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An analysis of the main factors on the wear of brushes for automotive small brush-type DC motor†

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Abstract

Some critical components in motors and generators have sliding electrical contacts. Electrical brushes are commonly used in those contact points to conduct current between the stationary and moving parts of a motor. Brushes are exposed both to mechanical and electrical loading. In this paper, studies on the wear of brushes against copper commutator were briefly reviewed. The main influential factors of brush wear are associated with both mechanical and electrical wear. Brush wear is affected by various factors including temperature, material properties, sliding speed, contact force, and interfacial and environmental conditions. The mechanical wear of brushes is proportional to the brush spring pressure and sliding speed, while the electrical wear of brushes is associated with current and contact voltage drop. To characterize the wear, a brush wear test machine was designed, and influential factors were measured such as electrical contact resistance, temperature, wear mass loss, and so on. The wear tests were processed using a small brush type automotive DC motor.

The main objective of this study is to investigate the effects of the wear behavior of copper-graphite brushes in a small brush-type DC motor. The variable conditions are with and without electrical current by changing the brush spring pressure and sliding speed, and the results are electrical contact resistance, voltage drop, brush surface temperature rise, and so on. Brush wear greatly changes with electrical current. This shows that the high current not only produces more Joule heating but also causes an increase in voltage drop, which will result in additional Joule heating.

Keywords: Electrical brush; Electrical contact resistance; Brush-type DC motor; Mechanical wear; Electrical wear; Brush spring pressure; Sliding speed; Voltage drop; Brush surface temperature

1. Introduction

Sliding contacts use brush wearing behavior as essential parts of electrical circuits to transmit electric power and signal between the moving and stationary parts of motors. The electrical brush-rotor system of the brush-type DC motor is engaged in the sliding contact movement of the commutator and brush, and many studies have been conducted on the complex phenomena of friction and wear at the interface [1-4].

The wear phenomenon at the interface is one of the representative applications influenced by mechanical, electrical, and thermal properties. Many interpretation methods for the friction, wear, and lubrication contact characteristics are at the surface of mutual contact movement. Recently, many researchers have been working on applications of electrical contact due to the rapidly increasing demand for electronics, machinery, and ultra-precise machines such as micro-computers [5-7].

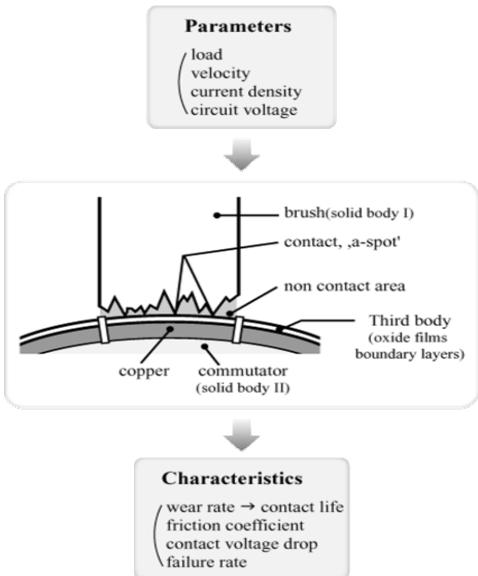

Fig. 1. Main parameters and surface characteristics through the phenomenon of contact between brush and commutator of the brush-type DC motor.

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However, the wear mechanism of brushes is very complex because many factors can influence it. Much research has been conducted to investigate the effects of contact voltage drop, surface temperature of brushes, coefficient of friction, normal load, sliding speed, current density, and others as shown in Fig. 1 [8]. In this research, the main influencing factors for brush wear are studied through the contact between brush and commutator. Contact load, sliding speed, and electrical current are changed, and the behaviors are measured and analyzed with the characteristics of contact resistance, voltage drop, brush surface temperature rise, and frictional coefficient using the experimental device of the electrical brush-rotor system.

2. Experiments

Fig. 2 shows the schematic diagram of the experimental device to conduct a wear experiment and to measure the contact resistance through the friction between commutator and brush. For normal load, a spring with a constant modulus of elasticity (spring constant) was embedded inside the brush holder in the brush-commutator assembly of the outer to control the brush's nominal reaction against the commutator. The rotation axis of the commutator was connected to the rotation axis of the servo motor through coupling for rotation at constant sliding speed, which could be measured through a proximity sensor. To measure the temperature at the contact of the brush in real time during operation, two T-type thermocouples were installed within 3 mm from the contact surface.

The contact surface temperature of the brush was obtained by measuring the bulk temperature of the two sites in the brush and by using the following Fourier's law for thermal conductivity:

$$Q = -\kappa A \frac{dT}{dx} \quad (1)$$

$$T = \left(\frac{T_2 - T_1}{x_2 - x_1}\right)x + T_1 \ , \ x_2 > x_1, T_1 > T_2 \ , \quad (2)$$

where Q is the heat transfer, κ is the thermal conductivity, A is the area through which heat flows, and x, x_1, x_2 are the positions of the measuring temperatures (T, T_1, T_2), respectively.

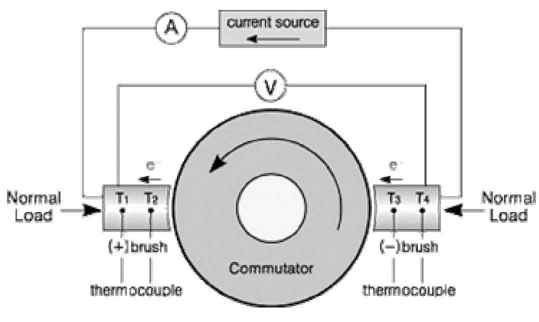

Fig. 2. Schematic diagram of the electric circuit for the brush-commutator wear test.

Fig. 3 shows the electric circuit designed to measure the contact resistance. The electrical contact resistance cannot be directly measured when the brush contacts with the commutator; therefore, the brush was connected to a circuit to measure the voltage between two poles (V_{R1}, V_{R2}, V_{RC}) using shunt resistance. As the current flows constantly in this circuit, we can measure the contact resistance by measuring the voltage and current. V_{R1} and V_{R2} are for measuring the static current by shunt resistance between the two poles, and we can obtain the contact resistance by checking the voltage drop.

The measurement accuracy of the shunt resistance (R1, R2) is 0.01 Ω ±0.5%, and the watt rating is 10 W. As the voltage measurement accuracy is 10V±0.05% and the current measurement accuracy is ±5 mA, the range of measurement error is very small. The sliding speed, temperature, voltage drop, and current were stored in real time at the data-processing speed using a PC-based data acquisition (DAQ) system. The changes in brush wear can be checked by measuring the weight reduction of the brush using a precise scale. Fig. 4 shows the experimental devices of the electrical brush-rotor system.

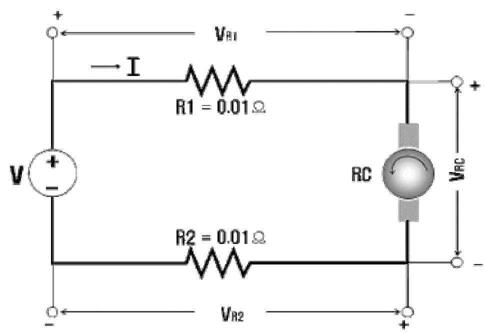

Fig. 3. Schematic view of electric circuit for contact resistance measurement; $V=V_{R1}+V_{R2}+V_{RC}$, RC (brush-commutator contact resistance), V_{RC} (contact voltage drop).

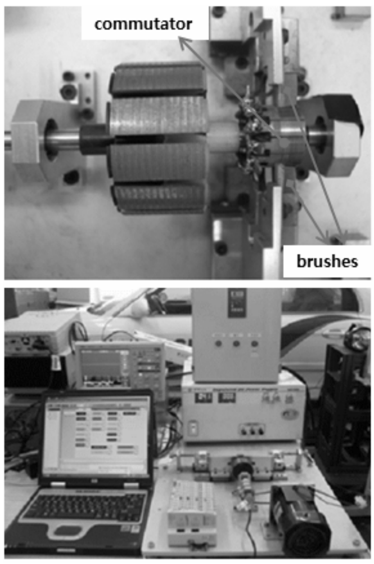

Fig. 4. Experimental devices of the electrical brush-rotor system.

This study used the copper-graphite brush, which is widely used in automotive motors. It corresponds to the stator in the motor structure. The commutator is a rotating body consisting of 12 bars with a diameter of 23.14 mm and an outer circumference of 72 mm. The brush size is 15 mm×7.9 mm×7.9 mm (width x length x height), and the contact surface is slightly curved.

3. Results and analysis

3.1 Brush contact surface temperature

The change in temperature at the brush contact site was measured in relation to contact load, speed, and current. When the current is not supplied, the contact load and speed vary, and the temperature is measured as shown in Fig. 5. The brush surface temperature increases as the contact load and speed increase. The observed temperatures do not exceed 50 °C. The surface temperature rises by the friction heat caused by mechanical sliding.

When the current is supplied, the electric resistance heat is generated at the contact surface as the current flows. As shown in the Fig. 6, the surface temperature rose up to 140°C as the current increases. This result indicates that electric resistance heat rather than surface friction heat is a more important factor that increases surface temperature. The difference in temperature between the positive (+) and negative (-) brushes was observed because the current flow is from positive (+) to negative (-).

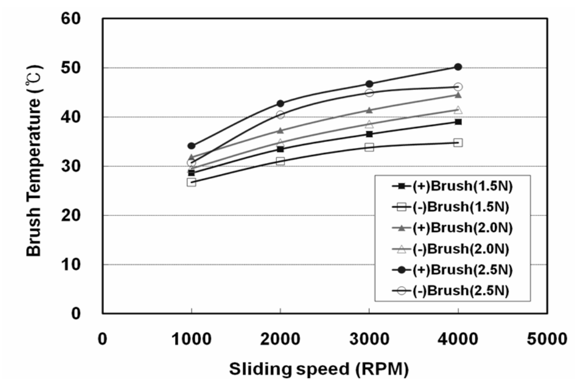

Fig. 5. Change in brush surface average temperature when sliding speed and normal load vary.

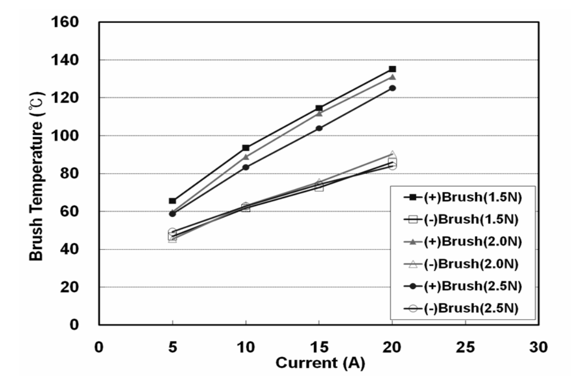

Fig. 6. Change in brush surface average temperature when normal load varies with the current at a sliding speed of 3,000 rpm.

3.2 Voltage drop and electrical contact resistance

The measurements of the voltage drop and electrical contact resistance of the brush and commutator are shown in Figs. 7 and 8, respectively. The electrical characteristic shows an inverse proportional relationship between voltage drop and normal load. The experimental results match Ohm's law, in which a higher current results in a lower voltage drop and a higher contact resistance. These characteristics also affect friction characteristics, as shown in Fig. 9.

The friction coefficient in most cases has a decreasing trend with the increase in load and current. The contact voltage drop and contact resistance, to which the lubricious film resistance between the brush and commutator was added, and the contact status of the brush and the resistivity of the brush itself that were factored in, are regarded as important contact characteristics. These are highly sensitive to temperature and change by commutator material, contact load, and sliding speed.

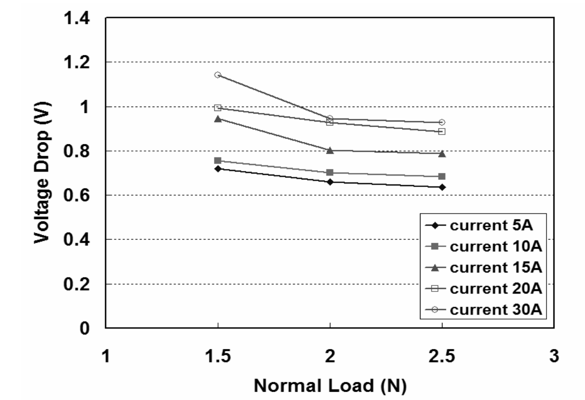

Fig. 7. Contact voltage drop as the normal load and current are varied at a sliding speed of 3,000 rpm.

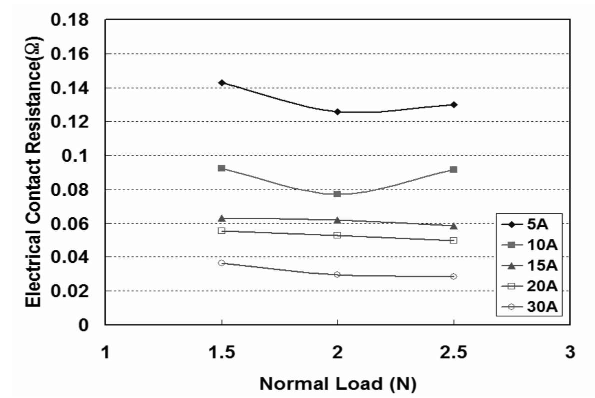

Fig. 8. Electrical contact resistance as the normal load and current are varied at a sliding speed of 3,000 rpm.

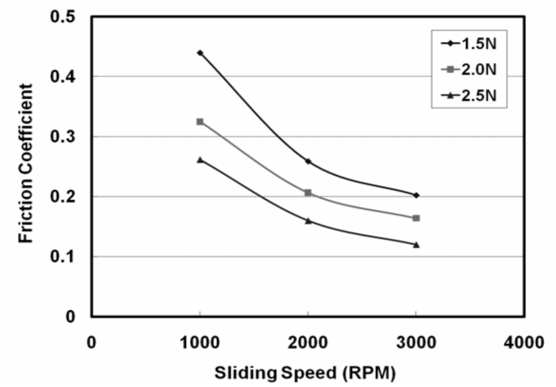

Fig. 9. Friction coefficient as the normal load and sliding speed are varied at a current of 20 A.

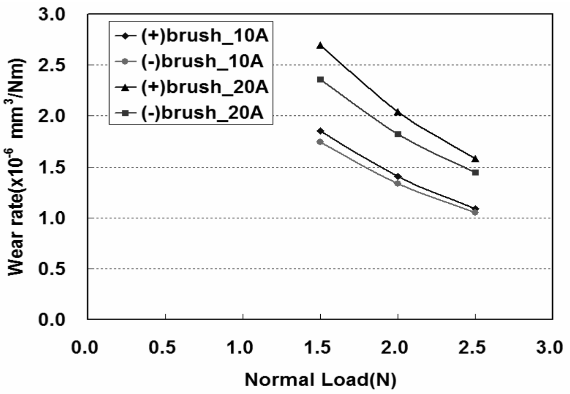

Fig. 10. Brush wear rate versus normal load at a sliding speed of 3,000 rpm through the direction of the current flow.

3.3 Wear characteristics of brush

Fig. 10 shows the change in the brush wear rate when normal load, sliding speed, and current are changed. As shown in this figure, the wear rate varies by contact load, sliding speed, and current. It was found that the difference between the values of positive (+) and negative (-) brushes was caused by current flow. It was also found that much wear occurred in the positive brush due to this reason. Furthermore, the wear was not greatly affected by sliding speed and contact load but was dominated by the current change. Therefore, with regard to brush wear, electrical wear by current supply is more serious than mechanical wear. As the area of current flow decreases, resistance increases. As a result, joule heat and contact temperature both increase. Therefore, the current supply increases the temperature of the contact surface by electrical resistance heat, which increases wear.

4. Conclusions

This study analyzed the important factors affecting brush wear characteristics in a brush-type DC motor, which is widely used in motor vehicles. The results are summarized as follows:

(1) When current was not supplied, the temperature of the contact surface of the brush was directly proportional to the contact load and speed, which was the result of friction heat. When current was supplied, temperature was dominated by electrical current rather than contact load and speed. The result seems to be due to the electric resistance heat.

(2) The results also indicate that the supply of electrical current causes contact resistance and voltage drop on the surface, which is also influenced by contact load and sliding speed.

(3) Measurements of brush wear by contact load, speed, and current indicate that wear were significantly influenced by current change. The degree of wear also depended on the direction of current flow. Brush wear had a close relationship with temperature changes at the brush contact site.

Therefore, with regard to electric wear characteristics, brush wear tends to accelerate with temperature increase at the contact surface, which is caused by contact resistance and voltage drop when current is supplied.

Nomenclature

Q	: Heat transfer
RC	: Electrical contact resistance
κ	: Thermal conductivity
$R1, R2$	: Shunt resistance
T, T_1, T_2	: Temperature or Celsius temperature scale
V_{R1}, V_{R2}, V_{RC}	: Circuit voltage

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