

FIBER BRUSHES:

*The Low Maintenance, Long Life,
High Power Slip Ring Contact Material*

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SUMMARY

Fiber brush technology allows the design of slip rings for high power, long life applications that have a minimum of 100 million revolutions of operational life with no maintenance.

INTRODUCTION

There are a number of long life slip ring applications that require power and signals to be delivered either on to or off of a rotating platform. A number of sensors can also be resident on the rotor that require delivery of electrical power to the sensors and signal transmission from the sensors to the controller. This transmission of electrical power and signals from the stationary structure to the rotating member is most efficiently accomplished with a slip ring. It is important to understand the design and construction of slip ring assemblies in order to properly evaluate their power capability and maintenance requirements. A maintenance-free, high power slip ring is possible with careful consideration of proper performance requirements and design constraints.

There are five very important characteristics of rotating platform applications that require specialized slip ring design considerations: (1) operational life, (2) environment, (3) electrical requirements (4) maintainability goals, and (5) and reliability requirements. These five operational parameters are critical in the selection of sliding contact materials used in slip ring assemblies. Table 1 presents a matrix of the performance parameters and their effect on slip ring contact selection.

This paper will discuss some of the shortcomings of traditional contact materials used in slip rings. An important sliding contact technology that allows high power, low maintenance, and high reliability assemblies to satisfy all five of the important performance characteristics will be discussed. These sliding contacts are called "fiber brushes."

Table1: The Effects of Operational Requirements on Slip Ring Contacts

Life	Continuous rotation for 100 million cycles requires contact materials with exceptionally good wear rates.
Environment	Contacts must be robust to survive hostile environments. The materials must be insensitive to humidity, temperature, and contaminating environments that can be present.
Electrical Requirements	Typical slip ring has high power requirements as well as signal-level requirements. The contact material must have good power (current) capacity as well as low contact resistance for good signal transmission.
Maintainability	Contacts should require no maintenance. The presence of significant amounts of contact wear debris or the need of lubrication violates this requirement.
Reliability	Contacts should not degrade significantly with time or be subject to sudden catastrophic failure. The presence of a significant amount of wear debris violates this reliability requirement.

TRADITIONAL SLIDING CONTACT DESIGN

Electrical energy is transmitted across the rotating interface in a slip ring assembly by sliding contacts. A brush, or wiper, slides on a rotating ring and maintains continual electrical contact during rotation (Figure 1 shows one such ring and brush configuration).

Most rotating systems strive to avoid contact

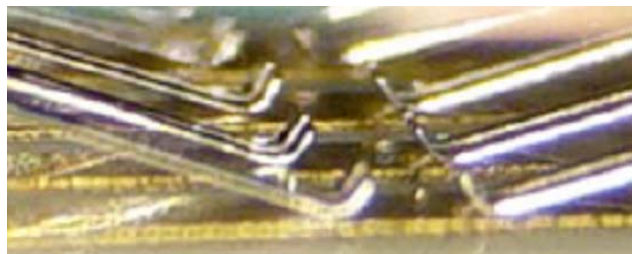


Figure 1: Noble metal sliding contact system for signals

between the rotor and the stator. However in the case of sliding contacts, intimate metal-to-metal contact is required between the stationary brush and the rotating ring for error-free electrical transmission. Appropriate materials and design criteria must be selected to reduce the wear of these materials in contact during sliding.

It is important to consider the contacts as a conductor of electrical power and signals. In the case of power transmission, the contact material must have sufficiently high conductivity to transmit electrical currents without overheating. The voltage of the transmitted power is not particularly significant for the contacts themselves, but the dielectric between the contacts must be sufficient to avoid arcing on power circuits. The ability of contacts to maintain voltage isolation during operation can be critical in the case of contacts that generate conductive wear debris during operation. This conductive wear debris build-up is shown in Figure 2. The danger is that this conductive debris will form an arc path leading to voltage breakdown between two circuits or a power circuit and ground.

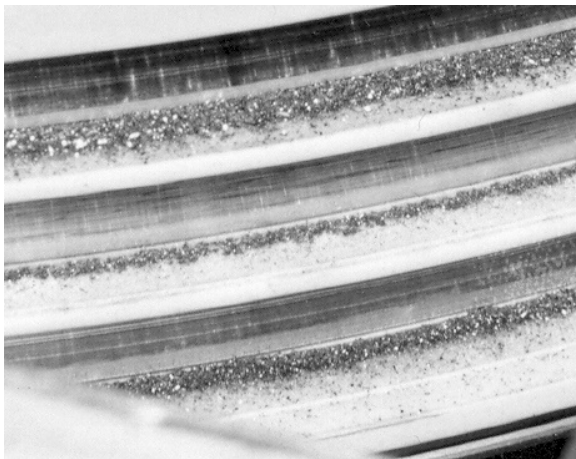


Figure 2: Close-up of ring showing metal/graphite wear debris

In the case of signal transmission through slip rings it is important to maintain signal integrity throughout the life of the slip ring. There is some small variation in contact resistance during rotation of a slip ring. Under normal conditions this variation is quite low. The variation in contact

resistance is measured with an oscilloscope as a peak-to-peak change in voltage at a constant current (often 50 ma). Most systems will perform correctly with 100 milliohms of contact noise. Noise is expected to be less than 40 milliohms with fiber brush contacts. Properly designed signal contacts will minimize any increase of this signal variation during the entire life of the slip ring.

There have been two primary contact designs used in high performance slip rings in the past. Contact materials made from carbon-based (graphite) composites have been quite common in large industrial slip ring applications as well as high current requirements for military slip rings such as those used in tank turrets. These sintered brushes are typically around 80% metal and 20% graphite (silver and copper are the most common), although for specific applications the graphite content can be as little as 5% and as great as 100%. The brushes typically are mated with a silver or copper alloy ring (see Figure 3). These composite brushes operate on the principle that the graphite provides lubricity for the system during rotation and the metal in the brushes provides the conductivity.

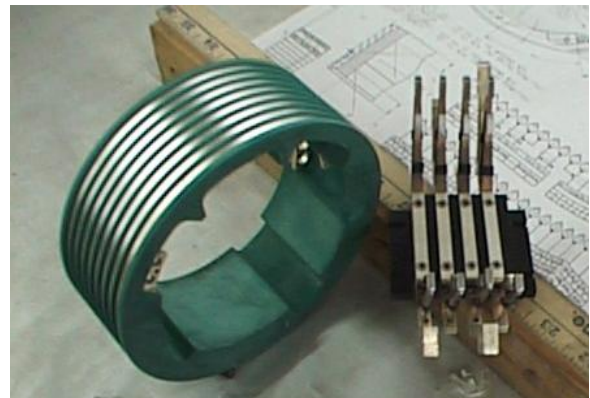


Figure 3: Silver graphite cantilever-style brush block with silver-plated copper ring module

Since these composite brushes are designed to wear preferentially to avoid ring wear, a sufficient length of brush is provided to allow maximum time between brush replacements. There are three problems with this material in high power and/or high reliability slip ring applications:

(1) The wear debris that is generated during operation is conductive, abrasive, and powdery and thus requires periodic cleaning; (2) this material is moisture sensitive and can wear unevenly if the relative humidity is less than 15% or more than 85%; and (3) when used for signal-level circuits, these composite brushes are very space inefficient.

To counter the disadvantages of composite brush materials, noble metal, monofilament brushes have been used in slip rings. These brushes are typically used on noble metal-plated rings or solid noble metal rings. The brush material is commonly a gold, silver, or palladium alloy, and the ring surface is often gold or silver-plated. These material combinations have a very long tradition in precision instrumentation slip rings as well as defense applications. Much of the work done on this slip ring construction occurred in the 1950's and 1960's during the development of precision slip rings for gyroscopes used in inertial navigation platforms for aircraft guidance. It was during this time that many of the materials, lubricants, and processes were developed.

The advantages of monofilament gold brush slip ring design over the composite brush design are primarily less wear debris generation and improved space efficiency for signal circuits. Unfortunately there is an important disadvantage to this contact system as well: limited current-carrying ability because of their relatively small size. However, this monofilament gold alloy brush design still plays an important role in the design of high precision slip rings by providing space efficient, high reliability circuits for signals.

It is becoming common to see slip ring designs that use graphite/metal brushes for power circuits mixed with gold monofilament brushes for signal circuits. This "hybridization" practice can produce acceptable results in applications requiring a relatively low number of revolutions on the slip ring assembly; however, the mixing of graphite/metal and gold-on-

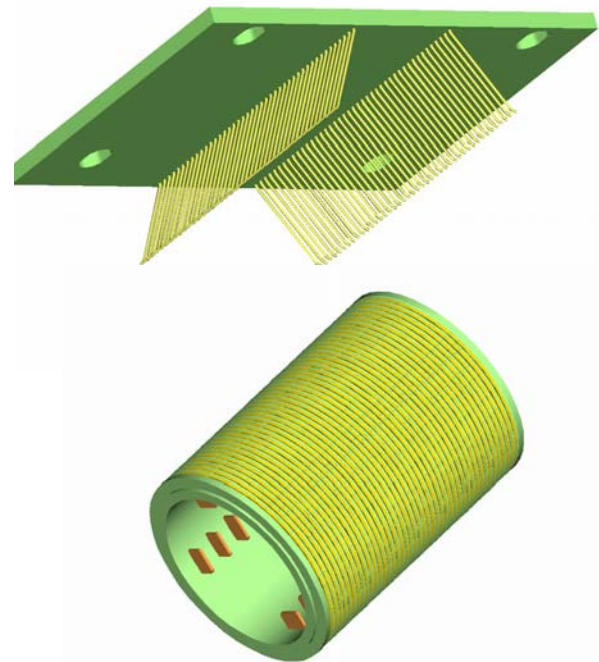


Figure 4: Noble metal ring and brush construction

gold brushes in one assembly can reduce reliability. The graphite/metal debris can contaminate the gold signal ring contacts. This contamination can produce an abrasive slurry, especially in the presence of contact lubricants and can lead to premature failure on the signal circuits, especially on noise (electrical) sensitive circuits.

As can be deduced from the previous discussion, the ideal contact material for slip ring applications would have the following properties:

1. Low wear-debris generation;
2. Good conductivity;
3. Scaleable for space-efficient sizing with high current as well as signals;
4. Low wear rate (long life);
5. No lubrication required.

FIBER BRUSHES: MAINTENANCE-FREE SLIP RING CONTACTS

Operational Theory: Fiber brush technology provides all the characteristics listed above for the ideal slip ring contact material. The fiber brush has evolved from important research conducted by Dr. Kuhlmann-Wilsdorf in the mid-1970's to improve the efficiency and reliability of high performance motor and generator commutator contacts (Ref. 1). Subsequent development work by Moog Component Group engineers led to a unique, patented approach for fiber brush contacts using tangential fibers of noble or precious metal (see Figure 5).

This tangential fiber brush design has been proven in a multitude of long wear, extreme environment slip ring applications. Three notable applications that have benefited from fiber brush technology have been helicopter rotor de-icing slip rings, radar pedestal slip rings, and wind turbine slip rings. Each of these applications requires long life, high conductivity for high power transfer, and operation in very difficult environments.

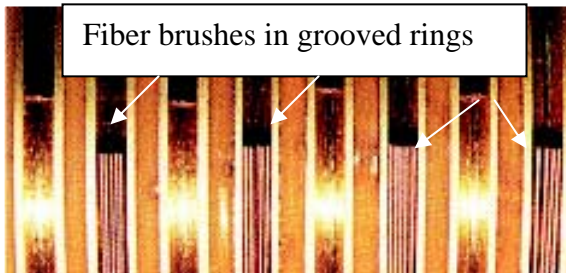


Figure 5: Fiber brushes installed in grooved ring

The fiber brush design involves the bundling of multiple metal filaments into a compact multi-fiber "brush" as shown in Figure 5. Typically these fibers are noble metal and the ring on which the brush operates is noble metal plated. The use of noble metals prevents oxides and coatings from forming on the contacts and allows very light contact forces. The very low contact forces of fiber brushes result in a very low wear rate. The multiple metal fibers provide very good conductivity and very high current density, so the fiber brush can be used for

both power and signal. And as a final benefit the fiber brush produces negligible wear debris.

The theory of the fiber brush as a sliding contact is based on multiple contact points with very light contact forces per contact point. In the case of traditional single element electrical contacts, the total force imposed on the contacts to establish good electrical contact are supported by just a few asperities, or microscopic high points, on the rings and brushes. To avoid excessive wear, lubricants are traditionally added to the contacts to help support the contact forces. In the case of metal-graphite brushes, a graphite film forms in the contact region to help support the brush. Monofilament gold brushes use hydrocarbon lubricants to help support the contact forces. But even with the lubricants, the metal in contact zone is severely deformed and is subject to wear with repeated rubbing.

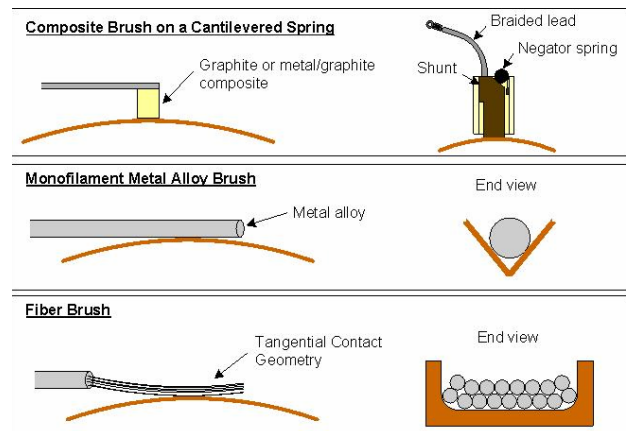


Figure 6: Comparisons of 3 slip ring contact technologies

Fiber brushes have multiple fibers to carry the electrical and mechanical load and the force on each fiber is extremely light. The multiple contacts allow even sharing of both the electrical and mechanical loads, and the contact forces are so light that often no lubricant is required. These light contact forces result in a very low wear rate.

Life: Contact life is one of the most critical slip ring performance parameters. Fiber brush technology has proven its long life capability in a number of applications as well as life tests. Results from numerous life tests demonstrate that fiber brushes

can be operated in excess of 100 million revolutions

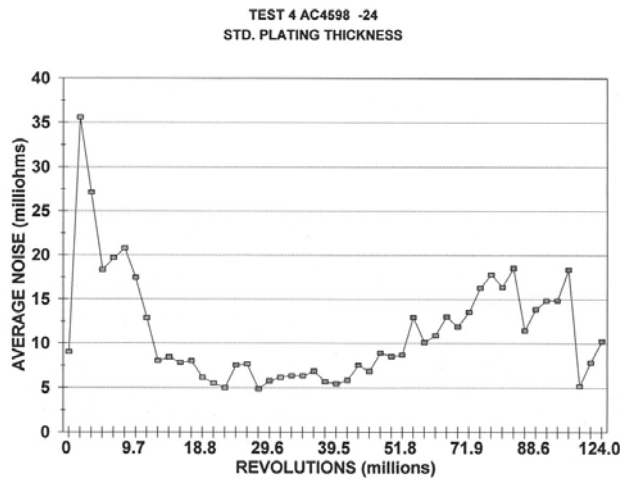


Figure 7: Fiber Brush slip ring life test data

with low contact noise, little debris generation and low wear.

The data in Figure 7 shows “contact noise” (in milliohms) over a 124-million-revolution life test. The results demonstrate an average of 24 channels with each channel operating at its rated current level (5-10 amps in this case). The data shows after a brief run-in period, the contact noise levels out and stays below 20 milliohms for the life of the test. This test was stopped at 124 million revolutions with no indication that the contacts were at the “end of life.”

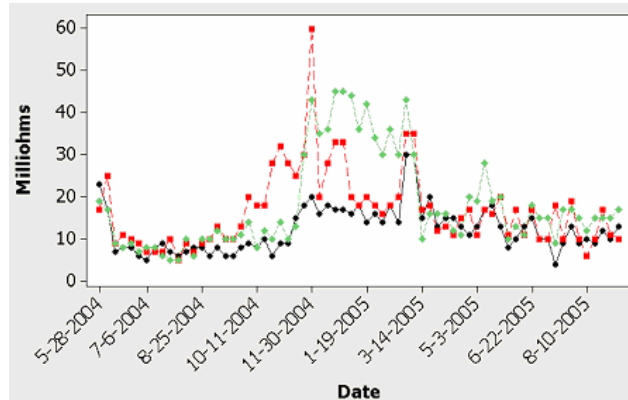


Figure 8: Fiber brush life test -136 million revs

Figure 8 shows a fiber brush slip ring life test run at 200 rpm on a diameter of about 70 mm. This test was stopped at 136 million revolutions with the slip ring still performing well. The chart shows the contact noise data from 3 circuit pairs. Figure 9 illustrates how little wear debris was created during this test. It is important to recognize that contact noise is monitored during life testing since this is one of the most reliable method of gauging the “health” of a slip ring. All the contact noise data in these two tests are well below acceptable values in terms of electrical performance of the contacts. The significant point about the contact noise data in both tests is that the values are not rising sharply at the end of the test. Contacts near the end of their life often exhibit a dramatic rise in contact resistance variation (noise).

Environment: Fiber brush contacts are much less sensitive to the environment than other slip ring contact technologies.

Temperature: Since the fiber brush contacts require very little or no lubrication, the fiber brush is very tolerant to both low and high temperatures. Fiber brush designs have been qualified in temperatures as low as -55C and as high as +80C.

Humidity: Metal graphite brushes require humidity between 15% and 85% to operate reliably. Fiber brushes can operate between 0% and 100% RH, in non-condensing environments.

Shock and Vibration: Fiber brushes have been qualified in very high shock and vibration environments. Their low mass and high damping result in a resonant frequency that is much higher than composite or monofilament designs. In addition the multiple contact points provide redundancy. These factors make the fiber brush quite resistant to shock and vibration problems.

Electrical Requirements: Fiber brushes have a well-documented capacity for handling electrical power. The current density that fiber brushes can safely handle is 5 times the current density of composite brushes, making fiber brushes a very space efficient solution to high current circuits. In addition, the low wear-debris generation of the fiber brush allows the fiber brush power circuits to maintain their dielectric isolation. Furthermore, the multiple contact points of the fiber brush design provide redundancy for superior reliability for power circuits.

Signal integrity is an important characteristic of slip rings. Fiber brushes accomplish signal integrity by having multiple independent contact points at each brush/ring interface producing low dynamic contact resistance. In addition, the low wear debris generated by the fiber brush gives improved signal integrity over the entire life of the slip ring. Wear debris generation is the most common cause of degradation of signal integrity in slip rings. The life tests of Figures 7 and 8 show the low contact resistance variation with rotation over the life of the slip rings with fiber brush designs.

Maintainability: Most Slip rings with fiber brushes require no maintenance throughout their life. Fiber brush slip rings typically do not require regular cleaning to remove wear debris. Figure 9 shows the appearance of fiber brush contacts after a 136 million-revolution life test. Of note is the absence of large amounts of wear debris. This lack of significant wear debris generation is the most critical factor in the ability of a fiber brush slip ring to maintain good voltage isolation on the power circuits during life tests.

Reliability: Reliability is an important consideration in the specification of a slip ring. There are several causes that can be associated with traditional slip ring failures in the field. Ring to ring shorting due to wear debris is one of the most common causes. This failure is most commonly associated with composite brush designs. Gold on gold single brush designs often fail due to improper lubrication. Excess lubricant, as well as insufficient lubricant, can cause accelerated wear and subsequent failure. Although minimal amounts of lubricant are sometimes used with fiber brush designs, fiber brushes are much less sensitive to lubricant quantities. Many designs perform with no lubrication at all. The fiber brush design eliminates both the wear debris and lubrication failure modes from the slip ring. In addition, the tolerance of the fiber brush to variations in humidity and temperature also serves to give improved reliability to the design.

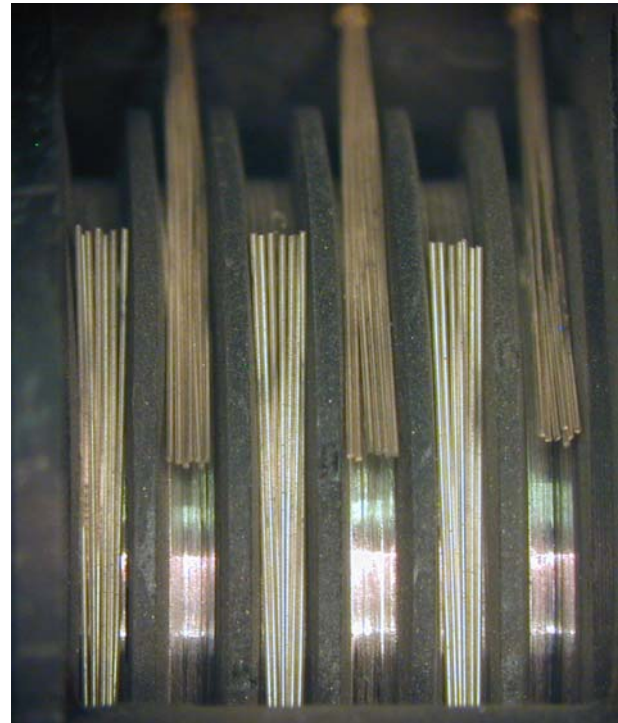


Figure 9: Fiber Brush contacts after 136 million revolutions

CONCLUSION

Slip rings designed with fiber brush contacts provide unequalled reliability, size efficiency and maintainability in slip ring applications requiring high power. The fiber brush has a long heritage in long life applications in rugged environments and has demonstrated that slip rings of diameters less than 300 mm using fiber brushes can operate in excess of 100 million cycles without brush replacement or maintenance.

REFERENCES

1. The reader is referred to Chapter 19, *Sliding Contacts* by Glossbrenner and Chapter 20, *Metal Fiber Brushes*, by Kuhlmann-Wilsdorf of an excellent reference book on Electrical Contacts (Paul G. Slade (ed), Electrical Contacts: Principles and Applications. Marcel Dekker AG, Gasel, Switzerland, 1999). These two chapters give an excellent introduction to sliding contacts in general and provide additional technical details on the principles of fiber brushes as sliding electrical contacts.