DESIGN VALIDATION OF A CRYOGENIC JOINT FOR THE SPATIAL FRAMEWORK OF HERSCHEL

by
Carlos Pereira
HTS AG
Wallisellen Switzerland
Tel +41 1 839 1254
Fax +41 1 839 1200
mail to: carlos.pereira@htszh.ch

The Herschel space observatory will capture the far infrared universe through three instruments: a camera (PACS), a high resolution spectrometer (HIFI) and a photometer (SPIRE) which sit on an optical bench and are cooled to less than three degrees above absolute zero. The cooling of these instruments is achieved by placing the bench inside a large cryostat containing a superfluid helium tank at 1.6 K and a circulation loop to deliver the helium to the bench. Both the bench and the tank are supported by a spatial framework consisting of two aluminium frames which straddle the helium tank (Figure 1).

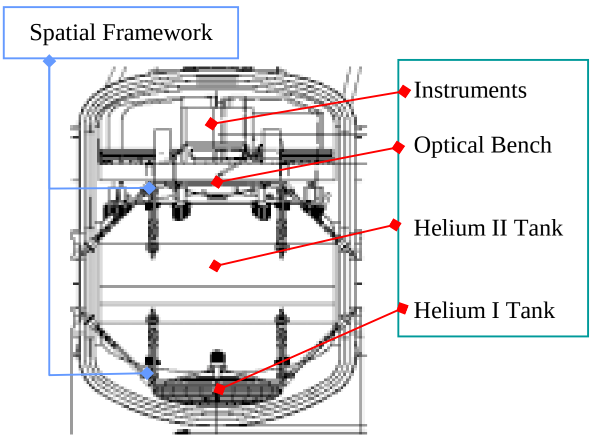


Figure 1- Location of Spatial Framework in the cryostat

The interface between the helium tank and the spatial framework has been designed to minimise heat loss by using low conductivity struts of reduced cross section and high aspect ratio. In addition this interface must compensate for the thermal contraction of the tank without inducing stresses on the optical bench. To this end the struts use coated ball and socket joints as end fittings. The design of these fittings and its validation from a tribological and structural perspective is the subject of this poster.

Two aspects govern the design of the fittings; ability to allow unhindered rotation about the axis of the strut and ease of fabrication. The locii of the rotation resulting out of the thermal contraction of the tank is given by a dual cone with 1 mm differential displacement between the two interfaces. Figure 2 shows the optimised design of the fittings once structural and thermal demands are considered.

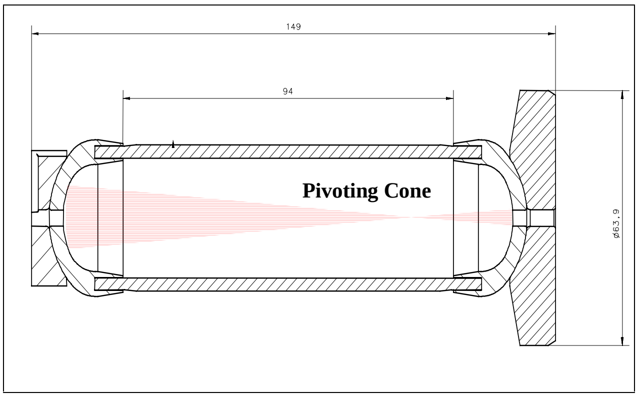


Figure 2 – Design of Interface Strut

The ball and socket surfaces are coated to reduce the coefficient of friction and minimise wear. The main functions of this coating are:

– Allow pivoting under large pretension force (60 kN in the axial direction)
– Avoid sticking under vacuum and at a contact temperature of 1.6 K
– Minimise particulate contamination of the cryostat arising through abrasion of the coating

Three coating candidates were selected based on heritage and expected performance parameters: diamond like carbon (DLC), sputtered molybdenum disulphide (MoS_2) and a molybdenum disulphide-graphite-antimony trioxide (MoS_2-C-Sb_2O_3) mixture. These candidates were tested for tribological performance (friction coefficient and wear) both after pre-loading at room temperature and under cryogenic conditions using the set-up of figure 3.

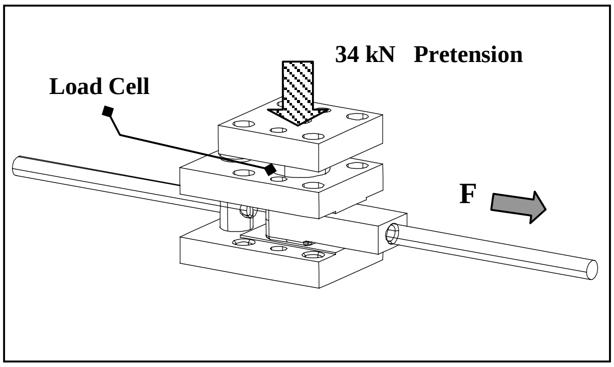
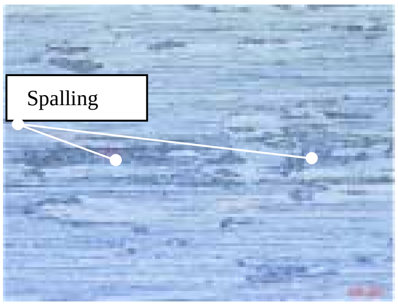
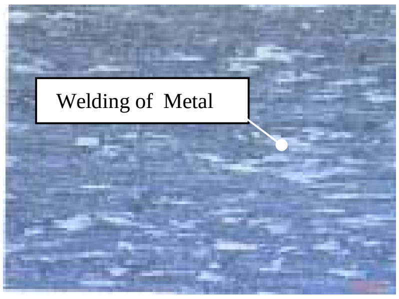


Figure 3 – Test Set-up for measuring friction coefficient

The testing revealed that the hard coating DLC performed very well at room temperature but had a marked tendency for spalling and cold welding in cryogenic temperatures (Figure 4) resulting in a high coefficient of friction. The graphite containing coating would lead to excessive particulate contamination of the cryostat as judged by an alcohol rinse performed immediately after the pull test. MoS_2 was chosen as baseline based on friction coefficient (0.105) and wear.



a. Spalling of Coating



b. Cold Welding of Metal to Coating

Figure 4 – Performance of DLC at 77K

The selected coating was applied on the upper and lower fittings of the strut as well as on the interface fitting to the helium tank and to the framework (Figure 5). Base material for the fittings is aluminium 2219 alloy.

Figure 5 - Coated aluminium fittings

The coated fittings were then bonded to a carbon fibre reinforced epoxy tube and tested for mechanical resistance and tribological performance following the steps shown in the flowchart of figure 6

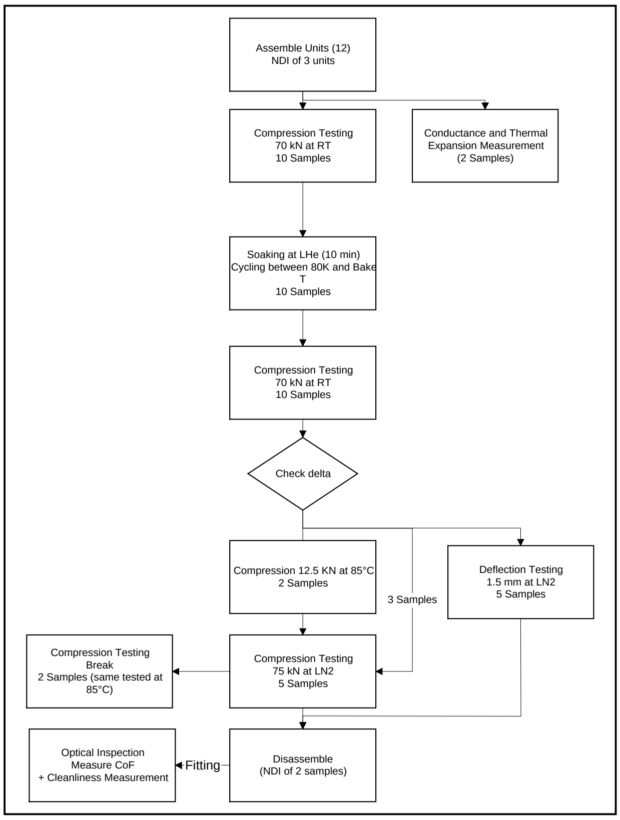


Figure 6 – Qualification testing of interface struts

The ultimate strength of the unit under compression exceeded 185 kN with the failure occurring in the fitting area (Figure 7). The resulting margin of safety is 2.1

Figure 7 – Compression failure of unit at 77 K

None of the coatings showed any damage under 70 kN compression loading and there was no significant difference in performance before and after cycling.

The coating showed a tendency to spall off in the larger fittings after immersion in liquid nitrogen (figure 8)

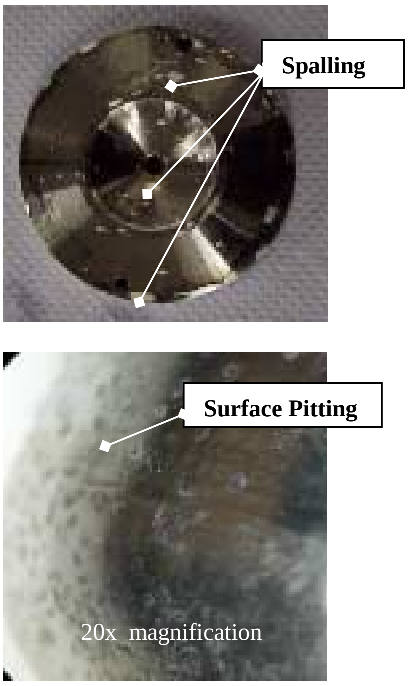


Figure 8 – Corrosion of MoS_2 Coating

Investigations indicated that this corrosion was due to the condensation of large amounts of water in the form of ice crystals when exposed to ambient moisture (Figure 9) and that it could be avoided by either soaking the fittings in an isopropyl alcohol bath or , better yet, by allowing the fittings to reach room temperature under a dry gas. Given that the units operate in the vacuum atmosphere (10^{-6} mbar) of the cryostat no water condensation will occur in the flight configuration.

Figure 9 – Crystallised water on the helium tank interface fitting

The more relevant test from a tribological standpoint consisted in the forced movement of the interface struts under 34 kN pretension in cryogenic vacuum. Figure 10 shows the schematic of this test .

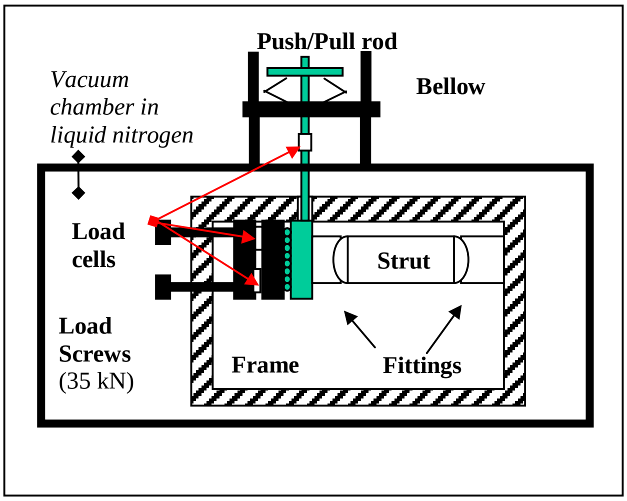


Figure 10- Test schematic for cryogenic testing under vacuum

The implementation of this set-up at HTS can be seen below. (figure 11)

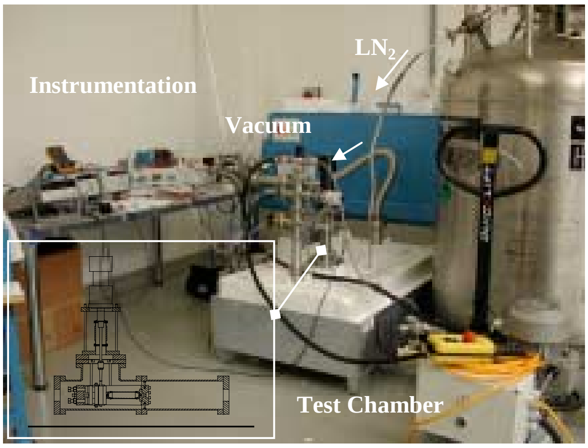


Figure 11 – Test Set -Up at HTS

The pretension and the force required to move the strut could be monitored during cooling. Due to shrinkage the pretension rises from 34 kN at room temperature to ca. 41 kN at 77 K. The struts were cycled 20 times at 1.5 times their expected displacement. This number of cycles corresponds to four times their expected cycling in the cryostat. A wear test was performed displacing one of the the struts 200 cycles.

The result of this testing can be seen in figure 12. The response consists of a series of peaks of decaying amplitude . It is possible to estimate the coefficient of friction by subtracting the friction characteristics of the set-up, measured through use of a dummy strut fixed at both ends.

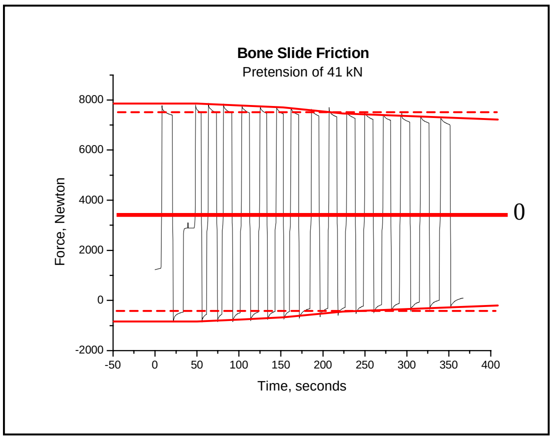


Figure 12 – Response Curve

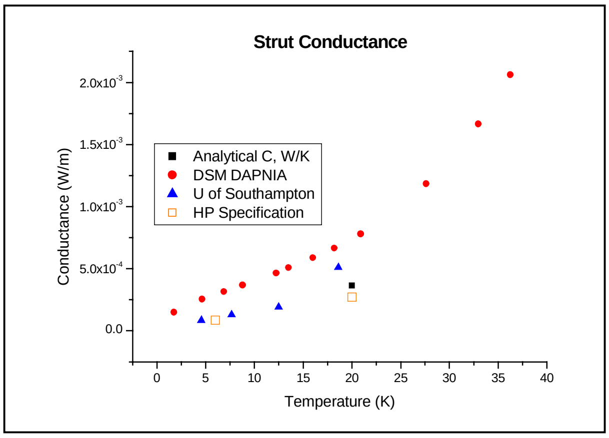


Figure 14 – Conductance of Struts

The result of the tests is a coefficient of friction lower than 0.1 under vacuum and at 77 K. No sticking or cold welding under the pretension force was observed. The appearance of the fittings after 200 cycles indicate very low wear (Figure 13). Minor scratches occur on the surface.

Figure 13 – Upper Fitting after 200 Cycles

A last test for validation of the design is conductance in the range 6 K - 20 K. Figure 14 compares test results measured at two institutions with analytical results and the specified value. The tested value at University of Southampton (UK) is slightly below the specified value at 6K and slightly above at 20 K. Given that the strut operating temperature is 1.8 K at helium tank end, 10 K at the other end, the value at 6 K is more relevant. Values reported by Dapnia (France) cover only the mid section of the strut and are thus not as representative of the finished strut.

Summary and Conclusions

The cryogenic expansion compensation mechanism of the Herschel Spatial Framework consists of a carbon fibre strut which ends in a ball and socket fitting and allows a linear displacement of 1 mm at either end while being held under a pretension force of 35 kN. Ball and socket are coated with a PVD deposited MoS_2. This coating was selected after extensive testing of its tribological characteristics and qualified for service both at cryogenic temperatures and in vacuum.

HTS developed this joint in close co-operation with the main contractor, Astrium GmbH and the Herschel prime contractor Alcatel Space. Their assistance in the verification and in dealing with technical issues proved to be invaluable.

Back to Contents