

Aeroflex Airflyte

Basic Slip Ring Design Guide

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Slip ring assemblies are specified when it is required to transfer electrical energy between members that possess relative rotary motion. Regardless of design or approach, basically they are slideably engaged electric couplings consisting of circular metallic rings and mating conductive brushes.

Because of the great variety of demands made upon the slip ring assembly, it is imperative that the system designer give thought to the space available and performance expected early in the design stage. This will enable the systems engineer working with a competent slip ring manufacturer to evolve a design without the necessity of compromising the basic goals the slip ring assembly is expected to perform.

The conditions listed below are not necessarily in their order of importance since it is impossible to determine beforehand which is going to be the major criterion for a particular design. In order to obtain optimum design conditions consideration must be given to all of the parameters.

CURRENT VOLTAGE

The electrical requirements generally determine the cross sectional area of the conductor (lead wire) which is normally assumed to be 10 milliamperes per circular mil. This will insure that no undue heating will occur to affect the dielectric properties of the slip ring insulation. Because the slip ring must work in conjunction with a brush (wire or block) the ring width is a function of the size of the brush. The thickness of the ring is usually much greater than is required to carry the current and is related to the diameter of the ring for mechanical reasons. As a rule of thumb, noble metal wire brushes will carry approximately 40% of the current of a copper wire of equivalent cross section and silver graphite material will carry approximately 300 amperes per square inch. The silver graphite block is usually mounted at the end of a BeCu spring member which has a conductivity of 45% IAS. If the current becomes very high (above 25 amperes) shunt wires will be required since the cross-sectional area of the arm will become too heavy and cease to act as a spring. The voltage problem is relatively easy to contend with, as most insulating materials have properties that will allow them to withstand 200 to 400 volts per .001 (mil). The major problem is the dielectric strength which is about 80 volts per mil clean air. (For normal use this figure should be derated to about 50 volts per mil at sea level). To increase the creepage path, raised barriers are necessary, especially in the presence of condensation.

Noise

Although noise is an electrical problem, the generation of noise is mechanical and measured as an AC signal generated by the change in dynamic contact resistance. Most slip rings exhibit changes in contact resistance of approximately .005 ohms. This value will be reduced after proper run-in procedures, which seat the brush against the slip ring. From the wear theory, it is known that all surfaces are composed of hills (asperities) and valleys distributed in random fashion. Through the mechanism of sliding friction, as more and more of the peaks come into contact with one another through shear or plastic deformation, there will be more and more surface area for the current to pass from one member to the other, thereby decreasing the contact resistance. Because of the difficulty of making statistical computations, physical measurements can be made that will provide empirical data of the performance. The noise voltage is approximately proportional to the change of contact resistance when small currents are being applied, but this does not hold true for values higher than 100 milliamperes. Eccentricity will also create noise because of the cyclic variation in circuit resistance due to the motion of the brush arm. This last condition is also encountered in vibration testing when the resonant point is approached. A method of minimizing noise is to start with brush and ring surfaces which are closely finished to provide a maximum of asperities of low amplitude so that there is a minimum of distortion before seating is accomplished. High pressure or large forces are not beneficial to this condition because rapid wear will ensue and shorten the useful life of the slip ring.

ENVIRONMENTAL

The environmental conditions to which a slip ring may be subjected will depend upon the end result that is to be achieved. Because the entire design is affected these requirements must be considered at the lay-out stage. Most MIL specs are quite specific and it is helpful to the component engineer if this information can be made available.

It must be pointed out that the slip ring itself is only part of a system, and that if the system is subjected to vibration and shock, because of the structure that surrounds the slip ring, it is almost impossible to foretell the resulting wave shape that the slip ring will actually encounter. At best, it is possible to determine the natural frequency of the brush and spring combination or the resonance points of the slip ring rotor. Temperature, humidity, altitude, salt spray and other forms of testing will result in a derating of the slip ring and must be left to the manufacturer. Acoustic noise which is now being specified in some missile specifications should be kept below 140 Db less the slip ring and its components become damaged beyond repair. Random vibration (white noise) is a requirement that can only be evaluated by testing and therefore must be considered beforehand. Hermetically sealed slip rings which may be filled with nitrogen or similar type gases are very difficult to keep sealed because of leakage along the shaft. To completely eliminate leaking a form of magnetic drive must be provided to obtain rotation of the device from within a sealed case.

SURFACE SPEED

- 1. Low speed: 250 feet per minute maximum**
- 2. High speed: 5,000 feet per minute maximum**

For low speeds a wire type wiper made out of a precious metal alloy (gold, platinum, silver, copper, nickel) can be used if the current is less than 5 amperes maximum. For other speeds, the use of silver graphite material is required (80% silver, 15% C, 5% MoS₂). At surface speeds over 250 feet per minute, without the benefit of lubrication, metal to metal contact will result in rapid deterioration of the surface by galling or seizing. The addition of graphite or MoS₂ to silver, plus water vapor normally present in the atmosphere will impart the lubricity needed at the interface of the brush and ring as one slides relative to the other. For surface speeds above 5,000 feet per minute, special consideration must be given to lubrication, cooling and ring-brush material combination. At altitudes above 60,000 feet with its concomitant low atmospheric pressure, the water vapor present is so minimal that most silver graphite brushes dust and deteriorate rapidly and other approaches must be considered.

WEAR

The wear factor in slip ring design is all important because the useful life of the unit depends upon it. The result of wear is deterioration of the surface which results in an unacceptable noise pattern. The mechanism of wear is based on the following parameters:

- Ring and brush material
- Relative hardness between the materials
- Lubrication
- Accuracy of the slip ring itself (eccentricity)
- Force
- Surface speed
- Heat generated and arc erosion

For normal sliding motion between two surfaces the most prevalent types of wear are material transfer and material erosion. In a good slip ring design the material erosion (loose particles) must be kept to a minimum to insure good noise free characteristics. Fortunately, the noble metals used in slip rings for their electrical properties also exhibit excellent material transfer and erosion characteristics when used in the proper combinations.

LUBRICATION

Under normal conditions, because of the metallurgical properties of the alloys in contact, lubrication is not necessary. However, for unusual applications, such as high vacuum, it is considered good design to supply either sacrificial or boundary lubrication.

STRUCTURAL STRENGTH & CONFIGURATION

The general configuration of slip rings can take either one of two shapes: Disc or Cylinder. In either instance, it must be realized that there are dissimilar materials involved in a design, all of which have different properties especially at elevated temperatures. These materials might be:

- Housing: aluminum alloy
- Shaft: aluminum alloy
- Bearings: stainless steel
- Hardware: stainless steel
- Insulation: epoxy resin with or without filler

Since many assemblies are purchased as complete units, it is important to understand the basic construction. Because of the many environmental conditions encountered, it is found that the bearing are of great importance. The bearings nearest the support is usually fixed, while the other bearing is retained on the outer race only. In this manner, allowance can be made for expansion or contraction and even some minor misalignment without subjecting the assembly to undue stress. Driving should always be accomplished by means of a flexible coupling to avoid unnecessary strains on the bearings.

TORQUE

In general, it may be assumed that the co-efficient of dynamic friction is approximately .2\ and the coefficient of static friction is approximately .3. In the event that the surface of the ring is V-shaped, then all values must be multiplied by 1.414 to compensate for the double contact.

The equation for torque is as follows:

$T = F \times R \times \mu \times N$ where

- **T = Torque in ounce-inches**
- **F = Force in ounces**
- **R = Radius of slip ring in inches**
- **μ = Coefficient of static friction**
- **N = Total number of brushes**

Because torque is a function of the force it is necessary to set some practical values for the pressure which the brush must exert on the slip ring. For silver graphite brushes, we have found that 15 PSI is the maximum required to produce good results. In the case of the wire wiper, the brush force that is usually required to obtain a clean signal will vary between 1 and 15 grams depending on the diameter of the wiper and the modulus of elasticity.

SPECIAL PROBLEMS

High VACUUM

In high vacuum (under 10^{-6} Torr), the major problem encountered is seizing which occurs when two clean metals are held in contact in the absence of water vapor and atmospheric gases. The absence of water vapor and oxygen makes it impossible for the ring to film and consequently reduces lubricity to a point of non-existence. Sliding friction under these phenomena produces galling, seizing, and dusting with consequential problems in the transmission of an acceptable electrical signal. To avoid this major problem encountered in high vacuum, lubrication of some type must be introduced either through artificial means such as controlled evaporation or actual inclusion into the material of some lubricant.

In the case of lubrication by wicking or similar means, the end result is a reduction in vacuum (From 10^{-8} to 10^{-4} Torr for instance) which will only last as long as the lubrication supply lasts. Additives such as MoS₂ are being used successfully and have provided a partial answer. The contact material must also be chosen carefully in order to provide a surface that can be plastically deformed. There is a need for much more investigation before phenomena of high vacuum are completely understood, so that satisfactory design can be specified.

Dry Circuitry

In critical applications it is often necessary to transmit current in the micro-volt region over a relatively narrow band pass (10KHz). This can be successfully achieved by choosing two compatible alloys and increasing the brush pressure to assure complete penetration of the surface film, and at the same time allowing for proper burnishing of the contact area. This will result in a low dynamic noise but unfortunately it will require some compromise regarding life, since forces will create greater torque and wear. Pick-up voltages of the order of one microvolt can then be transmitted. The most difficult problem is the measurement techniques required to monitor the ultra sensitive circuitry.

High Frequency

Since slip rings are often used as rotary joints to transmit currents and voltages in the RF or IF range, it has become necessary to consider a co-axial design. Because of the complexity of designing a rotary coupling with a relatively wide band width, other means are utilized and it has been found that slip rings can operate successfully up to 100 MHz. The basic problem is relatively simple: the slip ring must look like part of the transmission line and its characteristic impedance Z_0 must match that of the co-ax line. This impedance is usually 50 or 75 ohms.

The solution is not simple and requires a custom design which will be based on the requirements. These requirements are: VSWR, cross-talk, attenuation between circuits, insertion loss, and WOW. All of these requirements can be met with some compromise by using the proper type of shielding (electrostatic, electromagnetic, or both), adequate spacing between conductors and a dielectric material having a low K. The diameter of the slip ring is also very important because of its relationship to the wave length. The closer one approaches this value the more difficult it becomes to avoid an impedance mismatch which results in a high VSWR. Therefore, in order to obtain the best results the diameter of the slip ring must be kept as small as possible especially in the high frequency ranges. If a limited range is required, it is possible to obtain excellent results by tuning the circuits over this range using an LC network.

High Speed Slip Rings

The use of the high speed slip rings is generally confined to strain gages and thermo-coupling measurements. Because of the low level signals it is necessary to provide a slip ring that will be able to transmit these signals with an absolute minimum of dynamic noise. To avoid these results certain steps must be incorporated at the design stage.

- Static and dynamic balancing of the slip ring rotor.
- The use of pre-loaded precision ball bearings.
- Rigid housing to provide a support for this assembly.
- A compatible brush-ring combination that will provide the required life.
- Lubrication
- If it is at all possible, air or some other form of cooling should be provided.

In general, the diameter of the slip ring should be kept as small as possible to provide a low surface speed which reduces the generated heat and also lessens the dynamic unbalance. If the temperature variation across the slip ring can be kept at a minimum then the thermo-couple effect will be negligible and the error that may result will be less than the sensitivity of most measuring instruments. In order to extend the life of the brushes, a device known as a brush lifter is frequently being suggested. However, it is felt that this device presents a drawback since it becomes difficult for the brushes to position themselves exactly after having been removed from the rotating slip rings. The components of the brush lifter consist normally of simple levers and springs. Since all these components are elastic and exhibit some freedom of motion, it is normal that minor changes occur in the system. This in turn may adversely affect the proper seating of the brushes and result in a shortened life which is not the desired end result.