SARA®21 - A New Rotary Actuator for Space Applications

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Abstract

SNECMA MOTEURS and CNES have recently qualified a new rotary actuator called SARA®21, intended for fine orientation of space mechanisms. This SARA®21 is a very small, light and compact actuator designed around a new super-flat CSD 20-160 harmonic drive. Its optimized and robust design allows for great performance such as sustaining high loads and rotating into position with an extreme precision of 0.00625°. All characteristics, from lifetime functional behavior to strength against mission environments like launch vibrations, were demonstrated with margins during the 2003 qualification test program. The investigation described in this paper confirmed the good behavior of the SARA®21 components.

Introduction

For many years, SNECMA MOTEURS has developed Solar Array Drive Mechanisms for spacecraft, and more than 40 satellites and space vehicles are now equipped with SNECMA SADM products. This past and present experience has borne fruit to a new product called SARA®21. In association with CNES who co-funded the program, SNECMA MOTEURS has designed, developed and qualified a highly efficient rotary actuator for space mechanisms.

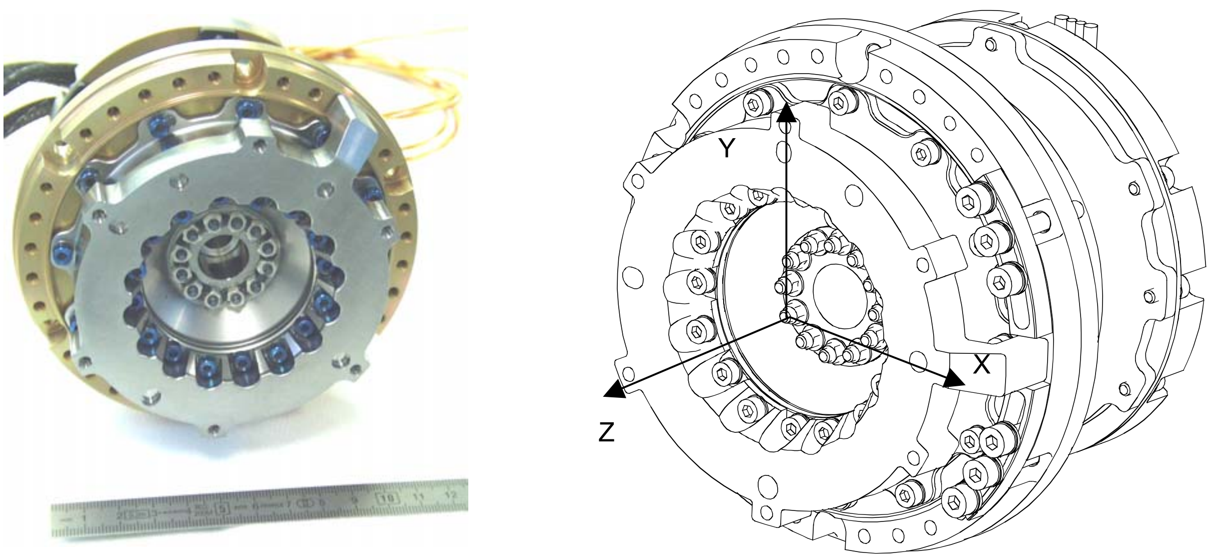

Figure 1. SARA®21 rotary actuator

It can be used for one or multiple-axis rotating mechanisms, such as for antenna accurate orientation, solar array deployment, or other specific applications. Its design has been highly optimized to minimize mass and increase compactness, mainly with the use of the new CSD 20-160 super flat Harmonic Drive component.

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Its performance has been thoroughly checked during a extensive qualification tests during 2003 that covered mostly functional, environmental and lifetime tests. The investigation performed has allowed control of the state of the new harmonic drive. Four flight models have already been delivered to our first customer ALCATEL SPACE for a scheduled launch date in 2004.

The SARA®21 function, design, performances and qualification test results are discussed more in detail hereafter.

Design Description

SARA®21 rotary actuator is intended for space mechanisms orientation as well as providing the associated positioning signal with extreme precision to the spacecraft on-board electronics. The SARA®21 main functions are:

- sustaining the mechanism: the actuator is able to withstand high loads and can absorb important environments throughout all lifetime phases, and in particular throughout orbit transfer phases
- rotating the mechanism: the actuator can rotate either in forward or reverse directions, and motion is not limited to a restricted angular zone. Rotation is also regular and highly precise, each step being equal to 0.00625°. Finally, it can operate over a great speed range.
- measuring the mechanism position: measurement is ensured by potentiometers that detect each motor step.

While fulfilling those required functions of the rotary actuator, providing low weight and compactness has been one of the major guidelines for designing the SARA®21. On the basis of its experience on SEPTA mechanisms, SNECMA MOTEURS has therefore chosen the CSD 20-160 Harmonic Drive as one of the key components of the rotary actuator. This element manufactured by Harmonic Drive® is composed of:

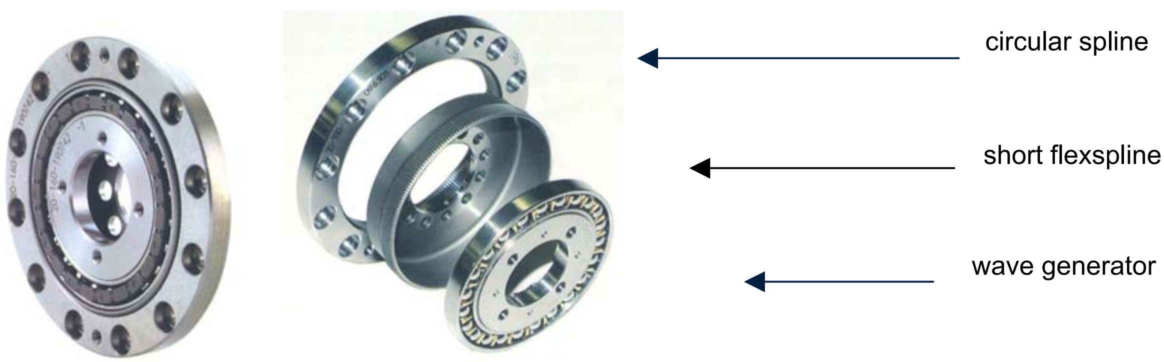

Figure 2. SARA®21 CSD 20-160 Super Flat Harmonic Drive

- a wave generator: a thin-raced ball bearing fitted out an elliptic plug serving as a high efficiency torque converter
- a circular spline: a solid steel ring with internal teeth
- a short flexspline: a flexible cylinder with external teeth and a flanged mounting ring

The complete element is a super-flat (type-20) harmonic drive gear box allowing a 160-reduction ratio. Its very small dimensions and high performances have allowed SNECMA MOTEURS to develop an optimized design for the SARA®21 in its entirety.

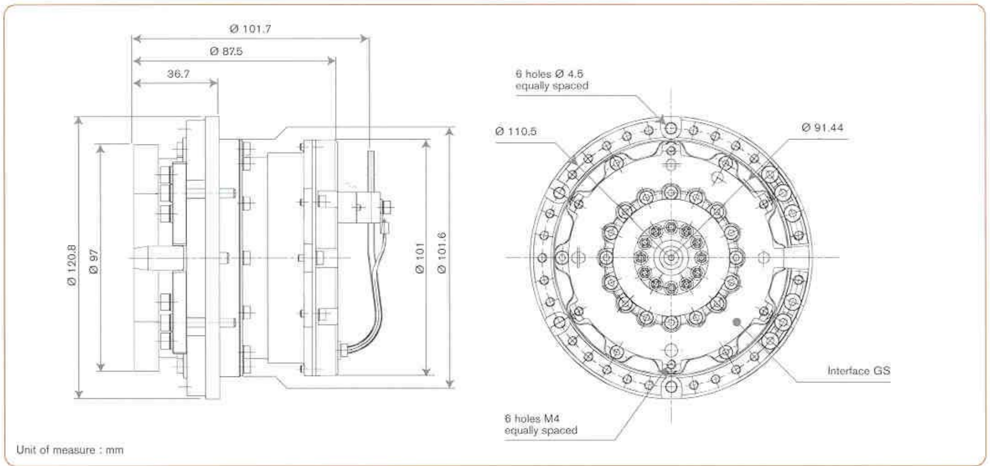

Figure 3. SARA®21 mechanical interface

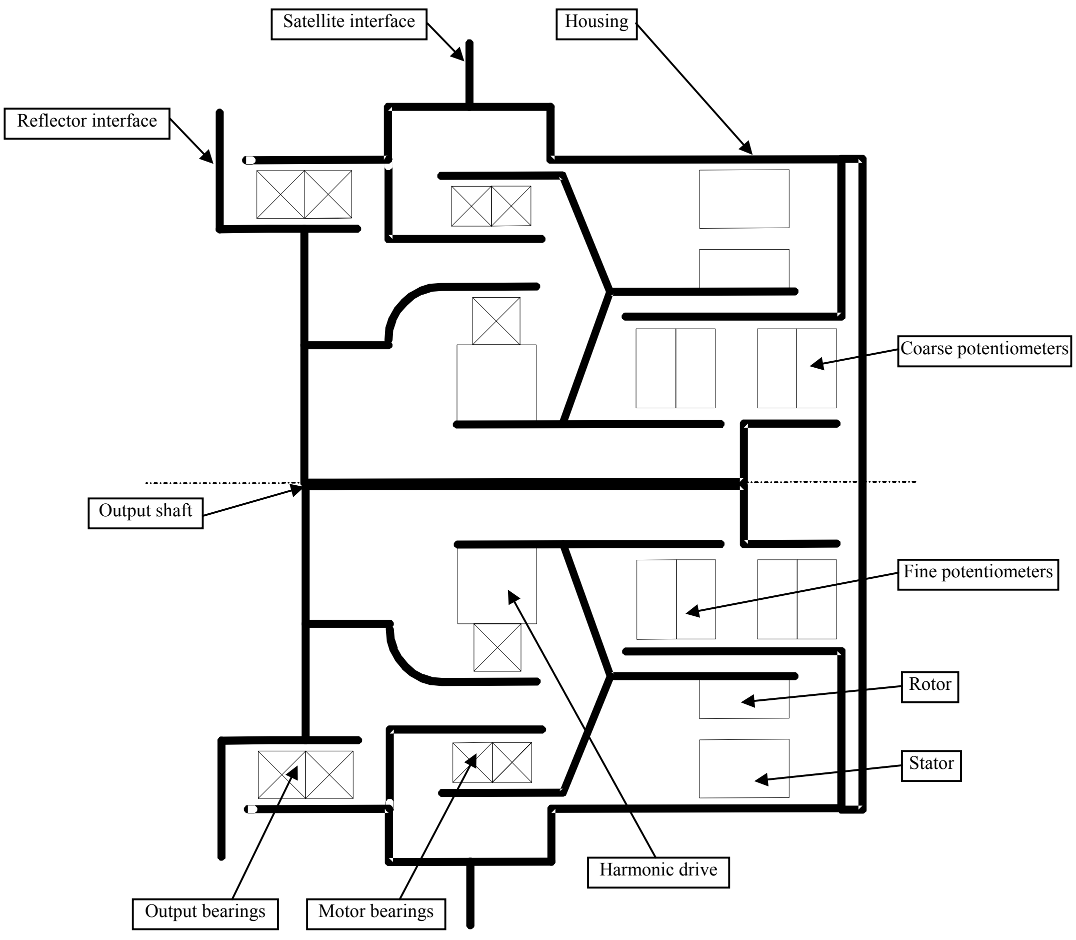

Figure 4. SARA®21 kinematic scheme

The other key components of the rotary actuator are:

- a two-phase permanent-magnet stepper motor with redundant stator windings that provides 360 steps of 1° per turn under 76 Ω. It is commanded simply by step-to-step mode, voltage-regulated (± 26 V) or current-regulated modes.
- duplex bearings that are lubricated and rigidly preloaded in order to give the SARA a great tolerance both to thermal gradients and vibration loads
- two fine and two coarse potentiometers (main and redundant) that provides a instantaneous measurement of the output flange angular position. The fine potentiometers are able to detect each motor steps, while the coarse potentiometers give non-ambiguous indication of which revolution the associated fine is on. Both fine and coarse have a full course of 357° (3° dead zone only).
- a housing that is composed of an aluminum alloy satellite interface, a titanium part that is glued the stator motor, an aluminum flange that the wires go through
- a titanium reflector interface

All are reliable components and some have even proven their efficiency on previous SEPTA® SNECMA MOTEURS mechanisms with very close configurations, such as the stepper motor (in its 285 Ω form), super duplex bearings and potentiometers.

Performance

The most important performance requirements for which the SARA®21 has been designed are:

Table 1. SARA®21 Performance

SPECIFICATION	UNIT	BASIS	DATA
Motor step angle	°	standard	1
Harmonic drive ratio	-	standard	160
Output step angle	°	standard	0.00625
Steps / revolution	-	standard	57600
Output shaft speed	step/s	maximal	200
	°/s	maximal	1.25
Axial stiffness	10^6 N/m	maximal	300
Radial stiffness	10^6 N/m	maximal	150
Bending angular stiffness	m.N/rad	maximal	50000
Torsion stiffness	m.N/rad	min / max	13000 / 25000
Axial load capability	N	maximal	10000
Radial load capability	N	maximal	8000
Flexion load capability	m.N	maximal	200
Power consumption (under 26 V)	W	nominal	10
Inertia capability	Kg.m²	maximal	200
Output torque	m.N	nominal	45
Holding torque	m.N	nominal	70
Detente torque	m.N	nominal	8
Non operating temperature	°C	min / max	-100 / + 100
Turn-on temperature	°C	min / max	-65 / + 95
Operating temperature	°C	min / max	-50 / + 85
Total mass	kg	nominal	1.8

Qualification Campaign

The SARA®21 has recently achieved an extensive qualification campaign during which the performances detailed above were verified and associated margins established with regards to our first customer ALCATEL SPACE operational requirements and specified environment conditions.

Following is a brief description of the most important tests the SARA®21 Qualification Model (QM) went through.

Functional tests

- Power consumption control
- Electrical controls: potentiometers or motor winding resistance and insulation
- Accuracy and output step size control + hysteresis / repeatability and linearity control
- Torque capability control
- Stiffness control (axial / radial / bending / torsion measurements) + combined loading tests

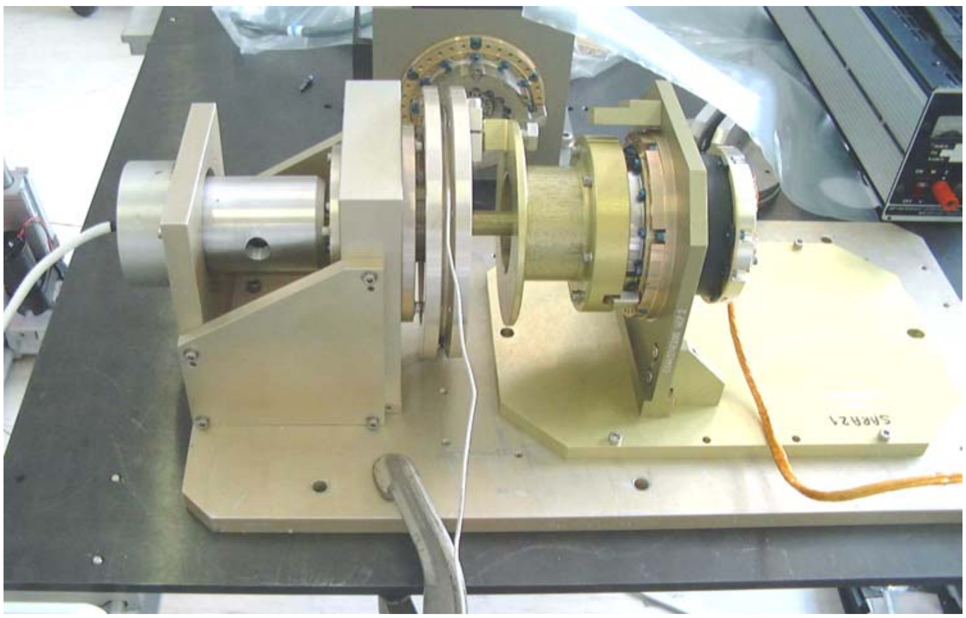

Figure 5. SARA®21 functional test set-up

Environmental tests

- Vibration tests: sine and random vibrations were performed along all three axes for 6 minutes, as well as torsion load vibrations along X-axis (Figures 6 and 7). The QM survived the vibrations with all frequencies superior to 385 Hz when vibrated with a 3-kg yoke mass.

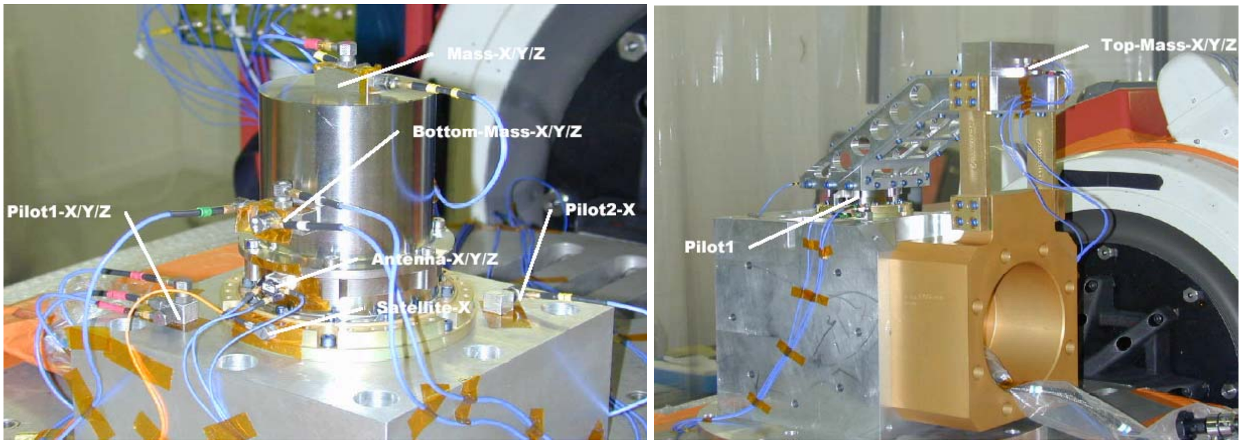

Figure 6. SARA®21 vibration test set-ups
(centered mass for sine and random + deported mass for torsion load)

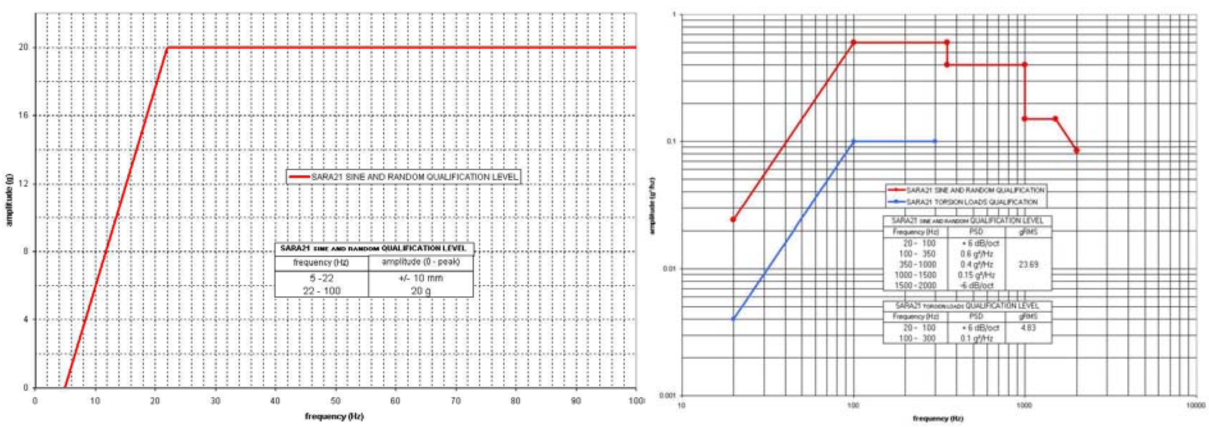

Figure 7. SARA®21 sine and random vibrations levels

- Shock test: Pyrotechnic shocks were simulated along all three axes at the levels shown in Figure 8. The QM survived those shocks without failure; performances were nominal after the tests.

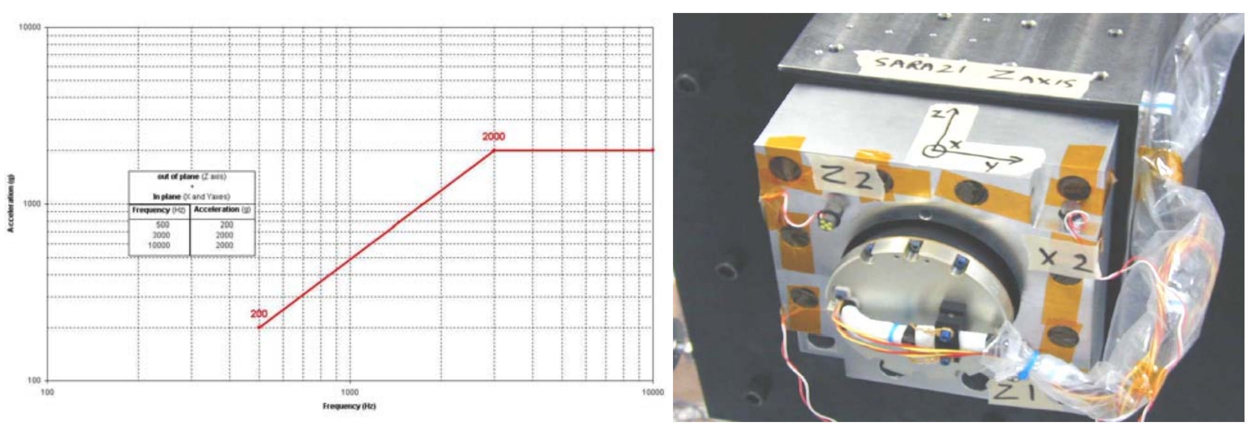

Figure 8. SARA®21 shock level and test set-up

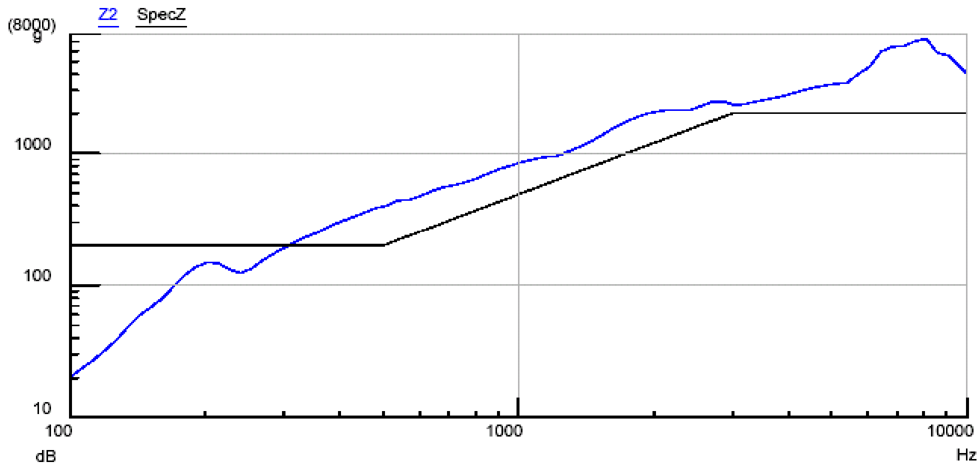

Figure 9. SARA®21 shock response spectrum along Z-axis

Thermal tests: Thermal tests were performed in ambient and vacuum conditions at the temperature levels given in Table 1. The QM survived those thermal cycles nominally. Temperature did not over pass 100°C for the housing and interfaces, nor 120°C for the winding. Regular functional tests such as power consumption controls, motorization margins and motor capability tests, were performed without detection of any degradation.

Figure 10. SARA®21 thermal vacuum life test set-up

Lifetime test
Lifetime test were performed in various thermal and vacuum conditions:

- ambient conditions cycles : 75 complete revolutions
75 cycles on 4°
1500 cycles on 0.2°
- vacuum conditions cycles : 20 complete revolutions
750 cycles on 4° (250 at 85°C, 250 at -50°C, 250 at 20°C)
975 cycles on 18° (325 at 85°C, 325 at -50°C, 325 at 20°C)
75000 cycles on 0.2° (25000 at 85°C, 25000 at -50°C, 25000 at 20°C)
- additional vacuum cycles : 50000 cycles on 0.2° at 20°C
20 cycles on 13.5° at 20°C

The second vacuum cycles were performed in addition to the scheduled qualification tests in order to gain more confidence within the SARA®21 by proving very comfortable lifetime margins.

Investigation

After completing the tests, an investigation was initiated to analyze the condition of the various components of the SARA®21 QM after completing the qualification tests.

The mechanical parts show very good condition after the qualification tests with only very slight fretting traces apparent upon some parts because of qualification vibration levels.

The harmonic drive has been fully disassembled and inspected. The lubricant was still present in nominal quantity without any specific marks, evolutions or loss. The geometry of the different parts was nominal without traces of load damage or degradations.

Figure 11. SARA®21 QM CSD 20-160 Harmonic Drive after qualification tests

This demonstrates the ability of the new CSD 20-160 Harmonic Drive to sustain very high loads with margin. Therefore, this component is very attractive for space mechanisms with a very precise position of the three harmonic drive parts (given by the bearings) and with a good lubricant.

The stepper motor was controlled and is fully operational with its nominal performance.

The potentiometers were checked too; only some slight marks were present on the tracks due to vibration loads for coarse potentiometers (local marks) and due to extended lifetime for fine potentiometers (circular marks). In each case, wear of the track / cursor was nominal without impact on signal.

Conclusion

The SARA®21 ability to sustain and position a reflector with extreme precision was demonstrated throughout a complete qualification test program during which all of a standard mission phases were taken into account to establish the environment conditions and levels of the tests.

The SARA®21 performance results were as expected and the investigation that followed on the qualification model has confirmed its small and compact design has been correctly sized.

Models are now ready to be integrated upon spacecrafts, and will soon be flight proven.