ADVANCED SLIP RING SOLUTIONS (ASR)

C. Courtois[(1)], M. Miler[(1)], A. Oriol[(1)], H.J. Jung[(2)], M. Fink[(3)]

[(1)]RUAG Space, Ch. De la Vuarpillière 29 – 1260 Nyon - Switzerland,
Email: camille.courtois@ruag.com , mickael.miler@ruag.com, albert.oriol@ruag.com
[(2)] ASTRIUM GmbH, 88039 Friedrichshafen, Germany,
Email: hans.juergen.jung@astrium.eads.net
[(3)] Aerospace & Advanced Composites GmbH, c/o Forschungszentrum, 2444 Seibersdorf - Austria
Email: markus.fink@aac-research.at

ABSTRACT

Advanced Slip Ring (ASR) is a project in collaboration with ESA to develop new technologies for future commercial and scientific slip ring applications. The main orientation is to increase slip ring capabilities to transfer high power by using new materials and processes for electrical and insulation parts.

The purpose of this document is to describe the ASR design with detailed description of the new integrated technologies.

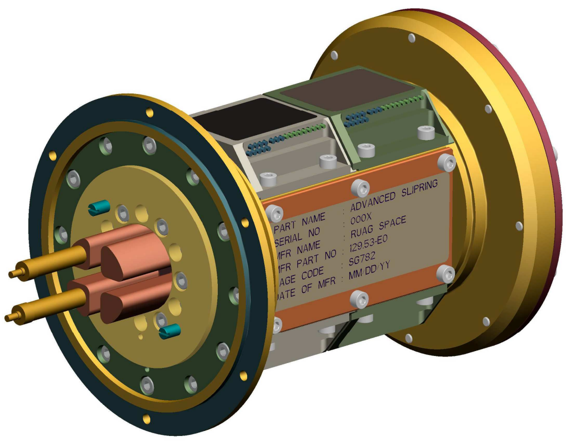

Figure 1 - ASR global overview.

1. INTRODUCTION

Since a few years, the request of slip ring for space applications are more and more demanding for adapted design to high power density and harsh environment (vacuum, high temperature, radiation…) both for Solar Array Drive Mechanics (SADM) with high power and scientific satellites. In order to fulfill these requirements, RUAG Space has developed an activity in collaboration with ESA to identify, select, develop and test new technologies for slip ring.

In the frame of this activity, the following companies have been also involved:

- ASTRIUM GmbH has collaborated for the definition of technical requirements and recommended development orientations.
- EPFL - Laboratory of Mechanical Spectroscopy has participated to the development of a composite contact material.
- AAC contributes to electrical contact material characterization and dynamic outgassing test.

Advanced Slip Ring (ASR) has been designed within the following technologies:

- New material for electrical insulation and thermal conductivity adapted to high temperatures.
- Wire brush connection with slicing process to replace wires soldering.
- Solid rod with high current density
- Integration of Angular Positioning Sensor

ASR is manufactured and will be tested to verify and validate the expected advantages of these new technologies.

2. GENERAL SPECIFICATIONS

In order to define the technical orientation for the ASR project, customer point of view was very valuable to know the needs for future development. Thus a study has been performed by ASTRIUM GmbH to identify the possible improvement of SADM slip ring performance regarding the customer needs. Several recommendations have been proposed:

- Reduction of internal heat generation: the sliprings appear generally as a hot point for the SADM, more precisely the rotor part, and this high temperature is mainly due to heat generation by electrical resistance at wires and brush-contact. Moreover the rotor heat dissipation is limited by radiation with stator structure and by conduction through ball bearings. The possibility

'14th European Space Mechanisms & Tribology Symposium – ESMATS 2011'
Constance, Germany, 28–30 September 2011

to increase this dissipation is limited and mainly depends on the SADM customer interface. Thus best orientation to reduce the temperature in the slipring is to reduce the electrical resistance inside the rotor part. The proposed solution is to use a solid rod instead of wires bundle.

- <u>Adapted material for higher temperature</u>: The increase of power transmission and therefore temperature is also limited by the maximum allowable temperature of standard used materials (solder, insulation resin…). Thus new materials are studied for insulation and electrical connection to increase the thermal conduction and also increase the temperature range allowable.

- <u>Electrical dynamic resistance for signal lines</u>: Noise on signal lines is a main parameter to insure data transmission. Thus it should be studied carefully that new technologies integrated in ASR have no negative impact on the electrical noise for the signal lines.

- <u>Integration of position sensor</u>: For current SADMs, the used sensors technologies is mainly potentiometers for continuous position control and datum sensors (switches, eddy current, hall sensor) for zero position measurement. Other SADM use also optical position sensor (encoder). But these both technologies have some inconvenient (failure apparition, radiation sensitive). Thus a contact-less position sensors which is studied for an ESA development project in RUAG Nyon is integrated in the ASR for testing.

3. ASR DESIGN

For the ASR activity, several Bread Board Models have been developed and tested for specific technologies detailed hereafter. A slipring which gathers together most of the developed technologies have been also designed as shown on Fig.1 and Fig. 2.

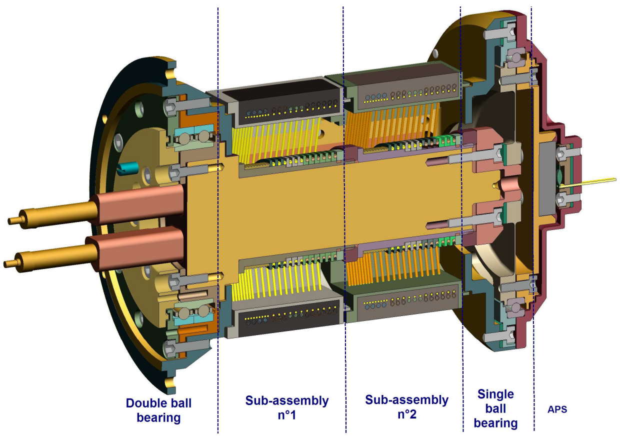

Figure 2 - ASR internal description

The ball bearings have been designed with stainless steel rings and balls, bronze cage and Braycote 601 EF lubricant to withstand vibration and shock load and high thermo elastic strain. Double ball bearing is mounting in an O-configuration and single angular contact ball bearing is preloaded with a flexible membrane which could absorb the axial thermal dilatation.
For optimization, the Angular Position Sensors APS have been directly integrated to the rotor and stator parts.
In order to be able to compare the results obtained for the new technologies integrated in the slipring and detailed in chapter 4, the ASR have been designed with two sub-assemblies each composed of one rotor and two brush holders. The detailed configuration of the slipring is given in Tab. 1 and Tab. 2.

<table>
<tr><th colspan="7">Sub-assembly n°1</th></tr>
<tr><td rowspan="3">Circuit</td><td>Name</td><td>Power return</td><td>Power n°1</td><td>Power n°2</td><td>Power n°3</td><td>Signal</td></tr>
<tr><td>Line #</td><td>1</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>Current</td><td>48 A</td><td colspan="3">5.33 A</td><td>0.5 A</td></tr>
<tr><td rowspan="3">Rotor Material</td><td>Cable</td><td>Solid rod</td><td colspan="2">HT cable</td><td colspan="2">Std cable</td></tr>
<tr><td>Connection</td><td>Hard solder</td><td>Std solder</td><td>HT solder</td><td>Std solder</td><td>HT solder</td></tr>
<tr><td>Insulated barrier</td><td colspan="2">Hard coating</td><td>Ceramic</td><td colspan="2">Resin A</td></tr>
<tr><td rowspan="3">Stator material</td><td>Connection</td><td>Std solder</td><td>Splice</td><td>Std solder</td><td colspan="2">Splice</td></tr>
<tr><td>Cable</td><td colspan="2">HT cable</td><td colspan="3">Std cable</td></tr>
<tr><td>Brush holder</td><td colspan="5">Resin A</td></tr>
</table>

Table 1 – sub-assembly n°1 configuration

<table>
<tr><th colspan="7">Sub-assembly n°2</th></tr>
<tr><td rowspan="3">Circuit</td><td>Name</td><td>Power return</td><td>Power n°1</td><td>Power n°2</td><td>Power n°3</td><td>Signal</td></tr>
<tr><td>Line #</td><td>1</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>Current</td><td>48 A</td><td colspan="3">5.33 A</td><td>0.5 A</td></tr>
<tr><td rowspan="3">Rotor Material</td><td>Cable</td><td>Solid rod</td><td colspan="2">HT cable</td><td colspan="2">Std cable</td></tr>
<tr><td>Connection</td><td>Hard solder</td><td>HT solder</td><td>Std solder</td><td>HT solder</td><td>Std solder</td></tr>
<tr><td>Insulated barrier</td><td>Resin A</td><td>Hard coating</td><td>Ceramic</td><td colspan="2">Resin B</td></tr>
<tr><td rowspan="3">Stator material</td><td>Connection</td><td>Std solder</td><td>Splice</td><td>Std solder</td><td colspan="2">Splice</td></tr>
<tr><td>Cable</td><td colspan="2">HT cable</td><td colspan="3">Std cable</td></tr>
<tr><td>Brush holder</td><td colspan="5">Resin B</td></tr>
</table>

Table 2 – sub-assembly n°2 configuration

4. DETAILED TECHNOLOGIES

4.1. Contact material

Composite contact material

In the frame of ASR activity, a contact material, gold allow reinforced with oriented carbon fibres, has been developed with EPFL. This technology aims to combine the advantages of carbon fibres with the properties of the gold material in order to obtain a brush material which offers high thermal conductivity together with low electrical resistance, good tensile strength and suitable wear rate.

The test setup has been manufactured to build material samples as shown on Fig.3. First trials have been performed with copper alloy injected inside the carbon fibres at 1100°C and under pressure through ceramic filter. Unfortunately, after several trials to optimize the set-up, the mix between copper and carbon fibres could not be achieved to obtain a uniform material and this experiment has been stopped.

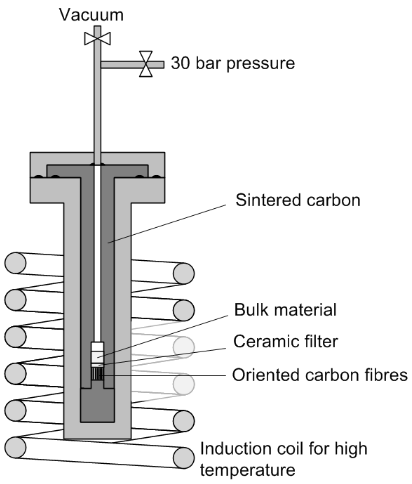

Figure 3 - Composite material test setup

4.2. Electrical technologies

Ceramic insulated rigid rod

For SADM sliprings which transfer high power, the return power lines have generally the same potential and are gathered in one circuit. With the ESA derating rule (ESA ECSS-Q-30-11A), a large number of cables is needed for the current intensity applied, impacting the volume of the rotor and the heat generation.

A proposed solution developed for ASR is to use a rigid rod composed of copper alloy conductor and ceramic insulation protected by a stainless steel sheath (Fig. 5). The main advantages of this solution are to work up to 1200°C and to decrease the electrical resistance for the same equivalent conductor section compare to wires bundles compliant with ESA derating rule. Fig4. shows the electrical resistance in case of return line with 48 Amps as required.

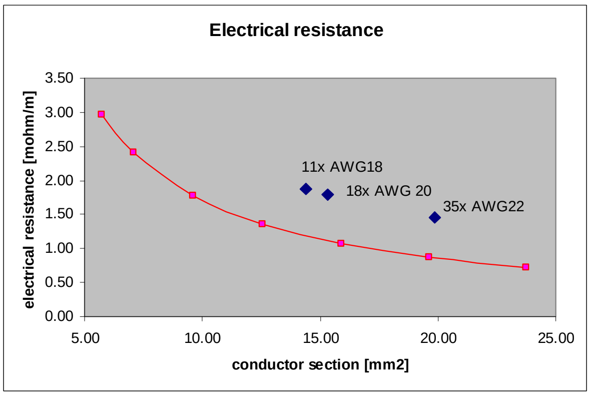

Figure 4 - Comparison of electrical resistance for solid rotor and AWG wires bundles.

But the main difficulty with this design solution appears for the rod connection on both tips. The rod is directly connected to the track by silver-tin solder as shown on Fig.5. On the other side, customer interface connection is done by wires and therefore requires a specific adaptation part which has been developed to connect the wires bundle directly on the rod.

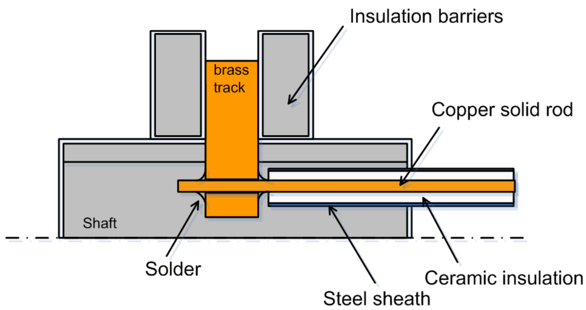

Figure 5 - Solid rod connection

High temperature cables

The maximum allowable temperature for standard ESA/SCC 3901 polyimide cables is 200°C. But for high power applicable it could be interesting to have higher temperature. In the frame of the Bepi Colombo project, tests have been performed in collaboration with TAS-I and ESA on standard cables and have validated the use of GORE cables ESCC 3901/009 (GORE-TEX and polyimide insulation) up to 260°C. Thus these wires are integrated in the ASR design and will be compared to the polyimide cables.

Wire/wire-brush connection

A critical point on the electrical lines is also the solder between wire and wire-brush. This connection is a hot point in the slipring and the allowable temperature is very limited for standard tin-lead-silver solder. Two solutions are integrated in ASR:

- High temperature tin-silver solder, validated up to 175°C
- Splicing of the wire on the wire-brush

The principle of the splicing is to crimp the wire on the wire brush with an adapted crimping ribbon made of copper alloy (Fig. 6).

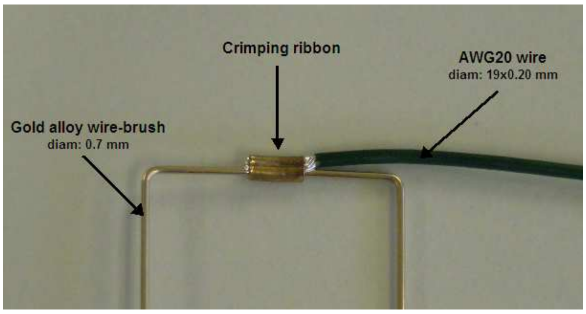

Figure 6 - Wire brush splice

Crimping trials have been performed including cross-section inspection and standard pull-out strength test to define the appropriate splice and tooling for different configurations (standard cables AWG20 and standard gold wire brushes with different diameters). Tab. 3 and Fig. 7 summarize the test results obtained with a same crimping ribbon of 4 mm width.

n°	Wire brush diameter [mm]	AWG wire	Total section [mm^2]	Pull-out strength test [N]
1	0.4	20	0.72	59
2	0.5	20	0.79	86
3	0.7	20	0.98	85

Table 3 - Wire brush splice

Figure 7 - Splice cross-section

The cross section inspections show a good quality contact between the wire-brush, wire strand and crimping ribbon. But depending on the wire brush diameter, the wire strands are differently distributed around the wire brush and the crimping ribbon is not completely rolled around wire brush/wire for the larger diameter (n°3). Thus supplementary tests have been performed with the chosen configuration for the ASR project (wire brush: 0.7 mm and AWG 20 wire) to adapt the ribbon dimension. Cross section inspection and pull out strength test have been redone with better results

n°	Wire brush diameter [mm]	AWG wire	Total section [mm^2]	Pull-out strength test [N]
4	0.7	20	0.98	102

Table 4 - Wire brush splice

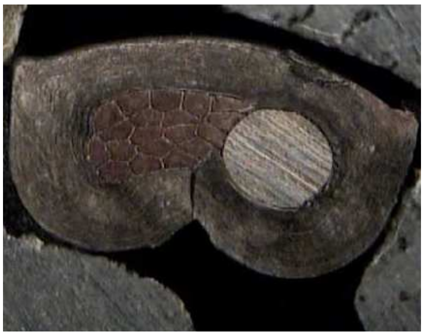

Figure 8 - Splice cross-section

4.3. Insulation material

Standard design of slip-ring involves insulating resin barriers stacked with the conductive tracks. These parts are machined with accuracy and hold the tracks to insulate them from the shaft and other tracks.
Standard glass reinforced resin B material have a maximum allowable temperature of 180°C. For some projects, it could be interesting to have material with a higher allowable temperature and also a CTE similar to adjacent metallic parts (aluminium for shaft and brass for track).
Three different technologies are implemented in the ASR design to be tested and evaluated regarding the aspects of manufacturing feasibility, costs, technical performances (good thermal conductivity to transfer heat generation through the rotor shaft, good electrical insulation …)

Specific Ceramic
Ceramic are very suitable for this applicable due to high electrical insulation, high thermal conductivity, very good stability and high allowable temperature (1000°C). But the main inconvenient is low machinability. Insulation barriers have been machined in a new type of aluminium nitride ceramic material. The obtained parts are suitable regarding technical requirements and are integrated in ASR.

Resin A
This resin has been also selected for insulation barriers and wire-brush holder to be compared with standard resin B. Resin A have been chosen for its good mechanical properties and its high allowable temperature 260°C. Glass fibre reinforced grade has been used for wire-brush holder as structural part.

Hard coating
The third solution chosen for insulation barriers is hard coating of aluminium parts. The particularity of this coating compare to standard coating is the possibility

to increase the thickness up to 150 microns and insure a complete covering of the surface with excellent electrical resistivity. Insulation barriers have been therefore machined in aluminium and treated with this hard coating before to be stacked on the rotor assembly.

4.4. Outgassing test at high temperature with AAC

In the frame of ASR activities, dynamic outgassing test should be performed by AAC at high temperatures on the several materials which are used for the slipring. The tests are performed without intermediate levels with constant rate of 1°C/min from room temperature up to high temperature where heavy mass loss is obtained. These tests will give information on outgassing behaviour for higher temperature than the standard test at +125°C.

4.5. Angular Position Sensor (APS)

Angular Position Sensor developed by RUAG Nyon with ESA activity (ESA Contract: 22854/09/NL/SFe) is integrated at rear side of the slipring.

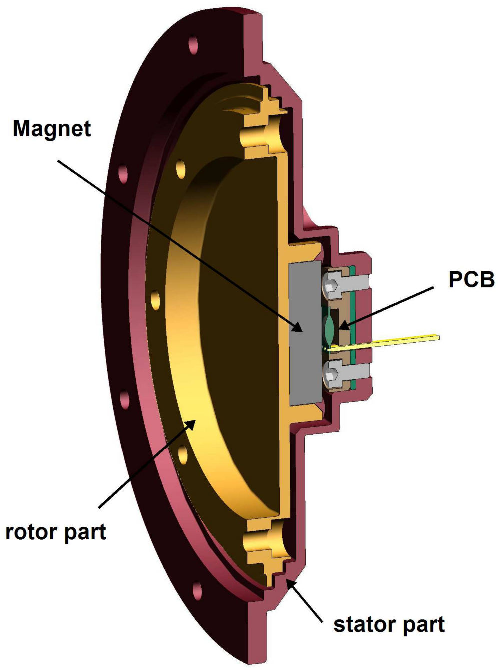

Figure 9 – APS integrated in ASR

The sensor, based on hall principle, is composed of a sensing element fixed on the stator and a rotating permanent magnet coupled to the shaft. Cold redundancy is ensured by two sensor components solder on each side of the same PCB. The sensor is encapsulated in ceramic for radiation protection.

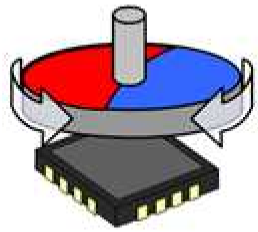

Figure 10 – APS configuration

5. TESTING AND CONCLUSION

The ASR is manufactured and assembled and will be tested according to the following test plan:

- Functional tests
- Vibration
- Functional tests
- Thermal vacuum life test
- Functional tests
- Corona test
- Functional tests
- Complete Strip-down

The aim is to verify the performance of the ASR regarding mechanical and electrical requirements and to analyse accurately the obtained results in order to compare the integrated new technologies.

After validation of the performances of these technologies, some of them could be integrated in future commercial and scientific slip rings.