Progress in mechanical engineering
Failure analysis of DC motor-brushes

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1. Abstract

High failure-rate was associated with DC motor-brushes which were widely used in several projects. The motor-brushes went through different inspections and analyses until the failure-mechanism and root-cause were identified. This work describes the investigation process.

Keywords: Motor-brush, Commutation, Current-density, Contact-spots

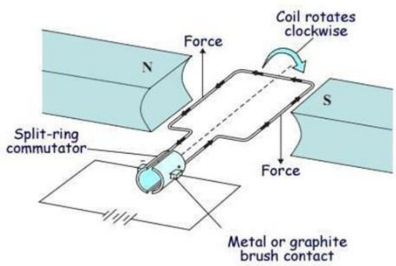
2. Introduction

Background

The high failure-rate which was associated with certain DC motor-brushes, served as a trigger to start an investigation to discover potential failure-mechanisms and root-causes.

The motor is utilized to up-lift/lower-down a gimbal in the elevation axis. In parallel, there is another DC-motor which is used as an azimuth-motor for the gimbal. The two motors are manufactured by the same vendor, but are a little different in their size and current-consumption. The brush-consumption of the elevation-motor was more than 20 times higher than that of the azimuth motor.

The motors are brushed-type DC electric-motors, which run from direct-current power source, provided via the carbon brushes.



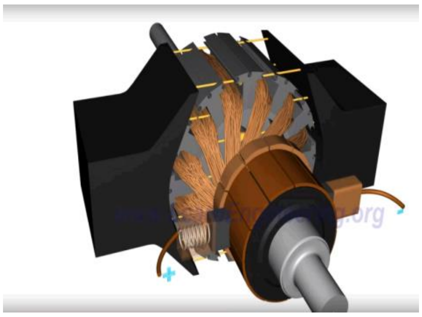


Figure 1 – a (right) and b: *A conceptual (a) and actual (b) arrangement of the brushless DC motor shows the interaction among the external magnetic field (here, supplied by permanent magnets), the brushes, the commutator on the armature and actual rotation. Images sources:*
Figure 1.a: http://www.cyberphysics.co.uk
Figure 1.b: http://www.youtube.com/watch?v=LAtPHANEfQo

To improve current-commutation, the vendor performs running-in for each assembled motor + brush-ring for duration of 30min so that the motor's brush will be shaped to the commutator.

Therefore, each motor unit is being sent to customers with its pre-assigned motor and brush-ring; however, when there is a need to replace the motor-brush (and thus, the entire brush-ring) the spare brush-ring arrives alone without preliminary running. The running-in process takes place by the assembly-line personnel after replacing the faulty brush by the new one.

For the replacement of the brush-ring, the workers in the assembly line use a unique cone-shape jig to assure the concentric positioning of the ring onto the commutator. This jig was provided by the vendor for this purpose.

Inspection-process

The first step in this investigation was to visually inspect the appearance of the defected brushes. Figure 2 shows a randomly-picked defected brush-ring, with its four carbon-brushes which was removed from the motor:

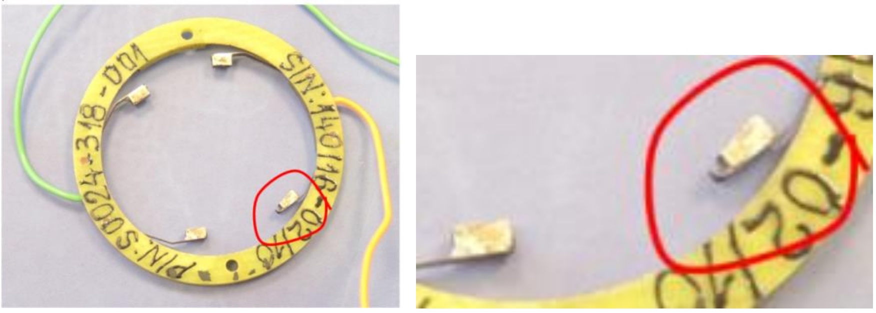


Figure 2*: A defected brush, which was removed from a motor exhibiting brush-disconnection*

As shown, the brush at the bottom-right position in the picture (red-cycled) was shifted from its designated location at the edge of the spring, upwards toward the plastic ring. This typical appearance made us assume that this phenomenon results from the melting of the soldering material which attaches the carbon brushes to the metal-spring. It implies that the temperature which was felt by the brush either exceeded 250ºC (vendor claims this is the melting point of the tin used) or that the tin's melting point is below this stated temperature.
Figure 3 shows the outcome of exceeding melting point when the motor is running – in this case, the brush disconnected from its original location on the spring in the upper left side of the picture, got caught between the rotating commutator and the brush-ring and as a result, caused such overheating of the system that the internal greasing material leaked out.

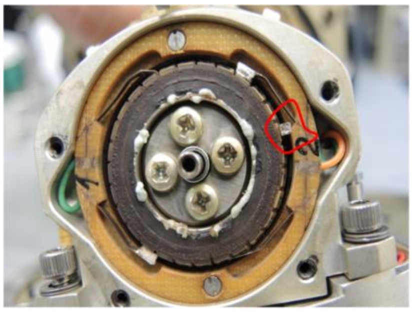


Figure 3*: Disconnected brush in an assembled Motor with brush-ring.*

An experiment which was carried out on a single motor-brush sample (Figure 4) revealed that the melting point of the soldering material was about 190 ºC – at this temperature range, bubbles started to appear between the string and the brush.

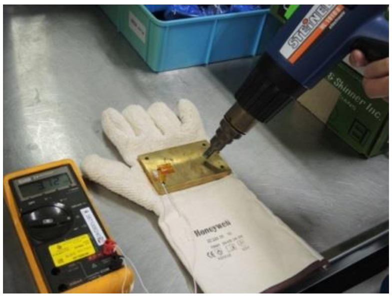


Figure 4: *Measuring soldering material's melting point*

This newly-discovered reduction in melting point temperature required further investigation, as it meant smaller safety-margins for the motor-operation. The preliminary calculations made to establish maximal allowable working time and voltage were no longer valid.

We therefore repeated the theoretical calculations, taking into account the updated reduced melting point temperature. However, even under these stricter conditions, the theoretical calculations made showed we were still not reaching soldering-material melting point temperature during operation. We hence needed to understand which other physical effects cause the temperature to increase that much.

At this point we debated which mechanism: mechanical or electrical, may have the greater impact on brush wear.

To eliminate the effects of mechanical parameters, we examined the spring pressure of several reportedly-defected brushes and found no issues. In parallel, we measured sliding speed during operation and also found no issues. We consequently decided to focus on the effect of electrical parameters on the brush wear.

In their article*, Wae-Gyeong Shin and Soo-Hong Lee show that with regard to brush wear, electrical wear by current supply is significantly more serious than mechanical wear. They demonstrated how as the area of current flow decreases, resistance increases and as a result, joule heat and contact temperature both increases. This supported our findings that the temperature rise of the brush's soldering material resulted from some sort of electrical failure in the current commutation from the carbon brushes to the commutator.

At this point we decided to visually examine brand-new brushes and their brush-rings (figure 6 - a, b and c). We found out that brushes on the same brush-ring each had its own different dimensions, some varied significantly (about 30% surface area differences).

Since current density is calculated as a function of supplied current divided by brushes' dimensions, the small-size brushes will have higher current densities and 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.

Figure 6: a, b and c *(left to right): Results of visual examination of brand-new brushes: Different brush dimensions and uneven contact surface.*

Additionally, we discovered that the contact-surface of the brushes was very rough and uneven. Since the entire commutating process between the brush and the commutator is based on points of contact** (see figure 7), it is important that the contact spots will be evenly distributed on the surface of the brush to maintain brush balance and avoid damage to the commutator's surface as seen in figure 8.

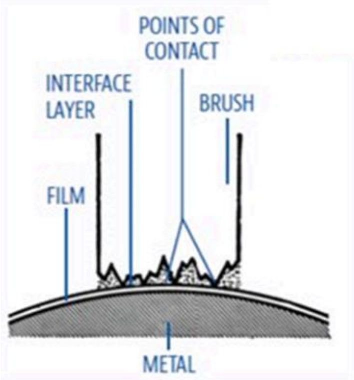


Figure 7*: Surface interface-layer between the brush and the metal commutator*

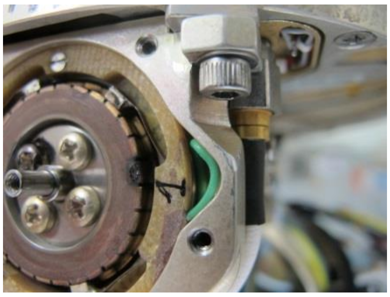


Figure 8*: Damaged commutator's surface in an assembled Motor with brush-ring.*

The last part of the investigation was to test the azimuth motor-brushes and see where they stand versus the findings identified at the elevation motor-systems. It turned out that the soldering material used to attach the carbon brushes in the azimuth-motor was also much lower than the stated 230ºC (about 200ºC). However, the other two failure mechanisms: different brush dimensions and uneven surface finish of the brushes didn't exist in these motor-systems and therefore the impact of the melting point reduction was not sufficient enough to cause the failures seen at the elevation motor-system.

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(Times New Roman 11 pt normal)

3. Contributions

All extended abstracts must be submitted using this template and format (as a word file). The prospective participants are asked to submit an extended abstract by May 18, 2018. No full papers will be required.

The authors will be notified about the acceptance by June 1, 2018.

An electronic collection of all accepted contributions will be distributed at the conference.

4. Paper preparation

All margins should be set to 25 mm. Use a one column format. The recommended type face is Time New Roman. All text must be full justified 11 pt. Use 12 pt bold lowercase for main headings. Leave an empty line between paragraphs.

When preparing the document, please keep in mind that most authors may print it in black and white.

Do not add any page headings or footnotes.

All Figures and Tables should be numbered and contain a caption (9 pt). Do not extend figures and tables into the margins.

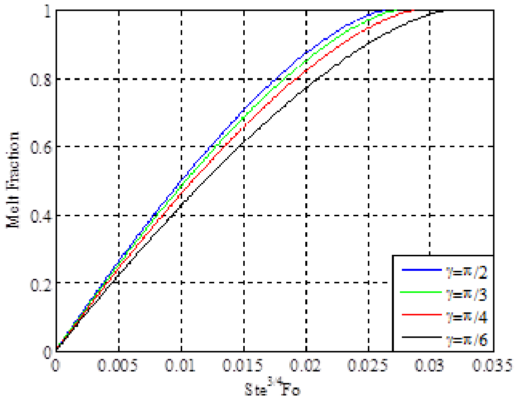

Figure 1. Example of figure

Table 1. Example of table

Country	Color	Units	People
Spain	Red	1	345
India	Blue	2	567
Brasil	Black	45	345

5. Conclusions

Oral presentations will take place. The organizers will assign each contribution to an oral session taking into account their evaluation and authors' preferences where possible.

6. References

Sample references are given below (10 pt):

[1] Kozak, Y., Rozenfeld, T. and Ziskind, G., "Close-contact melting in vertical annular enclosures with a non-isothermal base: theoretical modeling and application to thermal storage," *Int. J. Heat Mass Transf.*, 72, pp. 114-127, (2014).

[2] Tay, N.H.S., Bruno, F., Belusko, M., Castell, A. and Cabeza, L.F., "Experimental validation of a CFD model on a vertical finned tube heat exchanger phase change thermal energy storage system", *Proc. of Innostock 2012 - the 12th International Conference on Energy Storage*, Lleida, Spain, May 2012.