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Influence of contact parameters on the tribological behaviour of various graphite/graphite sliding electrical contacts

Dejan Poljanec[a], Mitjan Kalin[b,*], Ludvik Kumar[a]

[a] Kolektor Group d.o.o., Vojkova 10, 5280 Idrija, Slovenia
[b] Laboratory for Tribology and Interface Nanotechnology, University of Ljubljana, Faculty of Mechanical Engineering, Bogišičeva 8, 1000 Ljubljana, Slovenia

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ABSTRACT

Sliding electrical contacts are used in devices for the conduction of electrical power or the electrical signals between stationary and moving parts. The most widely used electrical-sliding system is still the conventional slip ring and brush assembly. In the last decade, the lifetime of ring-brush contacts was extended through the use of better contact-material combinations and design improvements. However, the extremely rapid electrification of many more components has put severe demands on this extended lifetime. This paper presents a novel, patented design for two sliding discs that allows the use of advantageous graphite/graphite contacts. In the literature there is a serious lack of understanding the performance of sliding electrical contacts with graphite/graphite pairs, which depends on the key contact parameters, as well as the influence and potential of the different available graphite materials. The normal load, the contact velocity, the electric current, and the three self-mated graphite contacts, i.e., hard carbon, electrographite and polymer-bonded graphite, were investigated. The results indicate that the contact conditions influence the performance, which is also very dependent on the graphite materials. The polymer-bonded graphite showed the best results in this study.

1. Introduction

Electrical components and systems, such as electrical motors, alternators, generators and many other electrical machines, are becoming increasingly important in many applications, for example, home appliances and, especially, in the automotive industry, due to the recent increase in the electrification of many automotive components that have to comply with environmental legislation [1]. Sliding electrical contacts are used in these devices for the conduction of electrical power or electrical signals between stationary and moving parts, with the most widely used conventional system being the slip ring and brush [2,3], typically referred to as a slip-ring assembly. The efficiency of a slip-ring assembly depends on the material properties of the brush and the slip ring, their geometry, surface boundary films formed in-situ in the contact, the surrounding environment and the operating conditions. To ensure efficient, reliable and long-term operation without failure and maintenance, several properties are needed, for example, a high wear resistance, good electrical and heat conductivity of the contact materials, a low electrical contact resistance and a low friction [2,4,5]. This makes slip rings with brushes one of the most critical assembly parts in these electrical devices.

In the last decade the lifetime of slip-ring assemblies was extended by better contact-material combinations and design improvements, like a smaller slip ring dimeter and, consequently, a lower sliding speed and sliding distance, or longer brushes [6,7]. However, longer brushes also mean a larger total electrical resistance of the brushes. With such a design, the roundness, run-out and contact-surface roughness also have an important influence on the slip-ring assembly's performance [8,9]. Despite the increased lifetime of the slip-ring assembly, even longer lifetimes are required in new applications.

Response to these demands is a new sliding electrical contact that was developed and patented [10]. It is based on an axial system of two graphite discs, with the stationary disc pressing against the rotating disc with an optimal contact force. The new system eliminates some of the classic design problems of slip-ring assemblies by increasing the contact area and, consequently, decreasing the electrical current density and the contact resistance.

The new system [10] is also expected to benefit from using a graphite/graphite contact-material combination [11], rather than classic systems where the stationary graphite brushes press against a metal rotating slip ring, often made from copper or bronze [3]. This should result in a lower wear rate and, consequently, lead to a longer lifetime. Namely, in classic sliding electrical contacts consisting of a graphite brush and a copper slip ring the initial wear of the brush is relatively

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* Corresponding author.
E-mail address: mitjan.kalin@tint.fs.uni-lj.si (M. Kalin).

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high, until a graphite transfer layer forms on the metal slip ring. This leads to a graphite-on-graphite sliding contact that decreases the wear of the brush due to the lubricating effect of the graphite low-shear sliding between the basal planes [9]. Graphite has been used in sliding electrical contacts for a very long time, because of its beneficial sliding properties resulting from the low shear basal planes [12], as well as it's good electrical conductivity. When sliding without any electric current the coefficient of friction for the graphite/graphite is relatively low (0.1–0.3) if the sliding is in reactive environment (air, oxygen, water vapour) [13]. However, when sliding in a vacuum, without any electric current, the coefficient of friction can be much higher (0.45–0.6) [13]. It has been reported that the reason for the good tribological properties in a reactive environment are the interactions between the graphite and surrounding water vapour or another condensed vapour [12]. In a reactive atmosphere the electric current decreases the coefficient of friction in a graphite/graphite contact, mainly because the electric current accelerates the absorption of gas molecules onto the graphite surfaces, which then decrease the adhesion in the contact [13,14]. However, by increasing the electric current through the contact, higher dynamical contact loads, higher sliding speeds, higher contact pressures or a lower environmental air pressure occur and increase the contact temperature, which has a negative influence on the gas adsorption and diminish or eliminate the beneficial lubricating effect of the electric current. Therefore, the coefficient of friction increases, the adhesive component of the wear does not decrease and the abrasive component of the wear remains important because of the orientation of the graphite crystal's basal planes [13].

The newly designed electrical sliding contact [10] that reduces the contact pressure and consequently the potential wear, which is usually the life-determining parameter for these systems, thus gives potential that a further improvement of the tribological behaviour can be achieved in electrical sliding contacts by taking advantage of the self-lubricating effect of self-mating, graphite-on-graphite contacts [2,15]. The positive aspects of graphite/graphite materials in electrical sliding contacts have already been observed for commutators operating in fuels [16–18]. This is currently one of the few mass-production applications of sliding electrical contacts that are based on the graphite/graphite material combination.

However, in spite of the above-mentioned studies, these are still relatively rare, and so the influence of graphite/graphite contact pairs subjected to a simultaneous electrical current remains unsearched and not understood in terms of the tribological properties and behaviour. For the successful operation of the new contact design of the sliding electrical contacts, the properties of different graphite combinations and an understanding of their tribological behaviour under specific conditions for a wide range of contact conditions is thus greatly lacking. In this study, the influence of the sliding speed, the normal load and the electric current on the properties and behaviour of sliding electrical contacts was investigated, by using three different, but commercially available, graphite material grades.

2. Experimental

2.1. Testing device

A dedicated tribological testing device, shown in Fig. 1, was developed and custom manufactured. The device has two sliding electrical contacts to enable a closed-loop electrical circuit. The 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 device enables on-line measurements of the normal contact force and the friction torque for each sliding contact, from which the coefficient of friction is calculated. To measure the force and the torque, multi-component sensors are used (M-2416, Lorenz Messtechnik GmbH, Germany). A stationary sample is fixed on this multi-component sensor by special sample holder from PTFE material, and so electrically and thermally isolated from sensor. With torque sensor the reaction torque, which is needed to withstand the rotational force from the friction of the rotating sample, is measured. The rotating sample is mounted on the shaft via another sample holder from PTFE material. Thermocouples are used for the on-line measurement of temperature at 1.2 mm below the sliding contact, placed in the stationary sample. A constant electric current was maintained from a positive 14-V DC supply to the stationary sample, through the sliding contact to the rotary sample and then by isolated wire along the shaft to the second rotary sample and over the next sliding contact to the stationary sample and back to the DC supply. The on-line contact-voltage drop is measured for each sliding contact using an auxiliary system of a brush and a slip ring in the middle of the shaft. The voltage drop is an indirect measure of the electrical contact resistance, which was calculated from the measured voltage drop by dividing by the electric current (Ohm's law). The shaft is driven by a frequency-controlled electrical motor. The data for the measured parameters is acquired using analogue-to-digital converters and then processed using National Instruments LabVIEW software. The wear of the contact materials was determined by weighing the test samples before and after the test with an analytical balance (XA 210 / X, Radwag, Poland), having a resolution of 0.01 mg and a repeatability of 0.02 mg. The mass loss was transformed to the specific wear (mm^3/Nm) to normalise the results for very different loads and sliding distances.

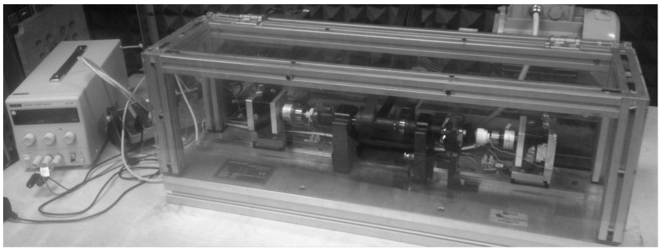

Fig. 1. Custom-made tribological testing device used for measuring the sliding electrical contacts.

2.2. Testing parameters

The contact conditions were varied to study the effect of sliding speed at 2.5, 5 and 10 m/s (corresponding to 3000, 6000 and 12.000 rpm), normal contact load at 1.25, 2.5 and 5 N (corresponding to 6.75, 13.5, and 27 kPa) and electric current at 0, 2, 4 and 8 A (corresponding to current densities of 0, 1.1, 2.15 and 4.3 A/cm^2). Testing parameters were selected according to the real application operating conditions. To simulate the broadest range of possible operating conditions occurring in the applications and as many contact conditions as possible, the tests 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. Each test was run for 24 h to obtain relevant long-term behaviour under steady state and with measurable wear. For every contact condition three or four 24-h tests were performed for each data point. Table 1 presents details of the contact parameters.

2.3. Materials

Three different graphite materials from well-established commercial grades were used in the tests. These graphite materials were selected according to the graphite supplier's recommendation and experiences regarding suitability in electric sliding end-user applications. The samples were made from the following materials: hard carbon, electrographite and polymer-bonded graphite. All were supplied by Schunk Carbon Technology GmbH, Austria. The main mechanical and physical properties of the selected graphite materials are listed in Table 2.