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Liquid Cooling Model Of Axial Bldc Motor

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***Abstract*— Brushless DC motors (BLDC) is electric motor with high efficiency and excellent controllability, and are widely used in many applications. This paper explains the analysis of a 5 kW liquid cooling BLDC motor numerically. This motor is an axial BLDC motor which is composed of a stator consisting of an armature and a magnetic rotor. Numerically analysis show that cooling temperature have significant effect on power and efficiency of motor. Lower of cooling temperature produce higher motor power and efficiency. Low temperature liquid cooling motor can produce maximum power up to 6 kW and up to 88.0 % of efficiency, while air cooling motor can produce maximum power up to 3.5 kW and up to 55.0% efficiency. From above calculation it can be concluded that proper cooling process can increase efficiency up to 33 %.**

Keywords—Axial, BLDC, rotor, stator, windings

I. INTRODUCTION

Brushless DC motors (BLDC) is electric motor with high efficiency and excellent controllability, and are widely used in many applications. The BLDC motor has power-saving advantages relative to other motor types [1]. This paper describes the modeling of heat transfer and cooling processes in liquid-cooled BLDC motors. Many studies have shown that the working temperature of an electric motor affects the performance of the motor. Temperature affects maximum power and efficiency. The higher the motor temperature, the maximum power will decrease and result in decreased efficiency [2].

This is because increasing temperature reduces the insulation resistance of the windings, generates thermal stress, and reduces efficiency [3].

One method to reduce the operating temperature of the BLDC motor is liquid cooling. In general, liquids have a higher thermal conductivity than air, which increases the rate of heat transfer from the motor to the surrounding air [4].

II. MOTOR DESCRIPTION

In this modeling, the BLDC motor used is the axial type BLDC which consists of the main components of the rotor, stator, bearings and casing. The motor stator consists of a copper wire wound on a core (armature). Armature core is made from pure iron powder with 99% Fe content mixed with carbon fiber resin as the bounding. The stator winding (armature) uses copper wire coated with an insulator with a total diameter of 0.6 mm. The rotor on the BLDC motor consists of 12 pairs of permanent magnets. The magnets used in axial Brushless DC motors are neodymium types which are strong magnets that have a very wide range of applications [5,6].

Figure 1. shows a stator which consist of a core and copper windings forming a core and armature unit.

Figure 1 Stator consist of core and armature

A rotor piece consist of 8 pairs of neodymium magnet is shown in Figure 2.

Figure 2 Magnetic rotor

General arrangement of the BLDC motor to be analyzed is described at Figure 3.

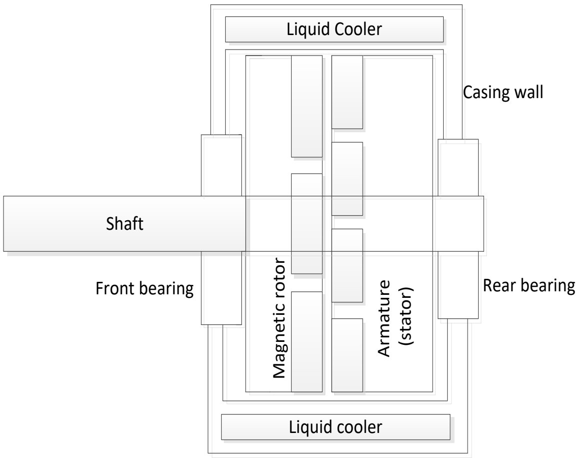

Figure 3 General arrangement of BLDC motor to be analyzed.

This motor has a nominal power of 5 kW and can generate maximum power of up to 7 kW at maximum speed 6000 rpm which electric input power of 60 V DC Maintaining the Integrity of the Specifications

III. NUMERICAL ANALYSIS

A. MODEL FORMULATION

This paper discusses liquid cooling process in a 5 kW BLDC motor. The motor input is electric power at voltage 60 V with 90% rate efficiency and operated of about 2000-6000 rpm. The motor consirt of an armature and single magnetic rotor. MAXWELL criteria is aplied for simulation do Electromagnetic losses such as coreloss and copper losses, while losses due to bearing friction are neglected [7]. Heat Generation on BLDC Motor Losses that occur in Electric Motors can be classified as resistive losses, Eddy current and hysterisis. Mechanical power of rotor is calculated based on Torque. In the case of Eddy curent below equation can be used [8]:

$$P_{ey} = K_e \frac{8}{\pi} \frac{f^2 B_m^2}{\beta_m} \quad (1)$$

where f is the frequency of the flux variation, Bm is the peak flux density, βm is the arc of the tooth and width of the mast respectively in the electric radians, Ke is the curve of the fit constant calculated from the data of the loss of the laminate.

The hysteresis is modelled using below equation [9]:

$$P_h = K_h f^{\alpha} B_m^{\beta} \quad (2)$$

where f is the frequency of the flux variation, Bm is the peak density of the flux Kh, Ke, α, β is the fit curve calculated from the data of the loss of the laminate.

Resistive model for heat transfer is described based of the following figure:

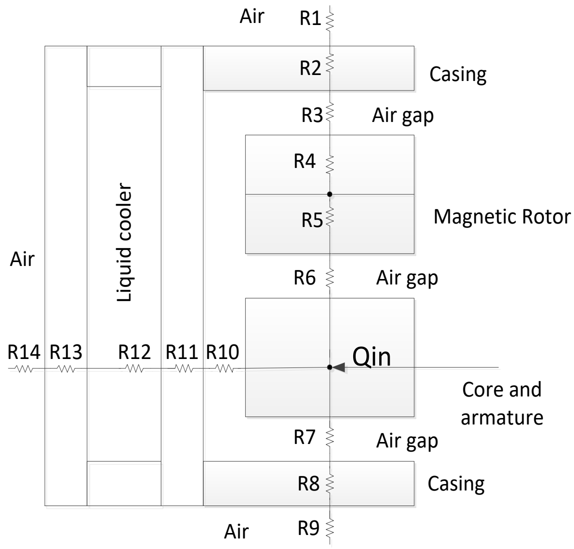

Figure 4. Liquid cooled motor thermal circuit model

Figure 4 shows the thermal circuit of liquid cooled motor, where heat generate from from core and armature is transferred to atmospheric air axially and also transferred to liquid cooler radially. Symbol R is represent thermal resistance of material and described as following:

- R1, R9 and R 14 are radiative thermal resistance from casing surface to surrounding air.
- R2, R8, R11 and R13 are conductive in casing wall.
- R3, R6, R7 and R 10 are air gap convective thermal resistance
- R4 and R5 are conductive in magnetic rotor
- R12 is convective in liquid cooler.

In this model air gap between the armature/core and casing, and air gap between core/armature and magnetic rotor uses Silicone Thermal Grease with a thermal conductivity of 6.2 W / mK as thick as 0.5 mm [10,11].

The magnitude of heat transfer *Q* from the Core and winding armature to the atmospheric air through air gap and liquid cooler depends on the convection coefficient where calculated based on following equation[12]:

$$Q = hA(Ts - Ta) \quad (3)$$

Where A is surface area, Ts is surface temperature and Ta is atmospheric temperature.

h is convection coefficient that described as [12]:

$$h = \frac{k}{D}(0.11)[0.5Re^2 + G_r P_r]^{0.35} \quad (4)$$

where :

k is thermal conductivity

D is diameter

Re is Reynolds number

Gr is Grasoft number

Pr is Prantl number

T_s is Temperature of surface (casing and core)

T_a is air or liquid temperature

Model of mechanical power of Rotor

Rotor rotation is governed by the mechanical equation below [13]:

$$J_m \frac{d\omega}{dt} = T_e - T_L + D_\omega \quad (5)$$

Where J_m is the total moment of inertia ω is the rotor speed; T_e is the electromagnetic torque, D is the damping coefficient and T_L is the torque required to drive the load.

B. CALCULATION PROCEDURE

The purpose of the simulation is to calculate the power and efficiency of the motor. Electrical energy is supplied to the motor with 60 V of voltage and 85 A of current. The input energy is transferred to mechanical energy (Pmech) and Electrical losses described above. The all parameter are calculated based on numerical using commercial software. The heat source of motor is on the winding and core where heatflux are transferred axially and radially.

C. CALCULATION RESULT

Result of calculation using numerical analysis based on commercial software was focused on effect of cooling media on the motor performance. In the first stage temperature distribution inside motor is calculated. In this case, 5 KW BLDC motor was cooled by water and set as 20°C. In this condition, thermal conductivity of water is 12 W/mK [12]. Numerical simulation result temperature distribution of motor radially and axially. It is shown in Figure 5 and Figure 6.

Figure 5 show that on motor casing radially the temperature distribution relatively symmetric, but in motor armature is seem higher temperature. Highest temperature occur at motor armature where in this point energy input is converted. Similar situation is shown in Figure 6 where temperature distribution at axial direction relatively balance from front to rear of the motor.

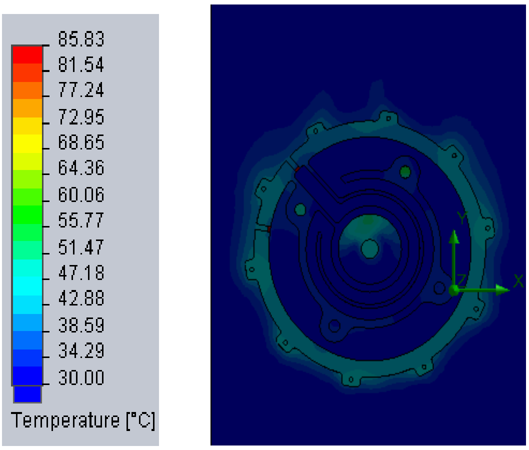

Figure 5 Water cooled Motor temperature distribution at radial direction

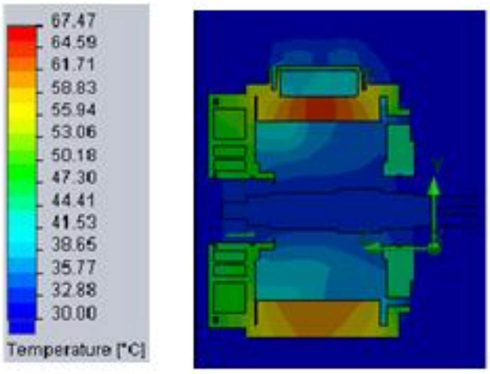

Figure 6. Cross section temperature distribution on water cooled BLDC motor

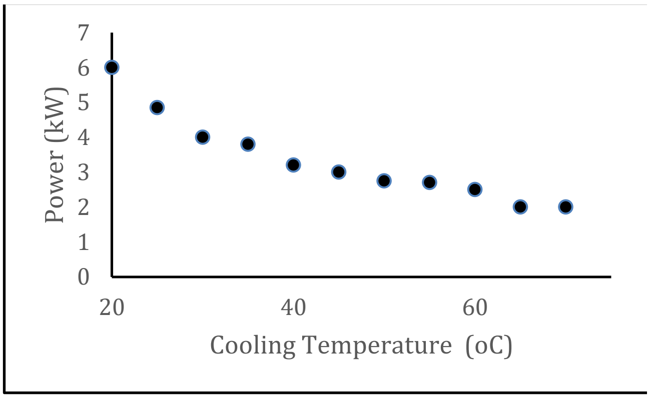

Figure 7 . Effect of cooling temperature to motor power.

Similar calculation using various water temperature and motor speed. Water temperature is set as 20°C, 22°C, 24°C, 50°C, 60 °C and 70°C and motor speed is varied form 1500 rpm to 3500 rpm

Based on numerical analysis, based on previous calculation procedure, motor power and efficiency can be summarized in Figure 7 to Figure 9. In this figure, effect of cooling temperature on motor power is explained. Figure 7 show that higher cooler temperature cause lower power. This is in line with the theory described in the introduction, that the higher the temperature causes the magnetic strength to decrease, causing the motor power to decrease. Low cooling temperature is capable of producing maximum motor power as shown in the motor specifications, 20°C water cooling can produce 6 kW motor power. In Figure 8 and Figure 9 show a close correlation regarding motor performance by type of cooling. Liquid cooler have higher heat transfer rate and provides a greater cooling rate so that the stator and rotor temperatures are relatively low, result in higher motor power (Figure 8). As power increases, the water cooledmotor efficiency is also higher than air-cooled motors. This can be seen in the Figure 9. From Figure 8 and Figure 9, it can be seen that liquid cooling motor can produce maximum power of 5.2 kW and up to 88.0 % of efficiency, while air cooling motor can produce maximum power up to 3.5 kW and up to 55.0% efficiency

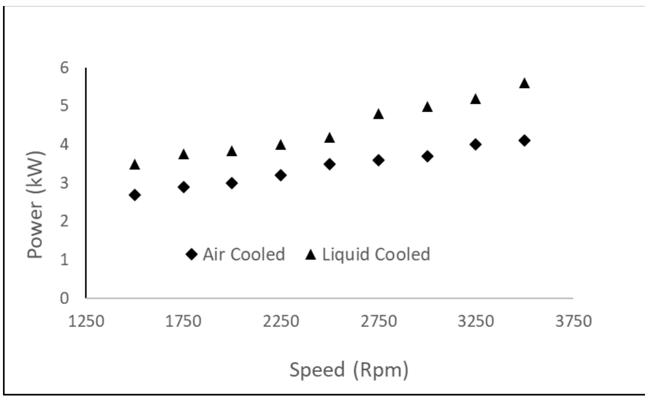

Figure 8. Motor power based on cooler type at various speed.

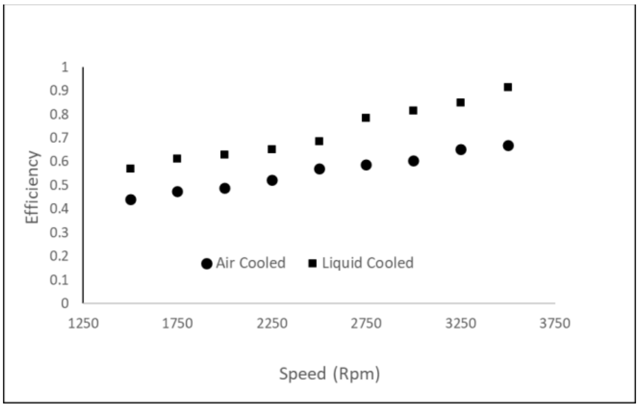

Figure 9. Motor power based on cooler type at various speed.

IV. CONCLUSSION

Numerical analysis of Effect of cooling temperature on 5 kW axial BLDC motor power and efficiency were presented. The motor power was calculated based on input power minus losses power and efficiency was calculated based power input and power output. Using commercial software calculation show that cooling temperature have significant effect on power and efficiency of motor. Lower of cooling temperature produce higher motor power and efficiency. Low temperature liquid cooling motor can produce maximum power up to 6 kW and up to 88.0 % of efficiency, while air cooling motor can produce maximum power up to 3.5 kW and up to 55.0% efficiency. From above calculation it can be concluded that proper cooling process can increase efficiency up to 33 %.

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