Design and Performance Analysis of Brushless DC Motor Cooling System for Low-Cost Manufacturing Process

Yoga Uta Nugraha 1, Arief Cahyadi 1, Juniono Raharjo 2, M Nur Yuniarto 3 and Alief Wikarta 3

1 Department of Electrical Engineering, Center of Excellence for Automotive Control & System, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
2 Department of Naval Architecture, Center of Excellence for Automotive Control & System, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
3 Department of Mechanical Engineering, Center of Excellence for Automotive Control & System, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: uta.utu@gmail.com, ariefc72@gmail.com, juniono10@gmail.com, muhammad.nur3006@gmail.com, aliefwikarta@gmail.com

Abstract. Thermal analysis on BLDC Motors is very important to be learned in order to obtain a low-cost motor design and have a high level of efficiency. The design of the existing motor cooling system uses a complex design that must use sophisticated machining tools and spend a lot of money in the manufacturing process. The purpose of this paper is to get the geometry of the cooling system on BLDC motor with simple manufacturing process thus saving the cost of production. The expected cooling system design is a simple geometry so that manufacturing can be done using 3-axis CNC machining. Design of cooling system using water-jacket with an additional cover. On this study, Author modeled the motor with Ansys Maxwell to obtain the heat source parameters of the motor geometry. Software Fluent is involved to perform the temperature simulation on the motor using the designed cooling system then validated with an experiment. Thermal analysis of this study compares motor performance with the use of water and oil. The flow rate compared to the radiator power efficiency.

1. Background

Currently the Brushless DC motor, or often referred to as BLDC, is a brushless motor that is controlled by a 3 Phase Inverter. This type of motor has been chosen as the prime mover of electric vehicles because it has high efficiency, high power density, and low noise. The motor consists of main parts such as stator, rotor, shaft, coils, housing, and bearings. Sometimes for large motors require additional cooling to accelerate the heat propagation from the inside of the motor to the surface of the motor.

In this paper we will discuss thermal analysis of cooling systems that can be applied to existing motors. The experimental method is carried out by simulation using the Solidworks Flow Simulation Software. The fluid cooling model that is often used is circular geometry. This requires a fairly complex design and manufacturing process. Therefore it is necessary to conduct research on making cooling systems that are cheap but efficient.

Chang et al. [1] in his research proves that differences in motor design will have an impact on the amount of motor losses that will be a source of heat. Baggu et al [2] in his research modeling thermal...
analysis using an electric equivalent circuit. Yoon et al [3] in his research proves that motor performance can be improved by improving the cooling system.

2. Motor Loss Source Model

2.1. Winding Loss
Winding the motor uses enameled wire with the main material being copper. Copper flowing current in an electric motor also produces copper losses can be formulated into:

\[ P_{cu} = 3I^2R \]  (1)

Where \( P_{cu} \) represents copper losses that are affected by current value \( I \) and internal resistant \( R \). Value of \( R \) affected by the length of the conductor \( l \), measured in metres (m), the cross-sectional area of the conductor \( A \) measured in square metres (m²), and \( \rho \) (rho) is the electrical resistivity (also called specific electrical resistance) of the material. The mathematical equation can be written as:

\[ R = \rho \frac{l}{A} \]  (2)

2.2. Core Loss
Stator and rotor are made of electrical steel material which is both a conductor and ferromagnetic. Therefore Stator and Rotor have losses called Hysteresis Loss and Eddy Current Loss. Hysteresis Loss is caused by the process of magnetization and demagnetization of the stator when an electric current is flowed in a forward and reverse direction. When the current is directed forward, the flux is positive. With the same energy rate, there is still a flux value so it needs reverse energy to make zero flux. This difference becomes one of the energy losses in the core.

While eddy current loss refers to Faraday’s Law where a conductor that moves to cut the flow of magnetic flux will cause an induced voltage. Core construction is shaped like a closed loop circuit so that the current flows individually to the core. This current is called the Eddy Current. To reduce eddy current effect, cores are usually made with layers of conductor with silicon laminates. Core loss values are obtained from simulation results using ANSYS MAXWELL electromagnetic simulation software.

![Figure 1. Coreloss Value](image-url)
2.3. Bearing Friction Loss
All bearings have friction loss. Factors that affect magnitude friction loss are influenced by type of bearing, bearing size, bearing design, load, oil viscosity, oil flow, and speed [4]. In this paper, friction loss is neglected.

3. Physical Model
The types of motors studied in this paper are Radial Brushless DC (BLDC) motors with axial way cooling and internal fans. This motor has a power rating of 20 kW with a voltage of 300 V. This motor is designed with 12 stator slots and 8 magnetic poles. The combination of the number of slots and poles has a winding factor of 0.866 [5]. The motor part consists of a stator and rotor made of electrical steel material, housing made of aluminum, shafts made of stainless steel, permanent magnet Neodymium N52, and coil winding.

4. Simulation Result
Thermal modeling is done using Solidworks Flow Simulation software. This software is a Computational Fluid Dynamics (CFD) embedded in Solidworks 3D software. Initially the motor operated full load at a speed of 3600 rpm, with a room temperature of 280°C, the results are shown in Fig.3.

![Figure 2. 2 CAD model of BLDC motor: (a) outside view, (b) cross section view](image)

![Figure 3. Cross section of thermal simulation without cooling system, (a) : Front View, (b): Side View](image)
From the simulation results it can be seen that when the motor is operated full load, the average temperature of the motor is 800°C. Therefore, this motor design requires additional cooling systems such as fans or water flow.

a) Cooling system with water flow
Water is a type of cooling fluid that is often used by motor manufacturers with medium to large capacity [6]. Besides being economical, the advantages of using water as a cooling medium will not cause crust on the channel. The cooling channel is designed with geometry as in Fig.4 to simplify and reduce production costs. Circular inlet and outlet with a surface area of 0.000785 m². Water flow rate is set at 8L / m.

![Water cooling line design](image)

**Figure 4.** Water cooling line design

The manufacturing process is carried out by utilizing a cylindrical ring shape on the housing then forming 20 axial holes. After that the main housing is zigzagged so that water can flow on all sides of the motor.

![Cross section of thermal simulation with watercooling system](image)

**Figure 5.** Cross section of thermal simulation with watercooling system, (a): Front View, (b): Side View

From the simulation results it can be seen that the temperature of the motor when operated full load by cooling water has better results than without cooling. The inside of the motor has an average temperature of 65°C while the housing has an average temperature of 33°C.
b) Cooling system with fan
The second experiment is using two fans on the inside. The shape of the fan is shown as in Fig. 6. The fan is paired with a shaft, so the fan has the same rotational speed as the motor. The fan is made of PLA material made with a 3D Printing machine. The results of thermal simulation using two fans and without cooling water are shown in Fig. 7.

![Figure 6. Water cooling line design](image)

(a) ![Figure 7. Cross section of thermal simulation with Fan cooling system, (a): Front View, (b): Side View](image)

Cooling design with the fan is only able to reduce the temperature in the rotor area. From the simulation results, the rotor temperature obtained from 60°C-70°C, at the stator section 70°C to 85°C. While the housing has an average temperature of 75°C.

c) Cooling System with Fan and Waterflow
The third cooling option is to use both water flow and fan. When the load and speed parameters are set to the same as before, the simulation results are shown as in Fig. 8.
Figure 8. Cross section of thermal simulation with Fan and water cooling system, (a) : Front View, (b): Side View

Figure 9. Fluid flow vector simulation

With the fan inside the motor, the air will circulate quickly so that heat rapidly travels through the main housing. As a result, the temperature in the motor and housing dropped dramatically.

5. Simulation Result
The motor generates thermal energy when operated due to mechanical or electrical factors. For medium to large capacity motors an additional cooling system needs to be provided to reduce the heat generated by the motor parts. If the motor is very hot will cause insulation failure on the copper wire and reduce motor efficiency.

Some ways that can be done to reduce the heat from the motor by using a water flow or fan. From the simulation results in this paper, the motor without cooling has an average temperature of 85°C on the inside of the motor, while the main housing is 75°C. While using water and fan, the average temperature of 65°C is obtained and the main housing section is similar to room temperature.
6. References

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