SEPTA®41 EV – A FULLY INTEGRATED SOLAR ARRAY DRIVE MECHANISM

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ABSTRACT

With a highly optimized and robust design, the SEPTA®41 Ev is light, compact, and currently the smallest SADA or Solar Array Drive Assembly of the mechanisms family produced by Oerlikon Space AG.

Its enhanced design allows also for great performances, in particular for use on micro-satellites platform such as the CNES MYRIADE platform. It is used:

- To drive the Solar Array over unlimited angular range, a broad speed range and with an accuracy around ±1° over 23 040 micro-steps.
- To transfer to and from the Solar Array power down to 185 W and up to 600 W as well as signals such as angular position.

To ensure those functions, the components are organized in two sub-assemblies:

- A Solar Array Drive Electronics (named SADE) which commands the rotation
- A Solar Array Drive Mechanism (named SADM) which supports the Solar Array and allows it to rotate at command

Originally developed in 2004 with CNES, the definition of the SEPTA®41 has been further improved for greater and more reliable performances.

Those performances, from lifetime functional behaviour to strength against mission environments like launch vibrations and EMC, were successfully met during the 2007-2009 qualification campaign.

In addition to 2 SEPTA®41 already in-orbit since 2005, 3 more SEPTA41®41 Ev flight models have been launched into space on-board satellites for both CNES and DGA and are operating nominally ever since.

This paper presents the SEPTA®41 Ev functions, a design overview and its performances.

1. INTRODUCTION

The original design of the Solar Array Drive Assembly called SEPTA®41 was developed and qualified in 2004, with active support from CNES who was the prime customer at that time and who co-funded the program. Since then, the original design has been replaced by a new enhanced version. Called SEPTA®41 Evolution, it is now the version produced by Oerlikon Space AG.

Figure 1. SEPTA®41 Ev SADA

Its design has been highly optimized to minimize mass and increase compactness, making it the smallest SADA in the mechanisms family produced by Oerlikon Space.

The SEPTA®41 Ev is well-suited for a large variety of micro-satellites (i.e. in the 100kg class range), like the MYRIADE platform developed by CNES.

Its performances have been thoroughly checked over extensive qualification campaigns from 2007 to 2009 that covered mostly functional, environmental and lifetime tests. The investigations performed along the campaigns have confirmed the good behaviour of the different components of the SEPTA®41 Ev.

From the original design to the Evolution enhanced version, 6 flight models have already been delivered:

- 2 SEPTA®41 are already in-orbit since 2005 on CNES DEMETER and PARASOL
- 2 SEPTA®41 Ev are already in-orbit since February 2009 on SPIRALE satellites
- 1 SEPTA®41 Ev will be in-orbit in November 2009 on CNES PICARD satellite
- And more are foreseen in the years to come (TARANIS, DEMETER 2)

The SEPTA®41 Ev functions, design and performances are discussed in details below.

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2. ENHANCED DESIGN DESCRIPTION

The SEPTA®41 Ev is intended for solar array drive and transfer of power and signals to and from the satellite.

Its main functions are therefore:

- Rotating the solar array: the SADA can rotate either in forward or reverse directions, over unlimited angular range. Rotation is steady over a broad speed range, and is precise with an accuracy around ±1° over 23 040 micro-steps.
- Sustaining the solar array: the SADA can withstand loads induced by the solar array throughout all lifetime phases, and in particular after deployment.
- Detecting the solar array position: measurement is ensured by a potentiometer.
- Transferring to and from the Solar Array power down to 185 W and up to 600 W as well as signals such as angular position.

To ensure those functions, the parts of the SADA are organized in two sub-assemblies SADM and SADE:

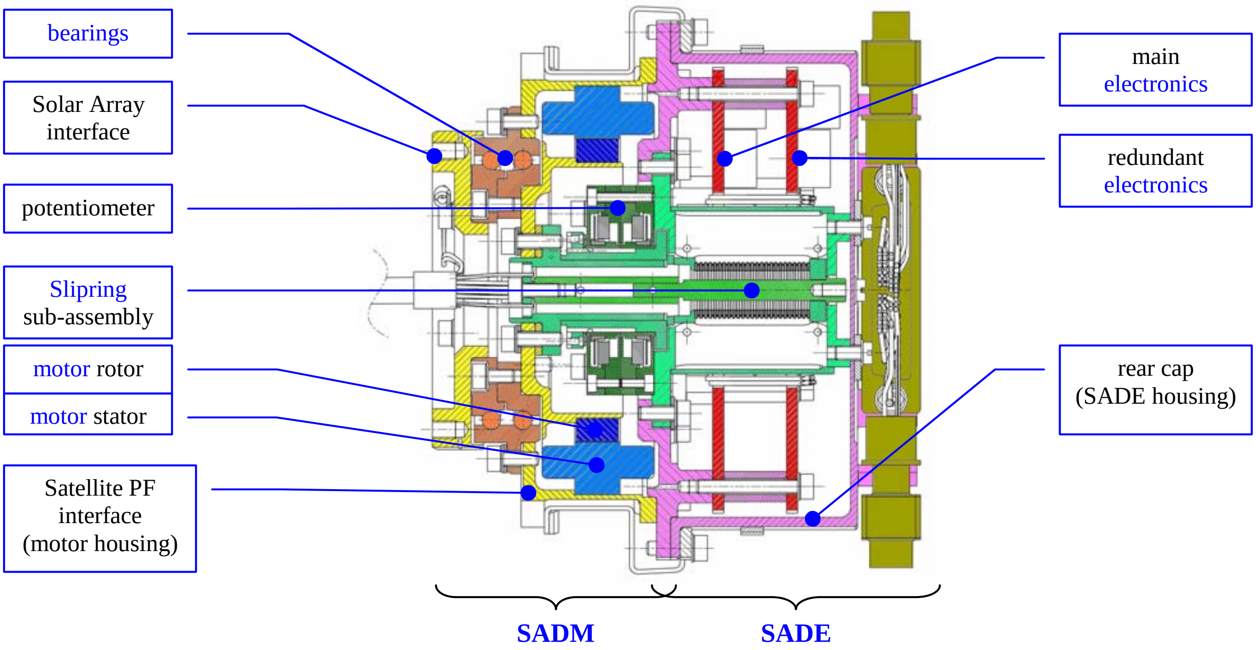

Figure 2. SEPTA®41 Ev cut view

The SADM sub-assembly is the Solar Array Drive Mechanism which supports the Solar Array and allows it to rotate at command.
To minimize mass and volume, the SADM is a direct drive concept (no reduction gear box), which offers an optimized total mass down to 1.65 kg and a highly compact volume as implied by dimensions in Fig. 3.:

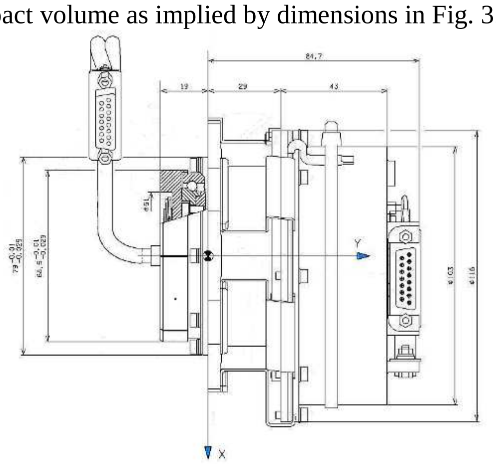

Figure 3. SEPTA®41 Ev main dimensions

The motor is a two-phase stepper motor with permanent magnet, including redundant high-impedance windings.

- Inherited from the SEPTA®31/32 design, it can operate under voltage or current-regulated modes.
- In SEPTA®41 Ev, it is driven in step-to-step mode, with 360 steps of 1° each. The electronics can also drive it in micro-step-to-micro-step mode: with 64 micro-steps per step, the total 23 040 micro-steps allow smooth rotation and fine relative positioning.

The pair of ball bearings links directly the motor motion to the Solar Array flange, so that one motor step equals one output angle (direct drive system).

- It is hard-preloaded in “O” configuration
- It has been thoroughly analysed and tested:
  - To establish the most efficient lubrication application suited for a direct drive mechanism, in particular under cold temperature conditions, which led ultimately on selecting Fomblin Z25 rather than a grease.
  - To characterise the ball bearing conductivity and how the thermal gradient between inner

and outer cages can affect the SEPTA®41 Ev's motorisation versus friction performances.

The enhanced slipring sub-assembly (SRA) has:

- 24 transfer lines, 22 of them for power organized in 11 pairs of tracks, each capable of transferring up to 1.6A at 34V, the 2 last ones used for grounding.
- A pancake-type potentiometer with main and redundant channels both used to detect the output angular position signals by comparison of output (0 to 5V) and input voltages (5V). This potentiometer relies on the same plastic film technology as the one already extensively used in potentiometers mounted in SARA®21. Both main and redundant channels have a full electrical course of 357° minimum (3° maximum dead band only).
- The enhanced version of the SRA features:
  - A central shaft assembly stiffer and thermo-mechanically more sound,
  - Improved design and manufacturing tolerances on parts contributing to internal functional axial and radial gaps.

The SADE sub-assembly is the Solar Array Drive Electronics which commands the rotation.

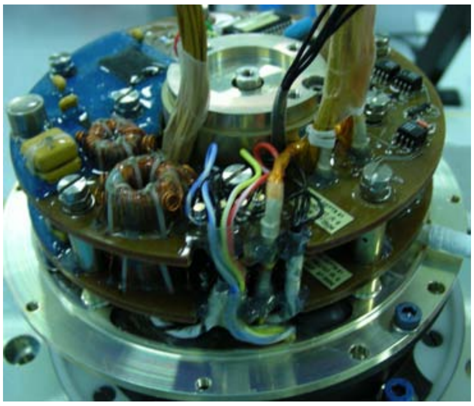

Figure 4. SEPTA®41 Ev SADE – electronics

The enhanced main and redundant electronics transfer the position signals or the motor commands orders from or to the Satellite On-Board Computer through a serial asynchronous and full duplex protocol link ensured by a RS422 interface circuit.

- They operate the stepper motor under voltage-regulated (24 to 34V) or current-regulated modes such as I_{max} = 72 mA or ⅔I_{max} or null, pending how power consumption is optimized.
- Slipring and potentiometer are also controlled
- Temperature is monitored with internal thermistors located nearby the main and hottest card.
- The enhanced electronics feature:
  - An improved lay-out in order to ease cabling activities which were difficult before due to the compactness of the cards,
  - Modified filters and added latch-up protections,
  - An improved grounding (no floating pin)

The SADE is designed with highly-integrated control electronic cards using several commercial on the shelf (COTS) components all compatible with a cumulated dose superior to 15 krads: Originated by CNES:

- This design approach allowed for miniaturisation beyond the limits imposed by the often bigger space-standard equivalents.
- The design approach is definitely a great advantage for supplying flight models at reduced cost, and thus adapted to often low-budget micro satellites.

Other main mechanical parts are:

- A Titanium-made Satellite interface flange, to which the motor stator is glued,
- A Titanium-made Solar Array interface,
- An improved internal flange supporting the cards,
- An Aluminium improved cap protecting the SADE.

3. PERFORMANCES

3.1. Characteristics

Table 1. SEPTA®41 Ev performances

SPECIFICATION		DATA	UNIT	
Step angular size		1	°	
Pointing Resolution		0.5	°	*typical*
Signal Accuracy		±1	°	*typical*
Steps per revolution		23 040		
Output step rate		3.84 - 25	Hz	min - max
(SADM shaft speed)		0.06 - 0.4	° / s	min - max
Stiffness *(qualified)*	Axial	1.2 x 10^8	N/m	*qualified*
	Radial	6 x 10^7	N/m	*qualified*
	Bending	2 x 10^4	Nm/rad	*qualified*
	Driving	13	Nm/rad	*qualified*
Load capability	Axial	1 000	N	max
	Radial	1 000	N	max
	bending	30	Nm	max
Slipring Tracks	Resistance	60	mΩ	*typical*
	Noise Level	3.5	mV_{RMS}/A	max
Power Transfer		185 - 600	W	min - max
Power Consumption *at 34V*		4	W	max
Inertia capability		1.7	$kg.m^2$	max
Torque	Output *at I_{max}*	0.22	Nm	*typical*
	Holding *at I_{max}*	0.31	Nm	*typical*
	Resistive	0.05	Nm	*typical*
Thermal	Non operating	[-30 ; +60]	°C	*qualified*
	Turn-on	[-30 ; +55]	°C	*qualified*
	Operating	[-20 ; +55]	°C	*qualified*
Total mass		1.65	Kg	
High Level sine *(4 – 100 Hz)*		15	g	max
random vibrations		0.9	g^2/Hz	max
(20 – 2000 Hz)		21.4	g_{RMS}	nominal
Shock		1 000	g	max

Table 2. SEPTA®41 Ev life capability

Ambient Cycles	350	cycles 360°	at Ambient
Vacuum Cycles	40	cycles ±90°	at Cold/Hot
Vacuum Cycles	4 200	cycles -30°/+90°	at Ambient
Cumulated IOB	> 38 000	cycles *cumulated as per June 08*	
Operating life	5	Years in orbit	

3.2. Motorisation Capability

As the required compactness of the SEPTA®41 Ev allows only for a direct drive system and no integrated reduction stage between the motor and the output stage, the motorisation capability of the mechanism has required extended analyses and tests for assessing the influence of all sub-systems likely on motion resistance.

- Ball bearing performances were refined by tests at component-level and as part of the qualification model in order to ensure a motorisation margin of 2 or more under any environment (½ of I_{max}). Focus was on thermal gradient criteria as shown in Fig. 4, minimal temperature and maximum heat flux.

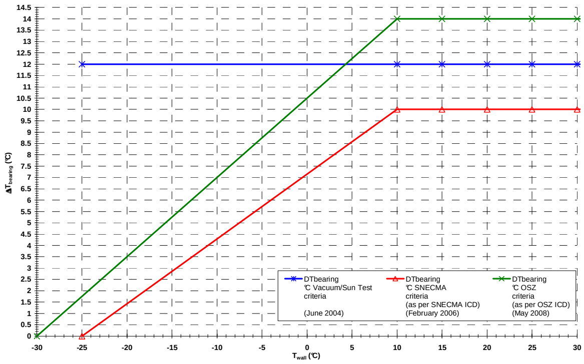

Figure 4. Thermal gradient bearing criteria

- A dedicated torquemeter was developed to measure precisely the slipring friction torque.
- A screening of all procured stepper motors was implemented to select only the motors with the best torque capability, and the effects of micro-stepping were analysed.

Ultimately, along the qualification campaigns, the SEPTA®41 Ev met and even surpassed all expectations with a motorisation margin impressively steady under all mechanical and thermal conditions and above 3 (⅓ of I_{max}) and torque values as given in Tab. 1.

The qualification also showed that within its operating voltage range, the SEPTA®41 Ev could sustain a boost mode without any critical thermal constraints, whether it was temperature levels or thermal exposition duration. This boost survival mode was implemented to power at the same time both main and redundant wirings of the stepper motor at I_{max}, and thus doubling the available torque, leading to a typical motorisation torque value of 0.42 Nm, high enough to compensate potential start-up blocking issues, especially under cold conditions.

4. LESSONS LEARNT

Although ultimately successful, the fine tuning of the SEPTA®41 Ev required more efforts than anticipated, mostly as a consequence of using COTS components.

- The procurement of such components is not trivial, as a minimum of traceability is still required. Screening of components and proper acceptance tests at card-level also need to be carefully defined, in order for example to confirm operating voltage range and no unstable electrical noise is generated, once all components are connected.
- The obsolescence risk and the potential need for relifing must also be carefully assessed.
- Confirming thermal boundaries proved challenging. Additional thermal analyses were conducted, this time with refined models at card-level, specific derating values at component-level, more detailed heat fluxes, and correlated to dedicated QM tests with instrumentation directly on the electronics.
- Those analyses and tests showed the SEPTA®41 Ev can reach thermal hot and cold boundary limits less stringent than originally thought, even under boost mode, as long as the electronic components are nominal and adequately mounted. This led to improving grounding and leaving no pin floating.

With those additional efforts, the qualification is successfully over. Implementing COTS components into the design approach of the mechanism is a strategy winner that will result in expected cost reduction, especially for recurring cost of increasing FM series production.

5. CONCLUSION

The SEPTA®41 Ev abilities to sustain and position a Solar Array while transferring power and signals was demonstrated throughout a complete qualification campaign during which all identified mission phases were taken into account to establish the environmental conditions as specified above.

The SEPTA®41 Ev performances were precisely characterised, showing values globally as expected and better than the original version, especially with regards to the limited effects of environmental conditions upon them. The investigations performed along the campaign on the original qualification model and subsequent retrofitted model confirmed all components were properly sized with full nominal performances.

The flight models which have been produced since have shown the same level performances if not better.

Additionally, new mechanisms are now being looked at by Oerlikon, such as small SEPTAs without electronics or compatible with voltage up to 50V, or a small rotary actuator with a hollow shaft, all inspired by the SEPTA®41 Ev in order to expand our offer for micro-satellites by capitalizing on the successful design approach and the lessons learnt during qualification.