

Development of Commutation Technology for In-vehicle DC Motor Directly Driven by 42V Vehicle Battery

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ABSTRACT

For DC brush motors directly driven by 42V vehicle battery, carbon brush deterioration due to high voltage arc is a major factor to determine motor life [1]. The brush deterioration is significant especially in multipolar motors with lap-wound armature because they allow a large circulating current to flow into their brushes and it decreases commutation performance [2], [3], [4]. In this report, we propose 1) a new brush material capable of preventing brush deterioration even under high-voltage conditions and 2) a new winding method to minimize circulating current under electromagnetic polarization and to suppress high-voltage arc. With each of these new technologies, DC brush motor driven by 42V battery can operate longer than that driven by 14V battery.

1. INTRODUCTION

There are growing concerns about global environmental protection and issues such as depletion and rising cost of resources, and automobiles are required to be more fuel-efficient. Reduction in part weight is now a common measure for fuel efficiency improvement while hybrid electric vehicles (HEVs) and electric vehicles (EVs) are increasing all over the world.

Employing a high voltage motor is one way to reduce part weight. When a motor is driven by a high voltage battery, the current flowing in it is reduced, thus harness weight can be reduced [5 and 6]. High voltage batteries are also equipped in HEVs and EVs and expected to offer enhanced safety and convenience as well as the weight saving advantage [7], [9].

In this study, we aimed to develop a low cost DC brush motors directly driven by 42V battery (we assumed 42V as representative high voltage value) with higher performance than the existing motors driven by 14V battery.

For motor directly driven by 42V battery, there are some engineering problems like high-voltage arc, leak and radio noise (EMC) [8 & 9]. The high-voltage arc causes carbon brush deterioration in DC brush motors used for accessories in vehicles, and it is a major factor to determine the motor life. The brush deterioration is significant especially in multipolar motors with lap-wound armature. Our experiment revealed that the life of the 42V spec motor (4-pole motor with 20-slot lap-wound armature, which was originally designed as 14V motor and was converted to 42V motor by simply modifying the wire diameter and the winding number to allow it to be driven by 42 battery with output characteristics similar to the original 14V motor) was reduced to one third of the life of the original 14V motor.

Then, we conducted commutation analysis and found that the circulating current due to electromagnetic polarization causes high-voltage arc and it deteriorates the brushes.

In this report, we propose a new brush material consisting of two kinds of graphite in optimal proportions. It can prevent the deterioration of motor and the reduction in life expectancy even under frequent circulating current and high-voltage arc conditions. With the brushes made of this material, the 42V spec motor above can operate equivalent to or longer than the original 14V motor.

Further, we also propose a new winding method to suppress the circulating current under electromagnetic polarization. This winding method allows a 42V spec motor to have a life equivalent to or longer than the original 14V spec motor without using the special brushes described above. Besides, this winding method can increase the options for brush material and reduce the lead time for brush material development.

We expect that these two new commutation technologies contribute a longer life of in-vehicle compact and lightweight DC brush motor where commutation conditions are more severe.

2. COMMUTATION ANALYSIS ON MULTIPOLAR MOTOR WITH LAP-WOUND ARMATURE

2.1 INVESTIGATION OF 42V SPEC MOTOR

2.1.1 Durability evaluation

Based on 14V 4-pole motor with 20-slot lap-wound armature, we made 42V spec motors by increasing the winding number three times and decreasing wire diameter one third to allow it to provide the equivalent output characteristics to the original 14V motor, and evaluated its durability.

Table 1: Durability evaluation conditions

Motor spec	4-pole motor with 20-slot lap wound armature
Winding spec	Ø0.43×60T (42V spec)
Ambient temp and humidity	25°C (RH: 45 to 65%), 90°C (RH: 3 to 5%)
Applied voltage	42V
Load (0.39 Nm)	Radiator, shroud, fan
Operation mode	30 sec ON and 30 sec OFF (at 25°C) Continuous operation (at 90°C)
Operation duration	500h

Table 1 shows the durability evaluation conditions. We conducted the durability test on the 42V spec motors for radiator fan. In order to simulate vehicle conditions, radiator, shroud and fan were fitted to the motors. As the durability in the normal temperature range, some motors were evaluated for the brush wear after 500h of intermittent running (30 sec ON and 30 sec OFF) in the room adjusted to 25°C. And as in the high temperature range, the others evaluated after 500h of continuous running in the temperature chamber adjusted to 90°C.

Fig. 1 shows the brush wear rate calculated by dividing brush wear length by time (500h). The average brush wear rate of the original 14V motors for radiator fan measured under the same conditions is also shown for comparison. The brush wear of 42V spec motor was significant and, at 90°C, its wear rate was more than 3 times the 14V motor's. This reveals that motor durability is reduced more significantly when it is driven by high voltage. Then, we conducted commutation analysis to identify the causes for this reduced brush durability.

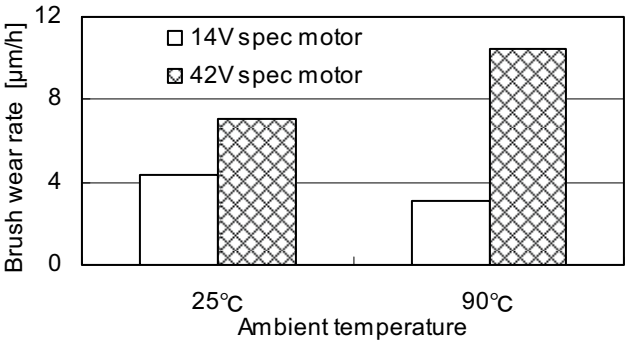


Fig. 1: Durability evaluation result

2.1.2 Commutation analysis

In multipolar motors with lap-wound armature, in general, circulating current flowing into brushes decreases commutation performance [4]. So, we measured and evaluated the circulating current of 42V spec motor.

The lap-wound armature has a number of internal circuits and each circuit generates induced voltage when it passes across the magnetic flux of each pole. The differences in magnetic flux between each magnetic pole result in the variation in induced voltage. The main reasons for the variation are 1) unevenness in the geometry and/or material of magnet circuit and 2) the differences in electrical conduction between the brushes of the same polarity.

These variations cause the electromagnetic polarization between parallel circuits and the circulating current flows from high to low side of induced voltage. Since it flows through brushes, the circulating current, in combination with load current, deteriorates commutation performance. To avoid the deterioration, it is necessary to prevent the circulating current from flowing through brushes. For this purpose, equalizers are used to connect the opposed segments where electric potential should always be equal in order to allow the circulating current to flow through them [4].

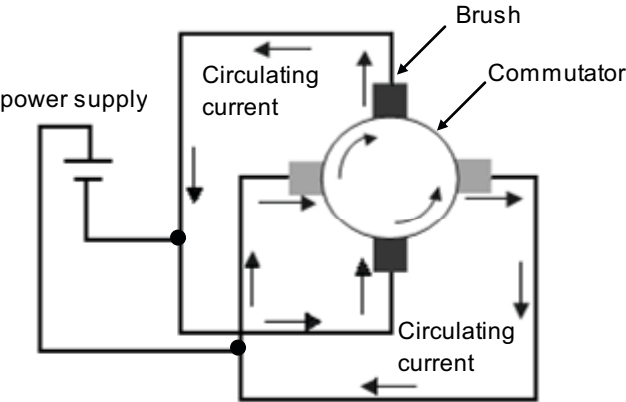


Fig. 2: Diagram of circulating current generation

Fig. 2 is the schematic diagram of circulating current generation in 4-pole motor. Electromagnetic polarization between parallel circuits causes difference in voltage generated in two opposed coils (induced voltage, reactance voltage, etc.) and so circulating current flows in the closed circuits as shown with arrows in Fig. 2.

This current passes through brushes and causes increased sparks between the brushes and commutator. But when equalizers are used, almost entire current flows in them, not through brushes, and spark increase can be suppressed and so brush durability can be improved. Since the circulating current flows in the equalizers as mentioned above, we thought it can be evaluated by measuring the current variations inside the equalizers.

We also evaluated commutation sparks. The commutation sparks can be quantitatively evaluated by checking the voltage waveform between brushes and commutator segments for voltage fluctuation at commutation ends (the moments at which the brush goes out of contact with each commutator segments).

The voltage fluctuations between brushes and segments at the commutation ends correlate with actual commutation sparks and we call the voltage at commutation end the “end voltage”.

Fig. 3 is the schematic diagram of the equipment and method for measuring the end voltage and circulating current. With a hollow armature shaft extended in the end (commutator) side, two electric lines connected to the opposed commutator segments were put through the hole in the shaft and pulled out from the shaft end and then tied together at their tips. Signals during armature rotation were read by the external data collection device (not shown in Fig. 3) connected to the tied line via a collector ring. Voltage fluctuations between the tied line from armature segments and either one of power supply lines to the brushes of same polarity (measured via the collector ring) constituted the end voltage waveform.

Circulating current was measured by reading the output signals from the self-made CT type ultra-compact current sensor attached in the tied line via the collector ring.

In order to see if the circulating current was correctly measured, we compared the measured waveform with the waveform simulated in Finite Element Method (FEM). Since an FEM model without geometric displacement has no electromagnetic polarization and causes no circulating current, we used the simulation conditions where two brushes of different polarity were moved by 10 degrees in a direction opposite to armature rotation direction as shown in Fig. 4.

The brushes of the actual motor sample were also moved in the same manner as in the FEM model. Then, the circulating current measurement was conducted.

Fig. 5 shows the circulating current waveforms from FEM simulation and actual sample measurement. The two waveforms were very similar to each other, thus the circulating current measurement method above was proved to be highly reliable.

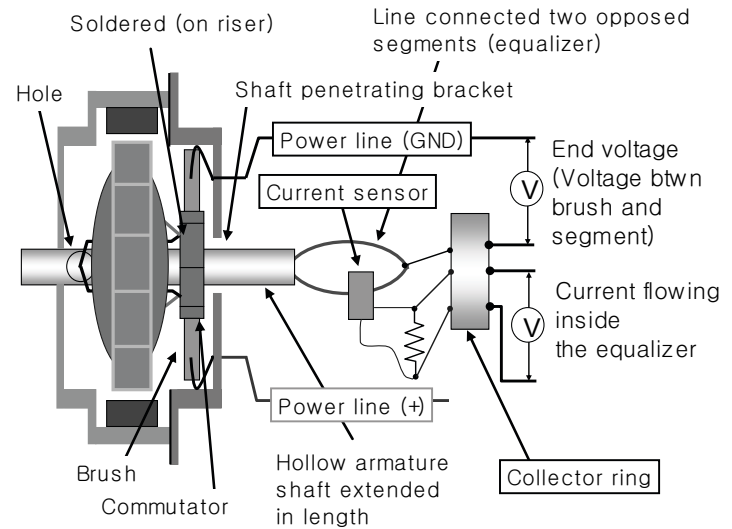


Fig. 3: Diagram of measuring device equipment

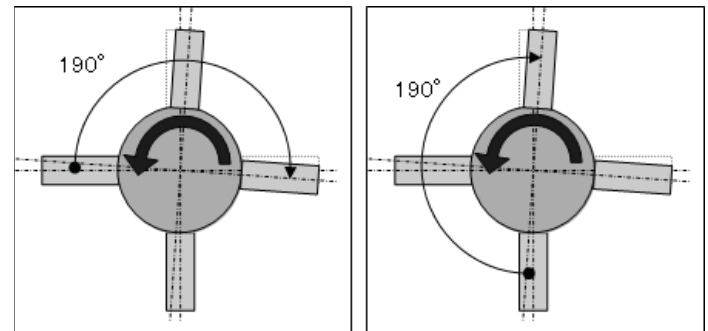


Fig. 4: Displacement in FEM model

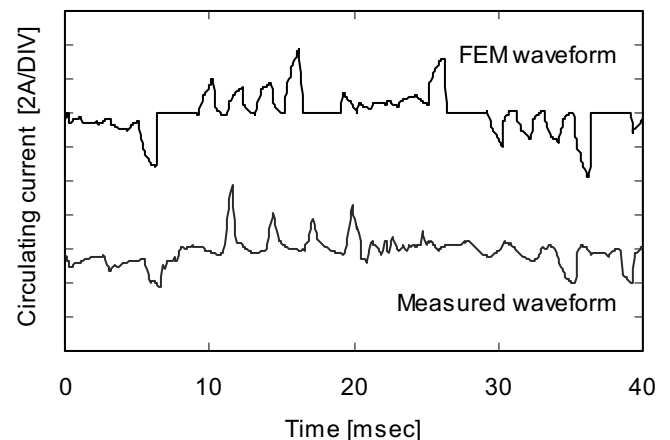


Fig. 5: Circulating current waveform: FEM (upper) and actual measurement (lower)

Table 2 shows the end voltage and circulating current measurement conditions. Fig. 6 shows the end voltage and circulating current measurement results. The end voltage waveform represents the voltage between brushes and segments. The electric potential