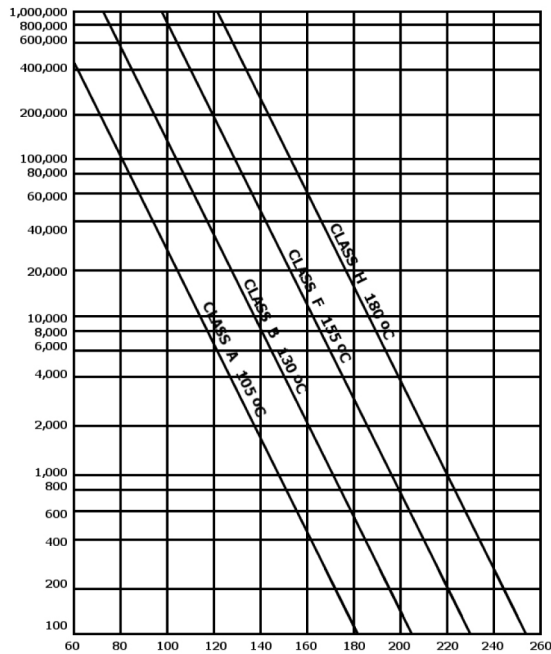


**Figure 1. Total winding temperature (°C) versus insulator life [8, 9]**

According to previous work [10, 11], a parallel flow design of liquid cooling housing was compared with the typical TEFC housing. The simulation result showed that the liquid cooling housing had more cooling capacity than TEFC housing. However, the best condition for parallel liquid housing was 0.5 kg/s inlet flow rate. With this condition, there was a disadvantage about a large coolant container in order to adopt such system to automobile. The objective of this study was to improve the liquid cooling system further by reducing the coolant flow rate and temperature. There were 2 concepts of flow pattern discussed in this study i.e. parallel pattern, according to the previous study, and series pattern, which was introduced in this study.

By using simulation approach, a new design of liquid cooling system was developed by applying the heat source which represented the condition occurred in TEFC motor at 100% rated load. Variables such as number of passages, and inlet flow rate were applied to the simulation to obtain a proper design for liquid cooling system. Finally, the calculated results of both models were compared via resulting temperature distributions.

## METHODS AND PROCEDURES

### Liquid Cooling System Design

In an attempt to improve the cooling capacity of TEFC motor, the cooling fan was to be replaced with the liquid cooling system. An advantage of the liquid as a cooling medium was a higher specific heat capacity. However, the system configuration could become more complex than that of the fan cooled system. The liquid cooling system would be comprised of a radiator, also acting as coolant storage, a coolant pump, a valve, and a motor housing providing a passage for liquid coolant. The schematic of liquid cooling system is shown in Fig. 2.

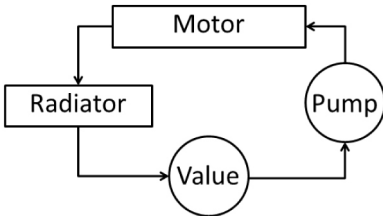


**Figure 2. Schematic of liquid cooling system**

The TEFC motor efficiency test data was obtained by using a dynamometer. The experimental data was applied in the heat transfer simulation to calculate the heat generation model. This obtained heat generation model was then applied for liquid cooling system simulation. Table 2 shows the heat generation in each component.

**Table 2. Heat generation model of 3.7 kW motor sample**

| Domain         | Heat Generation (W) |
|----------------|---------------------|
| Rotor          | 278.71              |
| Stator Core    | 123.32              |
| Copper Winding | 393.62              |

### Boundary Conditions

The simulation was calculated under an assumption of a steady-state condition, which was taking into account heat transfer equilibrium. The flow regime was a turbulence state with K-Epsilon model. In order to reduce calculation resources, the convection by air surrounding the external housing surface was assumed to be negligible. The air circulation inside housing was also neglected. The only cooling mechanism considered was coolant oil flowing in cooling passages such as those displayed in Fig.3. Inlet coolant temperature was assigned as 45 °C according to a typical coolant temperature from a car radiator. An outlet pressure was assumed at atmospheric pressure.

Each motor component was assigned as isotropic materials. In simulation model, there were four main domains of motor components i.e. housing, stator, copper coil, and rotor. The housing domain was assigned as aluminum. The stator and rotor domains were assigned as steel while the copper windings domain was assigned as copper. On the