ELECTRIC PROPULSION POINTING MECHANISM HOLD DOWN AND RELEASE MECHANISM DESIGN AND BREADBOARD TEST RESULTS

Paul Janu, Christian Neugebauer, Manfred Falkner, Ludwig Supper, Gerhard Mitterbauer, Hannes Weinhappl, Gerhard Traxler
RUAG Aerespace Austria (RAA), Stachegasse 16, A-1120 Vienna, Austria
Tel.: +43 1 80199 2740, Fax.: +43 1 80199 6950, Email:paul.janu@ruag.com

ABSTRACT

RUAG Aerospace Austria is currently developing the Electric Propulsion Pointing Mechanism (EPPM) and the BEPI Thruster Pointing Mechanism (BEPI TPA).
One of the key components of both mechanisms is the Hold Down and Release Mechanism (HDRM) for the Mobile Plate which is the support for the Electrical Thruster.
The HDRM supports the Mobile Plate during ground activities and launch campaign. It releases in orbit and retracts subsequently and allows therefore deployment and pointing within a wide range via the Pointing Mechanism.

RUAG Aerospace Austria was contracted by ESA for EPPM and by EADS ASTRIUM for the BEPI TPA to develop the Electric Propulsion Pointing Mechanisms, which consist of the Pointing Mechanism, the Mobile Plate, and the HDRM.

The main challenges for the HDRM are:

- Support of the Electrical Thruster during launch
  - Structural integrity of the EPPM at specified dynamic mechanical environment comparable to quasistatic loads of 40g
  - Provision of a low dynamic mechanical input into the Thruster
- Reliable release in orbit
  - Motorization margin i.a.w. ESA ECCS over the whole release motion
- Pointing capability of the mobile plate after release symmetric ±21 deg around both lateral axes
- Compatibility with a deployment around an offset axis up to 120 deg with following pointing capability
- Limitation of the release shock at HDRM release to the thruster allowables
- Compatibility with qualification temperature environment from -40° C to +150° C

For verification of the HDRM design a HDRM mechanical bread-board was manufactured and tested in early 2009.

The scope of this presentation is to present briefly the design of the HDRM breadboard, and to highlight the breadboard test results.

1. MAIN DESIGN FEATURES

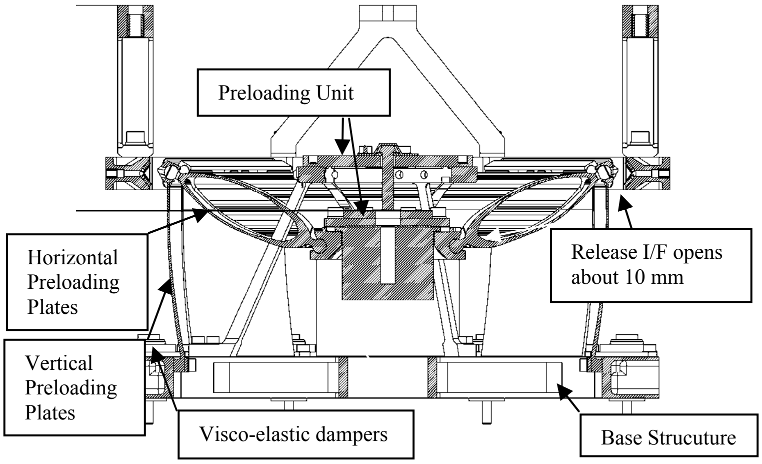

Figure 1-HDRM in released configuration – overview

Preloading: One central Preloading Unit is used for driving the inner parts of the Horizontal Preloading Plates (HPPs) (8 off) upwards. This leads to a radial outward movement of the outer parts of the HPPs and the upper parts of the Vertical Preloading Pates (VPPs) (8 off). The radial movement of the upper parts of the VPPs leads to the contact to the Mobile Plate and preloading of the release I/F.
The HPPs are designed as compliances and provide equal load distribution over all release I/Fs.
The VPPs are designed as quasi-hinges to avoid mechanical shock loads at dynamic vibration.
HPPs and VPPs are designed as springs and provide the motorization torque for the release.
The arrangement in preloaded configuration provides high stiffness (112 Hz in plane and 304 Hz out of plane) which gives the possibility to implement visco-elastic dampers between the HDRM and the S/C (direct load path). The

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fundamental modes of the damped EPPM are 70 Hz to 85 Hz in lateral and 220 Hz to 270 Hz in out of plane direction. The damped Hold Down and Release Mechanism provides low amplification (Q = 4 to Q = 6) and reduces the dynamic inputs into the Thruster significantly.

1.1 Motorisation of the HDRM

The motorization of the HDRM for the opening campaign is performed via the two motorization elements Horizontal Preloading Plates and Vertical Preloading Plates.

Horizontal Preloading Plates (HPPs):

The 8 HPPs are designed as spring elements which are able to be loaded with very high compression load, which is needed for preloading the HDRM. During preloading the axial deformation of each element is about 0.4 mm, which is used at the opening campaign for motorization during the first phase as long as the Release I/F is still in contact.

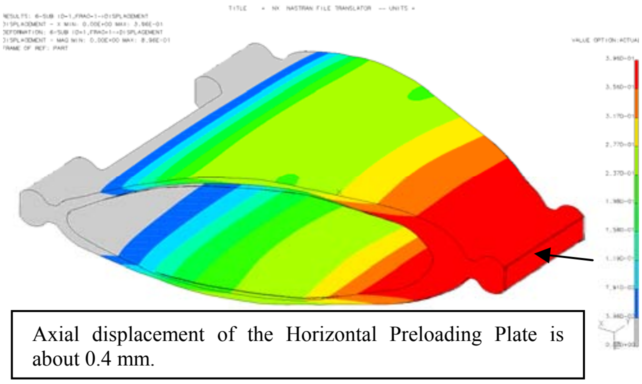

Figure 2-HPP displacement over axial load

Vertical Preloading Plates (VPPs):

The VPPs are also designed as spring elements with stored energy.

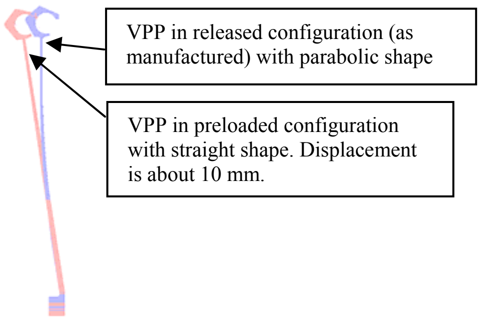

Figure 3-VPP in released and preloaded config.

1.2 Release I/Fs

The release I/F is a compromise of:

- provision of enough friction for transformation of the dynamic loads and
- low friction to allow opening in accordance with ESA ECSS reserve factors

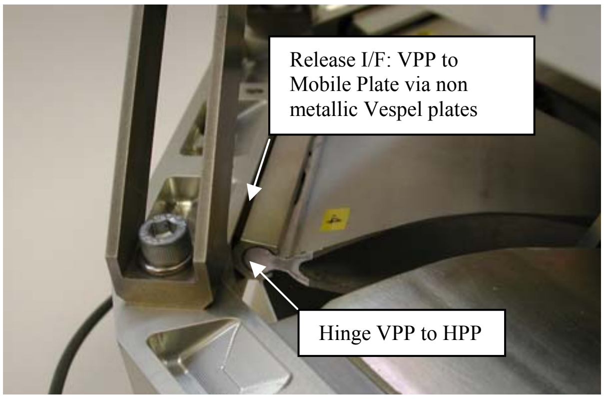

Figure 4 – Release I/F and hinge VPP to HPP

In the HDRM design both requirements can be fulfilled with adequate release I/F design and provision of the needed friction coefficients between the Vespel SP1 release I/F and the VPP surface. In advance a friction test program was performed.

1.3 Preloading Unit

The Preloading Unit consists of a static part which is connected via four struts to the Base Structure and a moving part which is connected to the HPPs via 8 hinges.

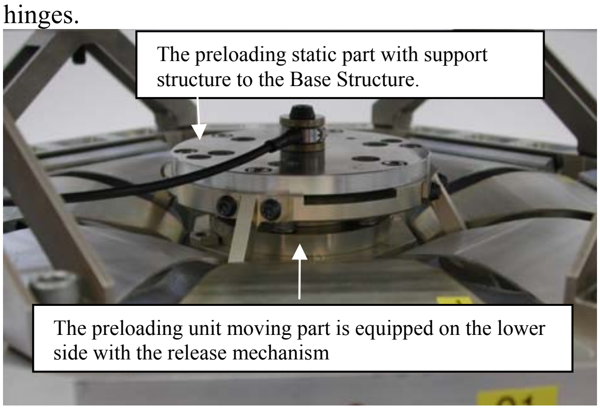

Figure 5- Preloading Unit in released configuration

The moving part is equipped on the lower side with the Release Device. For refurbishment of the Release Device the whole Preloading Unit is dismounted just by opening of 6 bolts.

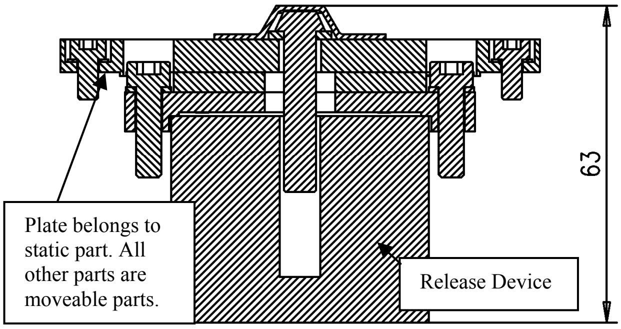

Figure 6- Preloading Unit in released configuration

2. RESULTS OF THE BREADBOARD TEST CAMPAIGN

2.1 Friction test set-up Vespel SP1/Aluminium

A test set-up was selected which is able to test friction with variation of

- contact loads (from 15 MPa to 60 MPa)
- relative motion speeds

Change of both coupling materials with different roughness and surface coating can be realized within this test set-up.

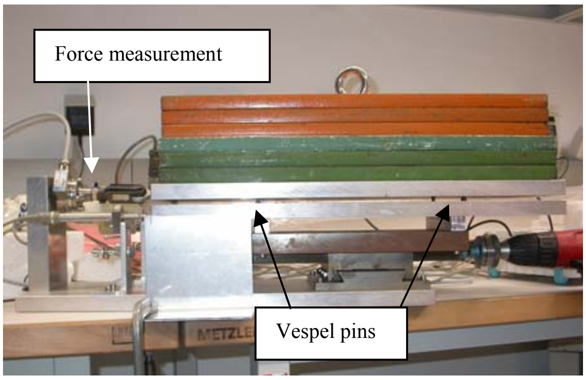

Figure 7-Horizontal Preloading Plate deflection calibration test set-up

Results of friction test Vespel SP1/Aluminium:

- Selection of a non metallic release I/F material
    - which is able to be loaded up to 60 MPa
    - which provides needed friction within small tolerances at
        - varying contact loads
        - varying relative motion speeds
- Establishment of required Ra and Rz to both contact surfaces to achieve the required friction coefficient
- Verification of the friction coefficients for all needed contact loads from 15 MPa to 60 MPa for needed relative motion speeds

All tests were performed at ambient temperature and ambient pressure. Tests in vacuum can be performed only on the fully integrated HDRM. The friction coefficient of Vespel SP1 is stable wrt. vacuum and humidity.

Vespel SP1 to Alu	Speed cw	Sliding-friction	Static-friction	Speed ccw	Sliding-friction	Static-friction
	mm/s	cw	cw	mm/s	ccw	ccw
15 MPa	1,793	0,342	0,418	1,173	0,340	0,423
30 MPa	7,210	0,311	0,372	7,232	0,309	0,400
60 MPa	1,692	0,337	0,337	1,184	0,296	0,390

Figure 8-Results of friction measurement test Vespel SP1/Aluminium

2.2 Force/deflection calibration of the Horizontal Preloading Plates

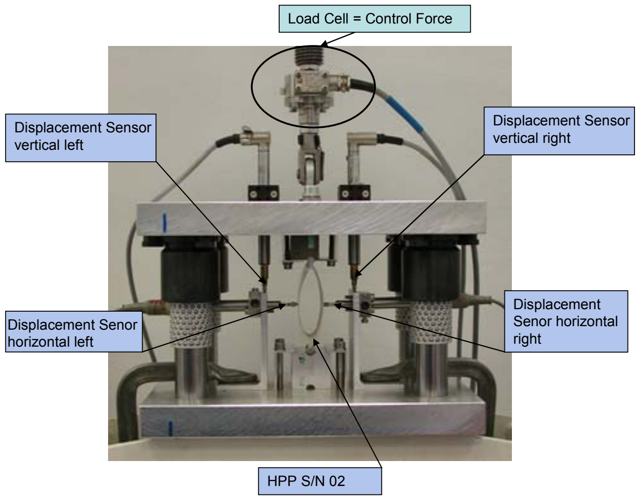

Figure 9-HPP deflection calibration test set-up

At this test each HPP is axially loaded prior to assembly into the HDRM. Displacement in load direction and normal to the load direction is measured by the use of linear variable differential transformers. In addition four HPPs were equipped with strain gauges.

Results of force/deflection calibration test:

- Verification of HPP structural integrity analysis
    - Two HPPs manufactured in one batch with the B/B test HPPs were loaded about 30% higher compared to the nominal loads. No plastic deformation and no fracture of the HPPs occurred.

- Verification of HPP displacement analysis in load direction and normal to the load direction.
    - The analyzed values correspond good to the analyzed values.
    - This implies achievement of the required manufacturing tolerances by the manufacturing process wire eroding.
- Verification that no need of strain gauge application on the HPPs is needed for verification of the preloading force. This can be performed by measurement of the deflection in the middle area by two point measurement from one side to the other side by a caliper. For such measurement a calibration curve displacement normal to load direction over force is needed.
    - Calibration via a dimensional measurement described above is accurate enough.
    - Better accessibility to the 2x corresponding measurement points must be applied to be able to perform preload verification during all phases of the program.
- Verification of the workmanship
    - Good uniformity among the HPPs can be provided. Maximum deviation is 7.5%.

2.3 Measurement of the motorization margin and verification of the coating of the HPPs at the hinge I/Fs on both sides

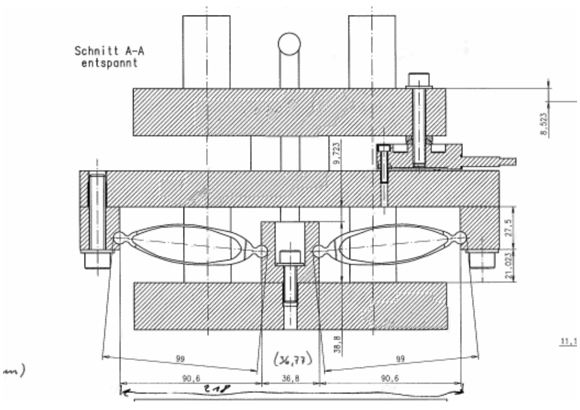

Figure 10-Horizontal Preloading Plate deflection calibration test set-up principal

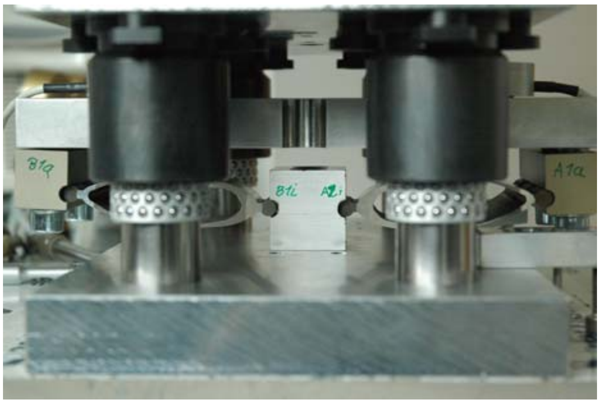

Figure 11-Horizontal Preloading Plate deflection calibration test set-up

Results of measurement of the motorization margin:

- Verification of the correct angular arrangement of the HPPs (about 10° from horizontal position in preloaded configuration)
- Verification of the coating of the bearing parts on both sides of the HPPs:
    - Verification of the robustness of the coating to survive 100 closure/ opening sequences
    - Verification that the friction coefficient under representative preload is low enough to fulfill the motorization margins of ESA ECSS .

The motorization margin was tested on 2x additional HPPs fully representative to the HPPs used in the HPP assembly.

The motorisation margin was measured only for the release phase from preloaded configuration (HPP preload 3500 N) to intermediate configuration (HPP preload 70 N). During this phase the angle from HPP axis to the horizontal plane is low (9.9° to 11.6°).

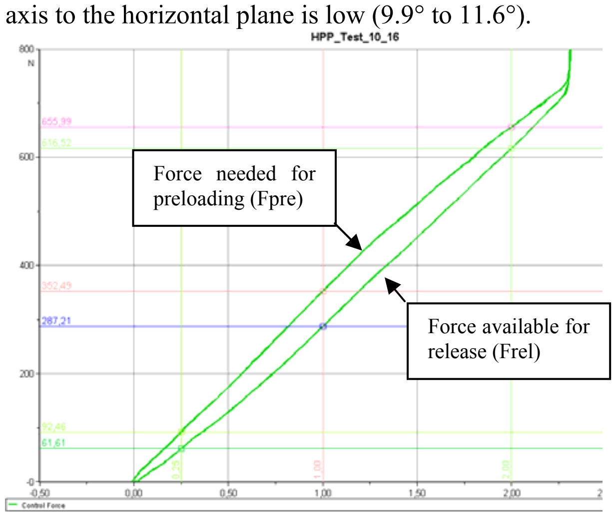

Figure 12-Verification of the motorization margin

Formula for analysis of the reserve factor:
Ffric = (Fpre - Frel)/2 - Ffric_test_set_up
Fmean = (Fpre + Frel)/2
Reserve Factor = Fmean / Ffric

s	0.25 mm	0.5 mm	1 mm	1.5 mm	2 mm
Fpre	92 N	175 N	352 N	513 N	656 N
Frel	62 N	129 N	287 N	452 N	617 N
Ffric_test_set_up	10 N	10 N	10 N	10 N	10 N
Ffric	5 N	13	22.5	20.5	9.5
Fmean	77 N	152	319.5	482.5	636.5
Reserve Factor	15.4	11.7	14.2	23.5	67.3

Figure 13-Motorization margin reserve factors

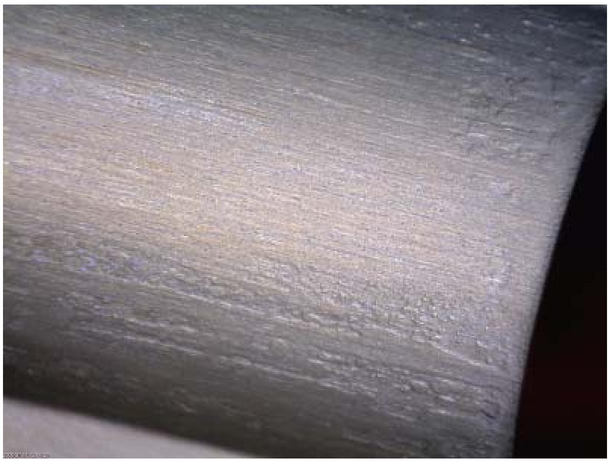

Figure 14-Contact surface of HPP before test

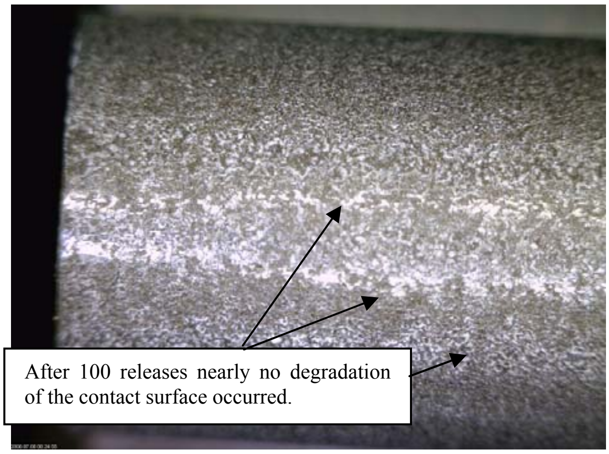

Figure 15-Contact surface of HPP after 100 releases

2.4 HDRM assembly test

Results of HDRM assembly test:

- Verification of needed preload distribution over the different HPPs. Therefore each HPP preload was measured via dimensional and if available via strain gauge pre load measurement.

Strain Gauge #	Result of strain gauge measurement	Analyzed preload force of HPP (linear interpolation)	Deviation from nominal value of 3500 N
1	2,8464 mV/V	3433	-1.9 %
3	2,8051 mV/V	3341	-4.5 %
5	2,9380 mV/V	3238	-7.5 %
7	2,9496 mV/V	3500	0 %

Figure 16- Preload of the HPPs equipped with strain gauges after assembly and preloading of the HDRM

- Verification of the needed global preload of the HPPs and if easy adjustment of the preload can be provided.
- Verification that the HDRM can be preloaded easily

2.5 Vibration tests w/o damping elements

Quasistatic, sine and random vibration test was performed out of plane (as on figure below) and lateral.

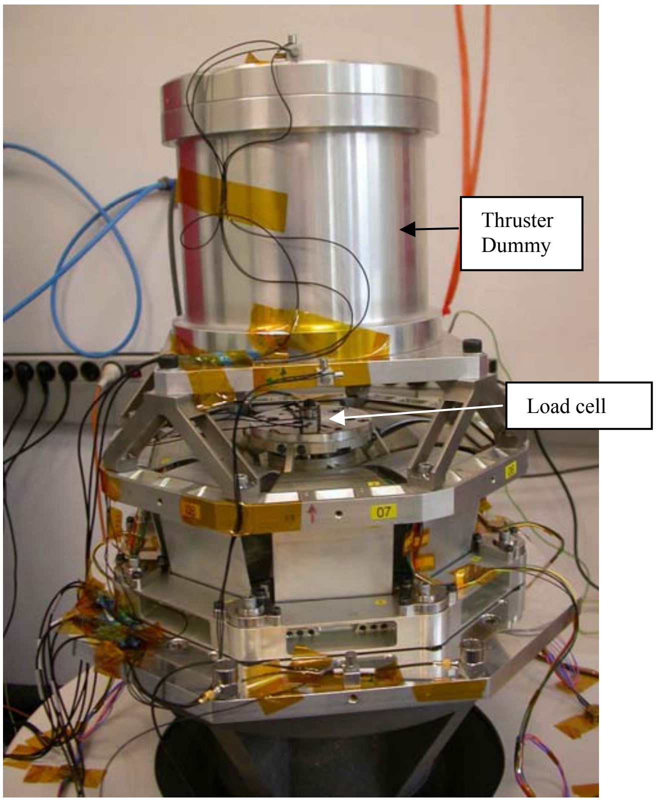

Figure 17 – Vibration Test for out of plane excitation

Test set-up:

- HDRM is mounted in preloaded configuration
- Thruster Dummy CFE from Thruster suppler is used, which is representative in mass and CoG. Stiffness is higher compared to the Thruster.

- A load cell for verification of the preload was mounted between the Release Bolt and the Preloading Unit. The results were recorded during all vibration tests.
- The strain gauges mounted on four HPPs were recorded during all vibration tests.
- The visco-elastic dampers were replaced by structural damper dummies.

Results of vibration test w/o damping elements:

- Verification of the structural integrity of the HPP under dynamic qualification loads
  - No fracture
  - No slippage at bolted connections
  - No slippage in the preloaded Release I/Fs
  - No slippage at the Preloading Unit and not overloading of the Release Device. The preload at the release device stayed always between 11500 N and 13300 N which is in line with the selected release device.
  - Preload of HPPs shall not deviate more than ±20 % from the nominal value 3500 N. Highest deviation was -18.6%

  At a first run slippage at one bolted connection occurred. After redesign and rework the test was started again.

  All objectives stated above could be verified.

- Verification of the analyzed Eigenfrequencies of the structure. The deviation lateral was smaller than 1%, the deviation out of plane was 6%.

2.6 Dynamic release tests

Test set-up for the dynamic release test provides a soft support for the Thruster Dummy. This was realized via spring elements between the Dummy and the support in out of plane direction and via the 2x cable supports in lateral direction.

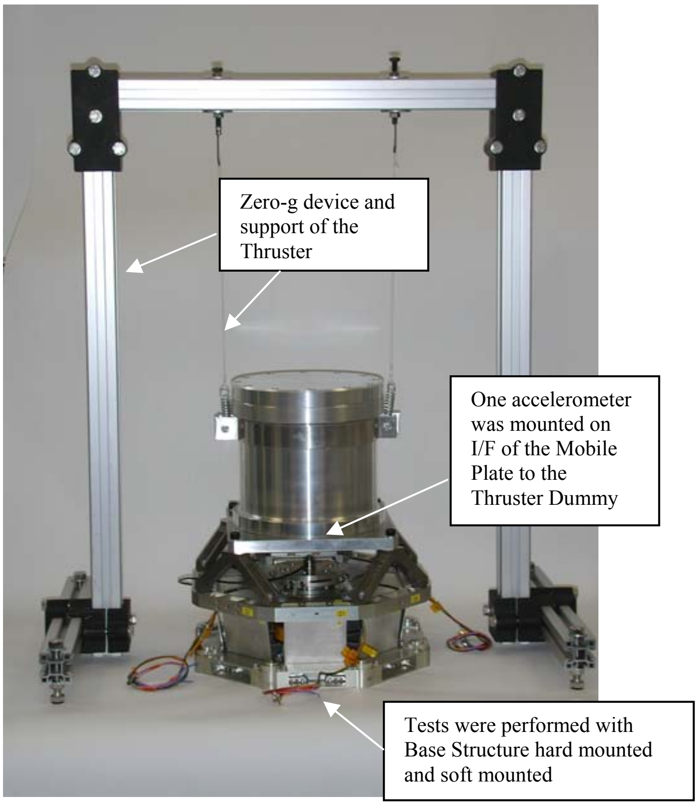

Figure 18 – Dynamic release Tests

Results of the dynamic release tests:

- The shock load spectrum is shown in the figure below. The shocks are about 10% higher than the required values. Measurement was performed close to the area of release shock induction. Release shock at Thruster CoG much less than 400g at 1 kHz.

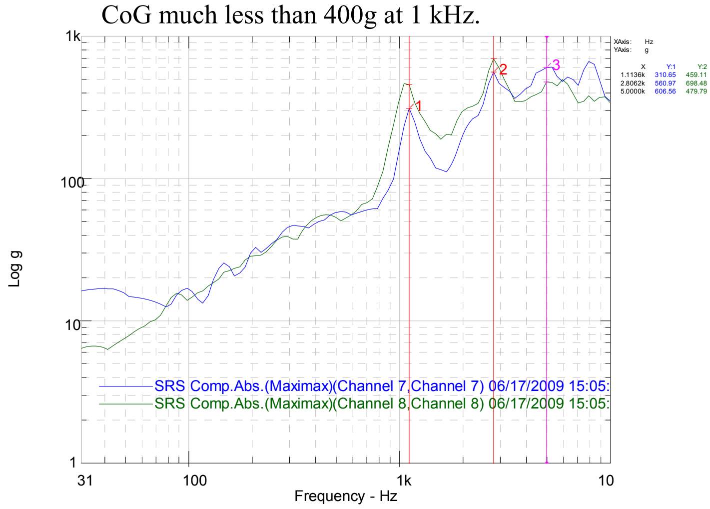

Figure 19 – Shock Response Spectrum (SRS) introduced into the Thruster at release at the Thruster I/F plate

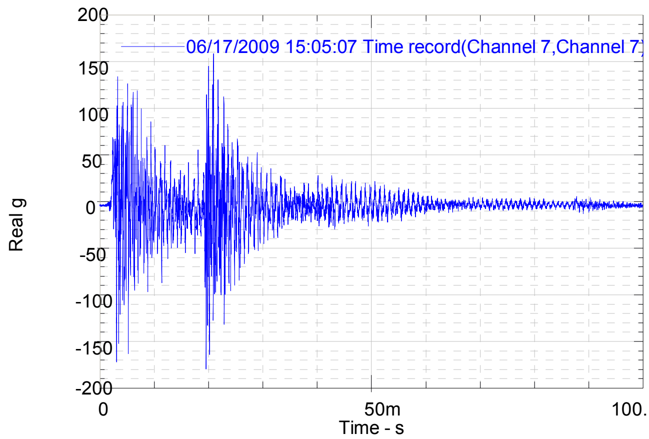

Figure 20 – Measured shock amplitudes over time introduced into the Thruster at release at the Thruster I/F plate

2.7 Global HDRM motorisation margin test

Test set-up:

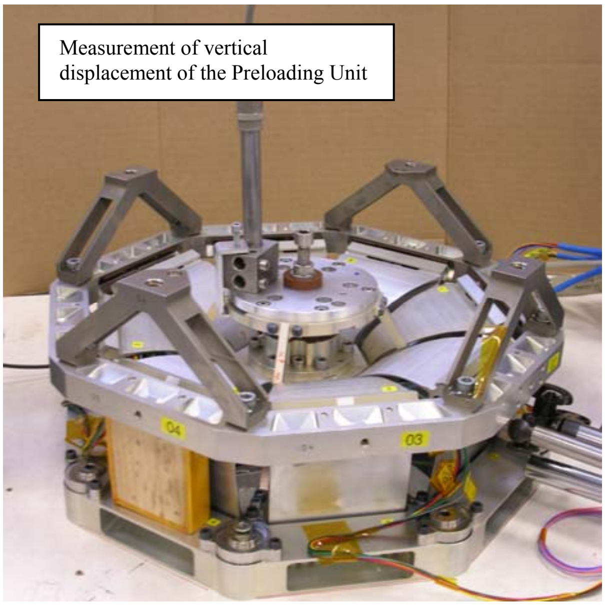

Figure 21 – Global motorization margin test set-up

Test results of the HDRM motorization margin test:

- Verification that the required motorization margins for the whole release sequence in accordance with ESA ECSS can be achieved as shown for one measurement in the figure below.
  Area between fully preloaded configuration to intermediate configuration: The safety margin is 1500%

  Area of intermediate configuration where the VPPs get into contact with the Mobile Plate:
  - Mean strain: (0.50+0.33)/2=0.415
  - Loss by friction: (0.50-0.33)/2=0.085
  - Safety factor: 0.415/(0.085*3.75)-1=30%

  The safety margin against ESA ECSS requirement is about 30%

  Area between intermediate configuration and released configuration: The safety margin is 380%

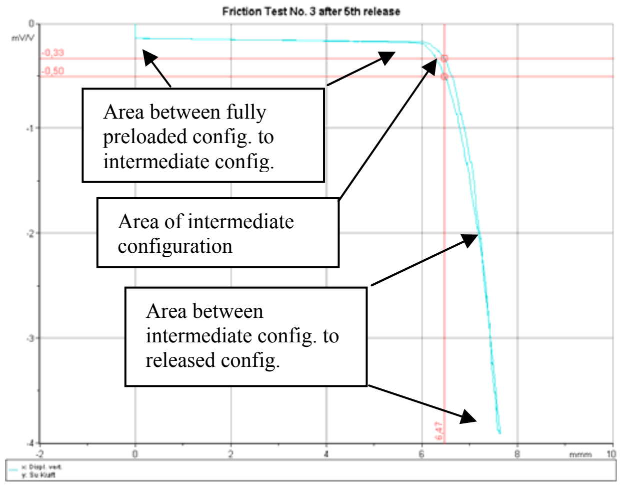

Figure 22 – Global motorization margin test set-up

3. CONCLUSIONS

The breadboard test program, although it is not fully finished and not fully reviewed by the customer, can be judged as very successful.

All HDRM related requirements can be achieved with the HDRM B/B design with the following modifications:

- Redesign of the HPPs is necessary to make HPPs more stable against introduced torque which comes from friction in the hinge HPP/VPP and HPP/Preloading Unit. Designs for such modifications have been established.
- Stiffness of top plate of Preloading Unit has to be increased. This is needed to shift a local mode from 816 Hz to higher frequencies.

4. LESSONS LEARNED

4.1 Kinematics suitability of the mechanism

- No blocking of the mechanism
  The kinematics of the mechanism prevents blocking. It is not possible to make the mechanism block by manual external load introduction from different orientations.

- The plays in the hinges between HPPs /VPPs and HPPs/Preloading Unit are fully sufficient to overcome all tolerances.

4.2 <u>Development and verification of the contact surfaces of the sliding surfaces between HPPs /VPPs and HPPs/Preloading Unit</u>

Engineering and structural analyses were performed not only of the basic material but also of the surface coatings. The compatibility to the high loads could be verified by test.
Despite the use of surface coatings, which are not typical for the used application, the resistance against wear and the friction coefficient was very satisfying.

This kind of surface mating may be used also for other applications.

4.3 <u>Development and verification of the contact surfaces of the release I/F from Vespel SP1 to the VPPs</u>

Via application of special surface roughness for both contact surfaces the needed friction coefficient could be provided. The friction coefficients are stable at variation of loads and relative velocities.
During the dynamic tests and motorization margin measurements the selection of the applied surface parameters was verified.
Also in this case the material Vespel SP1 is no typical material for a release I/F, which has to transfer high loads via friction.

4.4 <u>Use of the material Aluminium for the springs HPPs and VPPs</u>

Both groups of parts are highly loaded structural elements but also spring parts with high potential energy which provide the only source for deployment.
The use of aluminum for spring elements is quite unusual.
By the permanent measurement of the strain of the HPPs it could be verified that the preload of the HPPs stays intact over the whole test program.

4.5 <u>Stiffness analysis versus test results</u>

- First lateral predicted mode with 113.5 Hz and measured first mode with 112.8 Hz are very close together (0.6%).
- Second lateral predicted mode with 470.0 Hz and measured first mode with 473.5 Hz are very close together (0.7%).
- First out of plane predicted mode with 319 Hz and measured first mode with 299.9 Hz are close enough together (6%).

The transfer function per analysis is extremely accurate although the used model is a very rough finite element model.

4.6 <u>Structural analysis of all components is mandatory</u>

Especially all fasteners (bolts, pins, contact elements) have to be verified by analysis. Simple hand calculations showed high negative margins at the fasteners between VPPs and Base Structure which culminated in redesign, rework and retest of the HDRM after a first unsuccessful vibration test campaign.

A patent for the HDRM is filed.

5. ACKNOWLEDGEMENT

We gratefully acknowledge the support of the customer ESA Jean-Michel Lautier in conducting this demanding project.