IMPROVED CHARACTERISTICS OF SLIPRING ASSEMBLIES MAKING USE OF GOLD ON GOLD METALLIC CONTACTS.

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ABSTRACT

Power demands for the operation of satellite payloads are increasing steadily and as a consequence so does the power generation capability of solar arrays. In most cases, this energy has to pass through the Solar Array Drive Mechanism; in other words through a slipring assembly.
The use of new technologies for the manufacturing of slipring assemblies becomes thus compulsory.
Among these new technologies the use of precious metal alloy wire brushes in direct contact with gold or gold plated tracks is a real improvement. This technology permits to manufacture more compact slipring assemblies in a large range of electrical power capacity.
In the present paper some aspects of the design of such slipring assemblies is discussed as well as some tests conducted to verify the capacities of this technology to be adapted to medium to high power space applications.

1. INTRODUCTION

MECANEX has a long experience in the design and manufacturing of SlipRing Assemblies (SRA) for space applications.
A SRA consists in one or more brush blocks assembled together with a slipring rotor (Figure I). The brush blocks hold the brushes that perform the contact with the tracks on the slipring rotor.
Depending on the application the brush blocks and the rotor shaft can be delivered separately and then integrated by the customer. Most of the time they are however fully encapsulated. This means that the brush blocks are assembled on a structure (called housing in the present paper), together with the slipring rotor and its bearings.
The ratio of the transmitted electrical power on the volume of the SRA is a major design constrain. There is a considerable need in the increase of this latter ratio. Therefore the sizes of the different components of the SRA have to be reduced as much as possible. The reduction of the number of different parts also permits to gain on the volume of the SRA and of course any simplification of the assembly has a positive effect on the manufacturing cost.
The use of precious alloy wire brushes instead of sintered silver-graphite contacts is a very interesting solution in order to gain in SRA volume. The precious alloy wire brush material is also very interesting because the wear debris generation during the lifetime is smaller than with sintered contacts.

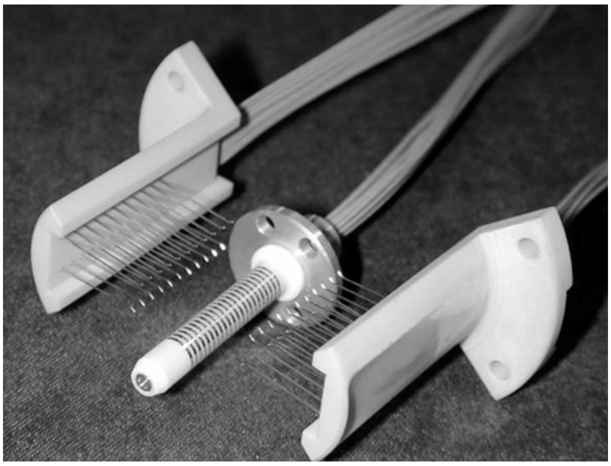

Figure I. View of a signal slipring assembly with the two brush blocks and the slipring rotor.

SRA's making use of precious metal alloy wire brushes rubbing on gold or gold plated tracks are already used since a long time in terrestrial applications as well as in low power (signal) space applications [1,2]. Now using this type of technology for medium to high power SRA's by a proper dimensioning of the system permits a dramatic increase of the transmitted electrical power in lower volumes.

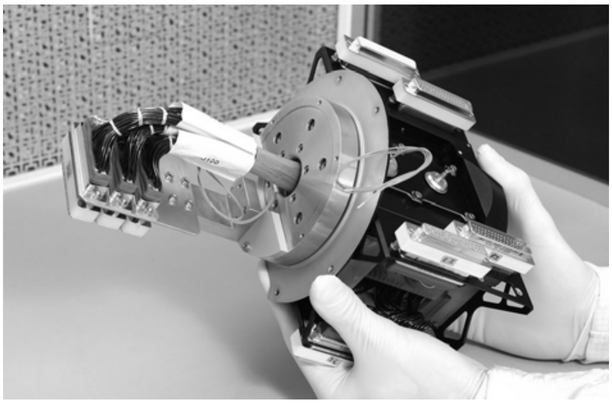

Figure II. 14 kW SRA for SADM application.

The main application of medium to high power SRA's is for Solar Array Drive Mechanism (SADM).

An other major advantage of the so-called gold on gold technology is that there is no need of lubricant on the tracks and brushes. This permits a longer shelf time without any maintenance and also a longer life duration in flight. There is also not the drawback linked to MoS_2 lubrication (sintered silver-graphite contacts are lubricated with MoS_2) when operating the SRA under ambient conditions : no limitation due to moisture absorption.
Until now MECANEX manufactured and tested SRA's for SADM applications up to a transmitted power of 14 kW. A photograph showing the compactness of such a device is showed on Figure II.

Some of the typical characteristics of SRA's making use of gold on gold technology are summarised in Table 1.

Size Diameter Length	 20 mm to 148 mm 48 mm to 250 mm
Mass (including flying leads)	0.05 kg to 6.5 kg
Rotation speed	15 rpm to 1 rpd
Drag torque (ambient condition)	4 mNm to 1.5 Nm
Transmitted electrical power	1 W to 14 kW
Nominal voltage (power circuits)	50 V to 104 V
Operating temperature	-50°C to +90°C
Operating lifetime	2 years to 15 years
Number of revolutions	$6 \cdot 10^3$ to $15 \cdot 10^6$

Table 1. Main technical characteristics of the gold-gold SRA range manufactured by MECANEX SA.

2. DESIGN

2.1. Materials

Different type of precious metal alloys exist for the manufacturing of wire brushes. In the present study only one specially selected gold-copper alloy was taken into account. The composition of this alloy is given in Table 2. This alloy has very good mechanical properties (Young's modulus about 110 GPa and yield strength $\sigma_{0.2}$ about 500 MPa) combined with good electrical and tribological properties.

Element	% mass
Au	> 70%
Cu	15%

Table 2. Wire brush alloy composition.

Depending on the size the tracks are either in plain gold alloy or in gold plated brass alloy. In the case of the plated brass, the gold plating treatment is very important in order to optimise the electrical performances of the SRA with regard to the wear rate. The specification of the gold plating treatment was defined in collaboration between MECANEX and its surface treatment supplier.

The insulating material is a ceramic loaded epoxy resin compound developed by MECANEX. This compound was chosen because of its low brittleness at low temperature and its capacity to bear stresses at high temperature without creep. The high temperature creep, mainly linked to the Martens transition temperature, depends in a large extend of the resin curing treatment. An increase of the highest curing temperature permits to increase the maximum usable temperature of the insulating material in a large extend. Now with this type of resin compound it is possible to reach working temperature up to 115°C without problem. A creep test example will be presented hereafter.

2.2. Assembly

In the present study only conventional MECANEX assembly types are presented (Figure III).

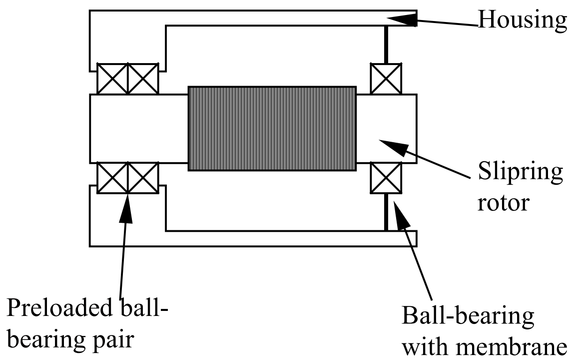

Figure III. Medium to high power SRA with conventional bearing arrangement.

The slipring rotor is mounted with two rigidly preloaded ball-bearings on one side and a single ball-bearing axially preloaded through a titanium membrane on the other side. The stator is composed of an aluminium structure (housing) holding the ball-bearings and the brush blocks. Depending on the electrical power to transmit one to four brush blocks can be attached to the structure (Figure IV).

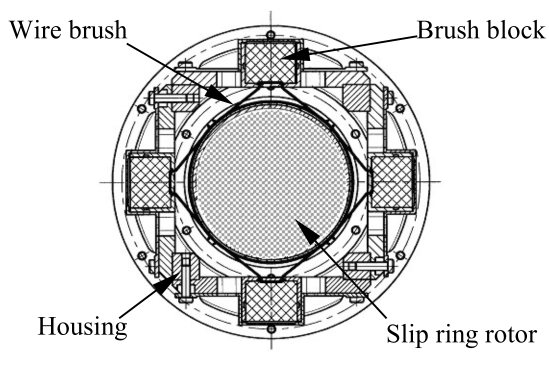

Figure IV. Section of a typical medium to high power SRA. Four brush blocks with each double V-shaped wire brushes per track are present on this design.

Several parameters can be adapted in order to increase the maximum allowed electrical power :

i) the number of brush blocks (1 to 4),
ii) the diameter of the wire brushes,
iii) the number of tracks.

Increasing the number of wire brushes in contact with the tracks (Figure V and Figure VI) has also an other positive effect. In fact the electrical noise is highly dependent on the number of contact points (stochastic noise effect).

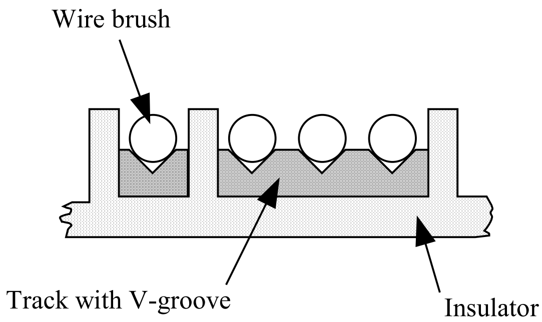

Figure V. Cross section of tracks and wire brushes. An example of three tracks at same electrical potential is presented.

For critical applications where the electrical noise has to be reduced as much as possible it is very interesting to increase the number of wire brushes, even if the electrical power to transmit is low and thus the power capacity over sized.

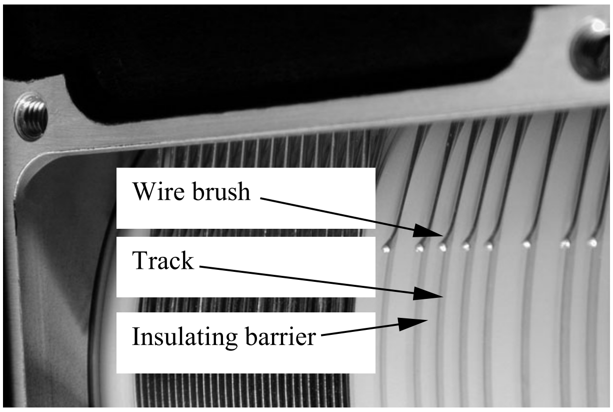

Figure VI. Close view of the wire brushes and slipring rotor of a medium power SRA.

One of the major design constrain is the number and cross section of the electrical cables inside the SRA. The available volume is limited as well inside the slipring rotor centre shaft as inside the brush blocks. The available volume inside the slipring rotor centre shaft is very limited due to the presence of an aluminium shaft used to obtain the requested stiffness of the assembly. This aluminium shaft acts also as a thermal conductor to remove the heat of the slipring rotor if properly interfaced to the rest of the whole mechanism (SADM for example). For future development heat sink on the rotor at SADM level could be an improvement. Some collaboration is needed between the SRA and SADM manufacturers in order to optimise the design.

The photograph on Figure VII shows that most of the centre volume of the slipring shaft is used by the cable bundle coming out of the SRA on the rotor side. Increasing the cross section or number of cables (i.e. the number of tracks) leads to an increase of the slipring rotor diameter.

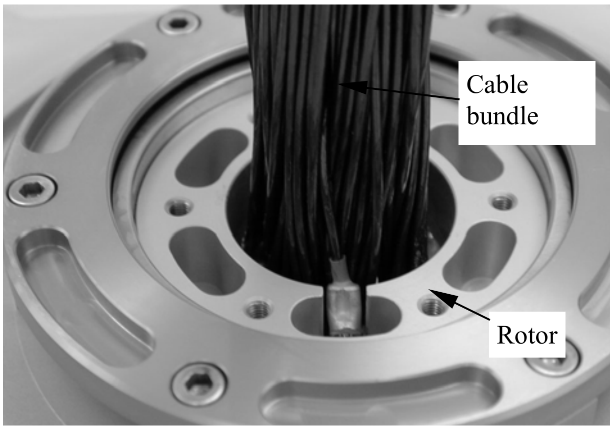

Figure VII. View of the cable loom output from the rotor of a SRA.

The cables participate in a large extend in the heating of the slipring rotor due to the electrical current flow. They participate however also to the removal of the heat from the slipring rotor if the rotor cable harness can be in contact with a cold interface (e.g. deep space at the back side of the solar panels).

Out of the cables an other important element in the heat generation inside the SRA is the wire brush - track system. In this system the track itself is of minor effect. Indeed the size of the tracks is mainly driven by the size of the wire brushes. The cross section of the tracks is thus most of the time much larger than the other elements of the electrical circuit.

The heat dissipation due to the wire brushes themselves (the resistivity of the used gold alloy is $1.45 \cdot 10^{-7}$ Ohm·m) and the contact point are not negligible. The electrical resistance of the wire brush can be reduced by increasing its diameter and reducing its length. However this will also reduce the deflection of the wire brush for a given contact pressure. The contact pressure of the wire brushes is adjusted by defining a proper deflection of the contact point (Figure VIII).

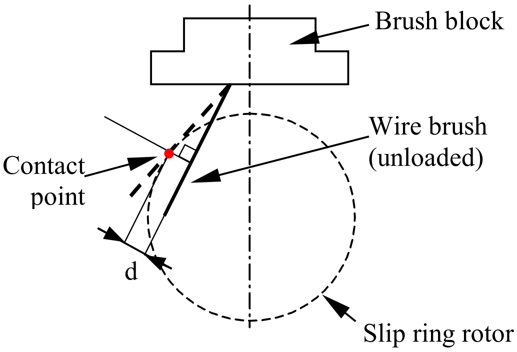

Figure VIII. Deflection d *of a wire brush (working position) with respect to the unloaded position (adjusted position).*

The quality of the electrical contact between the wire brush and the track depends on the contact pressure. An increase of the contact pressure improves the electrical characteristics. Tests have been conducted in the present study in order to verify this aspect (cf. hereafter). However an increased contact pressure promotes an increased wear rate and increases the drag torque.
Moreover the contact pressure must be adjusted in order to remain in the elastic domain of the gold alloy wire brush (yield strength is about 500 MPa).

3. MEASUREMENTS

3.1. Contact Pressure

Measurements of the electrical circuit resistance and of the dynamic electrical noise were performed for various contact pressures (the measurements were performed with a 4 wires technique, with a digital voltmeter for the circuit resistance and with an oscilloscope for the noise measurement). These measurements are presented in Figure IX. The assembly was fully representative of a medium power SRA. A circuit consists in 8 input wire brushes and 8 output wire brushes, resulting in a total of 16 wire brushes participating in the circuit. A preload of 80 mN, corresponding to a wire brush deflection of 0.5 mm was applied. This deflection (and thus the preload) was then reduced from 0.00 mm to 0.55 mm by increasing the distance between the brush block and the tracks on the slipring rotor. The SRA was driven at 1 rpm under air at ambient conditions. The rotor performed about 140 revolutions from the first measurement point (nominal contact pressure) to the last one (deflection reduced by 0.55 mm).

The two first electrical noise measurements (nominal deflection and deflection reduced by 0.04 mm) show a higher value. In fact this behaviour is always observed at the beginning of a test when the test atmosphere is changed around the SRA. A run in is always necessary in order to stabilise the electrical noise to its nominal value. This results from interfacial layers between the wire brush and the track that are produced by the chemical elements contained in the air. In the present measurement, this stabilisation occurred after 40 revolutions (third measurement with deflection reduced by 0.08 mm).
Out of the two first electrical noise measurements all the measurements were stable up to a reduction of the deflection of 0.34 mm (nominal remaining deflection of 0.16 mm). With a reduction of the deflection of 0.37 mm, the noise began to increase. Above a reduction of the deflection of 0.4 mm the noise curve slope becomes very steep.
The electrical resistance increases steadily with the lowering of the brush preload, up to a reduction of the deflection of 0.4 mm.

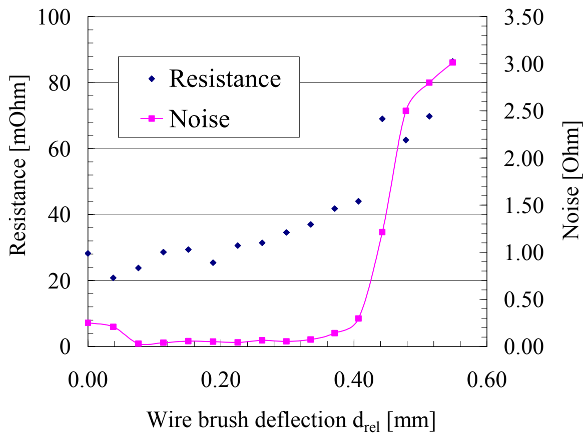

Figure IX. Effect of the wire brush preload on the contact resistance and on the electrical noise The relative deflection d_{rel} *is given with respect to the nominal adjusted deflection* d *= 0.5 ± 0.05 mm in the present test. The noise is a peak to peak value.*

The explanation given to this behaviour is that the measurement of the circuit resistance as function of the contact pressure is depending on the quality of the contact, which decreases when the contact pressure is reduced. The electrical noise is less dependent on the contact pressure. It is however very sensitive to the quantity of contact points. Most of the transition between a good signal and a noisy signal appends when the deflection is reduced by more than 0.45 mm. This corresponds in fact to the minimum adjusted deflection taking into account the wire brush preload adjustment tolerance only. In fact the noise transition begins slightly before. This behaviour is linked to the other geometrical tolerances of the assembly (concentricity and roundness of the tracks, location of the brush block on the housing, …). Thus the electrical noise begins to increase when the wire brushes begin to lose their contact with the tracks.
The measurements on Figure IX show however a compliance of the wire brush - track electrical contact system to a large variation of the preload. More than

68% reduction of the wire brush preload can occur without large variation of the electrical characteristics.

3.2. Thermal Stability of the Materials

Thermal cycles consisting in a heating to the given temperature, a dwell followed by a cooling to room temperature were performed on a representative SRA (see Table 3 for the thermal cycle parameters).

Dwell time at given temperature	12 hours
Dwell temperatures	5 levels up to 130°C
Heating rate	imposed
Cooling rate	relaxed
Atmosphere	air at ambient pressure

Table 3. Parameters of the thermal cycles during the resin stability test.

The brush block, manufactured out of standard MECANEX resin compound (in this case the curing temperature of the resin was 90°C. Higher curing temperatures can be applied for other projects), holds 4 V-shaped wire brushes (see Figure X for the definition of a V-shaped wire brush). The two single wire brushes part of the same V-shaped wire brush are Brush *n*.1 and Brush *n*.2 were *n* is the number of the V-shaped wire brush.
The positions of the wire brushes were controlled after each cycle. Five thermal cycles were performed up to 130°C.

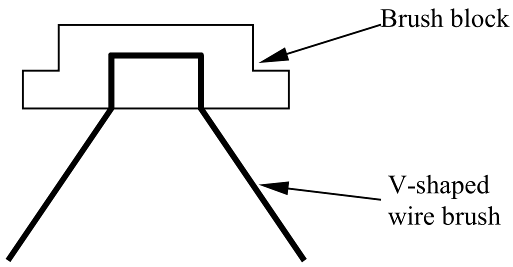

Figure X. Scheme of the geometry of a V-shaped wire brush.

The remaining wire brush deflections, as defined on Figure VIII, measured after each cycle, are reported in Figure XI.
Figure XI shows that the deflection of the wire brushes remains stable up to 120°C, in the range of the measurement uncertainty. At 130°C the graphic shows a displacement of the wire brushes. In fact the movements of the wire brushes at 130°C are slightly more complicate than a pure unloading of the wire brush due to the preload. Several other stresses due to the thermoelastic behaviour of the brush block assembly appear. The brush blocks are complex systems including material with different coefficient of thermal expansion : resin compound, gold alloy wire brushes, copper cables. As calculated with finite element methods and observed during the tests, the most loaded part remains however the resin brush block where the wire brush tails in.

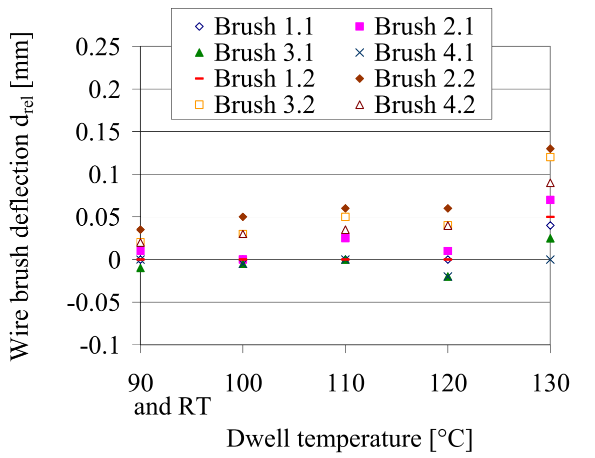

Figure XI. Variation of the wire brush unloaded deflection after different temperature dwells. The wire brushes are loaded at 50 mN during the thermal cycles. The relative deflection d_{rel} *is given with respect to the nominal adjusted deflection* d = *0.31* $\pm$ *0.03 mm in the present example.*

3.3. Lifetime Tests

Several gold on gold technology SRA's have undergone lifetime tests or are in-orbit. The characteristics of 4 representative SRA's with their tested lifetime are presented in Table 4.

	1	**2**	**3**	**4**
Brush ∅ [mm]	0.5	0.3	0.2	0.5
Preload [mN]	80	40	30	100
Hertz pressure [MPa]	80	89	107	86
Current [A]	15	2.3	0.1	11
Velocity [rpd]	1440	14k	4320	20
Tested life [km]	7.21	1.04	234.6	1.60

Table 4. Life test data for several different SRA types. The tested life is the equivalent linear distance covered by a single wire brush contact point.

The wear resulting from a lifetime test representative of a full GEO satellite life is very small and is very difficult to notice at track (Figure XII) and wire brush level. SRA No 3 only shows visible wear of the wire brush contact tip.

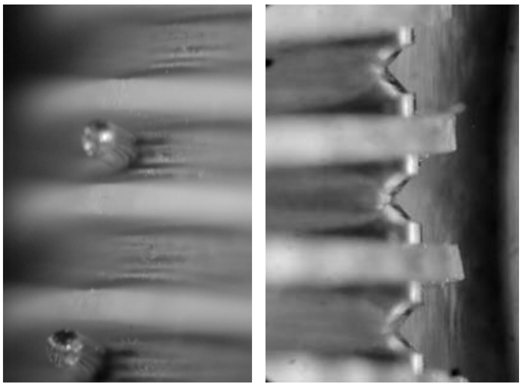

Figure XII. Close view of tracks and wire brushes after an accelerated lifetime test under vacuum (4.5 A per track, 10'000 revolutions).

Gold on gold technology medium power SRA's manufactured by MECANEX (in the 9 kW range) are already successfully flying. They have however not yet reached their end of life.

4. DISCUSSION

As shown during the measurements performed in § 3.1 a proper design and assembly must take into account all the uncertainties concerning the position of the wire brush with respects to the tracks.
These uncertainties are linked to :
1) manufacturing tolerances,
2) thermoelastic behaviour,
3) ageing of the material.

The manufacturing tolerances can be easily assessed. The thermoelastic behaviour is much more complicate to determine. Finite element methods permit to give some good approximations but need very detailed calculations. Tests on different SRA sizes have however given some good rule of the thumb for the dimensioning. The ageing of the materials is mainly linked to a possible creep of the resin. This can however be avoided in a large extend by a proper curing temperature.

The metal alloys could also show stress relaxation when submitted to temperature and stress during enough time. The gold alloy for example may have some stress relaxation at elevated temperature. According to the gold alloy data sheet, a stress relaxation could occur when the material is stressed at a temperature above 100°C. With an applied stress of 69-210 MPa, the initial stress in the gold alloy can be reduced by less than 10% after 600 hours at 100°C (Figure XIII).

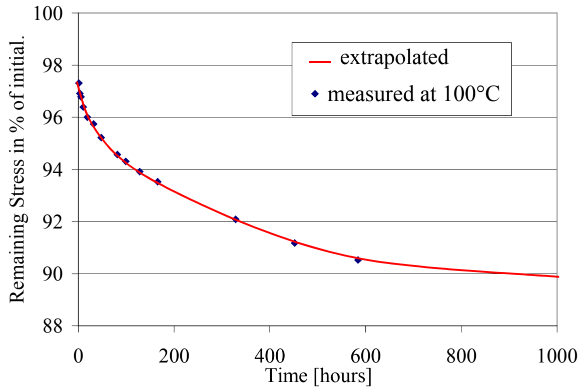

Figure XIII. Decrease of the adjusted elastic stress in the used gold alloy as a function of time.

The curve in Figure XIII is typical of a viscoelastic solid material. If a stress is applied on such a material, this stress will decays to a constant non-zero value. If the behaviour is extrapolated from the measured curve on Figure XIII for time larger than 200'000 hours (more than 22.5 years), the maximum stress relaxation will be less than 15 %. For an adjusted wire brush preload of 100 mN at the beginning of life the remaining preload will thus be more than 85 mN at end of life. A preload of 85 mN is considered as a very standard preload of the brushes for SRA's.

The deflection of the wire brushes must be maximised in order to avoid any reduction of the contact quality.
For a contact pressure of 100 mN and a wire brush length of 20 mm (diameter 0.5 mm), the deflection is 0.77 mm. The contact pressure can be doubled, doubling the deflection in the same time. The yield stress remains at an acceptable level (about 330 MPa). The Hertz pressure will increase at the contact point, leading to a higher wear rate. The wear rate is however not critical for GEO satellites applications (less than 6000 revolutions for a 15 years in orbit operations). The only parameter that could become critical is the drag torque of the SRA, which will double too (on medium to high power SRA's the main drag torque component comes from the wire brush friction).
If acceptable at SADM level an increase of the wire brush preload is thus a good solution to optimise the quality of the contact during the whole SRA lifetime.

5. CONCLUSION

The gold on gold metallic contact slipring assembly technology has proven its suitability for space applications. This technology has been successfully demonstrated over a large electrical power and temperature range. Several design constrains have been described during the present study and are taken into account in MECANEX's SRA expertise, allowing custom tailored solutions to be implemented, adapted to the most varied requirements..

Performance improvements can be gained with this technology through a close collaboration between MECANEX and its business partners, mainly in the definition of optimised interfaces.

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REFERENCES

[1] J.B. Mondier, F. Sirou and P.A. Maüsli, *Life Test of the SCARAB Instrument Slipring Units*, Proc. of 9th European Space Mechanisms and Tribology Symposium, Liège, ESA SP-480 (2001), pp. 99-106.

[2] M. Shmulevitz and A. Halsband, *The Design, Development and Qualification of a Lightweight Antenna Pointing Mechanism*, Proc. of 30th Aerospace Mechanisms Symposium, Hampton, NASA Conference Publication 3328 (1996), pp. 291-298.