E3000 High Power SADM Development

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ABSTRACT

Maintaining their history of successful SADM developments, and with the help of ESA, EADS Astrium have developed a new High Power (HP) SADM. This SADM has evolved from the successful Medium Power (MP) product and is due to start its qualification in September 2007. The MP unit was qualified to transfer 11 A current through 18 power circuits at 50 V potential (9.9 kW) in March 2003. Currently 32 units have been manufactured and tested with 18 currently flying. The HP SADM is designed to transfer 21 A through 12 power circuits, at both 50 V (13 kW) and at 110 V (28 kW). This has been achieved with only a 12 percent increase in mass from the MP design and negligible increase in volume. The reduction in the number of circuits (12 down from 18) allows to provide additional insulation between the high internal potentials (> = 110 V) to eliminate the risk of arcing, within the same SADM volume. The magnitude and impact of the internal circuit dissipations at 21 A has been mitigated by the novel use of materials for the conductive brush elements and the use of carefully matched resins to cope with the unavoidable higher internal temperatures whilst still maintaining manufacturability and robustness. The requirement for this SADM to drive a range of arrays required the development of an accurate dynamic model that would reliably predict the full range of array torque behaviour and confirm the meeting of torque margin requirements. In order to correlate this model, a large flexible test inertia has been developed to be used during thermal vacuum testing. Development activities included a trade off of 8 PSSR candidate designs in conjunction with RUAG Aerospace utilising detailed thermal analyses correlated to breadboard results; a life test breadboard including several old & new contact technologies with real time measurement of brush wire temperatures and actual contact resistances; testing of insulation resistance sensitivity to humidity; Paschen curve characterisation of the MP design to predict arcing risk; brush stress relaxation testing coupled with extensive testing of selected insulating resins. During the programme a new potentiometer was designed and developed in conjunction with Eurofarad, the potentiometer supplier.

Keywords: **High Power SADM, Slip-ring assembly, Solar Array, Drive Mechanism, arcing resistance, power transfer, datum sensor.**

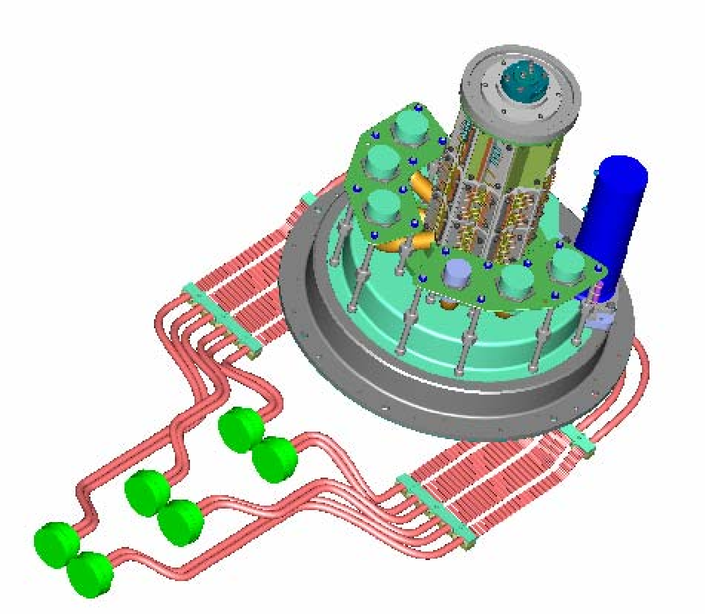

Figure 1: HP SADM, view from the spacecraft side.

1 BACKGROUND

The main driver for the HP SADM was to be able to transfer higher currents at higher voltages from the solar array to the spacecraft. The MP SADM had proven the use of the cylindrical design PSSR versus the earlier E2000 SADM pancake design, to carry 11 A at 50 V. This power loading was found to be at the limit of the materials temperature capability of the chosen slip ring technology. Applying 20 A current to the MP SADM design resulted in peak brush temperatures of 140°C and resin temperatures of up to 125°C. The 140°C was considered above the limiting creep temperature of the MP brush material and the resin temperature above the capacity of the incumbent resin. There were real concerns regarding the susceptibility of slip ring assemblies to arcing at the higher required 110V operating voltages (There have been in orbit failures attributed to arcing in SADMs, and the APSEE [3] study demonstrated the potential for arcing in slip ring assemblies under extreme conditions). This drove the requirement for designing in maximum insulation resistance between high and low voltage conductors.

Proc. '12th Euro. Space Mechanisms & Tribology Symp. (ESMATS)', Liverpool, UK, 19–21 September 2007 (ESA SP-653, August 2007)

The increased power was coming from larger array configurations, so the reaction torque behaviour of a variety of large flexible arrays had to be taken into account in considerations of the drive stepper motor and gearbox (SMG) and transmission capacity. It was determined that the MP SMG design was suitable for the predicted loads. The fact that EADS now had a data base of SMG performance figures meant that the rating of the motor could be based on measured performance rather than on the uncertainties of a new design mitigated by large design factors. This gave the advantage of a relatively light SMG well suited for the task. In order to validate the SADM performance a detail model of the SADM plus arrays was constructed and a large test inertia simulator designed and manufactured [1].
Anomalies encountered with standard potentiometer technologies led to the decision to develop a more robust potentiometer solution. This involved implementing a multi-element contact technology breadboard from which a preferred candidate was chosen and a model manufactured for qualification on the SADM [2].
The same MP bearings and pre-load were maintained with an improvement in the bearing performance achieved by using clamping forces more closely matched to the bearing pre-load and a refined installation and clamping sequence.
The following heritage features of the MP SADM have been maintained:

- Plug and play blind mate installation into the spacecraft.
- Maintains the same mounting flange dimensions to fit into the same sidewall aperture.
- Same transmission (SMG, pinion, ring gear)
- Same main bearing with lead plating lubrication.
- Same potentiometer interface and generic potentiometer housing.

The HP SADM assembly is virtually complete at the time of writing and only requires the installation of the potentiometer before entering its qualification test programme.

2 DEVELOPMENT PROGRAMME

2.1 PSSR Design Process

2.1.1 Brush technology & configuration

Due to the inability of the MP PSSR design to handle the higher voltages and higher temperatures predicted from the 1st iteration of the thermal model, even with repositioning of the power rings and additional thermal shunting towards the satellite sidewall, a new design process was initiated with a brainstorm session. It was clear at this point that four issues had to be resolved.

1) Incorporation of maximised insulation against high voltages.
2) The heat generation of the contact and the brush materials had to be reduced.
3) The heat had to be removed from the region of the contact and brush.
4) The insulator resins had to have higher temperature resistance.

The solutions were constrained within the defined volumetric (close to the MP SADM) and mass requirements and assumed no other major changes to the basic SADM concept with the exception of the array harness wire complement being increased by 50 % . 14 potential solutions were reduced to 7 feasible candidates. The solutions could be divided into 2 groups.

1) Those which increased the numbers of contacts, which caused volume, mass and manufacturing issues.
2) Those which maintained similarity to the MP configuration but reduced the internal dissipations and more efficiently transferred the internal dissipation out to the PSSR boundary radiative and conductive paths.

A number of novel solutions were included in the design selection process. Using a combination of detail analysis (particularly thermal) and some focussed breadboard testing a winning candidate was selected. Tab. 1 shows the critical brush temperatures measured for the 4 bread-boarded candidates:

Configuration	Breadboard Brush Temp as measured	SADM predicted temp
0: MP brush	133	146
5: Winning candidate	117	117
6:	125	122
8:	122	130

Table 1: measured and predicted qualification brush temperatures

The trade off was based on the parameters identified in Table 2.

Mass
Friction Torque
Contact noise (resistance variation)
Brush temperature noise
Debris/wear
Brush compliance
% of equivalent stress relaxation temperature
storeability
Contact heritage

Table 2: Trade off selection parameters

2.1.2 Breadboard

Due to programme constraints, the ready availability of an off the shelf rotor, and a natural inclination to try to stay with the MP style configuration, the breadboard hardware consisted of 4 MP style brush configurations. See table 1.

Fig. 4 shows the assembled breadboard PSSR.

All these solutions utilised the same cylindrical shaft with wire brushes running on gold plated tracks. It had been established during the MP programme and was clear from the more detailed HP preliminary thermal model that a critical area of performance was the brush and brush contact resistance and the heat generated in this area. To gain maximum confidence in the thermal predictions two of the technologies were implemented with both multiple and two single contact circuits. The actual resistance of these two single contacts was carefully monitored using a cross wire technique. This required the attachment of a very fine Chromel wire to the end of the brush, past the point of contact. The Chromel wire being very thin and with a poor thermal conductance minimised the heat conduction away from the brush. Further actual brush node temperatures were measured on a single brush for each of the technologies using a miniature thermocouple. The thermocouple wire was of very fine gauges and of 2 poor thermal conductors (Chromel & Alumel). Calculations showed that the heat loss up the thermocouple was < 2.5 % of that along the brush. The breadboard was then subjected to an accelerated life test in hot and cold vacuum and demonstrated very little wear or wear debris for any of the tested solutions. Additional in air development life tests were also conducted on some of these technologies.

Fig. 2 & Fig. 3 show the BOL to EOL volt drops traces for cold and hot conditions respectively. It can be seen that the multi contact noise is good in all cases. The chosen candidate was the best overall performer and most thermally stable in the extreme cases.

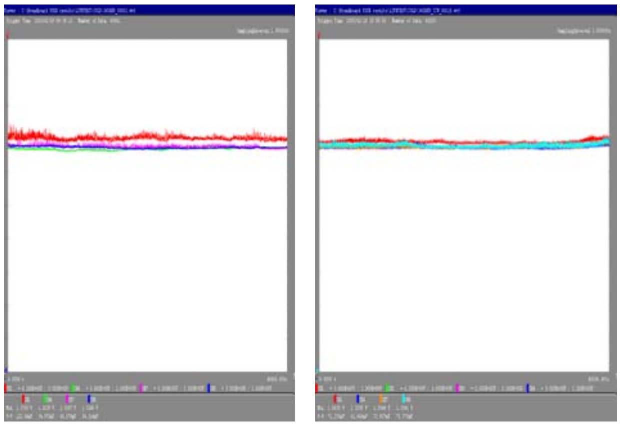

Figure 2: BreadBoard volt drops BOL cold to EO Cold.

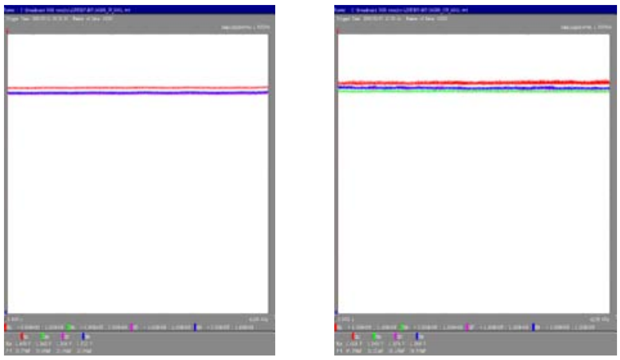

Figure 3: BreadBoard volt drops BOL Hot to EOL Hot.

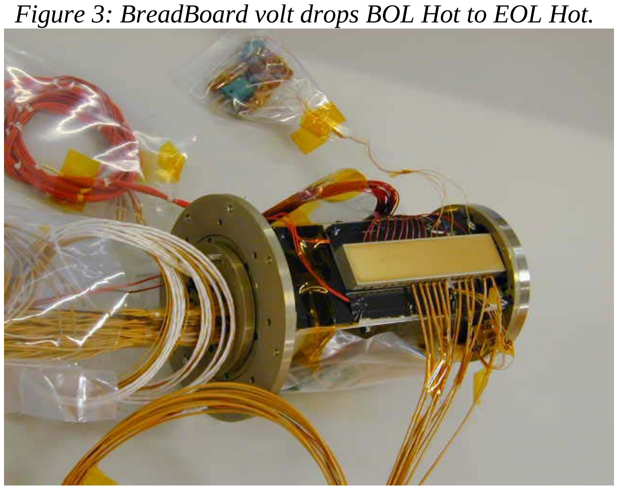

Figure 4: Breadboard PSSR

2.1.3 Insulator materials

From the breadboard testing and correlating of the detailed thermal analysis the qualification temperatures of the PSSR resins were determined. Having selected the prime brush technology candidate from the trade off, RUAG Aerospace, the PSSR supplier, then proposed a selection of up to 4 resins matched to the four distinct assembly areas. That is

- Brush holder - high temp resistance, dimensional stability and machineability
- Brush potting – good thermal conductance and potting capability
- Slip ring insulator – dimensional stability, machineability
- Shaft potting – thermal conductance, potability.

These resins were then subjected to an intensive test and validation campaign covering:

- CTE
- CME
- Mechanical Properties:
  - Young's Modulus
  - Yield strength
  - Ultimate strength
  - Elongation (before fracture) (at diff. T)
  - Elastic Modulus E' as a function of T
- Glass Transition Temperature (Tg)
- Electrical Resistivity
- Insulation resistance
- Manufacturing of brushblock & shaft breadboards
- Thermal cycling of manufacturing breadboards dummy assemblies

Another concern with some of the resins was raised regarding the change in insulation resistance (IR) vs humidity (RH) with IR near the specification limit of > 100 Mohm under maximum handling environment of 65% RH. Tests were performed on resin samples and finally on the QM PSSR to investigate this relationship. It was ascertained that the IR vs RH followed a mathematical relationship and was also purely a surface adsorption effect that rapidly recovered when exposed to lower humidity and vacuum. See fig. 5.
Maximised insulation was achieved by coating all the PSSR inward facing conductive surfaces, increasing insulator thickness and height between tracks, insulating as much of the exposed brush surface as possible without interfering with the contact and eliminating direct lines of sight between conductive elements which could not be insulated (slip rings & contact tips).

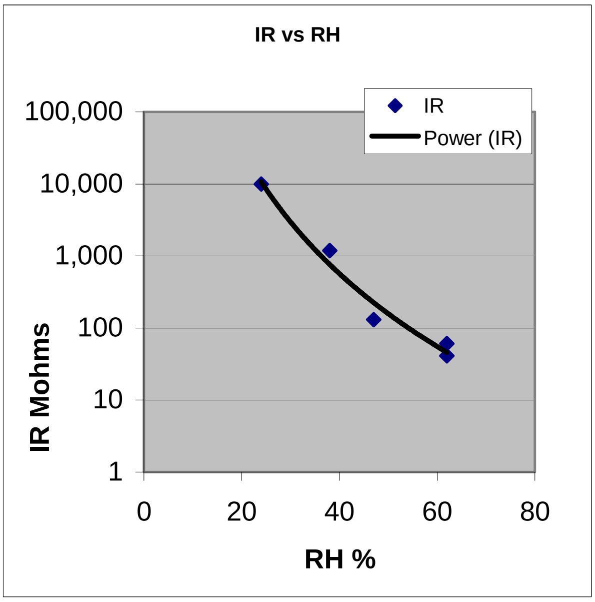

Figure 5: IR vs RH plot, multiple ccts

2.2 Design analyses

Design analysis of the HP SADM consisted of the normal thermal and stress/strength analysis against the predefined launch and operational environments. Other analysis included Radiation analysis, FMECA and WCA. The stress analysis was performed using a mixture of FEM models and hand calculations. The thermal analysis was performed using ESATAN. The thermo-elastic analysis was developed using a NASTRAN FEM

2.2.1 Thermal

As mentioned above the thermal performance of the SADM proved to be one of the 2 prime design drivers for the whole SADM design. The critical area being how heat was conducted from the SADM to the 2 principal heat sinks; the solar array and the spacecraft structure. Radiation is also a means for the transfer of heat energy to the spacecraft structure and it was clear both radiative and conductive heat flows had to be maximised to the thermal boundaries.
Detailed models were built up of the brush blocks in order to determine the maximum temperatures being developed within these sub assemblies.
From these detailed models predictions were made of the locations of maximum temperatures and identified areas where tuning the design could reduce the temperature in these regions to within the capability of the material properties.

2.2.2 Thermo-elastic Distortion Analysis

The PSSR design is based upon 'brush-on-gold' technology, consisting of metal brush wires running on gold plated slip rings. The conflicting requirements of low brush wire resistance, dictating larger diameter wires, and low stiffness, dictating small diameter wires, had been solved on the MP by carefully selecting the brush wire diameter and the preload. However on the HP the brush material had to be modified in order to achieve the thermal performance required. As it turned out it was possible to double the new brush compliance and remain inside stress and frictional requirements. Further the material selected had improved stress relaxation behaviour. This was demonstrated by a 6 month stress relaxation test conducted at elevated temperatures. See fig. 6.

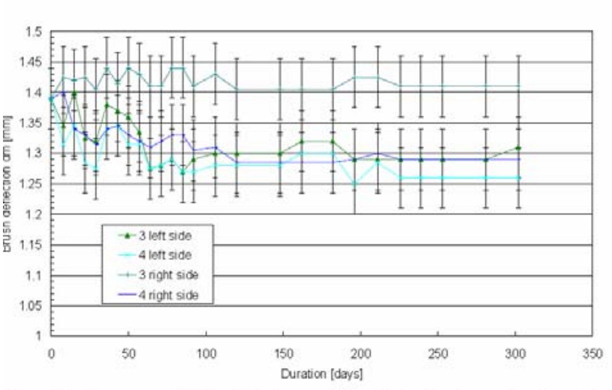

Figure 6: Stress relaxation plot for chosen brush technology

The breadboard life test and the PSSR friction tests confirmed the configuration as viable.

Fig 5. shows a typical output from the thermoelastic-distortion model.

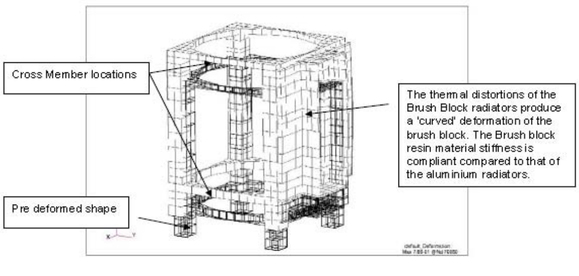

Figure 7: Thermo-elastic distortion of brushblock

2.2.3 Dynamic Performance Analysis

Dynamic performance of the SADM driving the deployed array has been simulated using a MatLab model. This model was used to assist confirmation of the sizing of the SMG. The SADM will be driven in micro-step mode consisting of 8 micro-steps, with 5 different combinations of mini-step and mark space periods [ref 1]. The model was used to predict the worst case oscillations of the deployed array when coupled with the motor when driven with the various drive waveform profiles, to confirm that the SADM would not backdrive and would meet the required torque margins.

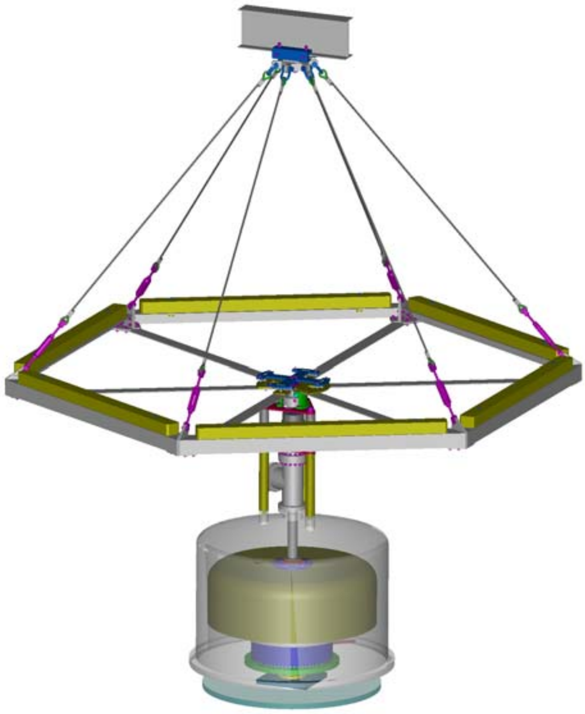

Figure 8: Solar Array Simulator above Thermal Vacuum test chamber

The Solar Array Simulator consists of a large hexagonal ring suspended on a series of wires, assembled with cross bracing to provide lateral stiffness . See fig 8. This rig simulates the largest SA that will be driven by the HP SADM and has an inertia of 560kgm^2, with a natural frequency of 0.1Hz. In order to achieve the required inertia the framework has been designed to take stainless steel weights that can be added to this framework in order to increase the mass up to 280kg to achieve the 560kgm^2 inertia. The inertia framework is suspended from an I-Beam through a large thrust bearing to offload the mass from the chamber and allow free rotation. Unlike the MP simulator this rig relies on a central spring assembly in combination with the inertia to provide the resonant behaviour.

2.3 Testing

Lessons learnt on the MP programme and the industry desire to be even more accurate in the representation of flight conditions during equipment qualification programmes has led to much more intensive and representative testing at SADM level. This has precipitated some new test configurations developed by the SADM team. The harness boundary temperatures are controlled much more carefully with the test harness conductors being 'exposed' to a conductive thermally controlled plate on the S/C side and a radiative thermal shroud running at liquid Nitrogen temperatures on the array harness side. In both cases redundant thermal sensors are thermally linked to the copper wires of the harnesses at nodal points.
The SADM is being subjected to 4 boundary temperature cases with 2 of these seeing both maximum and minimum current deliveries in qualification. During the life test this 6 condition sequence is being repeated 10 times through the whole life rotations. A further 7th eclipse condition is also being tested during the life test.
At the customer's request the SADM is being tested with power applied both during shock and vibration testing.

3 SUMMARY AND CONCLUSION

A HP SADM has been designed and manufactured following an extensive design and development programme under the scrutiny of ESA. A number of novel design features have been incorporated to achieve a high power to weight capability. A number of advanced and stringent verification techniques have been used to validate the design. A number of sophisticated test jigs and methods will be used to achieve qualification and proof of this robust new design.

4 References

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