LAUNCH LOCKING DEVICE FOR THE SEVIRI SCAN ASSEMBLY

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ABSTRACT

SEVIRI (scanning enhanced visible infrared imager) is the main instrument of the METEOSAT second generation (MSG). Within SEVIRI, the scan assembly (SA) presents the entrance aperture and provides the line-by-line scanning of the earth. An overall view of the SA is given in Figure 1. The scan assembly essentially consists of the scan mirror assembly (SMA) which comprises a plane mirror, supported by bearings and structure and driven by a linear drive. To convert the linear motion of the drive into a rotation a kinematic link employing two sets of flex pivots is used. Unacceptable mechanical loads on drive and flex pivots made it necessary to implement a Launch Locking Device (LLD).

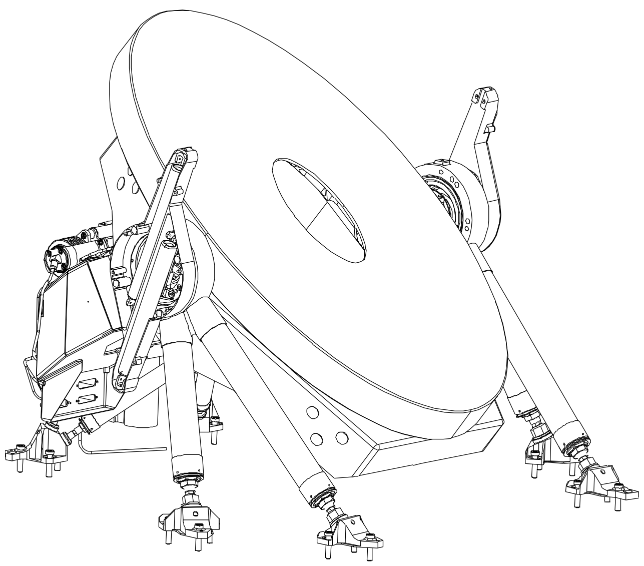

Figure 1: Overall view of the scan assembly (SA)

The LLD is composed of a clamping mechanism based on a toggle lever design. In-orbit it is released by a pin puller device in which the actuation force is produced by the expansion of heated paraffin. For locking the LLD on-ground, it is equipped with a pneumatic actuator which provides the locking force by the use of pressurised gas.

In this paper the functional design of the LLD, based on the key requirements, is described. The dependence of the performance on certain parameters of the mechanism kinematics and the elastic properties of its components is discussed. Design margins derived from the measurement results achieved during functional and environmental testing are shown. Based on the result of a correlated mathematical model, the detailed performance parameters of the SA LLD and their dependence on specific design features are described.

1. REQUIREMENTS

The LLD shall allow a protection of the drive and the flex pivots from unacceptable mechanical loads resulting from the response of the SA to vibration loads. For the drive a decoupling is achieved by connecting it to the SMA via a pre-loaded spring. This spring provides sufficient force to maintain a rigid connection between drive and SMA during SA operation. In launch configuration the SMA is driven against a hard endstop. Thereby the rigid connection is opened by about 0.5mm providing a mechanical decoupling of drive unit and SMA. Forces created by relative movements are thus limited to the forces in the spring. The loads in the flex pivots mainly result from the relative movement between drive and SMA in the drive direction, therefore a high stiffness of the connection is required.

The dynamic properties of the SA lead to high responses of the SMA in the direction perpendicular to the drive direction. Especially in the direction parallel to the axis of the SMA bearing a strong response was found, resulting in a relative movement of about 0.3mm if not constrained. To suppress this relative movement high forces would be needed. A LLD mounting interface design with sufficient strength to take these forces was found not to be feasible. Therefore the stiffness in this direction has to be low in order to limit the forces resulting from the relative movement.

The LLD needs to be released and safely latched only once after launch. For the rest of the in-orbit lifetime, the LLD will not perform any function. However, during ground testing a number of locking and release sequences have to be performed without accessibility to the LLD. Therefore both, release and locking function must be performed remotely controlled.

Initially the SA development started with a different design which proved to be not suitable in the first vibration test of a SA structural model. The new design of the LLD only started after all mechanical and electrical interfaces were already frozen. Furthermore an actuation device had been procured and a change to another one was also not possible due to the specific electrical interface.

The following key requirements have to be fulfilled:

- Provide a hard endstop for the SMA rotation
- Connect SMA to the supporting structure with high stiffness in drive direction
- Comply with a tension force of 4300N in drive direction
- Provide a low stiffness perpendicular to the drive direction
- Accommodate a relative movement in the direction parallel to the SMA bearing axis of 0.3mm
- Allow a remotely controlled locking
- Comply with the frozen mechanical and electrical interfaces
- Employ the STARSYS P35055 pin puller

2. FUNCTIONAL DESIGN

The LLD is separated into 3 main subassemblies, the mechanism, the actuator and the pin puller. In Figure 2 the principle design of the mechanism is shown. The interface loads are transferred via the 2 parts interfacing with SMA respectively support structure. The part on the SMA side is called spherical ball bracket (SBB), the one on the support structure side spherical reception insert (SRI). The loads in axial direction are taken by contact pressure in compression. In tension these loads are transferred via 2 clamps. The clamps are provided with an rather small angle on the contact surface. This allows to produce a high compressive pre-load on the contact surface of SBB and SRI with a clamping force lower than the axial interface load.

The pre-load on the clamps is achieved by moving the toggle levers into their centre position. This arrangement allows for a varying transmission ratio between the actuation force on the toggles and the clamp force. Far away from the centre position this ratio is less than 1, i.e. the clamps can be moved by small actuator travels. Closer to the centre position, the transmission ratio increases rapidly, at the centre position up to infinity. Thus very high clamping forces can be achieved. At the centre position, ignoring friction, the force on the actuator is zero. Once it passes the centre position it even changes sign, i.e. the actuator is pulled into the endstop. In order to reach the centre position an elastic deformation in the LLD is needed. This elastic deformation then provides the required pre-load on the clamps without any need of an additional holding force to maintain the locked condition.

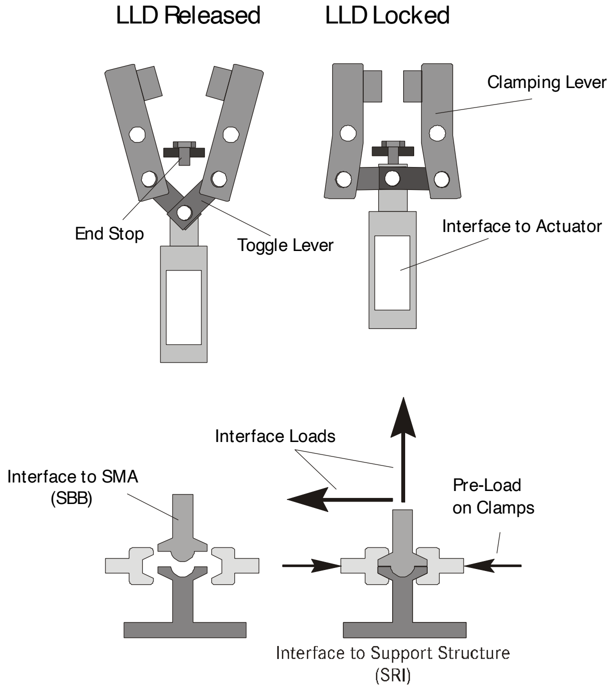

Figure 2: Principle design of LLD mechanism

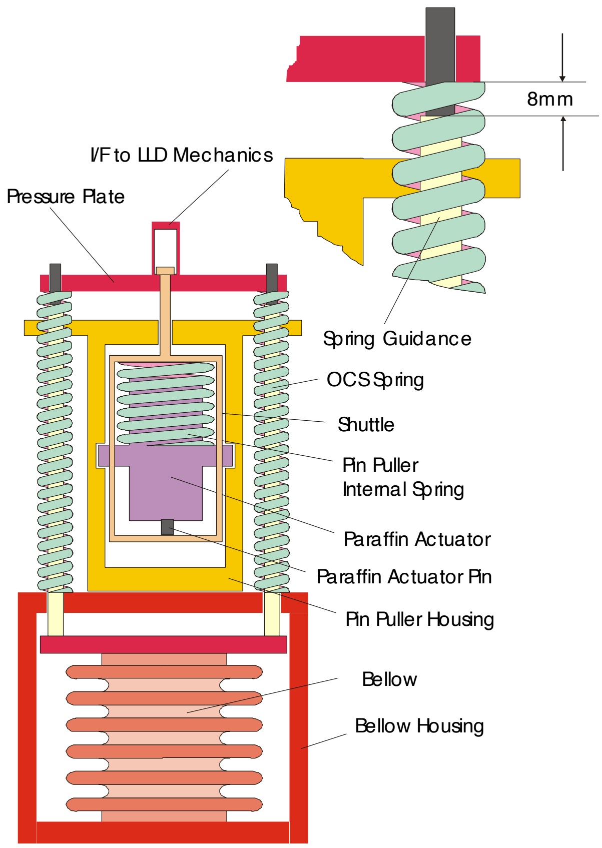

Figure 3: Schematic representation of actuator

A schematic representation of the actuator including the pin puller is shown in Figure 3. The retraction force is provided by the paraffin actuator of the pin puller. An enclosed volume of paraffin is heated. The paraffin expands while changing to liquid state and thus presses out a pin. This pin drives the shuttle which converts the paraffin actuator force into a retraction force of the pin puller. The force acts on the pressure plate which provides the interface to the mechanism.

In order to safely maintain the mechanism in locked state during launch, over-centre securing (OCS) springs are used. They permanently press the toggle levers against the end-stop. The pin puller can only provide high forces in the retracting direction, therefore a separate actuator is needed or the locking of the LLD. Since this is only used on ground, it was possible to employ a pneumatically driven unit. This is simply done by using a bellow which is pressurised to expand and to exert a force on the interface to the mechanism. The transfer of this force is done by 2 studs which also serve as guidance for the OCS springs. For the pressurisation of the bellow a thin Teflon tube with 3.2mm outer diameter is used which is routed through the spacecraft and is accessible from outside.

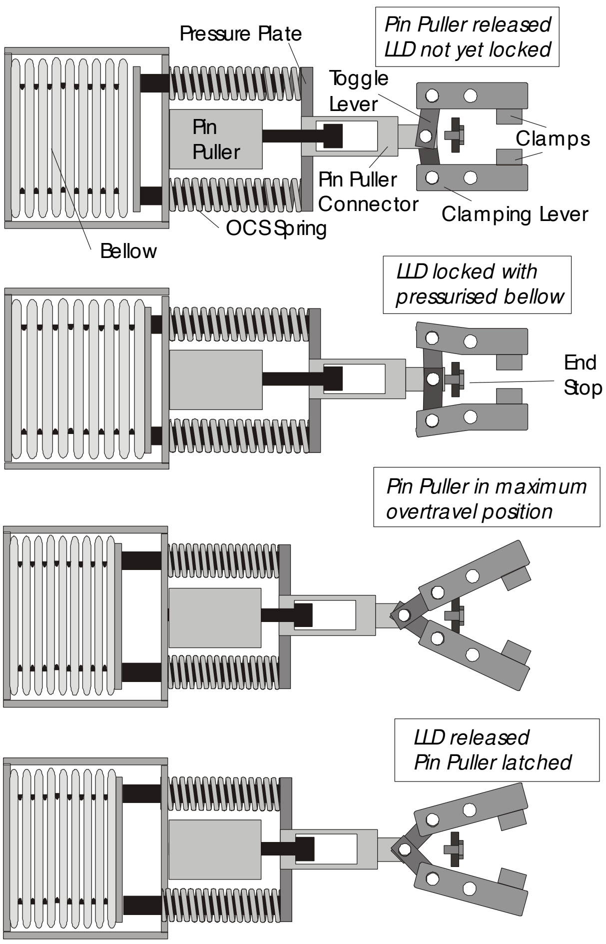

Figure 4: Schematic representation of the LLD function

A schematic representation of the overall LLD is shown in Figure 4. It shows the main events in a full operation sequence starting with the initiation of locking. The pin puller is in released state, i.e. fully extended. The OCS springs act on the toggle levers which has brought the clamps to contact with SRI and SBB (not shown here). The OCS spring force alone is not sufficient to achieve locking. For the final locking pressure is applied on the bellow. This then moves the toggle levers over the centre position up to the end-stop, deflects the clamping levers elastically and thus creates the clamping force of the clamps on SBB and SRI. Once the over-centre position is achieved, the pressure is removed.

For the LLD release the pin puller is activated, it pulls the toggle levers backwards. The pin puller needs a certain amount of over-travel in order to engage its internal latching mechanism. This situation is shown in the 3rd picture. After having reached the maximum over-travel position, the paraffin actuator heater is switched off and the pin puller starts to extend again until it reaches its internal latch position. The pin puller internal latch then takes the forces from the OCS springs and bellows and holds the mechanism in the open position. The unlatching of the pin puller is done by driving it again into its over-travel position. The internal latch has a toggle function which lets the pin puller alternately achieve the latched or the extended position.

3. PERFORMANCE DRIVING PARAMETERS

The clamps are provided with a slant surface. The angle of this surface determines the maximum force which can be transferred for a given clamping force. The angle has to consider a possible self-locking due to friction, $\mu \leq \tan(\alpha)$. The ratio between clamping force and maximum transferable axial load is shown in Figure 5. For zero friction this ratio is 1 for 45° and increases strongly with decreasing angle. The ratios for increasing coefficients of friction are also indicated in the plot, the vertical lines show the self-locking limit angles for each of the coefficients of friction.

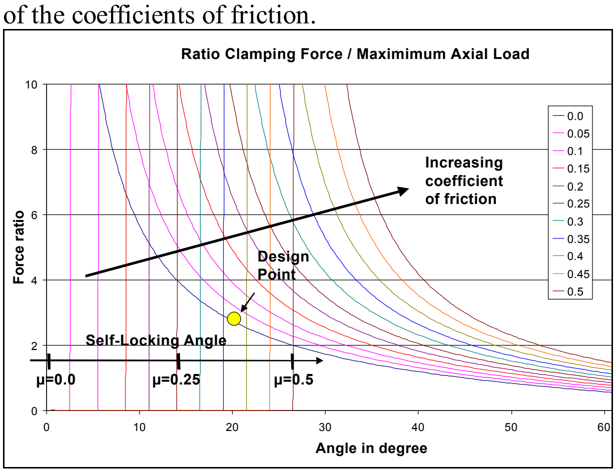

Figure 5: Ratio of clamping force and resulting maximum axial load

The selected surface coating was Vitrolube applied on one side of contact pairings. For a Vitrolube/uncoated Titanium pairing, a measurement in a representative test set-up has been performed. The coefficient of friction including the sticking effect was found to be 0.24. An angle of 20° was selected to provide an uncertainty margin towards the coefficient of friction of 50%. This selected design point is also indicated in the plot in Figure 5. The maximum axial load results from the loading in vibration testing. For this case zero friction has to be taken into account. The resulting force ratio is thus 2.75. The clamping force results from the mechanism strength analysis and was selected as 2500N. Thus the maximum transferable axial load is 6875N.

The lengths of the levers were essentially fixed due to geometrical and strength constraints:

- Available envelope
- No interference between the interfacing elements in the retracted position of the actuator
- Accommodation of a 30% actuator over-travel without fully stretched toggle/clamping levers
- Dimensions needed for strength reasons

The 2 remaining free parameters were:

- the stiffness of the clamping levers and clamps and their attachment provisions
- the amount by which the toggle levers are allowed to pass over the centre position.

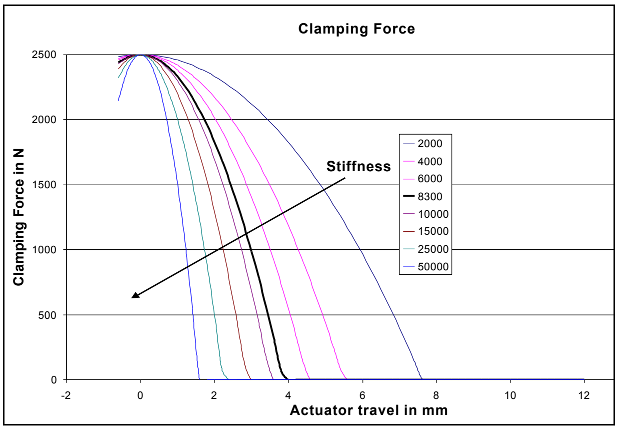

Figure 6: Clamping Force

The clamping force has been calculated based on the given geometry. In Figure 6 the clamping force is plotted versus the travel of the actuator for different stiffness values. The coordinate for the actuator travel is zero at the mechanism centre position and increases with the retracting actuator. For a low stiffness the adjustment of the clamps has to provide a large clamping lever deflection, therefore an early contact of the clamps occurs. At the centre position the high stiffness gives the highest sensitivity to adjustment errors. It can be seen that for the high stiffness a reduction in clamping force by 15% due to 0.6mm over-centre position results. A minimum of 0.3mm is needed to ensure that the locked state is maintained under vibration loads. Misadjustments of the clamps show much higher effects. For a change of 0.01mm the clamping force would be reduced by 20%. A thread pitch of 0.5mm leads to a screw rotation of 7° which can hardly be adjusted.

The actually achieved stiffness is 8300N/mm for which the clamp contact occurs at 4mm before centre position. An over-centre position of 0.3mm leads to a loss of clamping force of about 1%, a change in clamp adjustment by 0.01mm leads to a loss of about 3% in clamping force. These values are well within the acceptable ranges.

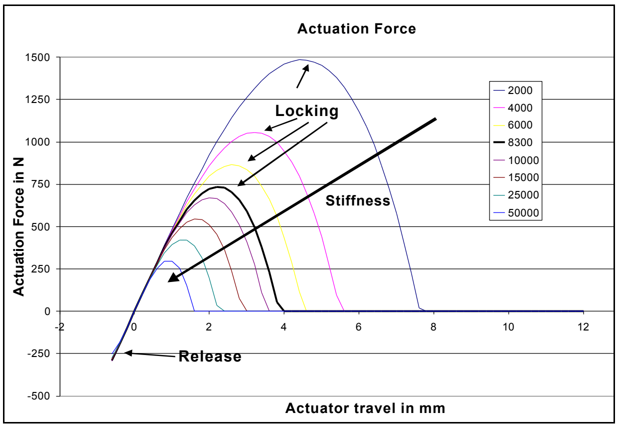

Figure 7: Actuation Force

The resulting forces needed for the actuation of the mechanism are shown in Figure 7. The forces needed for locking increase dramatically with decreasing stiffness of the mechanism. This is due to the early contact of the clamps. The toggle levers have at this point still a rather big angle which leads to low transmission ratio between force acting on the toggle levers and the force resulting at the clamps. The force needed for mechanism release is found on the negative axis. It is much less dependant on the stiffness since the geometry is the same for all stiffness values. The main driver for the retraction force is the over-travel. The differences in actuation force only result from the different clamping forces and thus somewhat smaller values for a higher stiffness are found. Actually theses effects would be covered by friction effects which are not considered here.

In summary it can be concluded that rather low stiffness is required in order to comply with the adjustment possibilities and to limit the sensitivity of the mechanism to setting and thermal deformation effects. This increases the actuation force needed for locking. However, locking is done on ground with a device that provides sufficient force and thus the mechanism can be designed towards insensitivity to setting effects without increasing the need for release force.

4. DESIGN DETAILS

An overall view of the LLD is given in Figure 8. Some specific design features of the LLD components shall be discussed here.

The material selection was made based on the individual needs of each component. The SBB has to accommodate large deformations and still to transfer high loads, therefore Titanium is employed. For the SRI steel is used. The contacting surface is coated with Vitrolube on SRI side. This coating provides a low coefficient of friction which is necessary to avoid self-locking at the edges of the spherical interface. Also this coating provides a high resistance against surface relative movement under high pressure loads, which was proven in a sample test. For the clamps high strength bonze was used. On SBB and SRI side the contact surface with the clamps is also coated with Vitrolube. Thus all contact surfaces are provided with a highly resistive low-friction coating. Different materials are used in order to avoid cold welding in case direct metal-to-metal contact should occur due to failure of the coating.

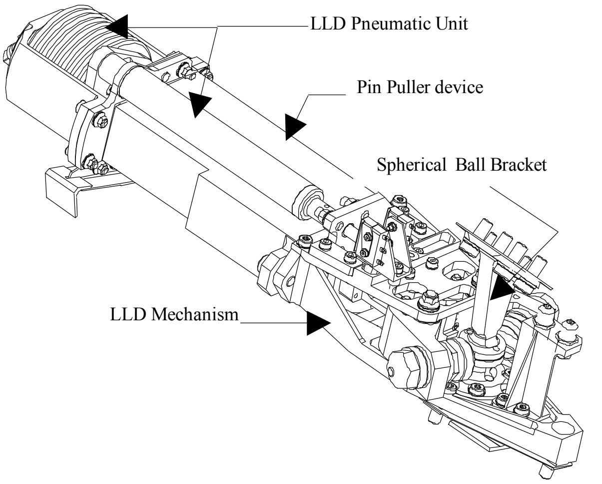

Figure 8: Overall design of LLD

The clamps themselves provide large cross-section areas in order to achieve a high bending stiffness with respect to the transfer of loads. The fixation of the clamps allows accommodation of misalignment without local increase of surface pressures by a rather long bolt interface with 5mm diameter.

The attachment of the clamping bolts to the rocking levers is shown in Figure 9. The inner cylinder stems via a spherical flange and a concave spherical washer against the clamping lever. Thus this cylinder can be laterally moved and can be tilted within the range given by the hole in the clamping lever. The clamping bolt is attached to this inner cylinder via a thread with allows to adjust the distance of the clamping surfaces from the clamping lever and thus to adjust the pre-load of the clamps. In order to maintain the position of the clamping bolt for a released LLD a counter screw is provided which stems via spherical washers on the clamping lever.

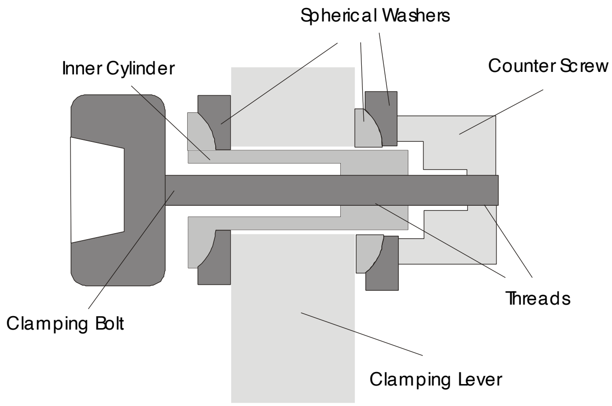

Figure 9: Schematic view of the attachment of the clamping bolts

The clamping levers provide the pre-load for the clamps. They are attached to a base bracket and support plate via bolts and can rotate on DU bushings. The pre-load on the clamps is maintained by a deflection of the clamping levers. In order to achieve a low sensitivity to thermal deformation and setting effects and to allow a sufficiently accurate force adjustment capability, a defined elasticity of the clamping levers has to be provided. This is achieved by a slot introduced between the bearings to the main bolt and to the toggle lever as shown in Figure 10. Thus it is ensured that the bending does not impact the alignment of clamping bolt, SBB and SRI. This slot furthermore provides a location which shows a strain that can accurately be correlated to the clamping force. Strain gages at this location are used to measure clamping pre-load.

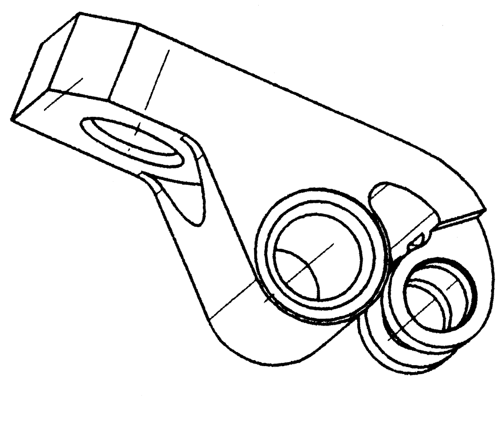

Figure 10: Clamping Lever

5. ACHIEVED PERFORMANCE

The LLD has successfully passed a full qualification program including vibration, TV, spin and lifetime testing. The achieved axial load in vibration was 4500N. Operation under TV (release) was performed under 0°C and 50°C. The locking inside the vacuum chamber was done under vacuum conditions via a feed-through for the pressure line without impact on the vacuum of the chamber. A lifetime test with 400 cycles was performed. In none of the tests a degradation of clamping force by more than 4% was found. The maximum reduction in clamping force occurred during vibration testing due to the clamps travelling further up the slant interface due to break-down of friction force. This rather increases the pre-load on the interfacing SBB-SRI surface. The actuation force was monitored in all tests using strain gages on the pin puller housing. Although these strain gages are not suited to measure an absolute value for the actuation force, they would provide a clear signal in case of a sensible change in actuation force. No change was noticed in any of the actuation's. The pressure needed for locking is an indication of the friction force inside the LLD. This pressure was always constant within the measurement accuracy.

A mathematical model which represents mechanism geometry, stiffness and friction based on measured values from all LLD components was established. This model was correlated with measurement results gained from the test on integrated mechanism and LLD. In Figure 11 a comparison of the measured actuation forces with calculated values is given. A further check of the model was done by comparing the measured and the calculated pressure needed for locking. The deviations were always within ±5%. On this model then the usual uncertainty factors (i.e. 1.5 for friction and 1.2 for spring forces) were applied in order to derive the force margin of the paraffin actuator which is the critical element for the in-orbit release of the LLD.

In Figure 12 the force margin as a function of the travel of the actuator is shown:

- At the initial retraction the toggle levers have to be moved away from the end-stop out of the over-centre position where the mechanism needs a high force, here the minimum margin of 2.1 is found.
- After passing the centre position the mechanism actually helps retracting against the springs, the force margin increases up to 3.4
- Once the clamps loose contact, the actuator has to retract against the springs.
- After half-way of retraction contact with the bellow is reached, the overall spring rate increases
- At the maximum over-travel of the pin puller the second minimum in force margin of 2.3 results from the maximum compression of the springs and the bellow.

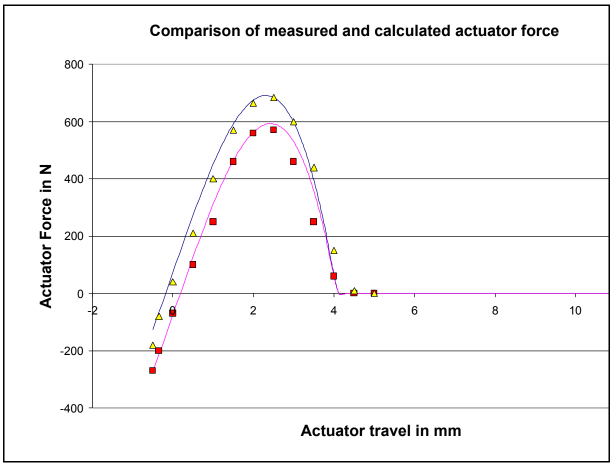

Figure 11: Comparison of measured and calculated actuation forces (locking and release)

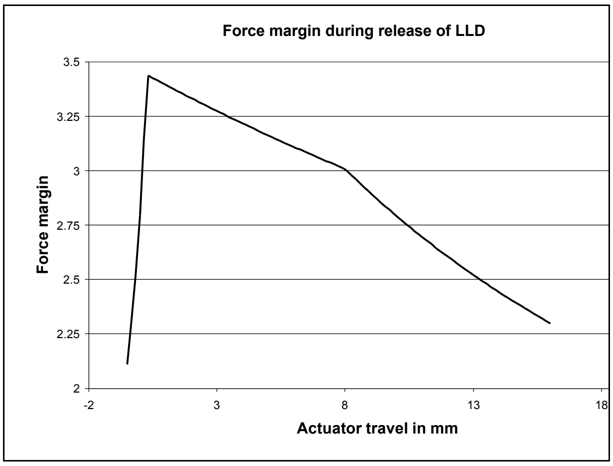

Figure 12: Force margin of the paraffin actuator during LLD release

6. CONCLUSION

The development of the LLD was successfully performed within the difficult technical and schedule constraints.

It was found that the LLD still provides further growth potential in terms of maximum transferable load and lateral deflections to be accommodated at the interface. A comfortable actuator force margin is provided.

The design facilitates the integration activities by limiting the sensitivities to adjustment inaccuracies. An end-to-end verification of the correct status of the LLD integrated in the SA is provided by a direct clamping force measurement and health check of the LLD in terms of changes in the actuation force.