Commutator fault detection of brushed DC motor using thermal assessment

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Abstract. In this paper fault detection of brushed DC motor is described. Recently, Thermal Signature Analysis (TSA) has become a common tool for fault analysis of AC induction motors. Currently, very little research has been performed using thermal signature analysis on brushed DC motors. This paper is a present fault detection of DC motors using thermal signature analysis. In order to organize the detection, the thermal behaviour of DC motor was analysed using the K-type thermocouple with data logger. The thermocouples were mounted on 4 part of the DC motor, casing, permanent magnet, brush and bearing. The initial measurements of thermal behaviour were realized by using healthy DC motor as a sample of a thermal behaviour. Furthermore, the measurements of thermal behaviour for the same type of motor with thick carbon impurities on commutator has been implemented to compare with the thermal behaviour of healthy DC motor. The significant observation on steady state temperature of thermal behaviour between healthy DC motors and faulty DC motor will be analysed. From the analysis of thermal behaviour between healthy DC motor and commutator fault DC motor, that can clearly recognize the commutator fault by through the different of characteristic temperature profile of DC motor.

1. Introduction
Nowadays, small DC motors are usually used in industry and the automotive. Fault detection of small DC motors have received rising attention among engineers and scientists to become reliable and more safes. Process failure can be affected in the loss of productivity, loss of equipment and also, human lives. In order to increase availability and the reliability of the installations for fault detection and diagnosis, growing in the development of procedures used are needed. Furthermore, early detection and diagnosis of damage can help out to avoid material harm, equipment failure and processing shutdown.

In recent years, various fault detection methods for electrical motors have been developed and established in the literature [1–6]. These various methods use different signals and sensors to detect electric motor faults, such as radio-frequency emission monitoring, acoustic noise measurement, vibration monitoring, motor current signature analysis, electromagnetic field monitoring, infrared recognition, thermal imaging analysis and temperature measurement [7]. Following to the sensor that uses on each method, thermal assessment such as thermocouple allow to use in temperature measurement method to detect commutator fault of DC motor.

Monitoring methods and concerning testing of low-voltage induction machines for stator insulation problem have been surveyed by Grubic et al. [8]. This research focusing on DC motors fault rather than induction machines, but there are some general knowledge’s we can applied. Liu et al. [9]presented the online fault detection and diagnosis of permanent-magnetic DC motor with fault of components open-circuit and fault of short-circuit between armature coils. These technique is using mathematical model
with sensors to analyse the fault mechanism on DC motor. DC motor diagnosis also presented based on the vibration spectrum and current analysis to detect commutator short circuit and displaced permanent magnet out of poles in polar axe [10]. Manana et al. [11] proposed the diagnosis in DC motor during manufacturing using thermal monitoring (thermal imaging) to detect field winding fault.

![Figure 1](image)

**Figure 1.** Particular study case in this paper: Normal commutator (right) and fault commutator (left) due to thick of carbon dust.

Following to the sensor that uses on each method, thermal assessment such as thermocouple allow to use in temperature measurement method to detect fault of electric motor. In this paper, detection of thick of carbon dust on commutator in brushed DC motor (Fig.1) using thermocouple to analyse the thermal behaviour on brushed DC motor. Thermal analysis on faulty motor will be done by comparing with healthy reference motor under different load.

2. **Proposed techniques based on recognition of temperature profile**

Temperature is a physical parameter that showing the existence of energy in form of heat. Electric motor generated heat from Copper Losses caused of the current flow passing through the conductors. It can be quantified using Equation 1.

\[ P_{\text{copper}} = R I^2 \]  

(1)

From the Equation 1, shows the losses are proportional to the resistance of the conductor R, which is the winding of the motor in the case of electrical machine and also proportional to the current square. In principle, the speed of a motor is proportional to the voltage, while the torque is proportional to the current as presented in Equation 2 and Equation 3.

\[ V = I R + E \quad ; \quad E = k_v \omega \]  

(2)

\[ T = k_T I \]  

(3)

Thus, as the load increase, the current increase and cause in consequence higher losses. In this paper, the speed will be maintained as a constant parameter by keeping the voltage apply to the electric motor at 5V. The current as a changing parameter, and it will be adjusted by changing the load. The brushed DC motor used in this study has the parameters as listed in the Table 1 below:

**Table 1.** Specifications of the Brushed DC motor studied.
The motor was instrumented by thermocouple as a temperature sensor on its bearing, brush, permanent magnet and casing.

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

The motor was instrumented by thermocouple as a temperature sensor on its bearing, brush, permanent magnet and casing.

**Figure 2.** Experiment setup of Dynamometer test bench.

2.1. Methodology
The primary step starts with instrumenting the motor with thermocouple on the part to be monitored. The most important part is the brush because brush is the close part with commutator side. The commutator cannot be monitored directly due to commutator is a rotating part of DC motor and it will cause of wavering of temperature data. Other parts are also instrumented in order to be compared with. They are casing, permanent magnet, and bearing. Once completed, the motor will be installed on the test bench as shown in Figure 2, and the thermocouples are plug-in to the data logger that record and show the temperature on a monitor in real time. Then, the load is applied to the brake system by assigning a mass that pull the cable on a brake system that apply a counter torque to the motor shaft. Therefore, the motor is turn on and accelerated to the reference speed which is set at 5V. Two of motor (healthy and faulty commutator) were tested with the circumstances of speed and load parameter as listed in Table 2. The healthy and faulty commutator motor are compared under the same speed at different load.

**Table 2.** Speed and load parameter of experiment.

| Speed × Voltage (Volt) | Loading   | Load × Current (Ampere) |
|-----------------------|-----------|-------------------------|
| 5V                    | No-load   | 0.5A                    |
| 5V                    | With load | 1.5A                    |

Once the speed and load set, only then the data acquisition of the temperature rise start to be recorded until the steady state reached temperature. When the steady state reached temperature, the motor will be turn off from the power supply and leave to cool down back to the ambient temperature. The data recorded are analysed and using graph plotted using the data.

3. **Result & Discussion**

The temperature data recorded for both healthy and faulty bearing motor are then plotted and shown in Figure 4 and Figure 5.
First things that can be observed is all of the components take around 7000 seconds to reach steady state temperature. For cool down time of all component to get back the ambient temperature also same. The steady state temperature, regardless the loading and fault, are in descending order started with the brush, the bearing, the casing and the permanent magnet. The highest temperature is brush component as expected, because brush as an electrical component that conduct current from the power supply to the rotating commutator that deliver the current to the stator of the motor. Therefore, both influence of mechanical friction and copper losses lead to very high temperature. Table 3 presents more detail about steady state temperature analysis for steady state temperature of heathy DC motor at different load and for steady state temperature of DC motor with faulty commutator also presented at Table 4. On the right
column of both tables, the temperature increase in percentage of the comparison between no-load and loaded case are presented. Accordingly, a bar chart presenting it is drawn in Figure 6.

**Table 3.** Steady state temperature of healthy motor at different load.

| DC motor part | Temperature for 0.5A DC motor (°C) | Temperature for 1.5A DC motor (°C) | Temperature Increase (°C) / % |
|---------------|-------------------------------------|------------------------------------|------------------------------|
| Bearing       | 24.21                               | 25.03                              | 0.82 / 3.39                  |
| Brush         | 28.55                               | 29.66                              | 1.11 / 3.89                  |
| Casing        | 24.11                               | 24.73                              | 0.62 / 2.57                  |
| P.Magnet      | 23.93                               | 24.54                              | 0.61 / 2.55                  |

**Table 4.** Steady state temperature of faulty motor at different load.

| DC motor part | Temperature for 0.5A DC motor (°C) | Temperature for 1.5A DC motor (°C) | Temperature Increase (°C) / % |
|---------------|-------------------------------------|------------------------------------|------------------------------|
| Bearing       | 24.62                               | 25.52                              | 1.05 / 3.66                  |
| Brush         | 30.02                               | 31.45                              | 1.43 / 4.76                  |
| Casing        | 24.45                               | 25.19                              | 0.94 / 3.03                  |
| P.Magnet      | 24.04                               | 24.76                              | 0.72 / 3.00                  |

**Figure 6.** Temperature increase in percentage (%) of the comparison between no-load and loaded case.
In general, from Figure 6, the percentage of temperature different of all components of DC motor with commutator fault are higher than healthy DC motor for both of case either with load or without load. From the Table 3 and Table 4, all of the data shows the faulty DC motor shows the increasing in temperature, but the highest temperature increasing is brush part. It is because the brush is contact directly on the surface of the commutator. When the commutator had problem or fault, the temperature of commutator is highest than others and it will be effect to the temperature of brush by copper losses on commutator. For others component, the temperature also increasing but not much such as on brush component. Following the comparison of temperature different in Table 5, these experiments can be concluded the brush DC motor had fault at commutator when the temperature different at brush (1.11°C and 1.43°C) component it higher than others component.

### Table 5. Temperaturadifferent (Δ Temperature) of DC motor between healthy motor and faulty bearing under no load and under load

| Part of DC motor | Δ Temperature (°C) (Faulty-H ealthy) |
|------------------|-------------------------------------|
|                  | Withoutload | Withload    |
| Bearing part     | 0.82        | 1.05        |
| Brush part       | 1.11        | 1.43        |
| Casing part      | 0.62        | 0.94        |
| P.Magnet part    | 0.61        | 0.72        |

4. Conclusion
The first conclusion that can be made is that faulty commutator due to thick of carbon dust increase overall motor component temperature. Experiments at no load and loaded case demonstrate that the commutator fault could be detected with analysis of both case of experiments. The temperature level on the all of component of DC motor with commutator fault are clearly higher than healthy DC motor. Therefore, the second step of analysis needed to diagnosis the commutator fault. The brush DC motor had fault at commutator when the temperature different at brush (1.11°C and 1.43°C). By different temperature between load and without load of fault and healthy DC motor at brush part are higher than others part that proved the DC motor fault. DC motor fault can be diagnosis by using thermal assessment.

In a perspective, the proposed diagnostic technique can be extended to higher power electric motor. In the future, we will analyse more high power electric motors and other faults with various operational parameters. Lastly, a standard temperature table related to load can be developed to help a faster diagnostic.

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