SENTINEL-1 SAR DEM DEPLOYMENT MECHANISMS RECOVERY

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ABSTRACT

The Sentinel-1 mission is encompassed in the Copernicus programme and each of the satellites carries a C-band Synthetic Aperture Radar (SAR) to provide an all-weather, day-and-night supply of imagery of Earth's surface.

This paper is prepared to inform of the development of the Deployment Mechanisms (DEM) of the SAR that are launched packed in stacks and have to deploy in orbit.

SENER has designed, manufactured, integrated and tested 8 deployment mechanisms (DEM), 4 for Sentinel-1A, that were successfully deployed some hours after it was launched in April 2014 and another 4 for Sentinel-1B that is envisaged to be launched next year 2016. Previously, GAIA satellite was launched in December 2013, the Sunshield that was successfully deployed after launch, was equipped, as the DEMs, with two Sener's Harmonic Drive Rotary Actuators (HDRA's). Hence, SENER HDRA actuators have now the flight heritage of six units.

Each antenna consisted of 5 stacks (named A to E panels) that are stored around the satellite and deployed once in orbit as per Fig.1:

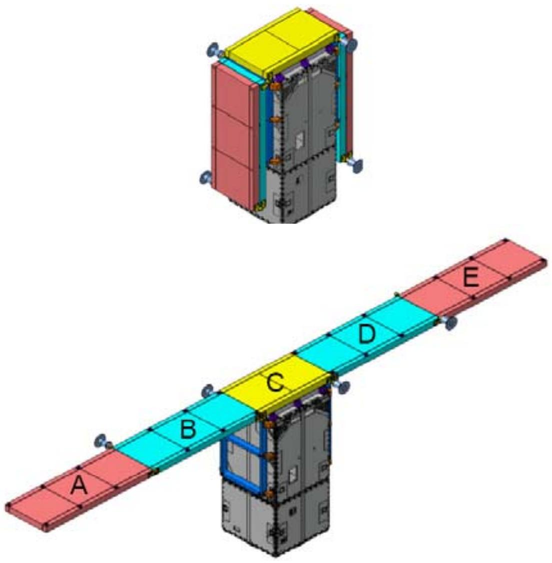

Figure 1.SAR in stowed and deployed configuration.

1. INTRODUCTION

Each DEM provides two different functions:

- Deployment: relative rotation of the panels from the launch configuration to the antenna operational one.
- Deployed preload: provide a compressive force between each of the two pairs of ICPs, locking panels rigidly after deployment.

So, the main constituents of the deployment mechanism (DEM) are:

- Deploying Hinge Mechanism (DHM)
- Deployed Preload Mechanism (DPM)

SENER developed a similar DEM mechanism for ENVISAT ASAR antenna, although the way in which the panels were stowed is different from the configuration selected here. In ASAR the five panels were stowed one above the other in one stack and therefore the overall antenna is stowed in one block. In Sentinel-1 SAR antenna one panel is fixed at the top of the spacecraft and the other four panels are stowed in pairs at both sides of the Spacecraft. The comparison of both deployment sequences is shown in Fig.2.

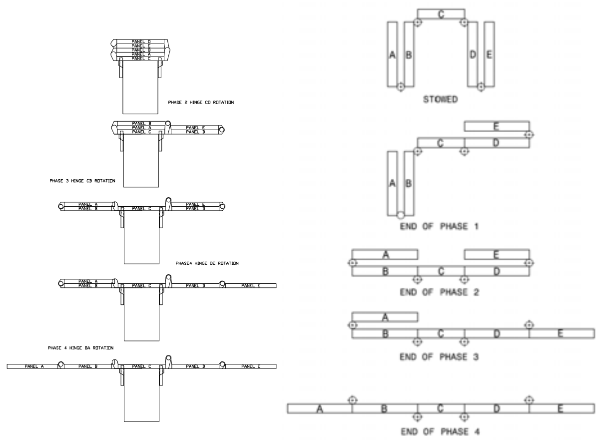

Figure 2. ENVISAT & S1 Deployment sequences.

One advantage of the configuration selected for the SAR antenna deployment is that the four hinges are equal or symmetrically equal.

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2. DEM DESIGN OVERVIEW

2.1 DHM Design

The DHMs are composed by two different subassemblies, The Active Hinge Assembly (AHA) and the Passive Hinge Assembly (PHA). A total of eight DHM have been manufactured for the Sentinel-1 A and B. Fig. 3 shows the four DHMs of the S1-B.

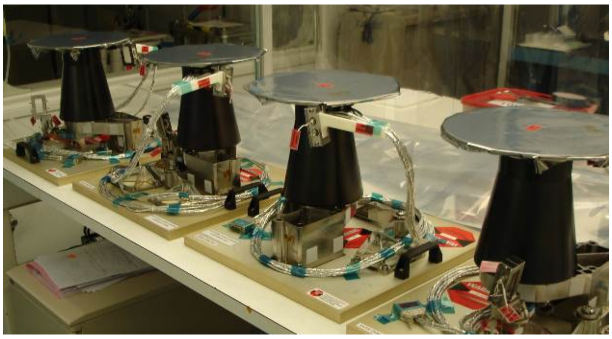

Figure 3. S-1B DHMs

The AHA includes all the active components of the hinge providing deployment motion from one side of the hinge line.

One of this parts is the actuator HDRA developed by SENER, that provides relative rotation between panels, it is composed by a stepper motor and harmonic Drive reductor of 160:1 ratio. Heaters, thermistors and potentiometer (rotation monitoring) are mounted on it. Fig. 4 shows a photograph of the HDRA. The assembled HDRA is an evolution of the described in [1] including main and redundant position sensors (potentiometers). Thus, a delta Qualification was performed on the HDRA.

Figure 4. SENER HDRA Actuator

The HDRA is joint to the fixed and moving panels by means of titanium brackets. It is also equipped with a harness routing system designed to minimize the resistive torque due to the harnesses motion during the deployment.

Whereas, the PHA is the second rotation point defining the hinge line. It is composed by one fixed and one moving brackets joined by angular contact ball bearings proving the required stiffness and allowing the smooth rotation of both Panels.

Fig. 5 shows one AHA and one PHA of the S-1B BA/DE hinges.

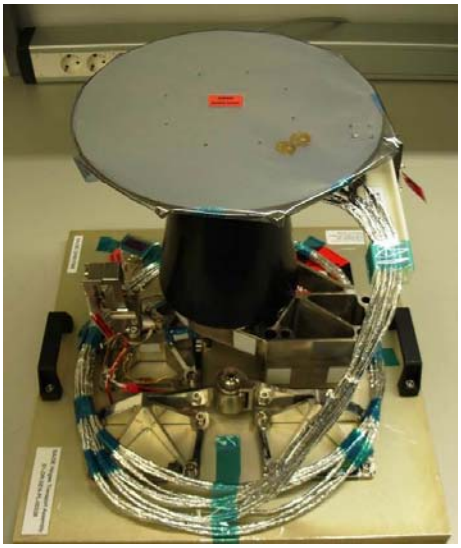

Figure 5. S-1B BA/DE DHM SN8

2.2 DPM Design

The DPM provides the force to joint adjacent panels to get a structural continuity. Each DPM includes two latches, one is the mirror of the other. A preload of around 1000 N is provided by each latch with a release force of only 14 N.

The DPMs are based on the design developed for the ENVISAT ASAR Deployment Mechanism. Further description can be found in [2]. Slight modifications to increase microswitches reliability have been implemented. Fig.6 shows the 10 latches manufactured for the S-1B satellite (two per each of the four hinges and two spare units)

Figure 6. S-1B DPM

The DPM´s are divided in two parts, the active one is mounted onto the fixed panel, whereas the passive one is mounted on the moving panel. Once the moving panel is reaching its final position the passive part activates a trigger that release the spring just after it is captured by a hook located in the active part. The pulling load of the spring preload two Interpanel Contact Points (ICP) in each panel corner. Fig. 7 shows a DPM couple, where both latches are symmetrical one to the other.

Figure 7. S-1B DPM

A total of ten DPM (twenty latches) have been manufactured for the Sentinel-1 A and B satellites.

3. DEM VERIFICATION CAMPAIGN

There are different levels of testing, at component level for the HDRA, at subassembly level for DHM and DPM and at DEM level. Fig. 8 shows the verification test flow.

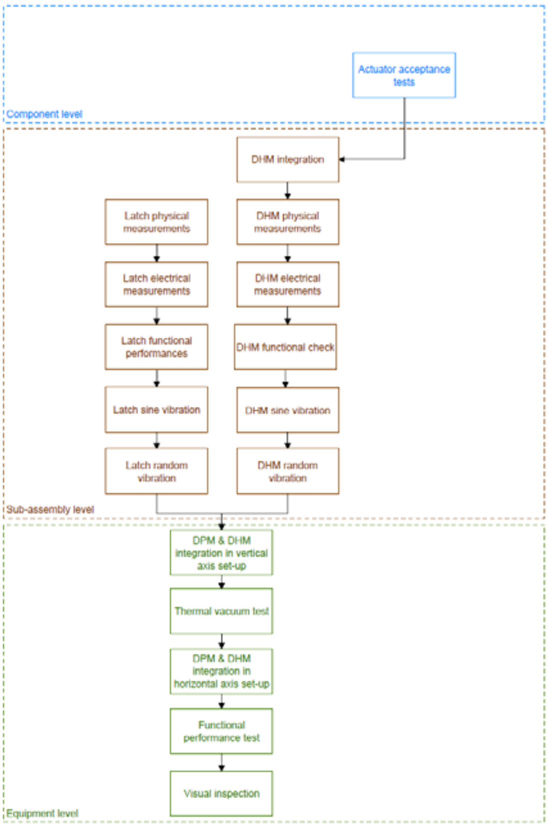

Figure 8. Verification Test Flow

The test at component and sub-assembly levels includes functional verification of the units and vibration tests. Fig. 9 shows the HDRA stiffness and functional test set up, Fig.10 shows the latches functional test performed to measure the latching resistive torque (shown in Fig. 11) and the Fig. 12 shows the DHM vibration test.

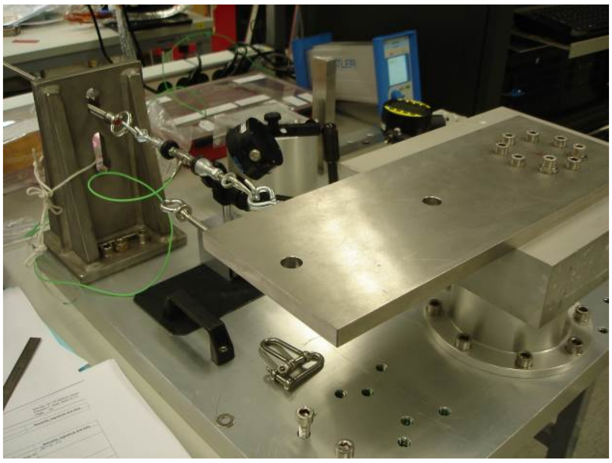

Figure 9. HDRA Stiffness & Functional test set up

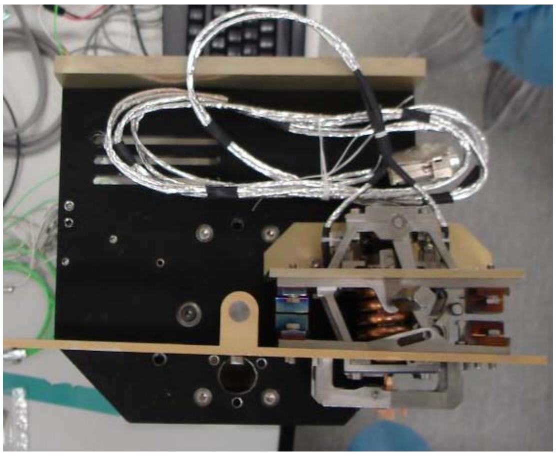

Figure 10. DPM functional test set-up

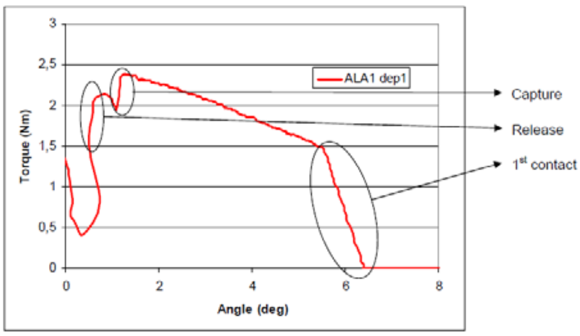

Figure 11. DPM Latching torque

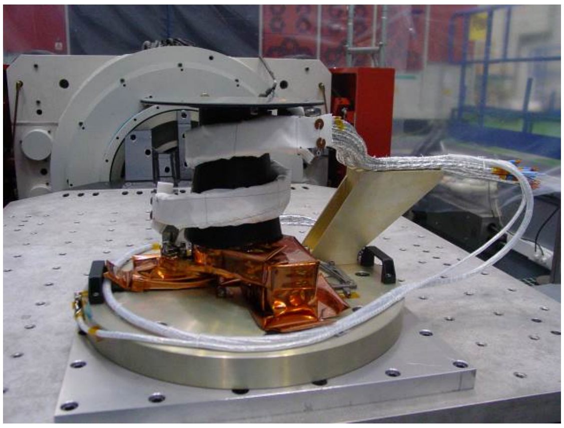

Figure 12. DHM Vibration test

After each of the sub-assembly is verified, both DHM and DPM are integrated together to perform the TV test and the functional testing. This functional testing includes deployments with representative inertia that are more deeply described in the section 4. Fig. 13 shows the TV set up for the DEM PFM.

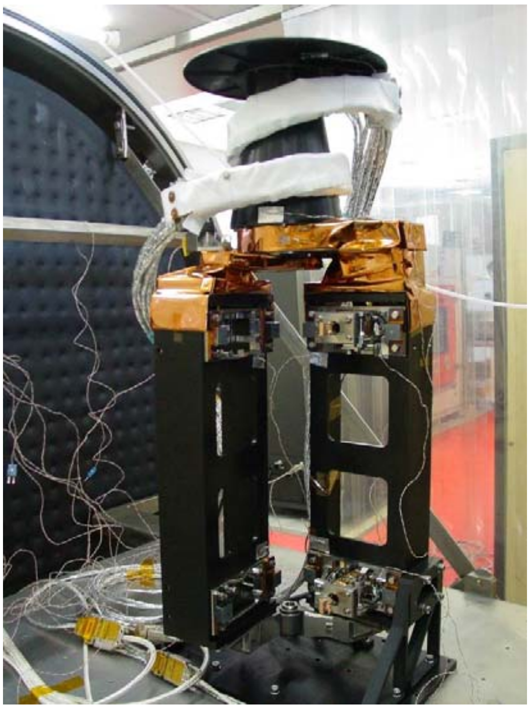

Figure 13. DEM TV test

4. DEM FUNCTIONAL TESTING

4.1 Functional Test-Rig Description

One of mayor challenges found during the AIT campaign is the development of the functional test rig with the representative inertia of the panels to be deployed. The total moment of inertia during in orbit operation is 370 kgm^2 for the deployment of the outer hinges (BA and DE) and 820 kgm^2 for the inner hinges (CB and CD). To simulate this huge inertia keeping under control the resistive torques, a 0-g set-up has been developed, the main requirements are:

- Representative of real inertia.
- Minimize the loads induced to the mechanism during deployment simulation.
- Representative of real panel stiffness.
- Capability of turning a minimum of 90º.
- Parasitic torque less than 1 Nm.

The main components of the test rig are; the support structure, the inertia frame which has been designed considering the height limitation of the clean room and the required 90º rotation while providing a total inertia of 868 kgm^2 with a mass of 490 kg; the turning mechanism, including the low stiffness springs to simulate the 0-g conditions and a controllable eccentricity allowing a 50 mm adjustment of the rotation axis and the centre of gravity (CoG); and fixed and moving panel dummies which include the IF to the DHM and representative of real panel stiffness.

Thus, the main characteristics of the 0-g set-up are:

- Optimized mass distribution along the inertia frame.
- Inertia frame hanging from low stiffness springs.
- Capability for alignment of frame rotating axis.
- Capability for mass balancing in order to place the CoG of the inertia frame as close as possible to the rotating axis.
- Stiff enough to minimize the deformation of the frame due to gravity effect during the complete deployment.

Three main sources of parasitic torques and forces have been identified:

- Parasite torque due to the CoG not being exactly in the rotation axis, which can be compensated by counterweights.

- Parasitic torque due the change of the shape of the frame due to deformations caused by its own weight and hence the displacement of its CoG. The variation of the position of the CoG of the frame between horizontal position and when turned 45º is around 0.1 mm leading to a torque due to of 0.29 Nm

  The effect of this parasite torque can be reduced with the eccentric bushings adjustment with an accuracy of 0.1 mm, the torque associated would be 0.32 Nm

- Parasite torque of 0.04 Nm caused by the friction in the bearings.

The torques caused by friction in bearings and by the change of the shape of frame deformed are unavoidable. The total parasitic torque must be under 1 Nm. Tab.1 shows the parasitic torque budget.

Table 1 0-g test rig parasitic torque sources

Part	Torque (Nm)
Balancing	0.33
Frame due to gravity	0.29
Frame due to ecc. acuracy	0.32
Friction	0.04
Total	0.98
Req.	1

4.2 Test Rig Adjustment

The alignment process is of paramount importance to perform a representative test and needs to be done for each DEM Functional test.

The first step is to balance the mass of the rotating elements before including the inertia frame by means of the counterweight system. Once it is balanced, the height of the hanging elements is adjusted until fixed and moving panel dummies are at the same height and the latches are closed. This allows mounting the DHM without inducing any load on them as the spring are holding the mass of the moving parts.

The Axis of the both parts of the DHM, which are the AHA and PHA, are aligned by means of flat mirrors located perpendicular to the axis of each element and with a cross marked in the axis. This alignment is done with a theodolite. After the adjustment of the test set-up, 5 deployments are performed without inertia.

The second part of the test is performed with the inertia frame assembled. The frame is balanced in terms of mass distribution and CoG position variation.

Then, the parasitic torque is measured and in case the required value is not reached, an iterative process is followed repeating the previous steps. Once it is achieved, the DHM output brackets are assemble and another five deployments are performed.

4.3 Test results

During the test, the following parameters are measured:

- Deployment duration
- ICP Preload
- Shock Response during latching
- Starting torque at different speeds
- Torque during latching sequence
- Sudden stop test at different speeds to verify that in case there is a sudden switch off of the motor, the HDRA is capable to maintain the position.

As the same test rig is used for the two possible configurations (BA/DE and CB/CD), the results obtained for the BA/DE are extrapolated to the real inertia values they will move. Fig.14 and Fig.15 shows the test set-up for the deployments without and with inertia.

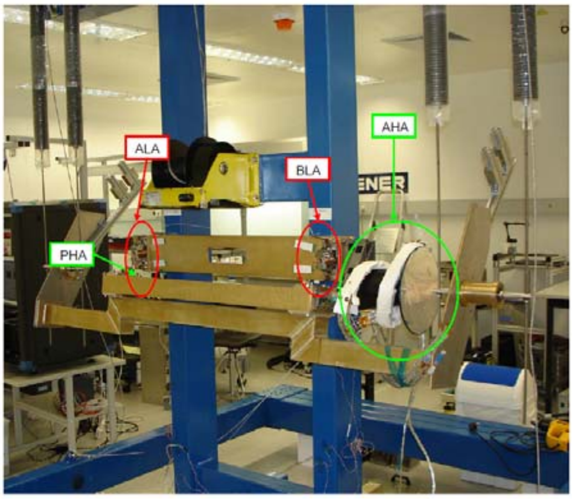

Figure 14. DEM PFM mounted onto functional test fixture (without inertia).

Figure 15. DEM PFM mounted onto functional test fixture with inertia frame

The test result are within the requirements for all the eight tested DEMs. As an example, the results of the DEM PFM are presented in the paper.

Tab.2 shows the deployment duration and Preload distribution in the ICPs. Fig. 16 shows the SRS of the accelerometer output recorded during latching shock

Table 2 Summary of test results for deployments of DEM PFM

Deployment	Inertia	Duration (s)	Total Preload (N)	Miminum ICP Preload (N)
1	No	1188	2010	470
2	No	1187	2000	455
3	No	1187	2005	450
4	No	1187	2005	445
5	No	1187	2010	445
6	Yes	1187	1975	420
7	Yes	1187	1965	410
8	Yes	1187	1970	410
9	Yes	1187	1970	405
10	Yes	1187	1950	405
Req.	N/A	<22 mins	N/A	>300

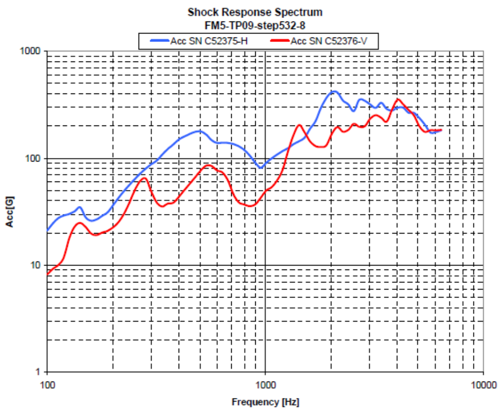

Figure 16. SRS during latch with inertia

Tab. 3 summarizes the results for the sudden stop tests. Fig. 17 the starting torque at different speeds.
The results fits with expected values considering the inertia involved on the deployment. The HDRA is capable to maintain the position if it is suddenly switched off.

Table 3 Summary of test results for sudden stop tests of DEM PFM

Test	Motor Speed (Hz)	Starting torque (Nm)	Stopping angle (º)	Deploying freq. (Hz)
1	14	3.7	<0.5	0.44
2	14	3.7	<0.5	0.44
3	26	6.7	<0.5	0.44
4	26	7.1	<0.5	0.43
5	48	13.7	<0.5	0.46
Req	-	N/A	<2	N/A

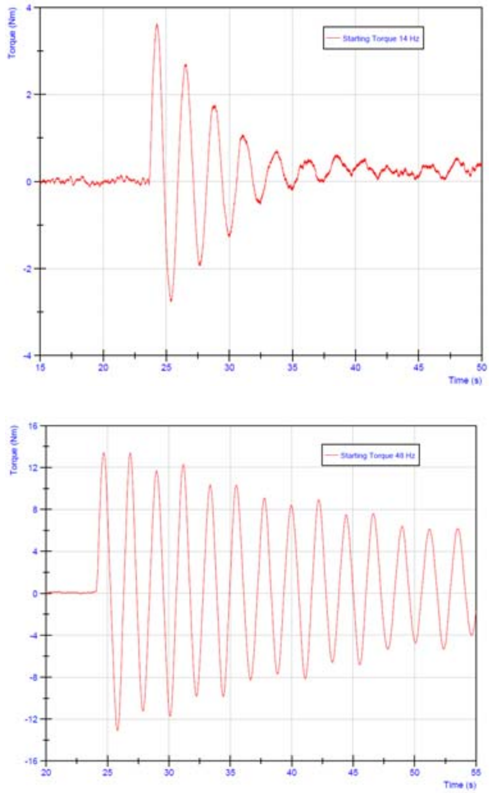

Figure 17. Starting torque during DEM PFM deployment with Inertia at 14 Hz and 48 Hz.

5. POTENTIOMETER FAILURE DURING INSTRUMENT AIT CAMPAIGN

5.1 Problem description

The qualification and acceptance tests campaign at SENER level was successfully completed. However during the AIT phase at instrument level, after vibration test, a malfunction of the potentiometer of the FM3 unit was detected. During the deployment of the second wing of the SAR, the potentiometer of the DEM FM3 was reading a constant value, instead of a progressive variation in the measured resistance.

A first stage of the investigation was an in-situ inspection of the unit mounted in the Instrument. The outcome of the investigation was that the potentiometer shaft was not rotating with the output of the actuator. As the repair of the unit was not possible in situ, it was disassembled from the SAR substituted by the FM7.

From the mechanical point of view, SENER actuator connects the rotating part of the potentiometer to the output shaft of the actuator via the pot shaft. This shaft was connected to the potentiometer rotor by means of the preload of a M12 nut (pot nut) and on the other side to the actuator output flange by means of a M3 screw (pot screw), a sketch is shown in Fig. 18.

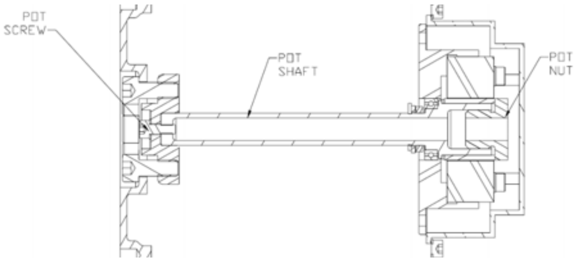

Figure 18. Sketch of the Potentiometer assembly.

A second part of the investigation was performed at Sener, where we confirmed that the root cause of the failure was the untightening of the nut due to the lack of fixation means. The adhesive applied was so scarce that there was no joint between nut and shaft.

The repair of FM3 was carried out with partial disassembly of the actuator including the potentiometer adjustment, nut gluing and an acceptance test campaign included physical, functional, vibration and thermal cycling tests.

Being the root cause of the failure an assembly procedure error, all the units required to be inspected and in some cases reworked to prevent possible failures.

5.2 S-1A DHMs Inspection and rework procedure

The availability of spare pot shaft, shown in Fig.19, allowed the development of the inspection and adhesive application procedure. Specific tooling was required, as the use of a thin endoscope for the inspection through the pot screw hole to avoid dismounting any part of the DHM and a syringe with a long dispenser to apply the adhesive, shown in Fig.20.

Figure 19. Investigation with pot shaft spare part.

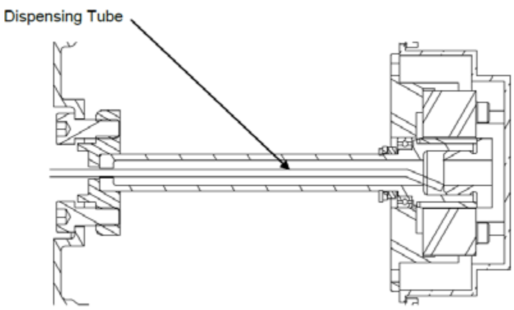

Figure 20. Sketch of the dispensing tube.

The units FM1, FM2, FM4 and FM7 were inspected and reworked in Customer clean room as the units were already integrated at instrument level and a disassembly of them would have led to the loss of SAR alignment. The developed procedure was compatible with that configuration as that area of the actuator was available just removing the MLI.

All the inspection and rework activities were performed through the pot screw hole, see Fig.21. The adhesive was checked by means of the endoscope and additional adhesive was applied by means of the syringe and the dedicated dispenser when required.

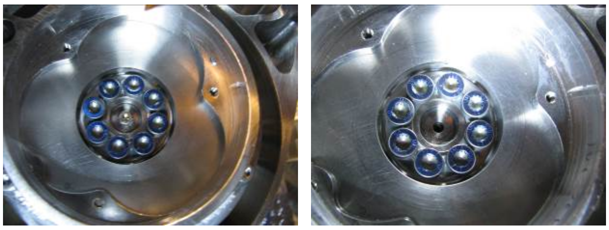

Figure 21. HDRA with the M3 pot screw assembled (right) and removed (left).

5.3 S-1B DHMs Inspection and rework procedure

Three other three units (FM5, FM6 and FM8) of the S-1B, which were not assembled yet onto the SAR, were sent back to Sener for the inspection and, if needed, for their rework.

The same procedure as for the previous models was followed. Fig.22 shows the results of the inspection of the FM6 before and after the rework, the quantity and distribution of the adhesive did not fit the requirement and an additional adhesive drop was applied.

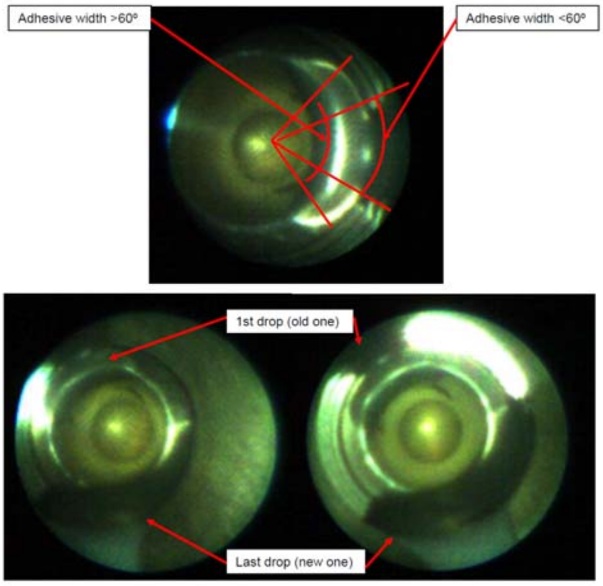

Figure 22. Results of the inspection for the FM6 before rework (up) and after (down).

6. CONCLUSIONS

The DEM Mechanism is based on the ASAR Deployment Mechanism developed by Sener for ENVISAT. However, several challenges have been faced by Sener during the development of the S1 DEMs. The main one was the substitution of the USA actuator by the one developed by Sener (HDRA) which finally demonstrated its capabilities by the successful deployment of the DEM's and in-flight correct behaviour of the potentiometers of the S-1A DEM's.

The failure of the pot nut fixation obliged SENER to develop a rapid inspection and rework procedure in all the S1 units. For the potential upcoming units, a inspection point has been established in the assembly procedure to check during the assembly process the proper application of the fixation adhesive.

On the other hand, the development of zero-g test rig with the representative inertia has allowed the verification of the units and its capabilities before the integration on the antenna.

7. REFERENCES

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