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Study of temperature rise in small brushed DC motor components under different speed

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Abstract. Each electric motor has a temperature rating that is related to the insulation grade of its winding. Exceeding the maximum temperature will lead to motor destruction. In this study, the temperature rise of components in a 250W brushed DC motor including the brush, bearing, permanent magnet and casing are observed as the speed of the motor changes. Knowing that the speed is proportional to the voltage supplied, the temperature of these components was observed at voltages ranging from 8 to 24 V with no load. The results show that despite running without load, the current increase proportionally due to resistance torque that increases with the speed. The maximum temperature attained in the brush at the maximum speed tested at 55°C. The following orders are the bearing, casing and permanent magnet. The order are the same regardless the speed level.

1. Introduction

Currently, many applications implement motor as the alternative source. For example, DC motors are regularly use in the most famous applications which relate to the process of heating and cooling of the motor. One of the applications involve is in automotive areas.

Thus, by using the motor actively can lead to the thermal behavior problems in the motor itself [1]. The most permanent damage done to the motor is thermal damage: melting or burning the winding insulation leading to short-circuiting and demagnetization of the permanent magnet. This can be referred to the Li Yan *et. al* [2] which presented that, because of high motor internal temperature will precisely weaken the characteristics of permanent magnet materials, the degree of fatigue of the rotor bearing and motor efficiency. Next, for the time being, this small DC motor is being used widely for low voltage range from 12-24V.

Recently, most of the literature was concerned about the thermal behavior of the motor especially on the heat transfer of the motor and the heat dissipation. Instead of that, during the motor running, some of the heat losses will dissipate such as copper loss, iron losses, mechanical losses, and stray losses. However, DC motor always involves into two types of losses; copper losses and iron losses [2]. The copper losses can calculate by using this formula below:

$$P_{copper} = R.I^2 \tag{1}$$

From the equation, the copper losses are proportional to the resistance, R that this comes from the heat loss of the winding in DC motor. Obviously, this resistance can relate to the basic principle of the voltage. For the DC source, the speed of a motor is proportional to the voltage, while the torque is proportional to the current as presented in Equation 2.

$$V=I\ R \tag{2}$$

Therefore, when the load is increasing, the current also will increase. As a result, more heat losses will generate. Other than that, the optimization problems that always include a coupled thermal-electromagnetic problem are becoming common increasingly between engineers and designers of the machines [3]- [4]. Hence, the heat transfer in the small DC motor needs to understand. The principles of DC motor clearly involve the process of heat transfer. In the previous study, the heat transfer can be dividing into three mechanisms [5]. All three-heat transfer mechanisms of conduction, radiation, and convection occur in the motor (Equation 3, 4 and 5). The equations show as follow;

$$\dot{Q}_{cond} = \frac{dQ_{cond}}{dt} = -\lambda A \frac{dT}{dx} \tag{3}$$

$$\dot{Q}_{conv} = \frac{dQ_{conv}}{dt} = h.A.\Delta T(t) \tag{4}$$

$$\dot{Q}_{rad}=\sigma.A.\varepsilon.F_{1-2}.(T_1{}^4\text{-}T_2{}^4) \tag{5}$$

A few speculations can be made [5]: Conduction happens over the solid part while convection and radiation occur in the air gap, inside air gap and the outside surface in contact with surrounding air. In a motor void of the magnet, the defenseless part towards heat is the winding. In function of the protection grade used, the motor can withstand an extreme temperature running from 150°C to 240°C [5].

In this paper, the main points that need to highlight are identifying the DC Motor component that has the highest temperature rise rate. Thus, comparison of the most sensitive components towards the temperature rise under different voltage can be done. Next, the effects of temperature rise in each component when motor running can be discussed [6]- [7].

2. Methodology

In general, this paper will be used a 250W of small brush DC Motor for observing the temperature rise. This can be presented in Figure 1 below;

Figure 1. A 250W of small brushed DC motor.

The specifications of the small-brushed DC motor can be detailed in Table 1 below;

Table 1. Specifications of the brushed DC motor studied.

Specification	Detail
Model	MY1016
Voltage	240 VDC
Rated speed	2650 RPM
Rated current	13.7 A
Output	250 W

For further information, components of brushed and brushless DC Motor can either simple or complex. For example, in the thermal term, the complex designs of components in the motor are the structure of rotor, commutator, bearing, open fins channel for the permanent magnet DC commutator motors (PMDC), winding and many more. Aldo Boglietti, Jacek Jurak, and Wenbo Wang [8], [9] and [10] can explain the complexity of those components more. These prove that the complex components are difficult to measure in thermal heat transfers, which need to be, used the different method. Thus, by having this experiment, some steps to measure the temperature rises are being set up. Normally the motor is designed to dissipate the heat to the outside of motor assemblies. Hence, some relevant components are taken to measure their temperature rises. The components include a brush, bearing, casing, and permanent magnet.

From these components, the main reason why brush is being chosen compares to the winding because the brush is not rotating and at the same time, winding will always rotating during the experiment. Considering the effect of the thermocouple to be rotating simultaneously with the winding, the brush is the most suitable components that can measure the temperature rise. Apart from that, if the thermocouple applies at the winding, this will damage the solder at the thermocouple and will cause disturbance during temperature taking. Next, bearing, casing, and the permanent magnet are being used because of these components easy to take the temperature rise and not rotating. Figure 2 below shows how the instrumentation of the thermocouple at the DC motor.

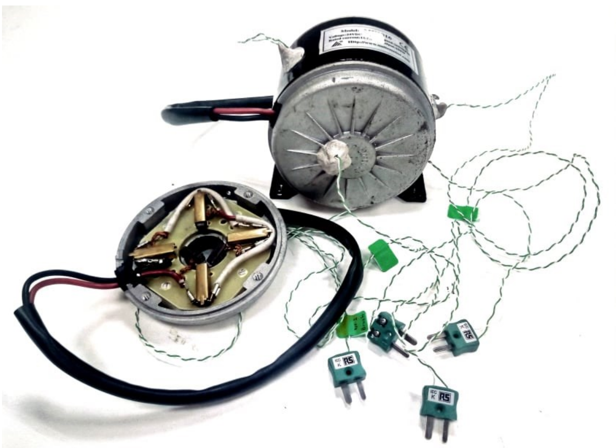

Figure 2. Component of small brush DC Motor to be measured.

Apart from that, Figure 2 shows some device that able to collect the data temperature. This device named as USB Thermocouple Data Logger. This USB will connect to the Pico Log Data Logger to observe graph pattern for temperature rise at the monitor.

3. Data Acquisition

Data acquisition of this experiment can display as the flowchart in Figure 3 below;

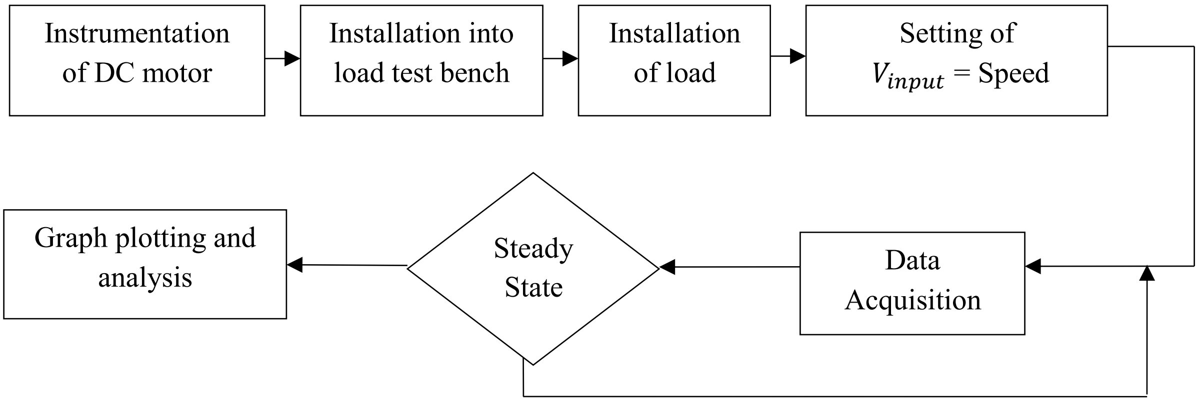

Figure 3. Flowchart of data acquisition.

Based on the flowchart above, this experiment involves seven steps. First, in instrumentation of DC motor, the motor will be placed at the top of the test bench. At the same time, apply the thermocouples at the selected components like the brush, bearing, casing, and permanent magnet. Meanwhile, at the test bench contain brake disc, sprocket and chain ring to form drivetrain. This both drivetrain and the DC motor will connect each other like a bicycle application. After that, the installation into the load test bench. This installation allows the load and the test bench connected to each other. This can be demonstrated clearly, when the load holder is built separately with the test bench. The load holder work as the parts that give some torque to the drivetrain when the electric current flows. To initiate this experiment, the loads need to be installed. For the first experiment, the measurements of the temperature rises are being done without adding load for 8V. Then, the installation of a different voltage will be repeating according to Table 2.

Table 2. Different value of current under different voltage.

Voltage, V (Volt)	Loading	Current, I(Ampere)
8V	No load	0.7A
16V	No load	2.0A
24V	No load	3.5A

After that, set up the voltage of 16V and 24V using U8031A Triple Output DC Power Supply for small DC motor to run. This voltage will represent the speed of the motor. Next, for data acquisition in DC motor components, the temperature rise will be recorded simultaneously by using the Pico Log Software data logger and then wait for the temperature of motor until achieve at the steady state before stopping the power supply. If the temperature rises are not in steady state, the process of data acquisition must be repeated. Moreover, this data logger will record the temperature rise for processes, heating, and cooling. When all the data had been collected, these data will be plotted in the graph and is analyzed according to the objectives of the experiment.

4. Results and Discussion

The entire graphs below show the process of heating and cooling of the DC Motor components for three conditions. The main components that had been tested in the motor are brush, bearing, casing, and the permanent magnet. Therefore, from that, the temperature rises and the time taken off the motor when heating and cooling as shown in the figures can be observed. According to these figures, the graphs show the temperatures of DC Motor's components over time for the constant load which this experiment does not consume any load or else 0.00kg. To be more specified, the red colour represents the temperature rise for the brush, the blue colour for bearing, yellow colour for casing, the purple colour for permanent magnet and the green colour for the ambient temperature.

4.1. Temperature comparison between components at different voltage.

In this experiment, Figure 4 shows the temperature rise of the motor when the voltage of 8V was acted on it. Then, Figure 5 is when the motor running at 16V and Figure 6, the temperature rise presented for 24V.

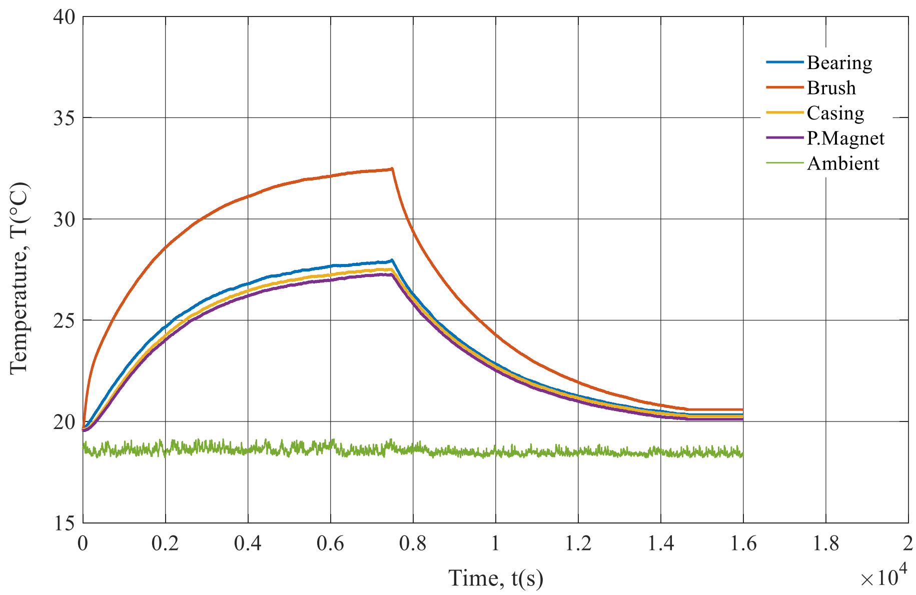

Figure 4. The temperature profile of healthy motor at no load for 8V.

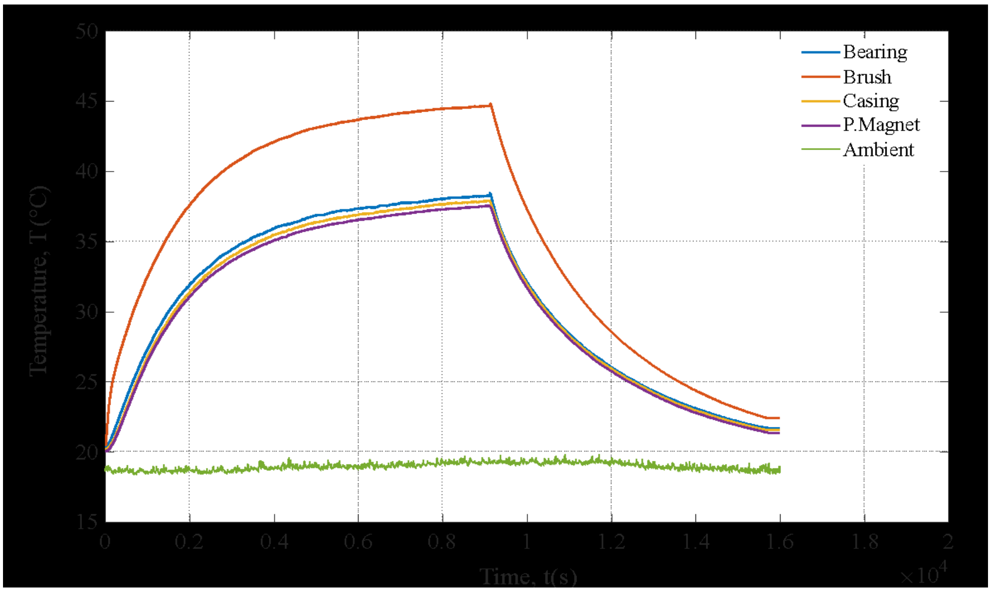

Figure 5. The temperature profile of healthy motor at no load for 16V.

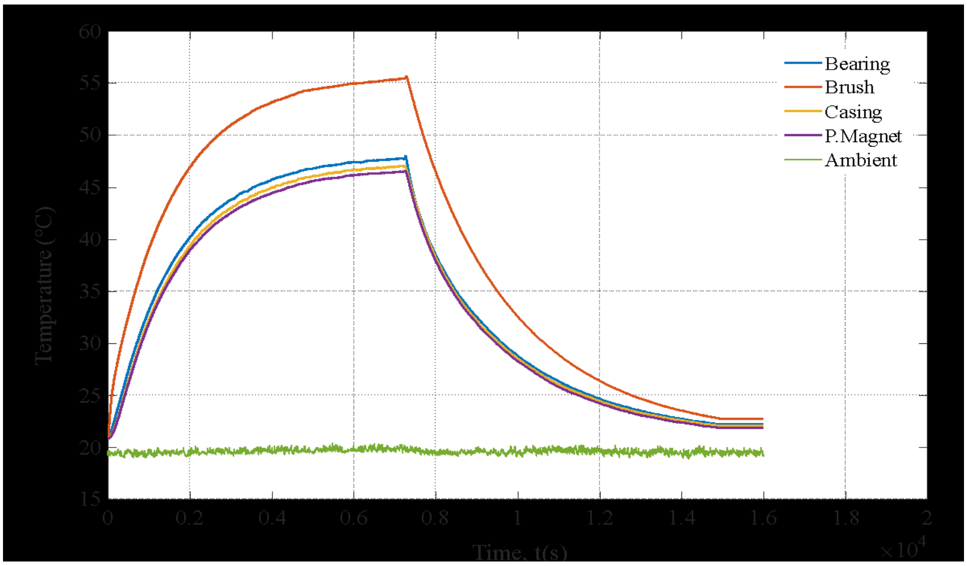

Figure 6. The temperature profile of healthy motor at no load for 24V.

Based on the analysis that has been made, the graphs show the heating process took almost two hours to reach the steady state while the cooling process took another two hours to reach ambient temperature. From the observation, obviously, the brush contains the highest temperature rise rate followed by the bearing, casing and lastly the permanent magnet. This is because; the brush is located the nearest to the commutator and the winding. After the current flow in the motor, the winding will release some heat losses when rotating and this heat loss later will transfer to the commutator. Because of the brush contact with the commutator, the heat loss from the winding will transfer to the brush by the commutator. Hence, the brush will simultaneously get hot and cause the temperature to rise. Next, the bearing contains the second rate because at the bearing there is no component that produces heat. At the bearing, only the friction causes heat. Besides, the temperature rise of the magnet and casing is not too high because the magnet is the closest component to the casing and casing is the outermost part, where convection toward exterior air happens. Thus, casing in contact with air more often compares to others and has the best air circulation around it. To make it clear, the temperature differences for each component can be summarized in Table 3.

Table 3: Temperature difference for each component.

Voltage, V	Temperature Difference, ΔT		
	T_{Brush} - $T_{Bearing}$	$T_{Bearing}$ - T_{Casing}	T_{Casing} - T_{Magnet}
8.00	4.53	0.38	0.15
16.00	6.02	0.70	0.19
24.00	7.64	0.75	0.21

4.2. Temperature of comparison between components at the different voltage.
For this part, each of the components had been compared the temperature rises between different voltages. This due to discovering what the effect of temperature rises the component will be heating either more when increasing the voltage or vice versa. This can be shown in Figure 7. In addition, the blue colour in the graph is data for 8V, while the red colour is for 16V and lastly, yellow colour for voltage at 24V.

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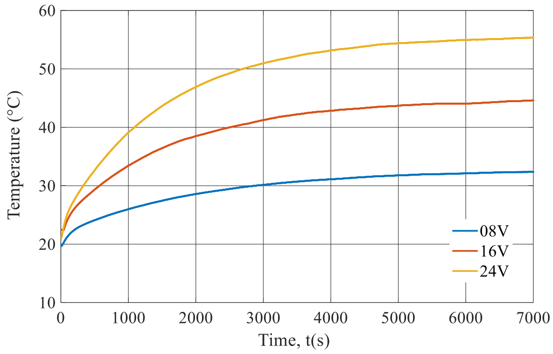
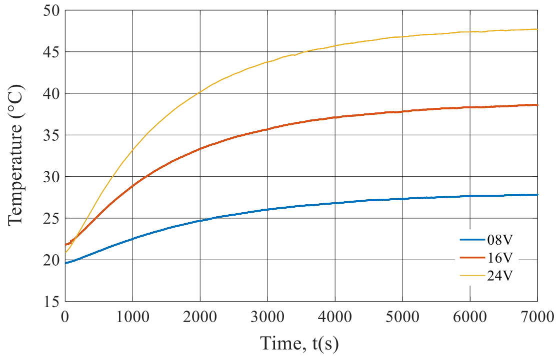
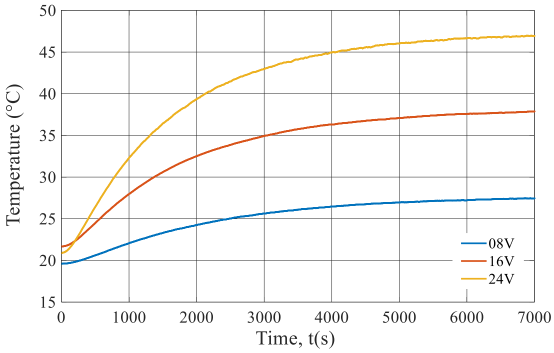


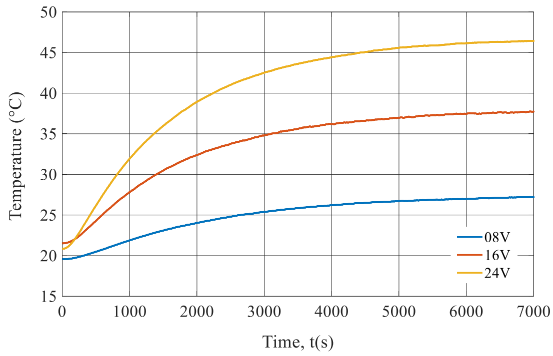
(a)



(b)



(c)



(d)

Figure 7. The temperature of: (a) brush; (b) bearing; (c) casing; (d) magnet, T (°C) against time, t (s).

From the observation, the temperature rises for each of the component are getting higher when the speed increases. This happened because; adding the voltage can cause some torque effect to the motor when running. Hence, the current supply will increase and cause the components to heat faster. To make it short, Figure 8 below shows the graph bar of the components at the temperature steady state for voltage 8V, 16 and 24V.

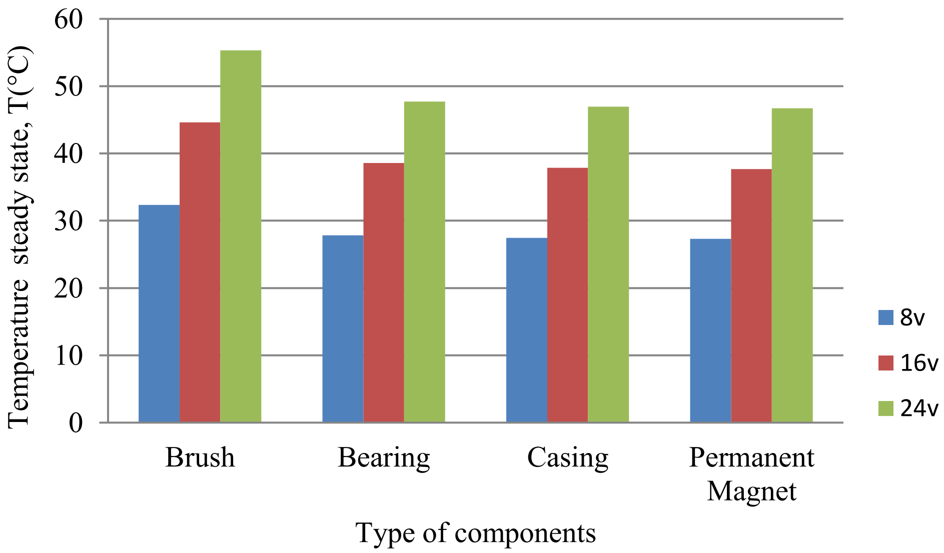


Figure 8. The temperature steady state against the type of components under different voltage.

5. Conclusions

Demagnetization of the magnet and the short-circuit always involves in the brush DC motor. These thermal damage problems happen when the process of heating is in progress. In this paper, the components of the DC motor and the comparison of the temperature rise under different voltage are being identified. Instead of that, the effects of temperature rise at the component are being analyzed. Preparing a test bench, which connects the DC motor with the drive train, helps in collecting the data of temperature rise. Later, this motor will deliver some heat from the brush through the motors' component and lastly to the outer space of the motor while it is running. As results, the temperature rise of DC motor will show which components are most sensitive towards the heat when different speed are been applied and finally the discussion on the graph pattern of temperature rise will be discussed.

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