SOLAR ARRAY ROOT HINGE BASED ON SHAPE MEMORY ALLOY (SMA) ACTUATOR

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ABSTRACT

The Solar Array Root Hinge based on Shape Memory Alloy actuator was designed and developed as a generic application for solar array of communication satellite

The interest of this development was to implement for the first time at TAS level a low-cost, reliable and lightweight actuator technology for solar array deployment.

This paper presents :

- The design of the root hinge, including SMA actuator description
- The development logic based on
  - Qualification status of the SMA actuator
  - Delta design of the SPACEBUS generic root hinge
- The qualification test sequence (functional test, vibrations, TVAC)

Results of a deployment test performed on ground at SMA rod, root hinge, then solar array level are presented.

1. INTRODUCTION

The Solar Array Root Hinge based on Shape Memory Alloy actuator was designed and developed as a generic application for solar array of communication satellite

This paper presents the design of the root hinge, including SMA actuator description.

The development logic considering TAS background is then presented.

Finally, results of a deployment test performed on ground at SMA rod, root hinge, and solar array level are presented.

2. DESIGN DESCRIPTION

2.1. SOLAR ARRAY SMA ROOT HINGE

Figure 1. Solar Array with its SMA root hinge

2.1.1. Function

The root hinge ensures :

- The main function of the root hinge is to manage the 90° deployment of a solar array w.r.t. the interface wall of the satellite from the stowed position to the deployed configuration.
- The interface with the Solar Array Drive Mechanism and the mechanical linkage between the solar array wing and the spacecraft

'15th European Space Mechanisms & Tribology Symposium – ESMATS 2013'
Noordwijk, The Netherlands, 25–27 September 2013

- The wing locking in deployed configuration
- The interface with the actuator (Shape Memory Alloy actuator) for deployment speed regulation
- Power and TM/TC connectors support

Root hinge ensures the solar array deployment motorization and the speed regulation of all the solar array central hinge lines. The regulation function is brought to other lines through the synchronization system.

2.1.2. Description of root hinge equipped with SMA actuator

The root hinge is mainly composed of two parts :

A mobile yoke bracket joined by a rotation pin and a ball joint to the fixed part of the hinge. This part is latched at the end of deployment by two latches released by cam devices.

The fixed part, interfaced on the Solar Array Drive Mechanism, holds the connectors on a “box” beneath the functional parts. Above the box, two parts are holding the ball joints in a male / female clevis.

The SMA cartridge is attached to both side of the hinge : one side is attached to the fixed bracket and the other side is attached to the mobile bracket.

The following view show the root hinge equipped with the SMA actuator.

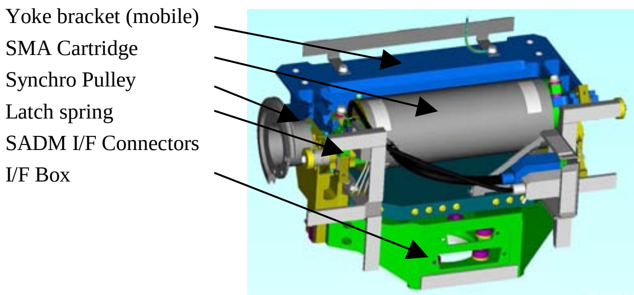


Figure 2. Solar Array root hinge main parts

2.1.3. Comparison with root hinge equipped with gear motor

2.1.3.1. Design

The generic SPACEBUS solar array root hinge is equipped with an electric motor for regulation of the deployment of the solar array.

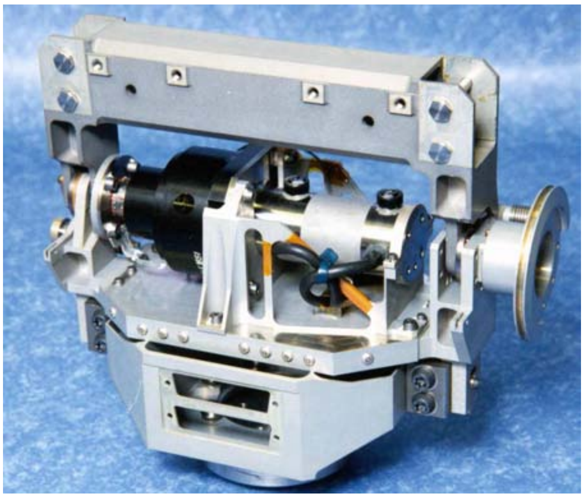


Figure 3. Solar Array root hinge with gear motor

The SMA cartridge is designed compatible with the generic SPACEBUS solar array root hinge interfaces (electrical interfaces as far as possible).

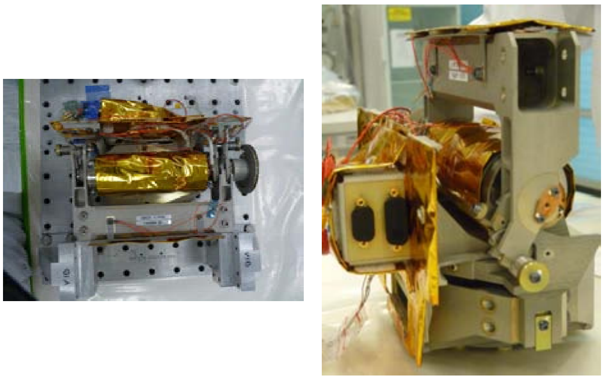
2.1.3.2. AIT operations

AIT operations will be specific to the SMA actuator which requires special attentions or layouts.

SMA can be used several times but has to be reconditioned for each new deployment. It is why an unclutching function on solar array is dedicated to ease operation of dismounting and re-assembly. This operation will be repeated several times and especially before flight and after test sequences.

It's the reason why a minimum of operation is performed with a maximum of reliability :

- Anti-error devices are used to avoid the assembly of an already used component
- Assembly of this component is done only when hinge is in stowed configuration.



Stowed position *Released position*

Figure 4. SMA root hinge

2.2. FOCUS ON THE SMA CARTRIDGE

This paragraph details the composition of the SMA cartridge.

The SMA actuator has been designed taking into account the following key design drivers :

- To guarantee that it is not possible to use nor mount an unconditioned SMA actuator on root hinge
- To have the best possible diameter/length fitting existing root hinge versus actuation angle and stiffness.

2.2.1. Main functions

The SMA ensures the deployment function but design is driven by two stringent and opposed requirements :

1. Need of a minimum motorization margin : motor torque shall be sufficient to guarantee this margin. The SMA Actuator is submitted to motorization torques from Solar Array Hinge line or resistive torque from Solar Array Hinge line.
2. Need to sustain and minimize the end of deployment latching torque : end of travel speed shall be small enough not to break the solar array structure.

The SMA Actuator is consequently used to motorize and speed regulate the deployment of the solar array at root hinge level.

2.2.2. Description

The SMA cartridge is composed of :

- A SMA rod equipped with heaters and thermistors,
- An interface flange equipped with strain gages,
- Mechanical interface brackets with root hinge,
- A cover made of aluminium, covered with Multi Layer Insulation
- Interface connectors,
- Interface screws, washers and insulating washers.

Figure 5. SMA cartridge

This actuator is designed as much as possible as an individual component installed on the root hinge.

2.3. FOCUS ON SMA ROD EQUIPPED

This paragraph details the composition of the SMA rod equipped.

2.3.1. Nickel Titanium alloy interest

SMA rod is made from Nickel Titanium alloy with high austenitic transition temperature.

The unique behavior of NiTi alloy is based on the temperature-dependent austenite to martensite phase transformation on an atomic scale, which is also called martensitic transformation.

The martensitic transformation causing the shape recovery is a result of the need of the crystal lattice structure to accommodate to the minimum energy state for a given temperature.

NiTi alloy senses a change in ambient temperature and is able to convert its shape to a pre – programmed structure.

2.3.2. Thermal design

Driving of the actuator is realized through the rod temperature. The SMA is then thermally designed to isolate the rod itself from the rest of the cartridge and to avoid to meet the transformation temperature before deployment.

The SMA rod is equipped with nominal and redundant heaters (which are wired in parallel or in series) delivering the needed power .

THALES ALENIA SPACE has a strong design experience for heaters bonding on SMA component This assembly is essential to guarantee the good actuation.

The wiring aims to achieve the needed total resistance

Heating power shall be sufficient to reach the end of transformation temperature taken into account the technological limit of heaters.
Heaters are sized to fit two main requirements :

- To provide in worst thermal cold case sufficient power to reach end of transformation temperature during solar array deployment phase.
- To respect in worst hot thermal case heating power density rules (technological limit of heaters).

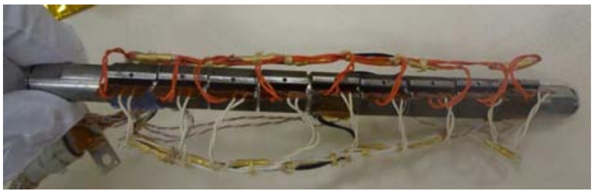


Figure 6. SMA rod equipped

3. MAIN PERFORMANCES

The total mass of SMA Actuator : < 550gr. The benefit of the SMA actuator concept is 1,3 kg savings on the Solar Array mass per wing and saving of the motor driving electronic.

About electrical aspects, the nominal power consumption is 36W.

The SMA Actuator is designed and conditioned to perform an angle actuation of more than 100° under a 15Nm of resistive torque, corresponding with the 90° deployment angle and 10° margin.

Alloy	TiNi
Nominal heater power	36 W
Angular need	> 90°
Transformation temperature	> 90°C
SMA actuator mass (cartridge)	< 550 g
Conditioning angle	130°±10°
Deployment duration	6 to 10 min
Torque capacity all along the angular stroke	> 15 Nm

Figure 7. SMA rod performances

4. DEVELOPMENT LOGIC

4.1.1. TAS heritage

TAS has more than 15 years experience in the use of SMA actuator for structure deployment.

4.1.1.1. SMA and deployable Radiator

Deployable radiators have been in development at THALES ALENIA SPACE Cannes (formerly Aerospatiale Cannes) since the 1995 to respond to the increasing capability of satellite's heat rejection, which was becoming a critical resource with respect to the considerable increase in power requirements for future satellite.

4.1.1.1.1. STENTOR technological satellite

The STENTOR satellite (Satellite de Télécommunications pour Expérimenter les Nouvelles Technologies en Orbite) initiated by CNES was an experimental program to validate, in flight, advanced satellite payload and communication technologies to prepare future generations of telecommunications satellites.

One of the major advanced technologies which was developed on STENTOR was the thermal control subsystem using several capillary pumped fluid loops. One of these loops was a 600 W Loop Heat Pipe (LHP) based on the deployable radiator, using a SMA actuator.

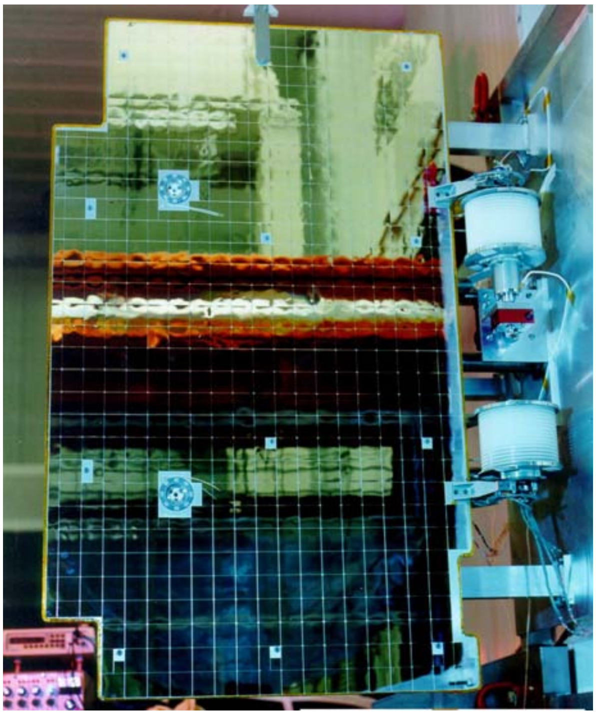


Figure 8. STENTOR Deployable Radiator

The Deployable Radiator One of the development driver of STENTOR Deployable Radiator project was the elementary qualification of heaters bonding on

SMA component. This assembly is crucial to guarantee the good actuation.

4.1.1.1.2. DELPHRAD studies

Late 1998, Alcatel Space, co-funded by the European Space Agency (ESA), started the development of a Deployable Lightweight High Performance Radiator (DELPHRAD). The 1200 W DR will be ground-tested by mid 2001 and is based on a SMA actuator for its deployment.

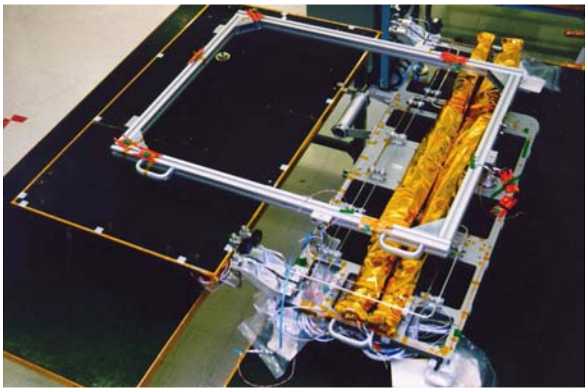


Figure 9. DELPHRAD Deployable Radiator

4.1.1.2. First studies for solar array application

The studies performed in 1999 and 2000 were performed just after STENTOR development, with STENTOR Engineering Model SMA. The objective was to analyze the applicability of SMA rod use for solar array deployment.
They mainly demonstrated that the SMA component inherited from the STENTOR development was under dimensioned for solar array application in the dynamically loaded braking operating mode.
Following these results, the SMA deployment study was reoriented by procurements of SMA components, with larger diameter.

4.1.1.3. ARTES activities for using SMA

In the early 2000s, ARTES activities were performed at SMA cartridge level, presented during 2005 ESMATS symposium.

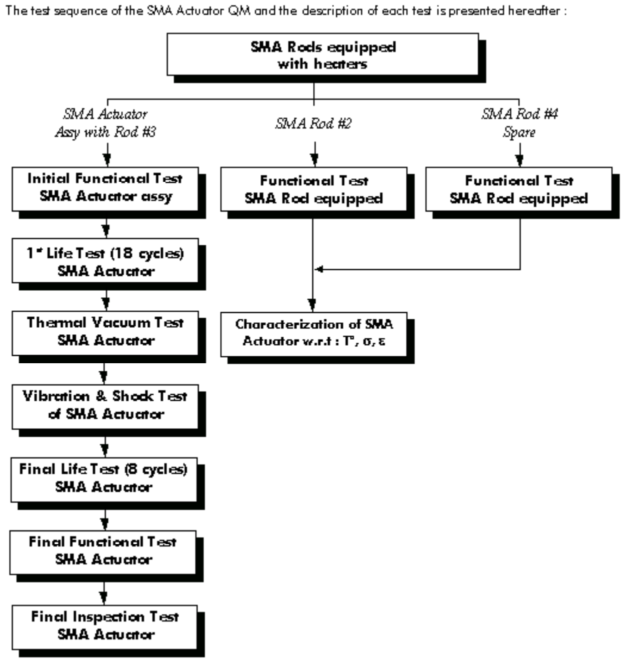


Figure 10. ARTES – SMA QM cartridge activities

A qualification test sequence including life time, vibrations and TVAC test was performed successfully on a SMA component of the same definition.

4.1.2. Development logic for solar array root hinge

The solar array root hinge has 3 levels of integration :

- SMA root hinge
- SMA cartridge
- SMA rod equipped

TAS has a high qualified heritage at SMA rod level mainly based on STENTOR and DELPHRAD Deployable Radiator activities.

ARTES activities performed in the early 2000s result in a qualification for solar arrays application of the SMA cartridge level.

SMA root hinge is based on the generic SPACEBUS root hinge adaptation (qualified and with a high flight heritage).

The qualification to perform aims to cover the upper level of integration : the SMA cartridge inside the root hinge. For example, life time test has not been done again in the frame of the telecom program.

4.1.3. Qualification test sequence performed

Qualification test sequence performed successfully is presented in the table hereafter.

MOTORISATION TEST AT SMA ACTUATOR LEVEL

ROOT HINGE ASSEMBLY

FUNCTIONAL TEST

VIBRATION TESTS

FUNCTIONAL TEST

THERMAL VACUUM TEST
hot case, cold case

FUNCTIONAL TEST

CARTRIDGE DISSASSEMBLY and EXPERTISE

Figure 11. SMA root hinge qualification test sequence

The critical tests of the qualification sequence are listed hereafter.

4.1.3.1. Vibration qualification test

Vibrations sequence to check that the SMA cartridge assembled inside the root hinge can sustain mechanical environment loads.

4.1.3.2. TVAC qualification test

Thermal vacuum ambient test aims to correlate thermal models (temperature homogeneity, thermistors measurement, …).

Thermal vacuum cold test aims to demonstrate that heating power is sufficient to deploy the solar array in worst cold case temperatures, with the minimum value of supply voltage.

Thermal vacuum hot test aims to check good health of heaters after deployment in worst hot case temperatures, with the maximum value of supply voltage.

5. DEPLOYMENT: ILLUSTRATIONS

On the following curves, the legend is the following :
- Angular position is in red
- Temperature is in green
- Heater voltage is in blue
- Torque is in purple
- Deployment status is in black.

5.1. DEPLOYMENT SEQUENCE AT SMA ROD LEVEL

The deployment sequence at SMA rod level is a good health check of the SMA after its first conditioning.
It consist with a deployment under a sufficient resistive torque in order to check its motorization capability.
Temperature starts to increase after the heaters are put ON. The heaters power is regulated on the rod temperature into a well chosen range. The load is applied before heating and the angle starts to move above 90°C.

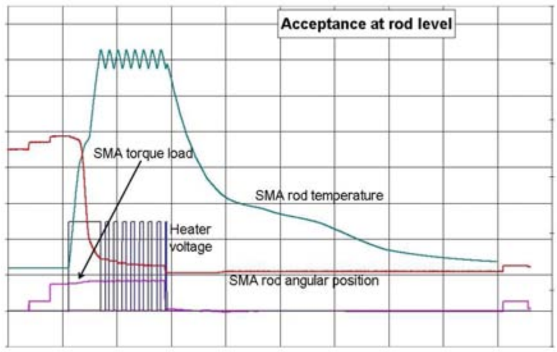


Figure 13. Motorization test at SMA actuator level

5.2. DEPLOYMENT SEQUENCE AT ROOT HINGE LEVEL

At root hinge level, the same type of curves is observed, without load. The difference is that the rotation is blocked after a 90° stroke and so the torque increases strongly while the heaters are ON. For simplicity reason, heating is driven by a duration (and not stopped by increase of the torque, for example). So, in order not to over stress the rod, a mechanical fuse is put in place. After the 90° stroke, the rod brakes the fuse and continue its stroke (angle information is no available any more). Then heating is stopped.

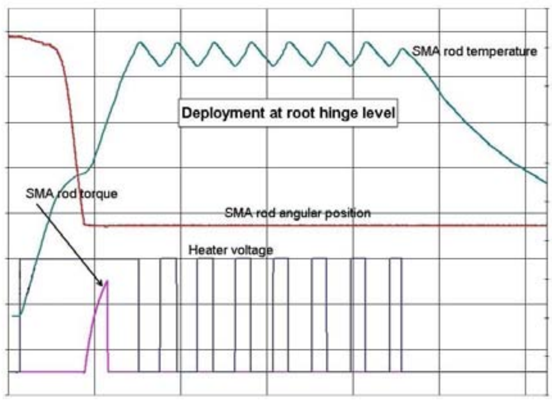


Figure 14. Ground deployment at root hinge level

5.3. DEPLOYMENT SEQUENCE AT SOLAR ARRAY LEVEL

The deployment sequence at Solar Array level is close to the one at root hinge level. It is detailed in the following chapters.

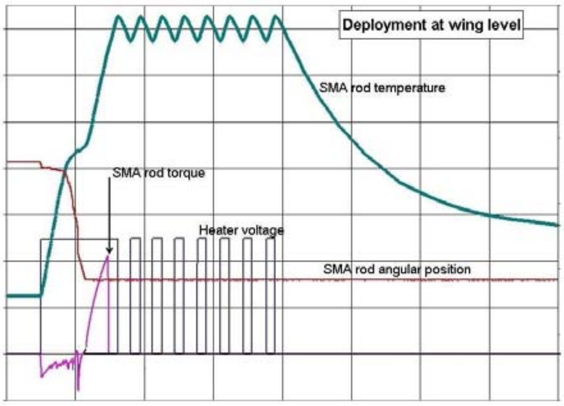


Figure 15. Ground deployment at Solar Array level

5.3.1. Deployment – Phase 1 : wing pyro release

First phase is the phase after the last Solar Array stowing point has been released, till the full damping of the wing (which tends to deploy by itself), before any actuation of the SMA rod.
The aim of this phase is to release the wing, which now applies a motorization torque on the SMA rod stiffness. Delay for heaters powering is set with sufficient margin to guarantee a null initial speed.

5.3.2. Deployment – Phase 2 : SMA actuation

Second phase consists in the actuation (heating power phase) of SMA rod till latching.
All along deployment, SA applies a motorization torque on the rod. The rod function is to regulate the speed deployment.
Nonetheless, the SMA rod is also designed to motorized the wing (see §5.1) in case the wing would have more friction than motorization torque.

5.3.3. Deployment – Phase 3 : SMA powered off

At the end of Phase 2, the 90° stroke is achieved.
Torque increases until the fuse breaking.
Then, after the nominal delay, heaters are powered off and the system cools itself.

5.3.4. Flight deployment

For flight deployment, the fuse has been removed: at the end of the stroke, the torque increases until a saturation value, and then falls down to zero during cooling.

6. LESSONS LEARNT

1. For this project, the solar array is an external sale. Therefore, the solar array is mounted on a non TAS platform. For ground testing, TAS standard tooling (thermal chamber, loading set-up) for SMA actuator conditioning are used out of TAS premises.

All the tools have been redesigned to ensure easy handling, transportation and use. A formal validation has been performed.

It was very important to anticipate as best as possible tooling activities.

2. Two SMA rods per wing are used to cover all the ground tests (TAS and customers): one for ground and one for flight.

All ground testing ran smoothly for this first application at solar array level, showing the easy use of such technology.

3. TAS heritage on SMA actuator mainly comes from STENTOR deployable radiator (1 panel deployed). A building block approach, at SMA actuator level, has been followed to equip solar array with SMA actuator technology.

The accomodation of the SMA actuator building block inside a root hinge has needed a significant engineering effort due to solar array specificities (number of panels, precision).

7. REFERENCE

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3. 1997 – Proceedings of the 7th European Space Mechanisms & Tribology Symposium, ESTEC, Noordwijk, The Netherlands, 1-3 October 1997. ESA SP-410. Deployment mechanism for STENTOR Deployable Radiator – P. KERHOUSSE and J. SICRE.

CONCLUSION

Thanks to a good and simple design concept, the solar array root hinge equipped with SMA actuator qualification test sequence was performed successfully.

This product proved its efficiency: light, cheap and easy to operate.

Satellite telecommunication equipped with THALES ALENIA SPACE Shape Memory Alloy root hinge is scheduled for launch in 2013.

This concept could be adapted for bigger solar array with a higher number of panels, or to much smaller appendices as telescope baffles.