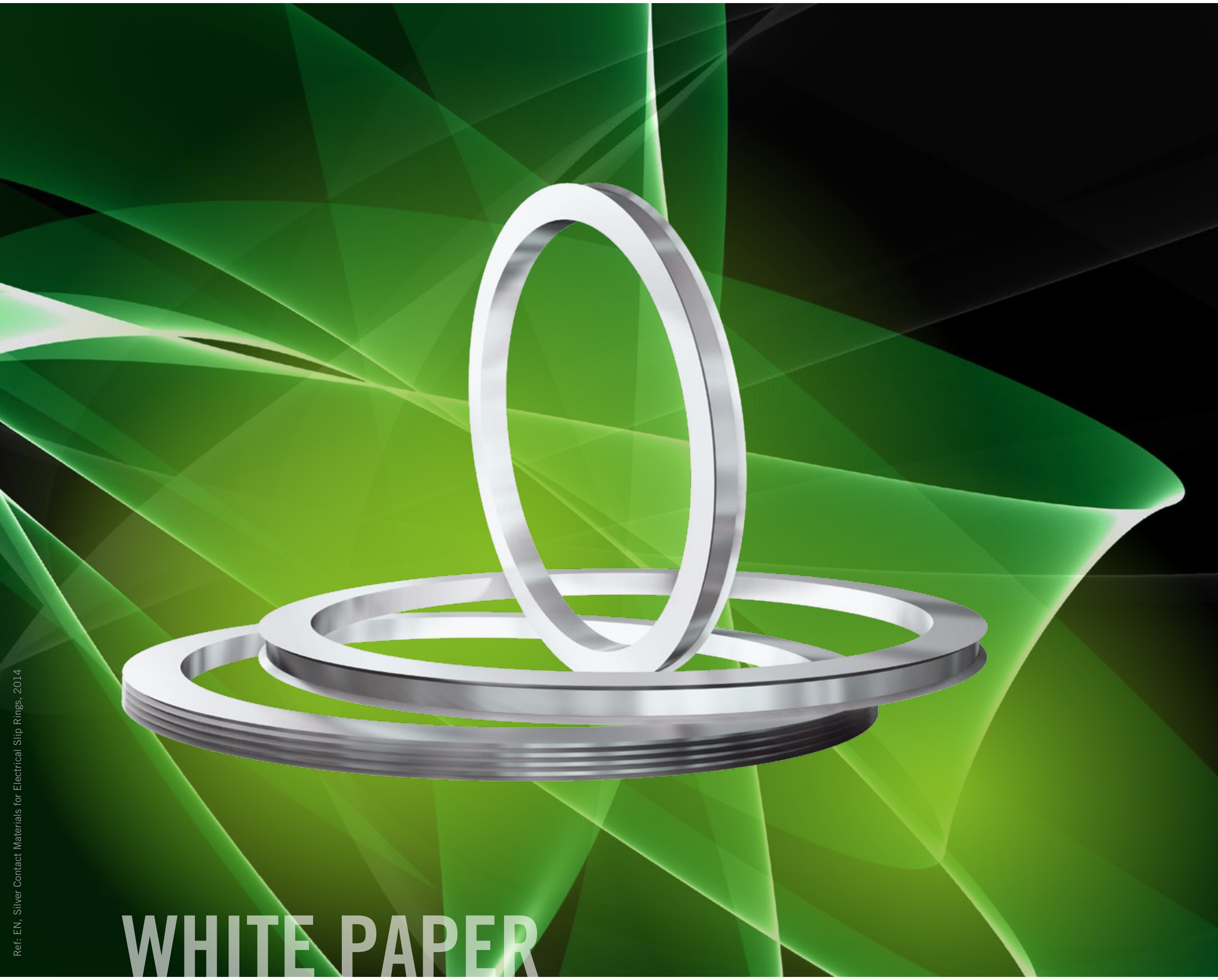
Heraeus



WHITE PAPER

Silver Contact Materials for Electrical Slip Rings

Ref: EN, Silver Contact Materials for Electrical Slip Rings, 2014

Silver Contact Materials for Electrical Slip Rings

Bernd Gehlert, Heraeus Deutschland GmbH & Co. KG

From 1981 Development Engineer at Heraeus, from 1985 Development Project Leader for electrical switching contacts, and from 1995 Head of the Contact Laboratory. Commencing 2004 a member of the VDE (Assoc. for Electrical, Electronic & Information Technologies) technical committee "Contact behaviour and switching" within the ETG-Q3 and ITG-9.5. From 2007 deputy chairman of the technical committee "Contact behaviour and switching". Numerous lectures on a variety of topics as well as publications and patents relating to the area of electrical contact technology.

CONTENT

ABSTRACT

Qualitatively high-grade electrical slip rings are constructed to a large extent with gold base contact systems. The cost pressure on electrical transmission systems, e.g. in wind turbines, has increased constantly over the last few years. Price competition between suppliers is determined by the potential for reducing costs. Due to the significantly lower cost of silver, the economic significance of electroplated silver surfaces on contact ring assemblies and silver alloys as sliding contacts has gained in importance. In many areas these materials offer a reliable solution.

Cylindrical slip rings with tangential sliding contacts are typical designs for the continuous transmission of current. The sliding contacts consist of individual spring wires, multiple-wire wiper contacts and so-called "bundle brushes". Several thin spring wires are gathered together in a bundle. The electrical load spectrum ranges from the transmission of data to the transmission of energy. Depending on the application, for the transfer of higher currents up to 250A several sliding contacts are arranged parallel on a contacting surface.

In the present work the contact behavior of various hard silver surfaces is compared for electrical slip ring system applications, and possible designs for sliding contacts are described.

1 INTRODUCTION

Precious metal contact materials are used in almost all fields of high value electrical slip rings. Oxidation and corrosion in the contact zones are thus avoided and the reliable transmission of signal current and load is made possible [1], [2], [3].

With regard to short term interruptions through lifting off, high contact reliability is enabled by dividing the electrical current being transmitted over as many contact points as possible. Running noise and voltage fluctuations are taken as a measure for the number of current interruptions. These quantities can be regarded as defining the useful life time of electrical slip rings associated with the sliding contacts. They decrease proportionally with the square of the number of current-conducting sliding contact points arranged in parallel [4].

Design solutions are offered by multiple-wire wiper contacts which are produced by micro-precision welding [5] or brush-like "bunch" sliding contacts with numerous crimped precious metal wires of hard drawn silver, palladium or gold alloys, Figure 1a and b. Furthermore, sliding contacts can be used that are made of sheathed wires produced by rolling, or of individual wires or stamped springs. Besides solid precious metal designs, solutions used to economize on precious metals include roll cladding, selective electroplating or welding [1]. Silver alloys which have good sliding contact properties but are not spring-hard can be welded to suitable support materials [6].

Typical contact partners are electroplated non-precious metal rings or structured circuit boards with hard silver or hard gold surfaces. For economic reasons the slip rings can also be selectively plated on the end surfaces of the cylinders.

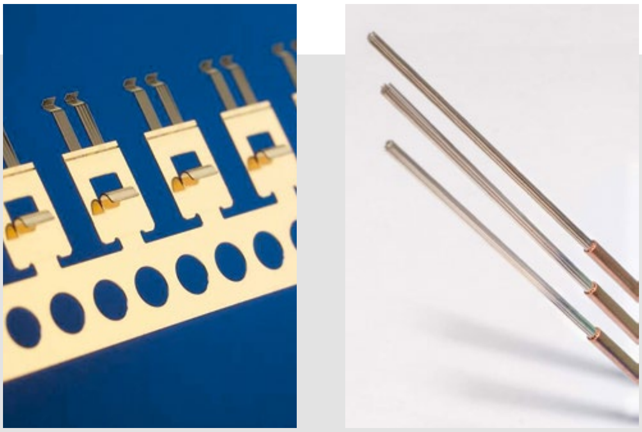


Figure 1: a) Welded multiple-wire wiper, AgPd alloy, 2 x 10 wires, d = 76 μm, l = 3.5 mm
b) Crimped bunch sliding contact in Cu sleeves, AgCu alloy, 14 wires, d = 0.25 mm, l = 55 mm

In view of the large number of material pairs to be investigated, a test in actual slip ring operation cannot be carried out. A preliminary selection was, therefore, initially achieved with a mechanical frictional wear test. Subsequently investigations were performed on selected silver surfaces using a model test facility [7] which simulates the operating conditions of slip rings as exactly as possible.

2 EXPERIMENTAL METHODS

2.1 MATERIAL SELECTION

The aim of this work was the contact-technical investigation of wear resistant electroplated silver coatings for electrical slip rings. In accordance with the application, silver coatings 10 µm thick with nickel intermediate layers were investigated on brass.

The Heraeus hard silver coatings that were investigated varied with regard to different organic-base brightening and hardening additives, Table 1. The hard silver 3 surface, which shows the highest resistance in the frictional wear test, was selected as the basis for investigating the influence of passivating surface finishes on the contact behavior.

A spring-hard silver-copper alloy (HV 160 – 190) was used as the opposing contact material in the frictional wear and current transmission tests.

No.	Ag – Coating 10 µm
1	Standard silver
2	Standard silver with increased brightener
3	Hard silver 1
4	Hard silver 2
5	Hard silver 3
6	Hard silver 3 with nano-dispersion addition
7	Surface finish on hard silver 3
8	Sn-containing silver tarnish protection
9	Electrolytic passivation
10	Polymer passivation

Table 1: Silver surfaces on test coupons for frictional wear investigations

2.2 TEST PROCEDURE

2.2.1 FRICTIONAL WEAR

Frictional wear depends in a complex manner on a range of parameters such as hardness, material combination, frictional path and normal load together with the geometry and surface finish. Wear tests were conducted under idealized conditions in a model experiment to obtain a comparative evaluation of the silver contact layer systems.

Figure 2 shows a schematic diagram of a simple frictional wear apparatus. The specimen holder with the test coupon is moved backwards and forwards against the opposing contact by means of an eccentric drive. The opposing contact/frictional partner (a wire d = 0.8 mm bent to r = 1.5 mm) is pressed against the test coupon by means of a lever arm. The frictional forces are measured with a load cell for up to 250 frictional cycles. The average frictional velocity v = 5 mm/s, the frictional path s = 5 mm and the contact force FK = 150 cN were maintained constant.

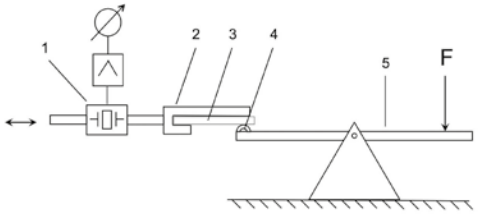


Figure 2: Principle of the frictional wear testing, 1 load cell, 2 test coupon holder, 3 test coupon, 4 frictional partner, 5 lever arm with weight

2.2.2 CONTACT RESISTANCE AND CORROSION

The contact resistance is determined with separate current and potential measurements to ensure that the measurements are not influenced by resistances in the leads [8]. The open circuit potential of the measurement circuit is limited to < 20 mV to prevent the applied potential breaking through foreign layers which might be present on the contact surface, and the measurement current is 10 mA [9]. The mechanical influences such as friction and closing impulse were kept constant and as low as possible. A gold plated measurement wheel was used as the probe contact and was turned by a few degrees after each measurement point to avoid transferring impurities. The static contact force (FK) was adjusted to 10 cN.

Atmospheres containing sulfur are particularly suitable for evaluating the corrosion resistance of silver contact materials. The samples were exposed to a flowing gas atmosphere with 1 ppm hydrogen sulfide (H2S) at T = 25°C and a relative humidity of 75% [10].

2.2.3 ELECTRICAL SLIP RING TEST

The investigations of the contact properties of electrical slip rings were carried out on a model apparatus [3], [7], without additional greasing. Bundle brush sliding contacts of a silver-copper alloy with 14 wires, d = 0.25 mm, and an effective spring length of 30 mm were used as the opposing contacts. The need for low mechanical wear necessitated a very low contact force. Increasing the a contact force above 0.5 cN per individual wire of a bundle brush sliding contact reduces the contact resistance only slightly, Diagram 1. Correspondingly, a sufficiently reliable contact is achieved with a contact force of 10 – 12 cN for the bundle brush sliding contacts consisting of 14 wires. In practice, influences from vibrations and oscillations in varying designs and applications of the current transmission modules should be taken into consideration.

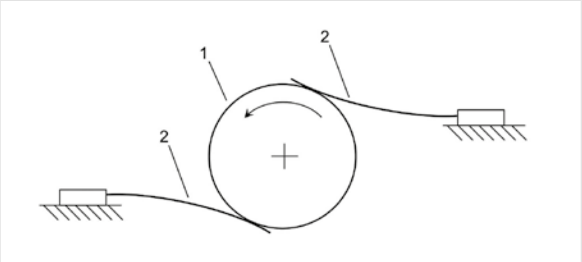


Figure 3: Schematic diagram showing the investigation of contact properties for electrical slip rings, 1 slip ring and 2 sliding contacts

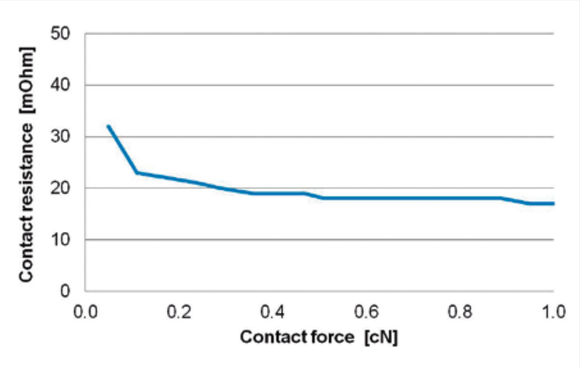


Diagram 1: Contact resistance as a function of the contact force, wire d = 0.25 mm AgCu alloy vs. electroplated Ag surface

For the slip rings used with d = 60 mm and a rotational speed of 150 rpm, the relative speed is 0.47 m/s. The load current at 24 V DC, 4 A ohmic load, is applied to the slip ring via two sliding contacts on separate tracks, Figure 3.

Failure criteria are excessive voltage drop / noise caused by bouncing / arcs between sliding contacts or the slip ring coating wearing through or total wear of the sliding contact wires. The tests were stopped after max. 100 million revolutions.

3 RESULTS

3.1 FRICTIONAL WEAR

In the following diagrams and figures, typical examples of the progress of the frictional force and the frictional coefficient f are shown corresponding to the relationship between tensile / compressive force and contact force.

The standard silver surfaces show increased frictional coefficients in the range of f = 1.5 even during the first frictional cycles, Diagram 2. The cause is an increased tendency to adhesion of the frictional partners. In the course of further frictional cycles, increased wear processes (e.g. work hardened wear particles of mechanically destroyed micro-welds) lead to the increase in frictional coefficient and subsequently to the rapid wearing through of the surface layer after 150 – 200 frictional cycles, Figure 4. The penetration of the silver layer is characterized by a rapid drop in the frictional coefficient. In this test, increased brightening agent in the silver plating bath has no influence on the mechanical wear resistance.

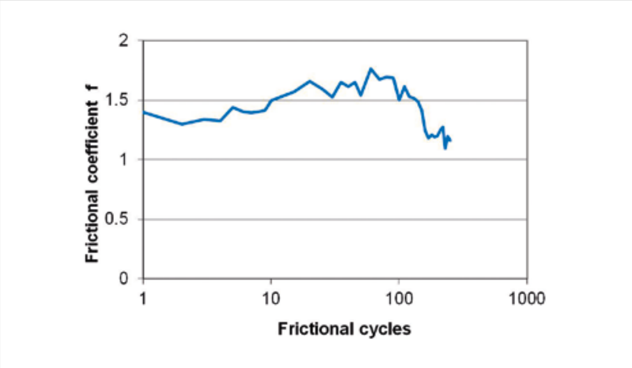


Diagram 2: Frictional coefficient vs. frictional cycles, standard silver

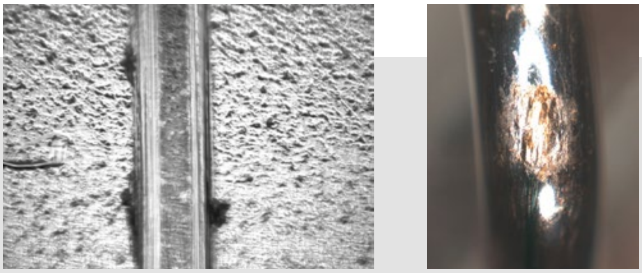


Figure 4: a) Frictional track on standard silver and
b) frictional partner after 250 frictional cycles

In comparison with the alternative silver surfaces, the hard silver coating 3 achieves good sliding behavior combined with low frictional coefficients during the first frictional cycles and the lowest wear, Diagram 3. No significant indications of wear or score marks are to be seen within the frictional track. The layer has not worn through at the end of the test after 250 cycles, Figure 5. An uninterrupted silver layer can still be seen in the metallographic section.

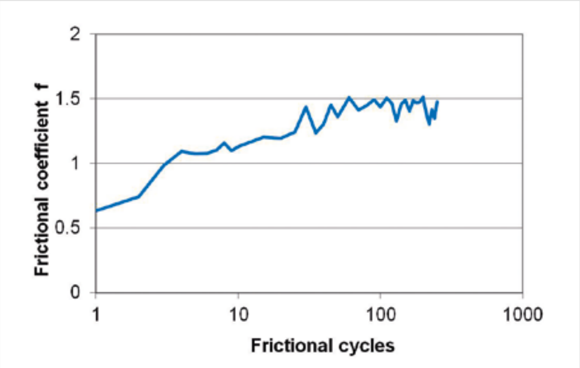


Diagram 3: Frictional coefficient vs. frictional cycles, hard silver 3

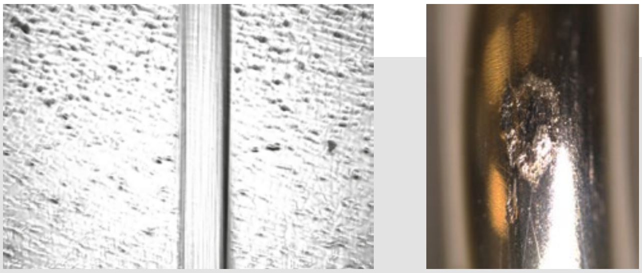


Figure 5: a) Frictional track on hard silver 3 and
b) frictional partner, no penetration of layer after 250 frictional cycles, see metallographic section

The hard silver 2 coating shows similar progress of the frictional coefficient. The wear resistance is, however, lower than that of hard silver 3. Besides slightly higher wear values, the appearance of the frictional track is also more distinct.

The coating hard silver 1 shows areas with local penetration within the wear track after only 250 frictional cycles.

The addition of a dispersion of hard nano-particles in hard silver 3 shows no influence on the wear resistance. The progress of the frictional force and the appearance of the frictional track are similar to the coating without an addition.

Table 2 gives a comparison of the frictional wear test results. Higher wear resistance and more favorable sliding behavior result from the increasing hardness of the coating. The assessments low, medium, good and very good correspond to the sequence of the frictional force progress and the distinctive form of the frictional tracks.

Surface	Hardness HV 0,025	Wear resistance
Standard silver	74 – 79	low
Hard silver 1	98	medium
Hard silver 2	132	good
Hard silver 3	160	very good
Hard silver 3 with nano-dispersion addition	170	very good

Table 2: Evaluation of frictional wear results

The wear resistant surface hard silver 3 was selected as the basis for investigating the influence of surface finishes on the contact behavior.

Electrolytic passivation and the Sn-containing silver tarnish protection showed no influence on the frictional wear behavior in the test. In contrast, the surface protective film of the polymer immersion solution prevents adhesion between the frictional partners. As with greased surfaces frictional coefficients in the range of $f = 0.1 – 0.15$ are measured, Diagram 4.

This corresponds to pure sliding friction without micro-welding of the frictional partners.

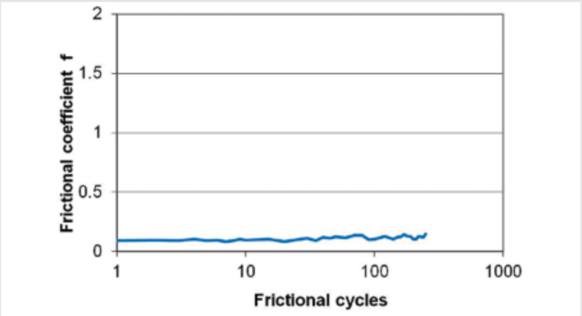


Diagram 4: Frictional coefficient vs. frictional cycles, hard silver with polymer immersion solution

Within the frictional track, Figure 6, no signs of wear can be seen after 250 frictional cycles, comparable with previous tests.

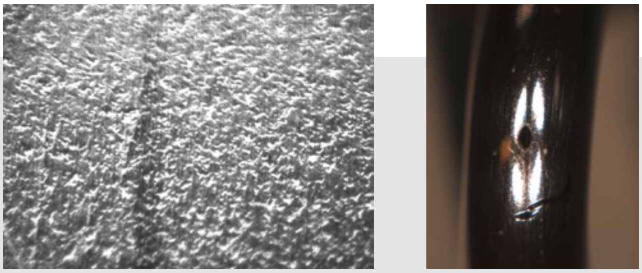


Figure 6: a) Frictional track on hard silver 3 with polymer immersion solution b) frictional partner after 250 frictional cycles

3.2 CONTACT RESISTANCE AND CORROSION

The contact resistance (RK) is influenced by the various electrolyte additions. With increasing hardness of the Ag surfaces (Table 2) the contact resistance also increases. Acceptable values of RK, < 3 mOhm, are measured with a contact force of 10 cN, Table 3.

Surface	R_x [mOhm]
Standard silver	1,8
Hard silver 1	1,8
Hard silver 2	2
Hard silver 3	2,1
Hard silver 3 with nano-dispersion addition	2,8

Table 3: Contact resistance in the initial condition, $F_K = 10$ cN

The metallic surface finishes have no significant influence on the contact resistance. In contrast, substantially higher contact resistance values, up to 20 mOhm, are measured on the sample with the polymer base surface finish, Diagram 5.

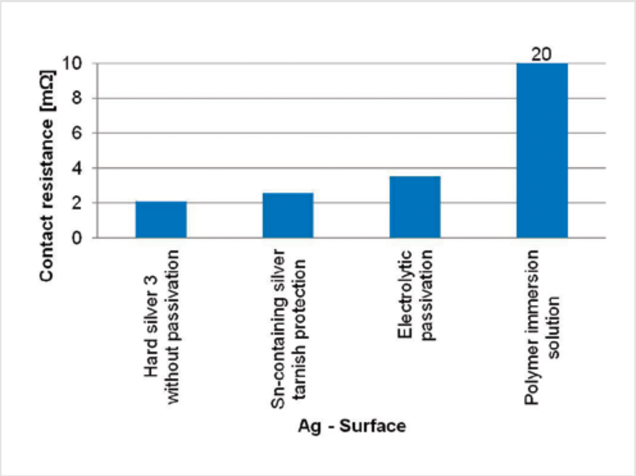


Diagram 5: Influence of the surface finishes on the contact resistance, $F_K = 10$ cN

After only 4 days exposure to flowing hydrogen sulfide atmosphere (1 ppm H2S, 25°C, 75% rel. humidity), a blue corrosion film has developed on the Ag surface without additional treatment, Figure 7a. The contact resistance increases to values > 100 mOhm.

The Sn-containing silver tarnish protection has no satisfactory protective effect against corrosion; the sample surfaces show brown-blue surface layers, Figure 7b. Corrosion protection is achieved with the electrolytic post-treatment and with the polymer base immersion solution. After 4 days exposure to H2S, no superficial tarnish layers can be observed visually, Figures 7c and d.

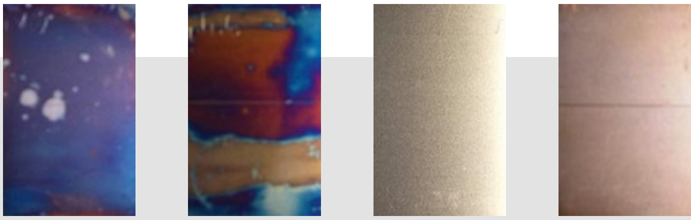


Figure 7a – d: Surface photographs after corrosive exposure: 4 d, 1 ppm H_2S, 25°C, 75% rel. humidity, a) without finish, b) Sn-containing silver tarnish protection, c) Electrolytic passivation, d) Polymer immersion solution

The results of the contact resistance measurements follow the same pattern as the visual appearance. Both on the untreated silver surface and the surface with Sn-containing silver tarnish protection RK values > 100 mOhm were measured. The best corrosion protection effect is achieved with the post-treatment in a polymer immersion solution. After 4 days exposure to H2S, RK remains almost unchanged relative to the initial condition with values of 22 mOhm. On the silver surface with electrolytic passivation an increase in RK to 28 mOhm was measured, Diagram 6.

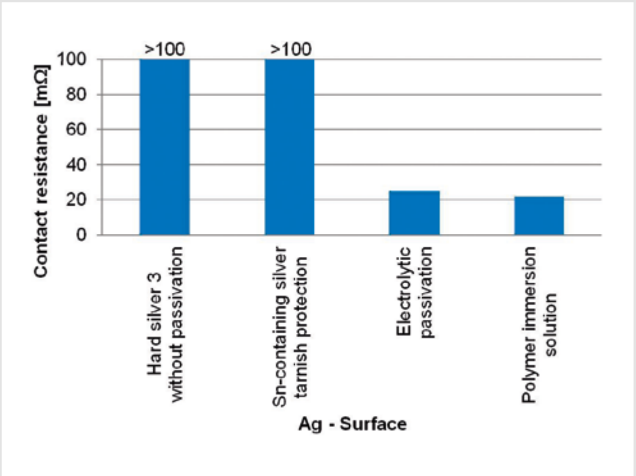


Diagram 6: Contact resistance: Corrosion protective influences of the surface finishes, $F_K = 10$ cN

3.3 ELECTRICAL SLIP RING TEST

In order to draw a conclusion about the current transmission behavior during relative movements, the potential drop between the sliding contact wires and the slip ring was measured at intervals with an oscillograph. Slip rings were coated with standard silver and hard silver 3 for these investigations. Hard silver 3 was also chosen as the basis for investigating the influence of the surface finishes electrolytic post-treatment and polymer base immersion solution. Some typical examples of the voltage changes as a function of the number of revolutions are shown below.

Diagram 7 summarizes the potential drop between the sliding contacts and the slip ring surfaces standard silver and hard silver 3 as a function of the number of revolutions. Up to the end of the test, current transmission was achieved without contact bouncing for the hard silver surface. This was confirmed by the relatively constant progression of the potential up to about 90 million revolutions. The increase in the potential drop up to 0.3 V is caused by increased wear of the slip ring surface at the end of its working life.

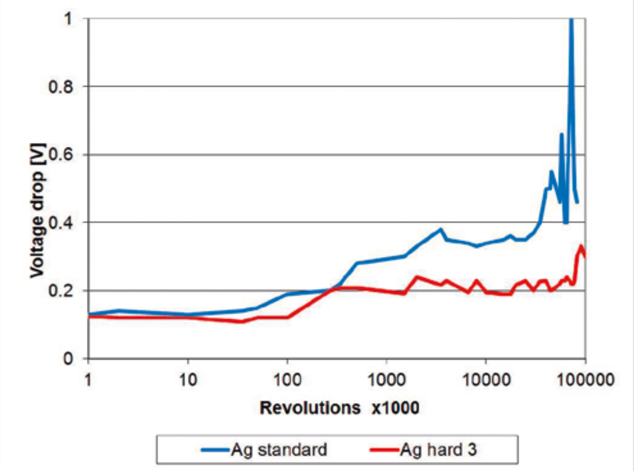


Diagram 7: Progression of potential during the service life test with the slip ring surfaces standard silver and hard silver 3

In contrast a shorter service life was achieved with the standard silver surface. A steep increase in the potential drop was measured after only about 60 million revolutions. Penetration of the coating on the ring surface could be seen on the friction tracks of some sliding contact wires. This also led to increased wear on the wires of the brush sliding contacts. After about 79 million revolutions some wires of the bundle brush contact are 100% worn away.

With the wear-reducing passivation surfaces on the slip rings a relatively constant and low potential drop was achieved up to the end of the test, Diagram 8.

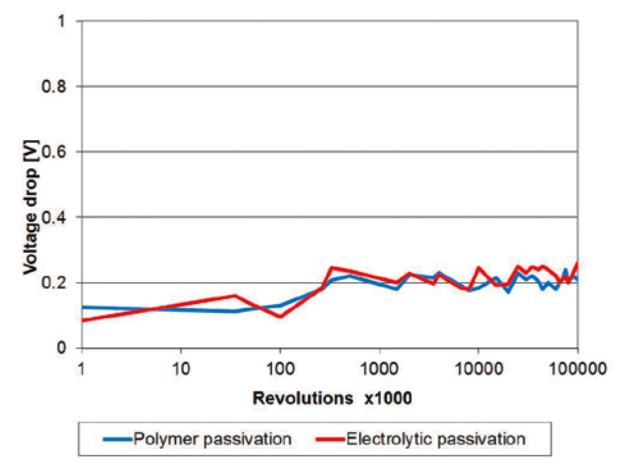


Diagram 8: Progression of potential during the service life test on the slip ring surface hard silver 3 with electrolytic and polymer passivation

The electrolytic post-treatment also led to an increase in the service life in the slip ring tests as a result of considerably lower contact forces compared with the frictional wear test.

No short-term interruptions with arcing were detected in any of the tests conducted.

4 SUMMARY

Considering the simple processing and low costs, hard silver 3 can be classed as a suitable contact layer for use as the surface of sliding contacts. The post-treatment in a polymer immersion solution and the electrolytic passivation offer an additional possibility for optimizing the contact coating system.

The brush shaped bundle sliding contacts made from a spring-hard AgCu alloy have proved themselves to be suitable contact partners for current transmission applications.

Depending on the application, the appropriate number of wires is between 10 and 30 with an effective spring length of 20 – 40 mm.

A summary of the results for the silver surfaces investigated with regard to their application as sliding contact surfaces is to be found in Table 4 according to the quality classes “very good”, “good”, “satisfactory” and “not satisfactory”. Determining factors for the classification were:

- Resistance to mechanical frictional wear
- Contact resistance
- Corrosion resistance in hydrogen sulfide atmosphere
- Electrical slip ring test.

The limits for the qualification classes are given below the table. The silver coating and the surface finish with particularly good contact properties for applications in electrical slip rings are highlighted by the markings.

Surface			**Investigation**		
	Hardness	**Wear**	**Contact resistance**	**Corrosion resistance**	**Electrical slip ring test**
Standard silver	+	+	+++	+	+++
Standard silver with increased brightening addition	+	+	+++	+	–
Hard silver 1	++	+	+++	+	–
Hard silver 2	+++	+++	+++	+	–
Hard silver 3	+++	++++	+++	+	++++
Hard silver 3 with nano-dispersion addition	+++	++++	+++	+	–
Surface finish on hard silver 3					
Sn-containing silver tarnish protection	–	o	+++	+	–
Electrolytic Passivation	–	o	+++	+++	++++
Polymer immersion solution	–	++++	+	+++	++++

Table 4: Summary and evaluation of the results

Evaluation hardness HV0,025:

+++	high > 130
++	medium 90 – 130
+	low < 90
–	not tested

Evaluation contact resistance at F_K = 10 cN:

+++	good < 5 mOhm
++	satisfactory 5 – 50 mOhm
+	not satisfactory > 50 mOhm
–	not tested

Evaluation wear, corrosion resistance, current transmission:

++++	very good	o	no influence
+++	good	–	not tested
++	satisfactory		
+	not satisfactory		

5 REFERENCES

1 VDE specialist report no. 69, Contact behavior and Switching, 22nd symposium Albert-Keil-Contact Seminar held in Karlsruhe, Germany from October 9th – 11th, 2013, published by VDE, Berlin, Offenbach, 2013, pp. 49 – 55

2 Paulsen, R.: Werkstoffe für elektrische Kontakte und ihre Anwendungen [Materials for Electrical Contacts and their Applications], TA-Esslingen 31010 / 71.626, February 2005

3 Vinaricky, E.: Elektrische Kontakte, Werkstoffe und Anwendungen [Electrical Contacts, Materials and Applications]. Springer Verlag 2002, p. 389

4 Schnabl, R.; Gehlert, B.: Lebensdauerprüfungen von Edelmetall-Schleifkontaktwerkstoffen für Gleichstrom-Kleinstmotoren [Service Life Tests on Precious Metal Sliding Contact Materials for Very Small Motors], Feinwerktechnik & Messtechnik 92, 1984, pp. 389 – 393

5 North, K. R.: Characteristics of Slip ring Noise. 3 rd Int. Res. Symp. On Elec. Con. Phen., University of Maine, Orono, Maine, 1966, p. 325

6 Gehlert, B.; Ungermann, H.: Mikroschleifkontakte [Sliding Micro-Contacts], Feinwerktechnik & Messtechnik 94, 1986, pp. 487 – 491

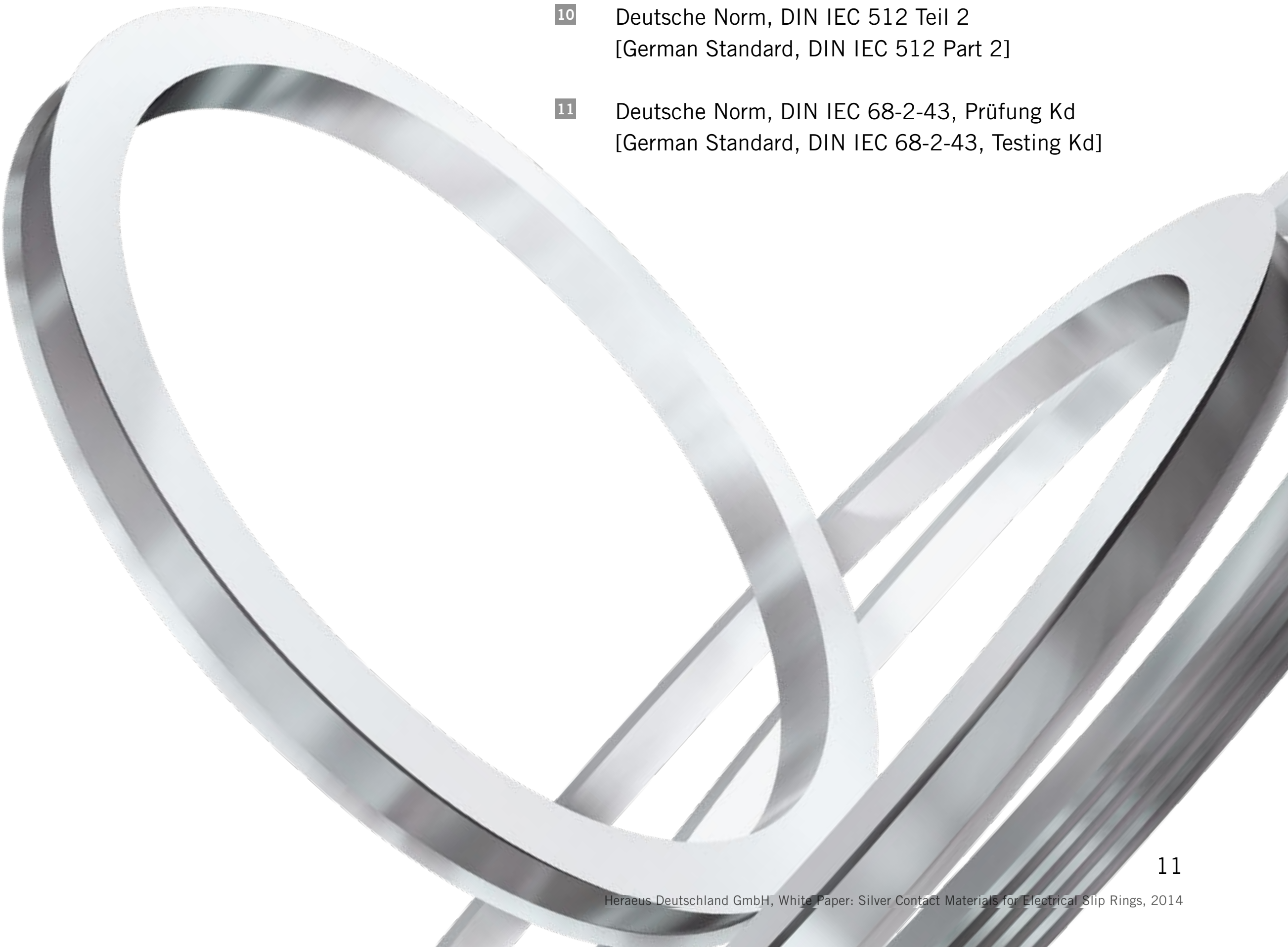
7 Gehlert, B.; Paulsen, R.; Prunzel, I.; Weiland, R.; Baake, P.: Edelmetallhaltiges Kontaktstück auf einem Federträger mit rotationssymmetrischem Biegemoment [Precious metal-containing contact piece on a spring carrier with a rotationally symmetrical bending moment], Patent Application WO 2012/048839 A1

8 Gehlert, B.: Lebensdaueruntersuchungen von Edelmetall-Kontaktwerkstoff-Kombinationen für Schleifringübertrager [Service Life Investigations of Precious Metal Contact Material Combinations for Electrical Slip Rings], 18. Albert-Keil-Kontakt-Seminar, Karlsruhe, VDE-Fachbericht 61, 2005, pp. 95 – 100

9 Gehlert, B.: Empfindliche Kontaktwiderstandsmessung [Sensitive Contact Resistance Measurement], Test-Kompendium 2004, Publish-Industry Verlag GmbH Munich, pp. 68 – 70

10 Deutsche Norm, DIN IEC 512 Teil 2 [German Standard, DIN IEC 512 Part 2]

11 Deutsche Norm, DIN IEC 68-2-43, Prüfung Kd [German Standard, DIN IEC 68-2-43, Testing Kd]



EN PDF 06.2016/N

Heraeus Deutschland GmbH & Co. KG
Heraeus Performance Products
Heraeusstr. 12 – 14
63450 Hanau, Germany
Phone +49 6181.35-5855
Fax +49 6181.35-3120
electro-technology@heraeus.com
www.heraeus-electro-technology.com