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SOLAR ORBITER/PHI FULL DISK TELESCOPE ENTRANCE WINDOW MECHANICAL MOUNT

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ABSTRACT

PHI is a diffraction limited, wavelength tunable, quasi-monochromatic, and polarization sensitive imager. These capabilities are needed to infer the magnetic field and line-of-sight (LOS) velocity of the region targeted by the spacecraft (spacecraft (S/C)).

PHI will consist of two telescopes: The High Resolution Telescope (HRT)[1] and the Full Disk Telescope (FDT). The HRT and the FDT will view the Sun through entrance windows located in the S/C heat shield. These windows act as heat rejecting filters with a transmission band of about 30 nm width centered on the science wavelength, such that the total transmittance (integral over the filter curve weighted with solar spectrum, including white leakage plus transmission profile of the pass band) does not exceed 4% of the total energy falling onto the window [2][3].

The HREW filter has been designed by SELEX in the framework of an ESA led technology development activity under original ESTEC contract No. 20018/06/NL/CP[4], and extensions thereof. For FDT HREW SLEX will provide the windows and it coatings.

The HREW consists of two parallel-plane substrate plates (window 1 & window 2)[5] made of SUPRASIL 300 with a central thickness of 9 mm and a wedge of 30 arcsec each. These two substrates are each coated on both sides with four different coatings. These coatings and the choice of SUPRASIL help to minimize the optical absorptivity in the substrate and to radiatively decouple the HREW, which is expected to run at high temperatures during perihelion passages, from the PHI instrument cavity.

The temperature distribution of the HREW is driven by two main factors: the mechanical mounting of the substrates to the feedthrough, and the radiative environment within the heat-shield/feedthrough assembly.

The mechanical mount must ensure the correct integration of both suprasil substrates in its correct position and minimize the loads in windows due to thermal induced deformations and launching vibration environment.

All the subsystem must survive to a launching vibration environment and fulfill optical requirements in an environmental conditions according o its position in the external part of the spacecraft with a pressure of 0.0013Pa and a temperature -163ºC <T< 230ºC.

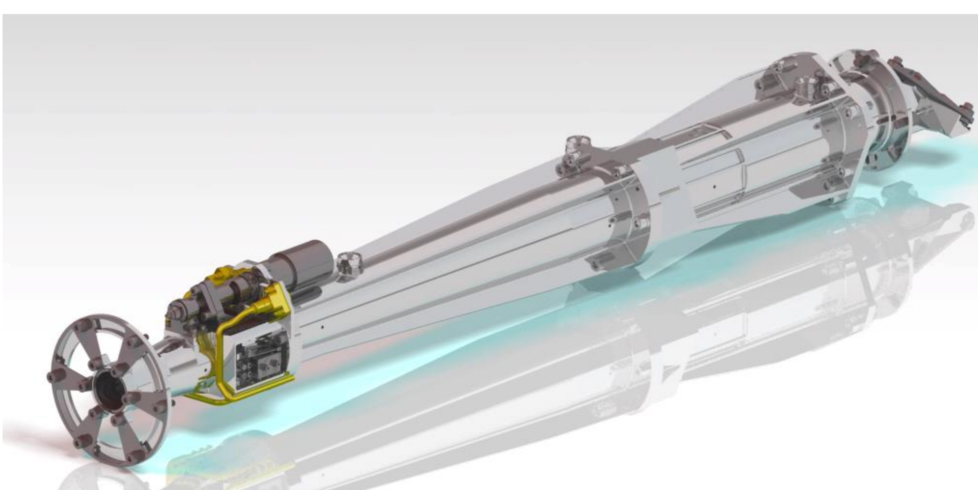

Fig. 1. PHI Full Disk Telescope

I. INTRODUCTION TO DESIGN, CRITICAL FACTORS

The first design factor is the relation between the envelope and the necessary clear aperture for the instrument functionality, the mechanical mount must ensure a minimum clear aperture of 42mm with a maximum envelope in its cylindrical part of 71mm.

The temperature distribution in the window will be another critical design factor who will come from the mechanical mounting in the thermal shield/feedthrougth and the radiative environment.

The mechanical mount must ensure the fixation of both Suprasil substrates centered and separated 2mm, and to minimize the loads for these substrates due to thermal induced deformations during operation, the direct contact between titanium mount and substrates must be avoided.

All the assembly must support the environmental conditions corresponding to its position in the thermal shield, 0.0013Pa, a minimum temperature of -163ºC and a maximum of 230ºC. It must support the vibration environment defined for launching avoiding any damage in optical elements and ensuring it functionality[1].

Envelope and clear aperture are the factors who force the preliminary design, while the environmental conditions will be more important during the detailed design.

We will start from the Selex predesign:

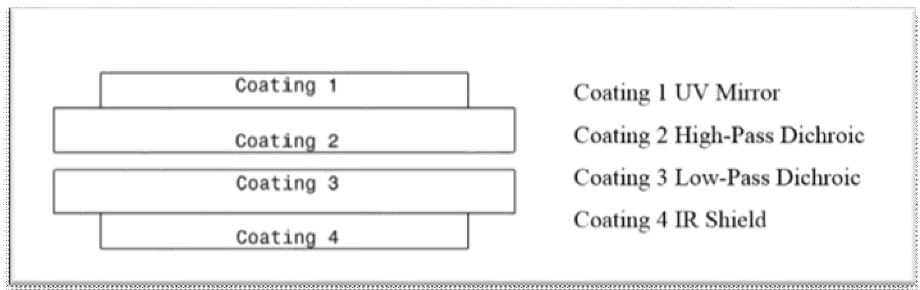

Fig. 2. Selex HREW

II. PRELIMINARY DESIGN (TOP-DOWN) AND DETAILLED DESIGN (BOTTOM-UP)

First stage for design will be to define the specifications directly applicable, in this case we have summarised the principal specification in the previous section.

And the most general requirements about a minimum clear aperture of 42mm with a maximum envelope in its cylindrical part of 71mm [6].

This requirements and the application of the negotiated IF with the feedthrougth (provided by ASTRIUM and designed by SENER) with the fixation system recommended by Selex configure the preliminary design.

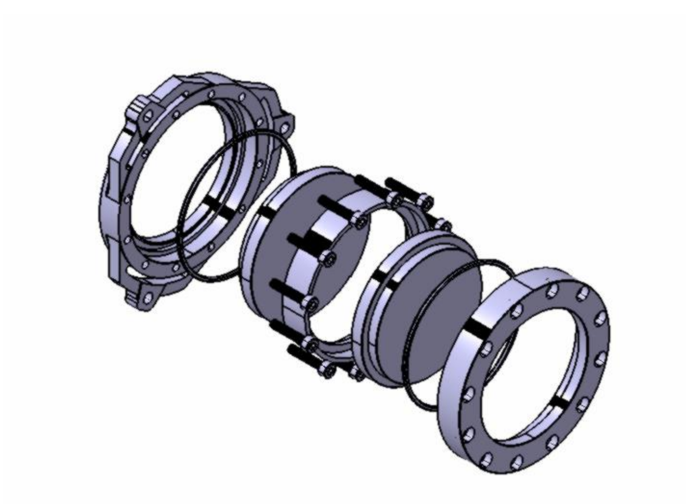

Fig. 3. Preliminary design

At this point we can start with a detailed design who may define anyone of the mechanical parts of the mounting [6].

A. Plastic Spacer

This element may ensure the 2mm separation between the two substrates and avoid eny posible contact between the substrates and the titanium mount.

We have considered different plastic solutions like Vespel and Tecasint poliimides, Torlon poliamidaimides and elastomers like Hytrel[7].

Finally, Vespel SP1 was selected due to its mechanical properties and previous results in similar uses.

B. Substrates mounting

The flexible mechanical support of the glasses is obtained with a C-Ring provided by HTMS (High Tech Metal Seals), with its C section it even ensure a correct venting of any internal volume.

The material selected is critical, for this case an Inconel 625 was selected due to its mechanical properties [8] and low Curie temperature. A gold plating treatment will ensure a softer contact with the glass.

C. Radial Loads

For to avoid lateral displacements on the glasses an element may absorb radial loads, this element will no be in contact with the glasses so soft contact is not a necessity.

For this application Cu-Be 1.8% was selected due to its mechanical properties [8]. Finally six flexible Cu-Be rings were added to the design.

III. DESIGN BASELINE

For to complete Detailed Design, the mount main structure has been adjusted to accommodate this elements and Design Baseline is fixed, this Baseline will be used during the test for the STM (Structural Thermal Model).

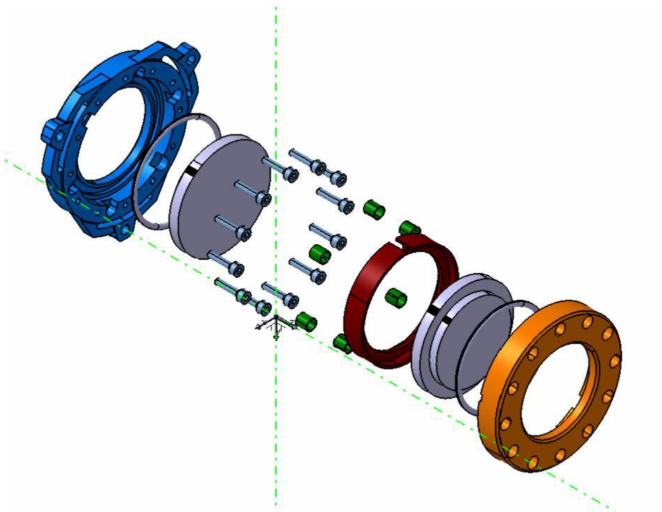

Fig. 4. FDT HREW Detailed Design

STM will be the first development model for the entrance window.

IV. STRUCTURAL ANALYSIS

Structural Analysis may ensure the survivability of the mount previously to it tests. In this case, specific load cases applied was provided by the instrument specification. This analysis has been carried out considering the worst case, who corresponds to the loads for the random case.

<table>
<tr><th>Axis</th><th>frecuency (Hz)</th><th>Qualification</th><th>Acceptance</th></tr>
<tr><td rowspan="4">X</td><td>20-120</td><td>34.82 dB/Oct</td><td rowspan="4">Qualification/2 (PSD) Qualification/1.44 (g-rms)</td></tr>
<tr><td>120-340</td><td>9.0 g2/Hz</td></tr>
<tr><td>340-2000</td><td>-17.02 dB/Oct</td></tr>
<tr><td></td><td>52.2 grms</td></tr>
<tr><td rowspan="6">Y - Z</td><td>20-120</td><td>21.67 dB/Oct</td><td rowspan="6">Qualification/2 (PSD) Qualification/1.44 (g-rms)</td></tr>
<tr><td>120-250</td><td>12.0 g2/Hz</td></tr>
<tr><td>250-400</td><td>-31.34 dB/Oct</td></tr>
<tr><td>400-900</td><td>-12.626 dB/Oct</td></tr>
<tr><td>900-2000</td><td>-8.68 dB/Oct</td></tr>
<tr><td></td><td>45.4grms</td></tr>
</table>

A. FEM Model

Special attention has been applied for the modeling of the flexible parts of the design, the Cu-Be flexible rings and the Inconel C-Ring [8].

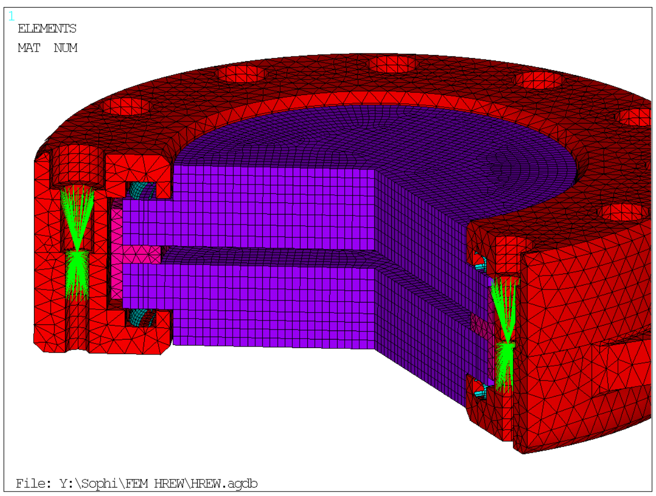

Fig. 5. FEM model detail

B. Modal Analysis

Modal analysis shows only one mode under 2000Hz who is consistent for the design stiffness, this firs eigenvalue appears at 1708Hz with an effective mass of 1,40E-15.

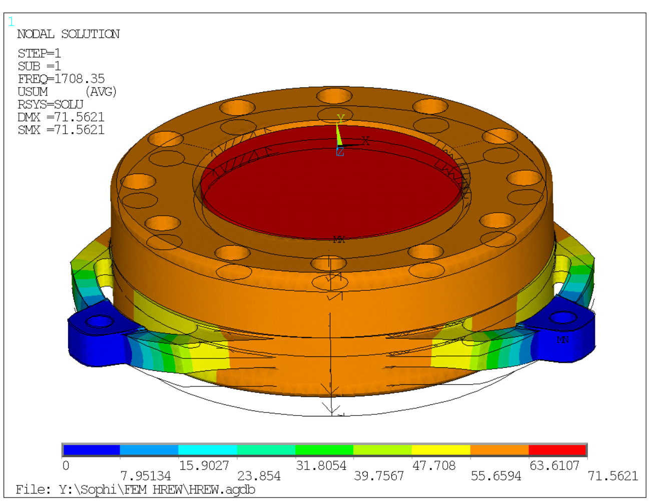

Fig. 6. FDT HREW First Eigenvalue

The first eigenvalue with a significant effective mass ratio appears at 2262Hz, and has a ratio of 0.2.

C. Random Analysis

The Von Mises 3σ stresses for the titanium mount were calculated and they are shown in **Fig. 7**.

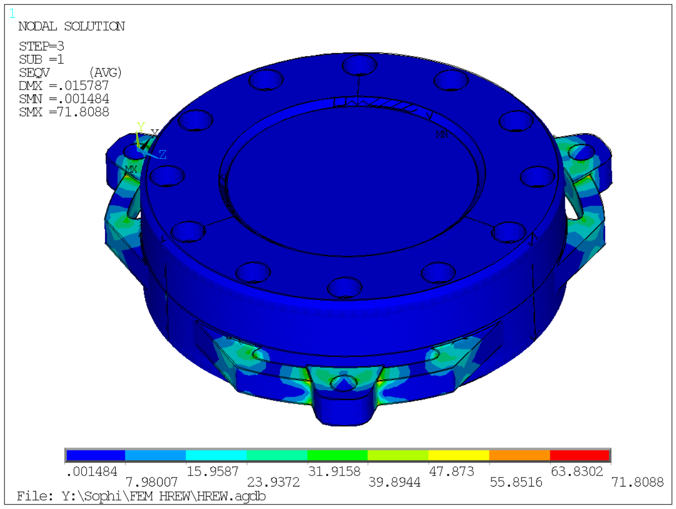

Fig. 7. Von Mises stresses in titanium mount parts

Additionally, the 3σ maximum stresses in the glasses were calculated and they are shown in **Fig. 8.**

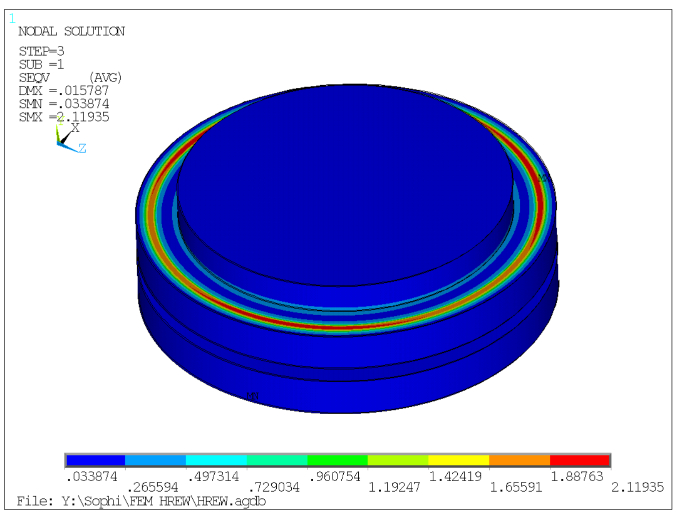

Fig. 8. 3σ maximum stresses in glasses.

D. Analysis results, Margin of Safety calculation

The Margins of Safety (MoS) were calculated applying the following equations:

$$MoS_Y = \left(\frac{\sigma_Y}{\sigma_{VM\ Max} \cdot K_P \cdot K_M \cdot K_Q \cdot FoS_Y} \right) - 1 \tag{1}$$

$$MoS_U = \left(\frac{\sigma_U}{\sigma_{VM\ Max} \cdot K_P \cdot K_M \cdot K_Q \cdot FoS_U} \right) - 1 \tag{2}$$

Where:
σ_y: yield limit
σ_u: ultimate limit
σ_{VMMax}: Von Mises stress
K_p: project factor
K_M: model factor
K_Q: qualification factor
FoS_y: factor of safety yield
FoS_U: factor of safety ultimate

Conservative margins has been taken into account: K_p = K_M =1.1; K_Q = 1,2, FoS_y = 1.25; FoS_U = 2. The results are presented in the following table. The obtained MoS are very positive and therefore it guarantees that no problem are expected in the titanium parts or the glasses [8].

	Loads	**Ks**	**Yield Limit**	**Ultimate Limit**	**FoS Y**	**FoS U**	**MoS Y (1)**	**MoS U (2)**
Random X Ti	73	1,452	830	900	1,25	2	5,26	2,92
Random X Suprasil	2,50	1,452	50	50	1,25	2	10,02	5,89

V. MODEL VERIFICATION

The entrance window verification is based in the development and manufacture of two base lines, one for the STM model and another one for the Flight Model (FM).

The big difference between this two base lines in our case is only in the substrates cover. The design of the STM base line uses two uncovered SK1300 (fused silica) from Oĉhara but the FM base line uses SELEX provided glasses as developed for ESA, contract number 20018/16/NL/CP.

In this case our STM is fully representative of the structure mechanical properties and some of the thermal but not all the final glasses are needed in order to test the thermal and optical properties.

In order to verify the model previously to the test campaign the low sine test could give us a data to compare with the calculated eigenvalues.

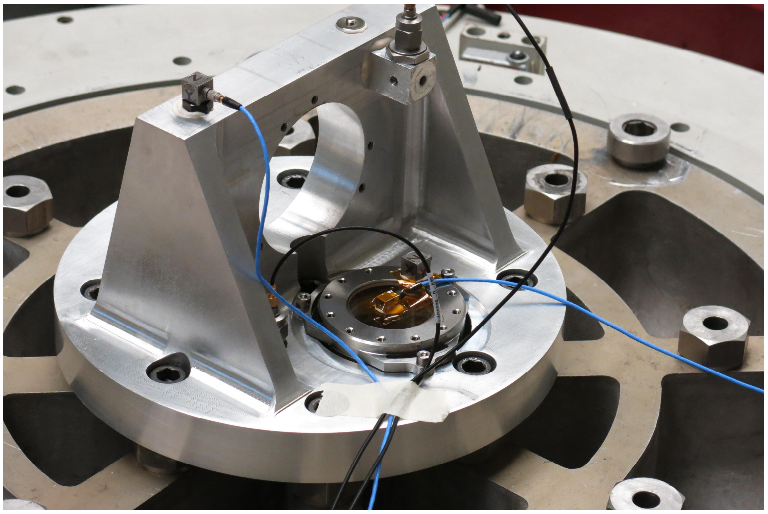

Fig. 9. Low sine vibration test

In this case performing a low sine vibration (X-axis), the frequency of the first mode can be seen: 1701Hz (model prediction: 1708Hz). This low variation ensure that the model

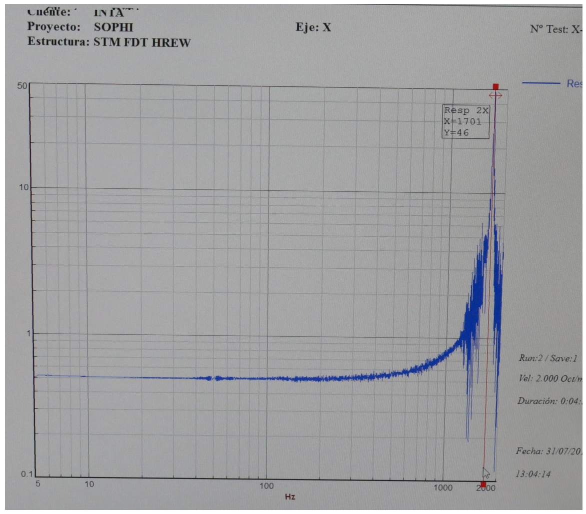

Fig. 10. Low sine vibration test

V. CONCLUSIONS

We have completed a tour through the design process for the PHI FDT entrance window mechanical mount, all the requirements for this mounting system are fulfilled and the design is compatible with the environmental conditions.

The analysis shows that the design is consistent and no damage will be expected due to launch loads.

Finally the consistency of the model and its representativity has been demonstrated by test showing a variation on the first eigenvalue of less than 0,5%.

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