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Influence of the contact parameters and several graphite materials on the tribological behaviour of graphite/copper two-disc electrical contacts

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ABSTRACT

This paper reports on the performance and tribological mechanisms in a newly developed design for an electrical sliding contact in terms of sliding velocity, normal force and electrical current during 24-h experiments. Copper discs were run against hard-carbon graphite, electrographite and polymer-bonded graphite. The average wear rates of the copper discs against the three graphite materials were reduced to 10^{-8} and 10^{-7} mm^3/Nm, and the graphite discs to 10^{-6} mm^3/Nm, which is for 1 and 1–2 orders of magnitude less, than copper slip-rings and carbon brushes in conventional systems, respectively. The coefficient of friction was 0.2–0.4, depending on the conditions, which is comparable to the values of conventional electrical sliding contact. Tribofilms are generated in almost all contacts, and crucially determine the contact performance. The polymer-bonded-graphite/Cu formed the most compliant tribofilms that unify and decrease the local contact pressures and temperatures, and have the largest surface coverage that reduces the wear and contact resistance, which in turn reduces the contact instabilities and so the friction.

1. Introduction

Numerous devices and machines require the conduction of electrical power and electrical signals between moving and stationary parts. To achieve this, a system of slip rings and brushes is typically used, such as in electromotors and alternators, which are commonly used systems in all vehicles, many home appliances, etc. Electrical sliding contacts are thus among the most crucial components of electrical machines in terms of their reliability, efficiency and operating life. To meet the tough demands made by these machines, both materials in the contact need good electrical and heat conductivity, and good wear resistance. Above all, low friction and wear and a small electrical contact resistance are needed in the contacts [1–3]. It is known from previous studies that these properties and the performance are determined by the developed boundary surface films [3–7], which are greatly affected by the environmental and operating conditions, and primarily by the type of material in the contacts, in particular the many graphite materials that are used in these contacts [8].

In automotive applications, the recent very strict environmental regulations and requirements for extended life times, i.e., longer service intervals with no maintenance, especially in commercial vehicles, require more efficient and durable systems and sub-systems. In recent decades the lifetimes of slip-ring systems were extended by contact-material improvements and various design solutions, such as smaller slip-ring diameters or the prolongation of brushes [9,10]. The traditional slip-ring system consists of a rotating slip ring, generally from a good conductive metal such as copper or bronze [11], and against this slip ring there is a radially pressed brush, which in most cases is made from a graphite material. With such a design, geometrical and manufacturing irregularities, such as roundness, radial run-out and contact surface roughness, greatly influence the slip ring's performance [12,13]. To eliminate some of the traditional slip ring's weaknesses and further extend the life time, recently a new principle for a sliding electrical contact was developed and patented [14], Fig. 1.

In contrast to the radial contact of a slip ring and brush system, the new design consists of an axial contact of two discs, so that the stationary disc is pressed against the rotating disc. With such a design the contact area increases and so the electrical current density and the contact resistance decrease, which allows for a small and compact device and low sliding velocities. Although sliding electrical contacts were investigated for a wide range of applications, configurations and conditions [1–7,11,13,15–46], the above-mentioned design is new and therefore there is are no detailed tribological investigations. In particular, the new design uses the closed-contact concept, which tends to maintain the generated boundary films that are entrapped between the two discs, which means the operating conditions and the effect of the

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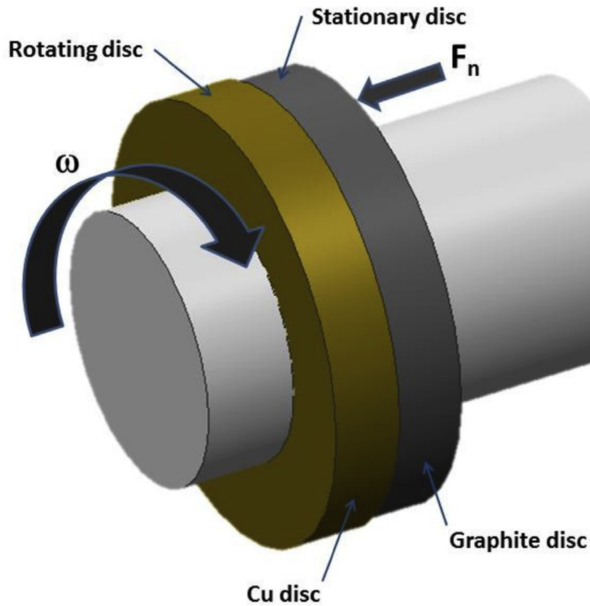

Fig. 1. Schematic of the new contact design concept for electrical sliding systems.

materials on the formation of the boundary films are critical. Accordingly, to reveal these effects for the successful integration of the newly proposed sliding electrical contact system into the application, the influence of the sliding velocity, the normal contact load and the electrical current, and the influence of the contact materials, i.e., various types of graphite materials, on the tribological end electrical performance of the sliding electrical contact were investigated.

2. Experimental

2.1. Testing device

A dedicated tribological testing device was developed and built to investigate the newly designed contact principle, Fig. 2. This testing device consists of two sliding electrical contacts that form a closed-loop electrical circuit. The sliding contact is in the shape of a disc with an outer diameter of 19.5 mm and an inner diameter of 12.0 mm. The stationary sample is fixed on a multi-component sensor that measures the reaction torque, which is needed to withstand the rotation that comes from the fiction of the rotating sample. The multi-component sensor also measures the normal force, and the coefficient of friction is calculated from both measured components as the quotient between friction torque and normal load at the mean disc radius. Thermocouples that measure the contact temperature on-line are placed 1.2 mm under the sliding contact in the stationary samples. All the sliding discs are electrically insulated from the multi-component sensors and shaft, driven by the frequency-controlled electrical motor. A constant electrical current was maintained from the positive 14-V DC supply to the stationary sample, through the sliding contact to the rotary sample and then over the wire through the hollow shaft to the second rotary sample and over the next sliding contact to the stationary sample and back to the DC supply. The electrical contact resistance was measured on-line by monitoring the drop in the contact voltage for each sliding contact using an auxiliary system of a brush and a slip ring in the middle of the shaft. The data for the measured parameters was acquired using analogue-to-digital converters and then processed with National Instruments LabVIEW software. The wear of the contact materials was determined by weighing the test samples before and after the test using an XA 210/X (Radwag, Poland) analytical balance with a resolution of 0.01 mg and a repeatability of 0.02 mg. The mass loss was transformed to specific wear (mm^3/Nm) to normalise the results at the different loads and sliding distances. The results represent the individual wear of each disc, to analyse the wear behaviour of each material, as well as the total wear of both discs, to indicate the overall appropriateness of the specific contact pair.

2.2. Testing parameters

To simulate the broad range of operating conditions that occur in the final applications, and to vary as many of the contact conditions as possible with a limited number of tests, they were performed in the following test matrix: two contact parameters were fixed at their intermediate values, and the third parameter was varied in the selected range. To study the effect of the sliding velocity, the tests were performed at 2.5, 5 and 10 m/s (corresponding to 3000, 6000 and 12 000 rpm), for a normal contact load at 1.25, 2.5 and 5 N (corresponding to 6.75, 13.5, and 27 kPa) and to study the effect of an electrical current equal to 0, 2, 4 and 8 A (corresponding to a current density of 0, 1.1, 2.15 and 4.3 A/cm^2). For each test condition, two-to-four 24-h tests were performed to obtain the relevant long-term behaviour under steady-state conditions and with measurable wear. Table 1 presents the details of the contact parameters.

Since we used a flat-on-flat contact geometry, special attention was paid to obtain a completely parallel position between the two discs, which ensures the appropriate experimental contact conditions. To

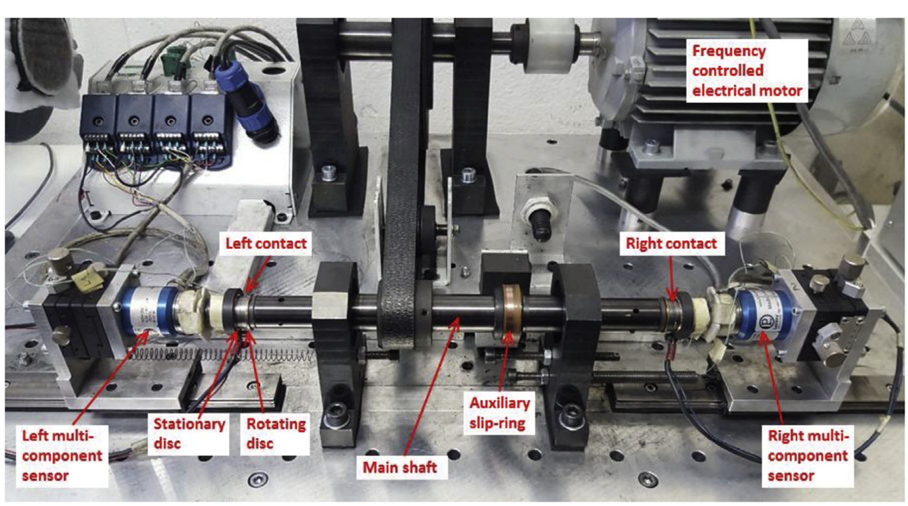

Fig. 2. Custom-made tribological testing device used for measuring the electrical sliding contacts.