LOW SHOCK RELEASE UNIT – EASY RESETTABLE AND 100 % REUSABLE

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## 1. Abstract

The paper presents a non explosive, easy resettable low shock release unit which can be actuated multiple times without any refurbishment (100 % reusable). The current design is able to release a tensile load of 16 kN at a weight of approx. 475 grams. The qualification testing is finished. An unit with an enhanced load capability is under investigation. The current unit is designed for a holddown & release mechanism of solar arrays; however various applications are possible.

The release unit principle is the conversion of tensile preload into rotational energy, providing a smooth preload relief within a short time. After actuation, the unit can be easily reset instantly. Neither replacement nor refurbishment of any component parts is necessary. This 100 % reusability and the related savings of costs for refurbishment or replacements are unique features.

The unit functional principle and the results of the performed qualification programme are presented hereafter.

## 2. Functional Principle

The core of the low shock release unit (LSRU) is a roller screw comprising a threaded spindle engaged with a nut. The thread of the spindle is designed as non-self locking multiple thread. Engaged with the corresponding roller nut, a small axial force applied to the spindle induces a rotation of the nut.

In non-operational mode the roller nut is locked. One end of the spindle is attached to the load which is to be released. The other end of the spindle is engaged with the locked roller nut. For release, the roller nut is unlocked; the tensile load applied to the spindle initiates the rotation of the nut, leading to a disengagement of both parts and a release of the load. In order to ensure a safe release, a pull out spring is to be used, providing axial force over the entire thread engagement length. The pull out spring is not part of the LSRU.

The roller nut is mounted to a roller screw housing pivoted in the LSRU housing by means of two bearings. The roller screw housing provides a gap for the locking mechanism. The latter one consists of a spring loaded lever with a compatible locking nose; in locked condition, this nose is engaged with the gap of the roller screw housing, preventing rotation of the roller nut. One end of the locking lever is pivoted on the LSRU housing. The other end engages with two magnetic actuators by means of a rocker arm; the magnetic actuators and the rocker arm build up a redundant actuation system.

The total release actuation comprises the following sequence: One or both magnetic actuators release the spring loaded locking lever. The spring force disengages its locking nose from the gap in the roller screw housing. The tensile load on the spindle induce the rotation of the unlocked roller nut, disengaging the spindle.

Fig. 2-1 shows a view of the LSRU with its main components in locked condition.

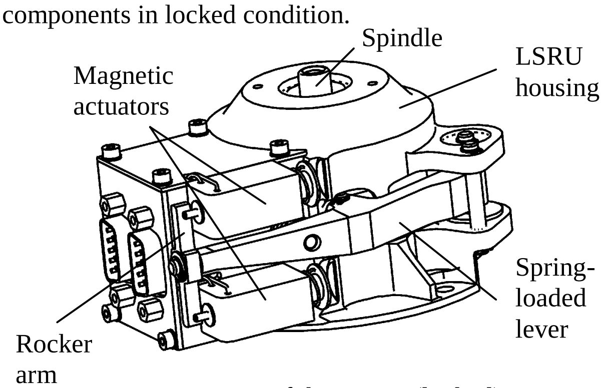


Fig. 2-1: View of the LSRU (locked)

Fig. 2-2 shows a photo of the roller screw assembly (spindle engaged with roller nut).

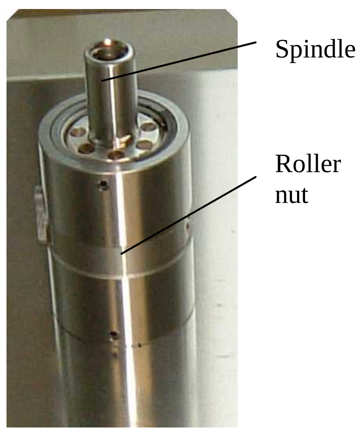


Fig. 2-2: View of roller screw assembly

## 3. Purpose and Technical Data

The LSRU is designed to release a stowed solar array for deployment in orbit. For each solar array wing, several release units are used. The technical properties and interface data comply with the requirements of a current satellite solar array programme. The release unit can be used for any other release tasks with similar loads.

The LSRU main technical data are summarized below:

**Technical Properties**

- Max. release load: 16 kN
- Proof load: 18 kN
- LSRU mass (with spindle): 475 g
- Typical release time: 120 ms
- Shock output: < 1000 g's

**Electrical interface**

- Actuation voltage 24 – 35 V
- Actuation current 180 – 590 mA
- Pulse duration 40 ms

The LSRU is capable to accommodate loads which act not exactly vertically. The misalignment capability is approx. 3 °.

## 4. Qualification Programme

The LSRU was subjected to an extensive qualification programme. The requirements are derived from a current satellite solar array programme.

The qualification programme comprised testing of 3 units, being subjected to different test sequences. The qualification testing comprised dimension & mass measurement, electrical check, proof load test, performance at ambient, sine & random vibration, thermal vacuum cycling and performance under TV, post TV performance at ambient and strip down & inspection. One unit was subjected to shock measurement, creep test, static test on housing and ultimate load test.

The following paragraphs characterize the performed qualification tests.

### 4.1. Dimension & Mass Measurement

The dimension & mass measurement comprised the control of functional and main interface dimensions; the unit mass had to be less than 550 g. The actual mass is approximately 475 g – including the spindle.

### 4.2. Proof Load

The typical test setup used for mechanical tests consists of the LSRU and the holddown (HD-) stack, comprising the holddown bushing, HD-pin, pull out spring with cap and fixation nut. This setup corresponds to the typical configuration of a complete holddown point of a stowed solar array. Fig. 4-1 illustrates the principle of the test setup.

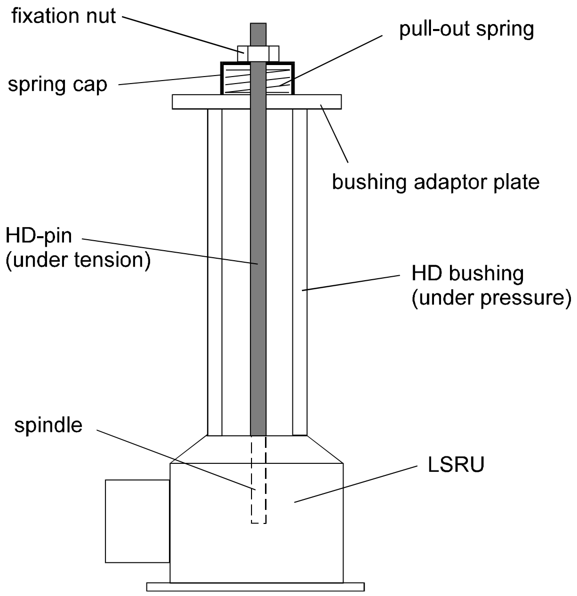


Fig. 4-1: LSRU in typical test configuration (HD-assy)

The pretension is applied to the LSRU via the HD-pin, the reactive force acts on the bushing adaptor plate of the HD-bushing, as illustrated in fig. 4-2.

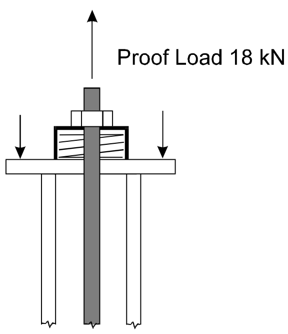


Fig. 4-2: Application of preload during proof load test

For the proof load test, a tensile force of 18 kN was applied to the LSRU for 2 minutes, using a tensile testing machine.

The units sustained the load without any damage.

### 4.3. Electrical Check

The electrical check addressed the reliability and functionality of the magnetic actuators. The test consisted of a resistance check of the solenoids, a functional performance test at the lower and upper voltage limit, an insulation resistance check and a conducted susceptibility check.

The values obtained during resistance check and solenoid insulation test versus ground were well within the requirements.

Also the functional performance test revealed no anomalies. All actuators performed at 24 V and 35 V (40 msec.); the according actuation current was in the specified operational range.

Within the conducted susceptibility test a pulse of ± 28 Vpp (10µs) was injected into the power lines. No unintended actuation was observed.

### 4.4. Performance at Ambient and Force Margin Check

The force margin check is a confidence test addressing the actual axial force, which is necessary to initiate the rotation of the roller nut until the complete release of the HD-pin. Fig. 4-3 illustrates the test setup.

The test was performed by applying small load increments to the integrated HD-pin until the spindle had fully released.

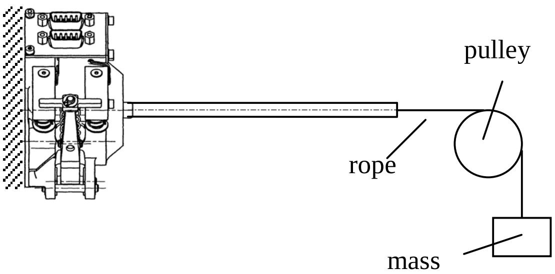


Fig. 4-3: Test setup for force margin check

Three runs of the test were performed on each unit. The averaged minimum forces were between 2.98 N and 3.46 N. The max. force to be applied was 3.73 N. The actual minimum force of the pull-out spring (see fig. 4-1) at the end of the spindle engagement is 15.17 N, thus a minimum force margin of 4.1 is provided.

The test focus of the functional performance at ambient was to demonstrate the reliability of the units performing multiple releases. The test setup is shown in fig. 4-1. A preload of 16 kN was applied to the HD-pin with a tensile testing machine and the locking nut was fixed. The units were actuated several times in horizontal and vertical condition. The release times were determined using an optical sensor.

All release actuations (in vertical and horizontal configuration) were successful. The average release time was 114 ms. The release times turned out to be very consistent, the standard deviation was only 4 ms. A release without preload - only with pull-out spring - typically took 450 ms.

### 4.5. Sine & Random Vibration Test

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

- Sine resonance search
- Sine vibration, qualification level
- Sine resonance search
- Random, qualification level
- Sine resonance search

Above sequence was applied consecutively for x-, z- (inplane) and y-axis (out of plane). The response was recorded by two 3-axses accelerometers attached to each unit housing and connector box (E-box), as shown in fig. 4-4.

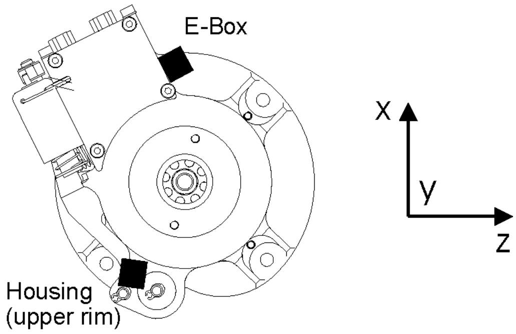


Fig. 4-4: Position of accelerometers during vibration test

The units were preloaded to 16 kN, using the test setup in fig. 4-1. The enviromental conditions are summarized in table 4-1.

Table 4-1: Input loads used for vibration test

| **Resonance Search** | | | |
|---|---|---|---|
| Axes | Frequ. [Hz] | Acceler.[g] | Sweep |
| All | 5 – 2000 | 0.5 constant | 2 oct./ min. |
| **Sine Vibration** | | | |
| Axes | Frequ. [Hz] | Level | Sweep |
| Y (out of plane) | 5 – 17 | ± 12 mm | 2 octaves/ minute |
| | 17 – 50 | 14 [g] | |
| | 50 – 80 | 8 [g] | |
| | 80 – 100 | 5 [g] | |
| X, Z (inplane) | 5 – 20 | ± 11.2 mm | 2 octaves/ minute |
| | 20 – 45 | 18 [g] | |
| | 45 – 80 | 10 [g] | |
| | 80 – 100 | 6 [g] | |
| **Random Vibration** | | | |
| Axes | Frequ. [Hz] | Level | Global |
| Y (out of plane) | 20 – 100 | + 6 dB/oct. | 15.5 $g_{rms}$ |
| | 100 – 600 | 0.250 $g^2$/Hz | |
| | 600 – 2000 | - 6 dB /oct. | |
| X, Z (inplane) | 20 – 100 | + 6 dB /oct. | 16.0 $g_{rms}$ |
| | 100 – 850 | 0.2 $g^2$/ Hz | |
| | 850 – 2000 | - 6 dB /oct. | |

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

Table 4-2 shows the eigenfrequencies and associated responses of each resonance search after sine and random qualification run in x-, y- and z-direction (unit 3).

Table 4-2: Eigenfrequencies and accelerations before and after test runs - identified during resonance search in the corresponding direction (unit 3)

| Axis | Position | Frequency [Hz] | Accelerat. [g] | Frequ. shift [%] |
|---|---|---|---|---|
| **Eigenfrequ./acceleration before vibration** | | | | |
| X | Housing | 365.9 | 3.6 | - |
| | e-box | 365.9 | 1.5 | - |
| Y | Housing | 1531 | 1.6 | - |
| | e-box | 1797 | 2.5 | - |
| Z | Housing | 344.6 | 4.9 | - |
| | e-box | 344.6 | 5.1 | - |
| **Eigenfrequ./acceler. after sine vibration** | | | | |
| X | Housing | 365.9 | 3.6 | 0 |
| | e-box | 365.9 | 1.4 | 0 |
| Y | Housing | 1520 | 1.9 | -1 |
| | e-box | 1821 | 2.2 | 1 |
| Z | Housing | 344.6 | 4.5 | 0 |
| | e-box | 344.6 | 5.2 | 0 |
| **Eigenfrequ./acceler. after random vibration** | | | | |
| X | Housing | 340.0 | 4.3 | -7 |
| | e-box | 337.7 | 1.7 | -8 |
| Y | Housing | 1422 | 1.6 | -7 |
| | e-box | 1773 | 3.6 | -1 |
| Z | Housing | 331.0 | 5.1 | -4 |
| | e-box | 331.0 | 5.2 | -4 |

The comparison of all pre- and post qualification level eigenfrequencies showed shifts of up to 8 %. Especially after random vibration obvious eigenfrequency shifts could be noted. However, such frequency shifts are normal for this type of boltet units; the screwed interfaces experience some setting effects, causing slight losses in pretension which result in reduced resonance frequency. These shifts are no indication for degradation or damage.

Fig. 4-5 shows a typical response spectrum of the LSRU during random vibration run. Fig. 4-6 shows the arrangement of 3 units on the shaker table, ready for testing.

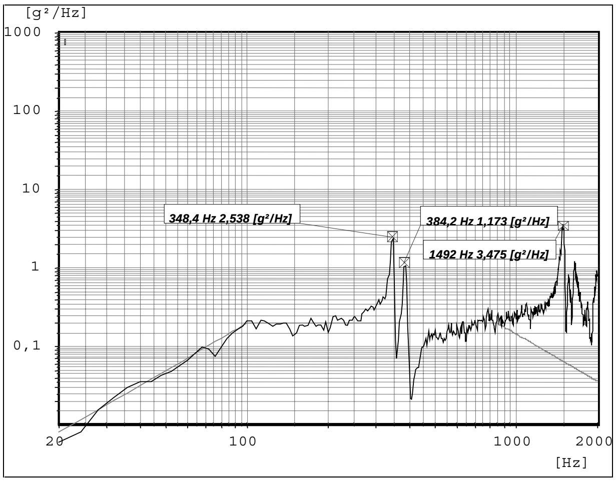

Fig. 4-5: Random qualification test (Unit 2, E-box, x-direction)

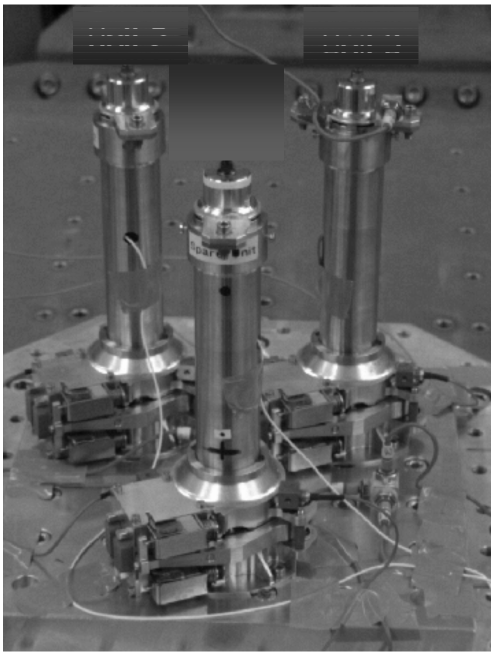
Fig. 4-6: Arrangement of LSRU’s on shaker table

## 4.6. Thermal Vacuum Cycling and Functional Performance under TV

The purpose of this test was to verify the release performance of the LSRU’s under thermal vacuum conditions. The units were installed in the TV chamber directly after the sine & random vibration test – without performing a release actuation inbetween. The test setup remained unchanged (see fig. 4-1). The preload was 16 kN.

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**

- Pressure < $10^{-5}$ mbar (cold)
  < $10^{-4}$ mbar (hot)
- Low temperature - 115 °C ± 2 °C
- High temperature + 120 °C ± 2 °C
- Dwell time min. 10 min (till steady state conditions T ± 2 °C are reached)
- No. of TV cycles 5, starting with hot

**Environment during functional performance at TV**

- Low temperature - 60 °C ± 2 °C
- High temperature + 110 °C ± 2 °C
- Actuation voltages 24 V / 35 V (actuation of primary & redundant actuators each)
- Actuation pulse width 40 ms

(Other parameters as during TV cycling)

The temperatures were controlled via two thermocouples on the housing of each unit and one on top of each test stack. The release duration of one unit was measured with an optical sensor. Fig. 4-7 shows the test setup installed in the TV-chamber.

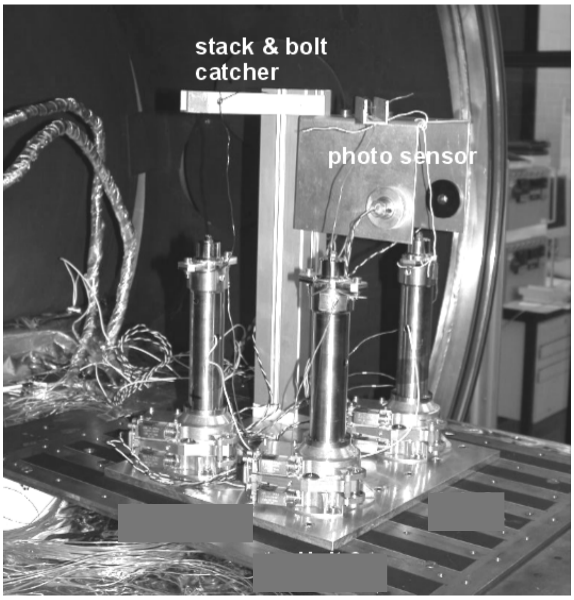


Fig. 4-7: Setup of TV test

The TV-cycling phase was passed through without any anomalies. All units released at the required temperatures; for all releases both actuators performed successfully (as required).

Fig. 4-8 illustrates the evolution of the TV test performance.

After the TV test, a post TV functional performance test at ambient was performed; the units released without anomalies.

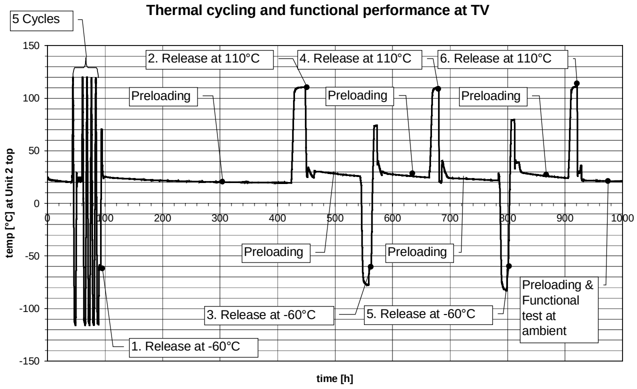


Fig. 4-8: Evolution of the TV test performance

## 4.7. Shock Measurement

Purpose of this test was to identify the LSRU shock output during release. The test was performed on one unit. The unit was mounted on an 1x1 m aluminum honeycomb plate (20 mm core height) with 2 aluminum facesheets on back- and frontside (each 1mm thick). The test plate was suspended vertically with 2 elastic ropes. The preload was 16 kN.

The shock output was recorded by four 3-axes accelerometers attached to the following positions:

- ACC1: On the back side below the shock source
- ACC2: On the front side in a distance of 100 mm
- ACC3: On the front side in a distance of 200 mm
- ACC4: On the front side in a distance of 300 mm

Fig. 4-9 shows the used test setup.

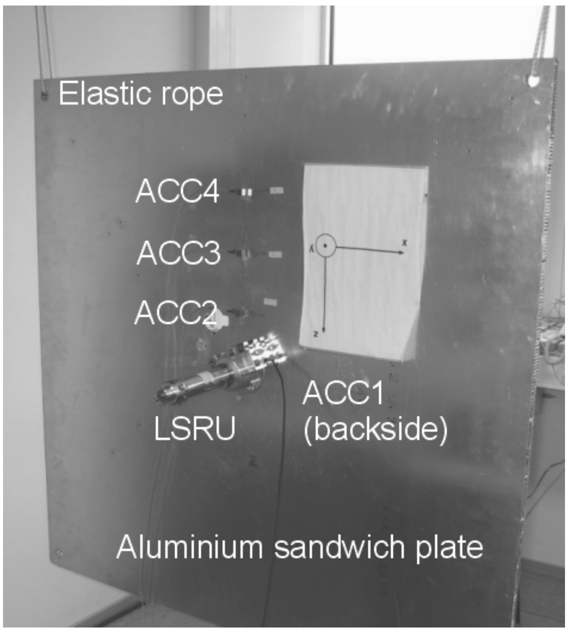


Fig. 4-9: Shock measurement setup

The max. acceleration below 2500 Hz was 450 g, measured on the backside of the test plate in z-direction; the max. acceleration in total was 1000 g at 4000 Hz –

measured at ACC2 (z-direction). Fig. 4-10 shows the time response and the according shock response spectrum of ACC2 (x-direction).

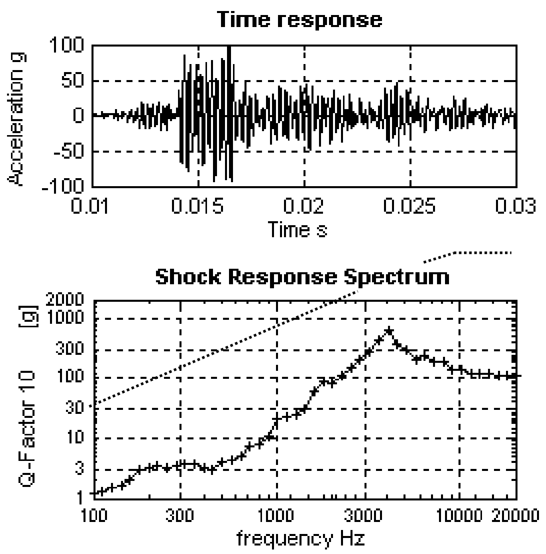


Fig. 4-10: Time response & SRS of ACC2 (x-direction)

Compared to conventional pyro-cutters, above shock response spectrum is very moderate; Pyros typically cause accelerations of more than 1000 g at 1000 Hz and up to 10000g between 5000 Hz and 20000 Hz (dotted line in fig. 4-10). Thus this LSRU reduces the shock output by at least one order of magnitude; besides it still offers potential for additional reductions.

### 4.8. Creep Test (+ Force Margin Test)

The creep test addressed the long-term behaviour of the preloaded unit. Potential setting effects and loss of preload were to be assessed. The test was performed on one unit. A preload of 16.9 kN was applied at the beginning of the 4 weeks test duration. The preload was monitored with a strain gage applied to the HD-pin.

The preload of 16.9 kN did not change over the entire test duration. At the end the unit was actuated and released without anomalies (release time 107 ms).

A 2$^{nd}$ force margin test was performed on the same unit after the creep test, in order to assess potential functional degradation. The test setup was identical as for the 1$^{st}$ test.

The three runs averaged minimum force required to release the spindle was 3.35 N which is very close to the 1$^{st}$ test run.

### 4.9. Static Test on Housing

The static test on housing addressed bending loads acting on the unit during flight. The housing had to be tested to a bending moment of 280 Nm at the HD-bushing interface in x- & z-direction. The test was performed revealing no anomaly.

### 4.10. Ultimate Load Test

The ultimate load test was a pull test to verify the maximum restraining capability of the unit. The LSRU was mounted on a base plate and the HD-pin was engaged. The force was applied with a tensile testing machine to the HD-pin till rupture (see fig. 4-11).

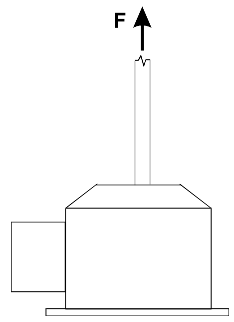


Fig. 4-11: Test setup for ultimate load test

The test was performed on one unit, which finally sustained a tensile load of 23.3 kN, when the housing failed.

It could be demonstrated that the roller screw load capability is $\geq$ 23.3 kN. The design of the housing can be easily adapted to enhanced loads, if requested.

## 5. Conclusion

The post test strip down & inspection revealed no unusual wear or damage.

The qualification of the Low Shock Release Unit was thoroughly completed.

The test success criteria were met:

- All functional tests showed nominal values
- No degradation or damage was observed

The LSRU mechanical load capability of 16 kN could be verified. The shock output was considerably less than the shock of a typical pyro-cutter. Summarizing the qualification has been successfully performed in accordance with the applicable test procedures.

The above mentioned results encouraged the development of a LSRU design with a capability of 33 kN.

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