HIGH LOAD LOW SHOCK RELEASE UNIT (30 kN)

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ABSTRACT

The paper presents a non-explosive, resettable High Load Low Shock Release Unit (LSRU) with a maximum preload of 30 kN. It provides a standardized electrical interface - compliant to Alphabus and Eurostar3000 satellites, releases within less than 100 ms and produces release shocks of maximum 500 g's (SRS) at 4 kHz. The release principle is the dissipation of tensile preload by conversion into rotation, providing a smooth but quick preload relief. The LSRU is fully resettable, it contains almost no consumable items and can be used multiple times. Each reset can be executed within seconds by only a few hand movements.

The unit is ITAR-free and available on the European market.

1. FUNCTIONAL PRINCIPLE

The main part of the LSRU (Low Shock Release Unit) is a planetary roller screw comprising a threaded spindle engaged with a nut containing rollers. The thread of the spindle is a non-self locking multiple thread with low friction. A small axial force applied to the spindle induces a rotation of the nut body and a smooth disengagement of the spindle (see *Figure 1-1*).

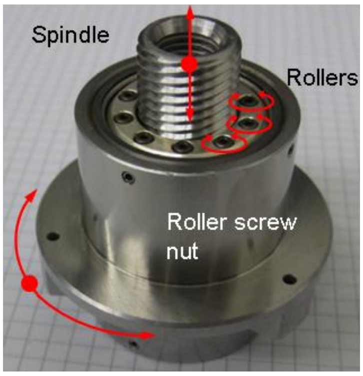

Figure 1-1: Roller screw assembly

In the LSRU housing the roller screw is supported by an axial ball bearing carrying the load and a radial needle bearing acting as guidance bearing.

The locking and unlocking of the roller screw is realized by a lever, engaging a cog into a groove in the rotational counterpart (rotor). This locking lever is spring-loaded and is pivoted on one end in the LSRU housing. It is actuated by a redundant system of magnetic actuators. *Figure 1-2* and *Figure 1-3* show cross-sectional and bottom views of the LSRU.

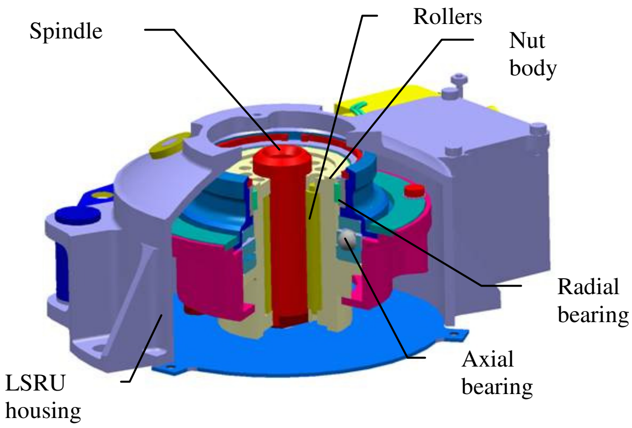

Figure 1-2: Cross-sectional view of LSRU

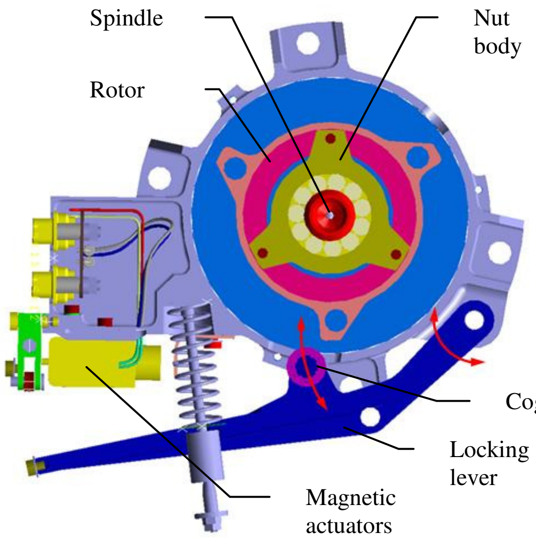

Figure 1-3: Bottom-view of LSRU

In non-operational mode the roller nut is locked. The upper end of the spindle is attached to the (tensile) load which is to be released. The lower end of the spindle is engaged with the locked roller nut. For release actuation one of the electromagnetic actuators is activated,

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retracting a pin of a spring loaded bracket system. The bracket tilts and releases the spring loaded locking lever which unlocks the roller screw. The preload induces the rotation of the roller screw nut body leading to a disengagement of both members and a release of the load.

The dissipation of preload energy by rotation admits a smooth load release with a low mechanical shock.

In order to ensure a safe release, a pull out spring is to be used, providing sufficient axial force over the entire thread engagement length. The pull out spring is not part of the LSRU.

Figure 1-4 shows a view of the LSRU with its main components in unlocked condition.

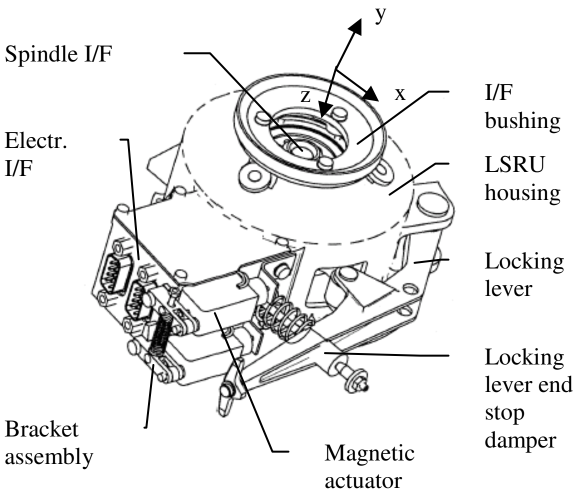

Figure 1-4: LSRU in unlocked condition

2. PURPOSE AND TECHNICAL DATA

The LSRU is specifically designed to hold down a stowed solar array during satellite launch and release it in orbit for deployment. The tensile hold-down (HD-) force is acting on a HD-pin - which is connected to the LSRU spindle - versus a bushing stack which is supported by the LSRU housing (see *Figure 2-1*). The bushings are part of the solar array panels. After release actuation the HD-pin (with LSRU spindle) is disengaged from the LSRU and is retracted to the outermost panel, driven by the pull out spring on top of the HD-stack. For each solar array wing, several release units are used.

The technical properties and interface dimensions comply with the requirements of Eurostar3000 and Alphabus solar arrays. Nevertheless the LSRU can be used for any other release purpose such as e.g. satellite separation, payload- , antennas release etc.

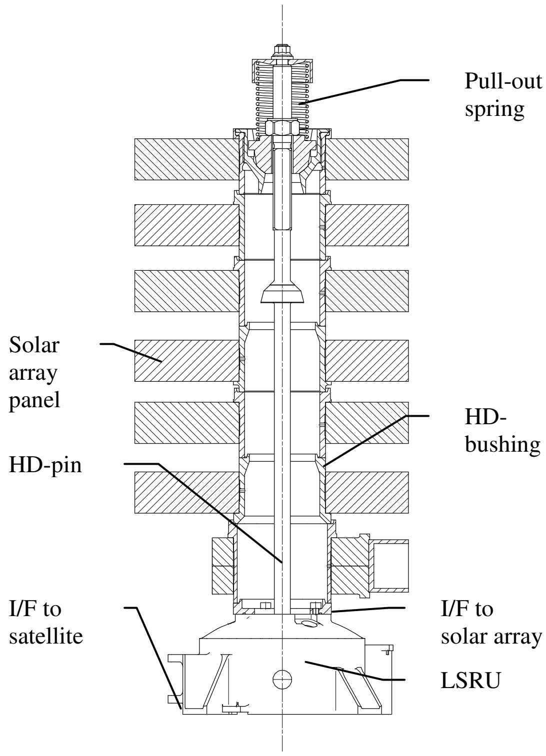

Figure 2-1: Cross-sectional view of integrated HD-stack (Alphabus solar array design)

Technical Properties

- Nominal preload:	30 kN
- Max. preload (proof load):	33 kN
- Min. preload (over full stroke):	100 N
- Typical release time at ambient:	< 1 s
- Misalignment capability (half cone):	1.4 °
- Shock output (typically):	500 g's @ 4 kHz
- Qualification temperature range (op.):	- 95 °C / + 120 °C
- No. of actuations before flight:	10
- Mass:	900 g ± 5 %

Mechanical interface

- LSRU footprint:	60 x 84.95 mm pattern (f. M6 bolts)
- LSRU height:	53.5 mm
- Spindle I/F	M 10 x 1.25
- Max. interface loads:	F_x = 6000 N F_y = 6000 N F_z = 4400 N M_x = 150 Nm M_z = 350 Nm

Electrical activation interface

The LSRU can be activated either by a voltage controlled or a current controlled interface (preferred). The interface characteristics are given below:

- Activation voltage (voltage controlled I/F): 21.3 V ± 1.1 V
- Pulse duration: 22 s ± 1 s

- Activation current (current controlled I/F): 0.7 - 0.9 A
- Pulse duration: 40 ms

After each activation the LSRU can be easily reset by a few hand movements.

3. QUALIFICATION PROGRAMME

The LSRU was qualified for Alphabus and Eurostar3000 solar array requirements. The qualification programme comprised testing of 3 units which had been subjected to different test sequences. The complete qualification test plan, illustrating the actual test sequence is given in Table 3-1.

Table 3-1: LSRU qualification test plan

Qualification Test Plan			
Test	**Unit #1**	**Unit #2**	**Unit #3**
Dimension & mass measurement	X	X	X
Friction measurement of roller screw & bearings	X		X
Visual inspection	X	X	X
Proof load	X	X	X
Electrical check	X	X	X
EMC check	X	X	X
Force margin check (magnetic actuators, brackets, locking lever)	X	X	X
Functional performance at ambient	X 8 act.	X 1 act.	X 1 act.
Creep test (4 month)			X
Shock output measurement		X	
Sine & random vibration test	X	X	
External shock impact on LSRU		X	
Static test on housing (non-destructive - part 1)		X	
TV cycling & functional performance at TV	X 6 act.	X 6 act.	
Multiple functional performance at ambient	X 38 act.	X 2 act.	
Force margin check (magnetic actuators, brackets, locking lever)	X		
Ultimate load test till rupture		X	
Strip down & inspection	X	X	X
Static test on housing till rupture (part 2)		X	
Friction measurement of roller screw & bearings	X		X

The main qualification tests outlined in above table are detailed in the following paragraphs.

3.1. Friction measurement of roller screw and bearings

In order to verify a sufficient actuation margin (> 2) a friction measurement was performed for the roller screw and supporting bearings. After being exposed to a static load of 33 kN (axial bearing, roller screw) the friction was measured under rotation at dedicated test loads (axial bearing: 10 kN, roller screw: 50 N).

The friction measurement was performed at the beginning and at the end of the qualification testing sequence, revealing no significant degradation.

3.2. Proof load

For the proof load test, a tensile force of 33 kN was applied to the LSRU for 1 minute. The admitted preload relaxation was < 5 %. For testing a flight representative test stack as shown in Figure 3-1 was used.

3.3. Electrical check, EMC check

The electrical check addressed the reliability and functionality of the magnetic actuators. The test consisted of a resistance check of the solenoids, an insulation resistance and grounding resistance check and a diode verification test.

The EMC check (electromagnetic compatibility) was performed to prove the compliance of the magnetic field strength caused by the permanent magnets which are part of the magnetic actuators with the system requirements ($|H| \leq 80$ A/m outside a specified half sphere centred to the magnetic actuator position).

3.4. Force margin check

The force margin check was conducted to verify sufficient actuation margin (> 2) for all moving parts of the LSRU. The test addressed the magnetic actuators, the bracket assembly and the locking lever (see Figure 1-4).

3.5. Functional performance at ambient

The purpose of the functional performance test was to prove the nominal release performance of the LSRU. The tests were performed using the flight representative HD-stack (see Figure 1-4). The preload for all functional tests was 30 kN. Several tests were performed taking into account different types of misalignments. All functional tests were initiated electrically with release time monitoring. Figure 3-1 shows a typical test setup.

The functional performance test was performed for all 3 qualification units before and after the environmental tests. Unit #2 was subjected to totally 52 actuations to verify the margin with respect to the full possible performance history (max. 10 on-ground actuations before flight) of one LSRU.

The typical release time at ambient conditions was 60 ms.

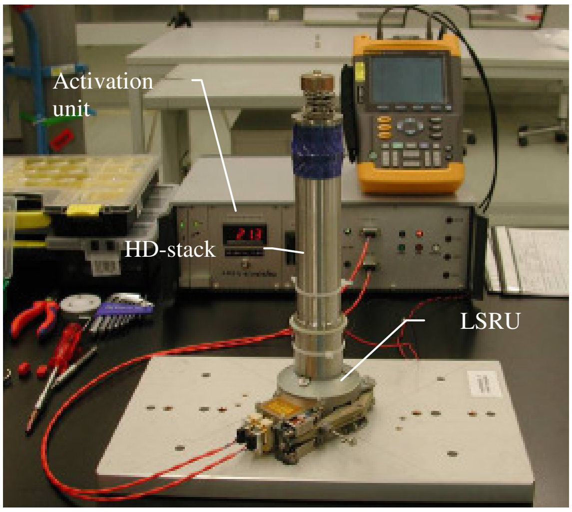

Figure 3-1: Setup for LSRU functional performance test

3.6. Creep test

The creep test addressed the maximum potential storage duration of a Solar Array which is stowed and ready for flight (4 month for E3000/ Alphabus solar array). During this phase the preloaded LSRU must not relief more than 5 % of the preload (initially 30 kN). The test setup was similar to Figure 3-1. The preload was continuously monitored with a strain gauge applied on the HD-pin.

The actual preload loss after 4 month was < 0.5 %. Subsequent to the creep phase the functional performance of the LSRU was verified.

3.7. Shock output measurement

The shock output measurement was performed to characterise the typical shock impact of the LSRU to the satellite structure during release actuation under flight representative conditions. The test stack was mounted on a 1x1 m aluminium honeycomb test plate with 1 mm aluminium facesheets on both sides, vertically suspended (see Figure 3-2).

The shock output was measured in all 3 axes directions at different distances from the shock source (100 - 300 mm). A test sequence of 9 actuations was performed to characterise potential level variations.

The initial maximum shock level of about 500 g's at 3.5 - 4 kHz was observed at 100 mm distance from the LSRU (see Figure 3-3). The tests revealed an increase of the shock levels with increasing number of test runs, caused by a degradation of the locking lever end stop damper (see Figure 3-4) - which is the main contributor for the output shock.

Starting with a new damper after 2-3 actuations the shock level slightly increased and exceeded the requirement in small frequency bands. After the 8th release the shock level significantly increased. After damper replacement the level was nominal again.

As a conclusion a damper replacement after each 2 - 3 actuations is recommended.

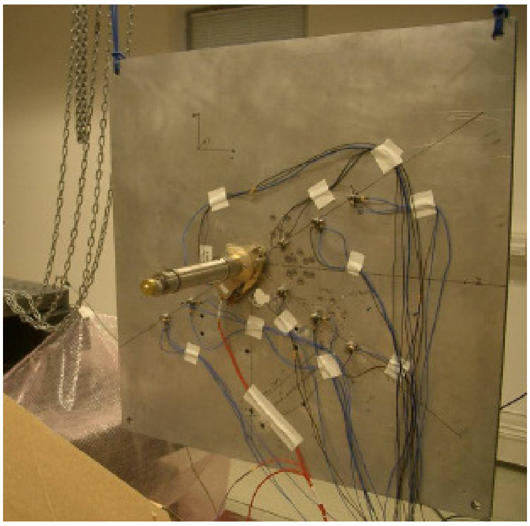

Figure 3-2: Test setup for output shock measurement

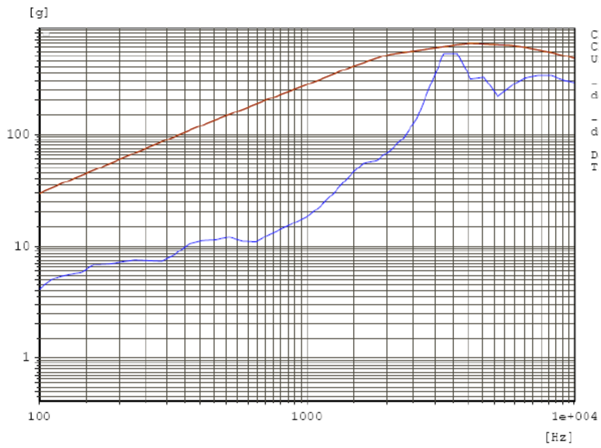

Figure 3-3: SRS, pos. 2x, 100 mm from source, 1st run

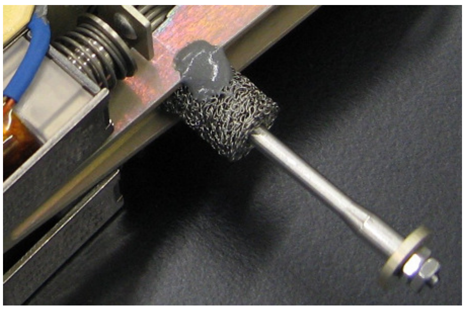

Figure 3-4: Locking lever end stop damper

3.8. Sine & random vibration test

The units #1 and #2 were subjected to a sine & random vibration test. The test comprised the following sequence:

- Resonance search
- Sine vibration, acceptance level
- Resonance search
- Sine vibration, qualification level
- Resonance search
- Random, acceptance level
- Resonance search
- Random, qualification level
- Resonance search

Above sequence was applied subsequently for x-, z- (in-plane) and y-axis (out of plane). The response was recorded by each 2 3-axes accelerometers attached to the units housing.
The units were preloaded to 30 kN, using a short HD-stack. The qualification levels are summarized in Table 3-2.

Table 3-2: Input loads used for vibration test

Sine Vibration Qualification Levels			
Axes	Frequ. [Hz]	Level	Sweep
All	5 – 20	35 mm	2 octaves/ minute
	20 - 100	20 g	
Random Vibration Qualification Levels			
Axes	Frequ. [Hz]	Level	Global/ Time
Y (out of plane)	20 – 100	+ 10 dB/oct.	16.54 g_{rms}/ 180 s
	100 – 400	0.50 g²/Hz	
	400 – 2000	- 8 dB /oct.	
X, Z (inplane)	20 – 100	+ 6 dB /oct.	7.66 g_{rms}/ 180 s
	100 – 200	0.3 g²/ Hz	
	200 – 400	- 18 dB /oct.	
	400 - 1500	0.005 g²/ Hz	
	1500 - 2000	- 10 dB /oct.	

After each test run a visual inspection was performed. The units showed no anomaly.

The comparison of the pre- and post vibration testing resonance frequencies revealed no shift in frequency or amplitude.

3.9. External shock test

After sine & random vibration testing unit #2 was exposed to an external shock impact. The unit was preloaded to 30 kN using the short HD-stack from vibration testing. The shock was introduced in out-of-plane (y-) direction and in one in-plane direction (x). 2 accelerometers were used for monitoring.

The specified external shock levels were:

20 g's at 100 Hz (SRS)

1200 g's at 2000 Hz (SRS)

The unit survived without any degradation or unintended release actuation. Figure 3-5 shows the test setup for the in-plane excitation, Figure 3-6 shows the according shock level record.

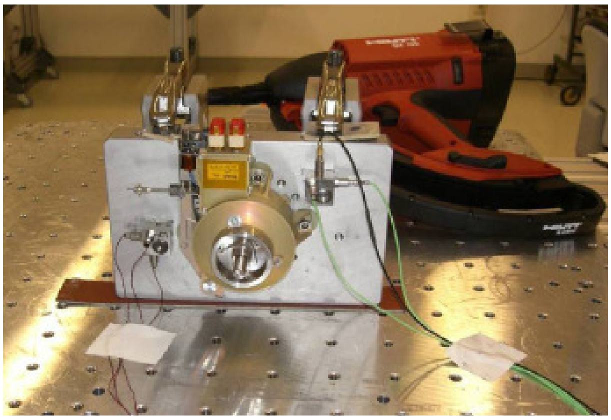

Figure 3-5: External shock test setup (in-plane)

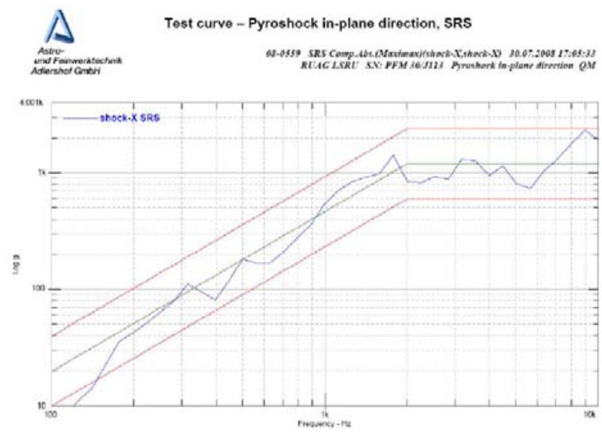

Figure 3-6: Shock level (SRS), in-plane excitation

3.10. Thermal vacuum cycling and functional performance under TV

The purpose of this test was to verify the release performance of the LSRU under thermal vacuum conditions. The units #1, #2 & were installed in the TV chamber using the HD-stack of Figure 3-1. The preload was 10/30 kN. Throughout the functional tests several misalignment configurations were implemented.

The TV test comprised a TV cycling phase, followed by a LSRU performance test phase at hot and cold temperatures. The environmental conditions are summarized below:

Environment during TV cycling & functional performance tests

- Pressure: $< 10^{-5}$ mbar
- Cold temperature: - 95 °C +0/- 5 °C
- Hot temperature: + 120 °C -0/+5 °C
- No. of TV cycles: 10
- No. func. performance tests: 6 for each unit (3 @ hot, 3 @ cold temperature)

The temperatures were controlled via two thermocouples on the housing of each unit and one each on top of the test stack. The release duration of was measured by continuity measurement between LSRU housing and HD-pin. Figure 3-7 shows the test setup in front of the TV-chamber.

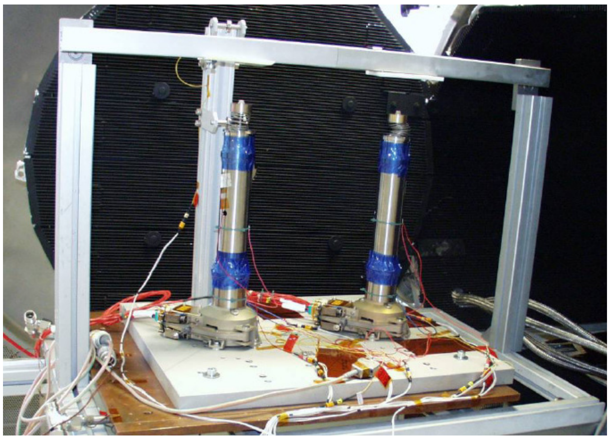

Figure 3-7: Setup for TV test

The monitored release durations ranged from 59 ms (preload 30 kN, release at hot) to 224 ms (release at 10 kN, release at cold).

3.11. Static test on housing

The static test on housing addressed the mechanical interface loads acting on the unit during flight. The specified loads are given in § 2.

The static tests comprised 2 test steps: During the 1st step the specified interface loads were verified. In the 2nd step - at the end of the qualification testing - the LSRU external housing was tested to rupture. In order to prevent a potential damage on the LSRU internal parts, the 2nd test step was performed with the "empty" housing. Figure 3-8 shows the test setup for the latter step.

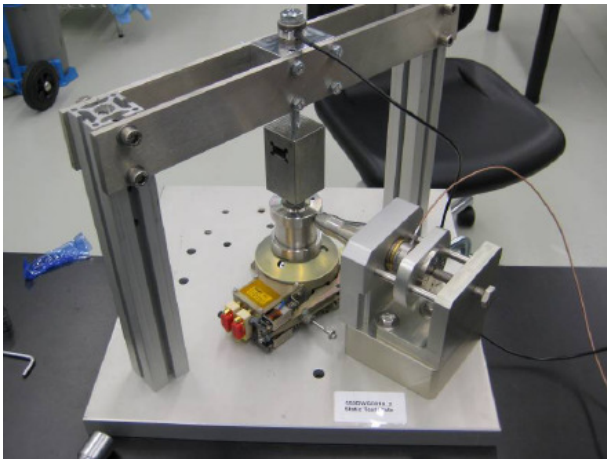

Figure 3-8: Setup for static test on housing (til rupture)

The rupture of the LSRU housing (crack close to a fixation strut) occurred at a lateral force of 17100 N which is equivalent with a bending moment of 1710 Nm (height of force introduction 100 mm), providing a comfortable margin with respect to the specification. Figure 3-9 shows the broken LSRU housing.

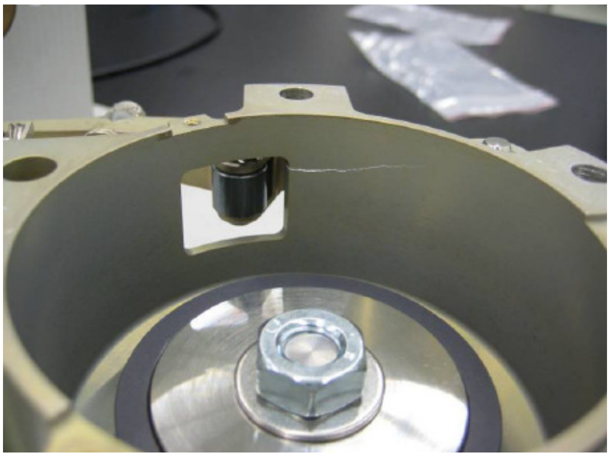

Figure 3-9: Broken LSRU housing (after static test 2)

3.12. Ultimate load test

The ultimate load test was a pull test to identify the weakest part of the LSRU and to demonstrate its safety with respect to tensile loads. The tensile load was transferred by a dummy pin engaged with the LSRU spindle. The reaction force was shouldered by a thrust bearing on top of the LSRU housing, which is the flight representative load path. The force was introduced by a tensile testing machine.

The load was increased to a maximum value of 52.5 kN, when initial indications for a permanent deformation could be observed. The specified load of minimum 37.5 kN was reached without any degradation. Figure 3-10 shows the test setup, Figure 3-11 the according force vs. stroke diagram.

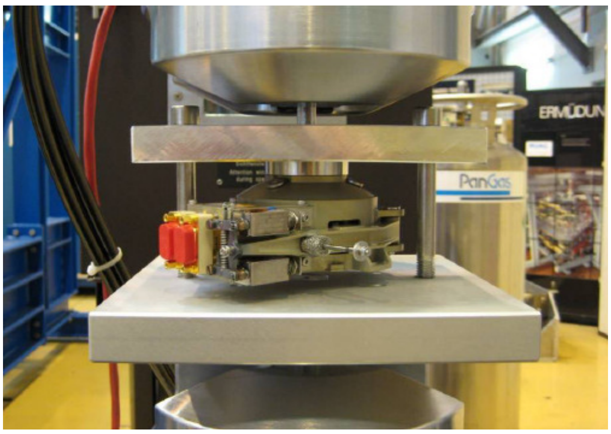

Figure 3-10: Setup for ultimate load test

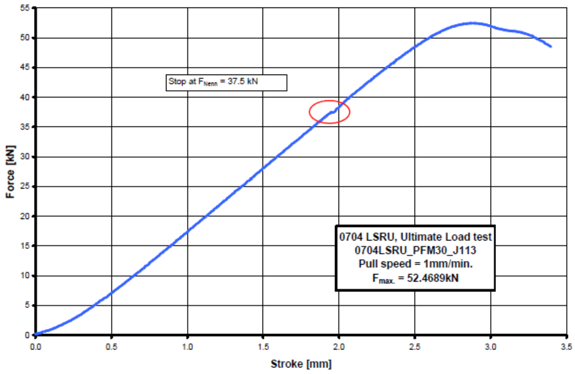

Figure 3-11: Force vs. stroke diagram (ultimate load test)

4. CONCLUSION AND QUALIFICATION STATUS; PLANNING

All qualification tests on component level were successfully completed as well as all post qualification testing inspections and measurements. In addition to that, all qualification tests on Alphabus solar array level have been successfully completed.

The LSRU is fully qualified for Alphabus and Eurostar3000 solar array. It will be used on the 1st Alphasat satellite. The implementation for the next generation of Eurostar3000 solar arrays is initiated and the use for additional solar array programmes is already agreed.

The LSRU is available for other applications on the European market.

5. LSRU PROCUREMENT INFORMATION

The LSRU was designed by Astrium GmbH, Germany. Manufacturing, assembly and qualification testing was performed by RUAG Aerospace, Switzerland.

Manufacturing and acceptance testing of future LSRU lots will be conducted by RUAG Aerospace.

The LSRU is a 100 % ITAR-free product.

6. ACKNOWLEDGEMENT

The LSRU development and qualification testing was co-funded by ESA under the contract no. 17701/03/NL/US. The support of Pierre Coste and Jean-Michel Lautier is gratefully acknowledged.