DOORS MECHANISM FOR FEEDTHROUGH OPERATION IN SOLAR ORBITER FDM SUBSYSTEM

Javier Viñals [1], Cristina Borque [1], German Jaio [1], Borja Provedo [1]

(1) SENER, Avenida Zugazarte 56, 48930 – Getxo (Spain), Email: javier.vinals@sener.es; cristina.borque@sener.es; german.jaio@sener.es; borja.provedo@sener.es

ABSTRACT

The ESA Solar Orbiter is an interdisciplinary mission to the Sun. It consists of a single spacecraft which will orbit the Sun in a moderately elliptical orbit, using a suite of advanced Remote-Sensing and In-Situ instruments to perform a detailed observation of the Sun and surrounding space.

SENER is contractor for the delivery of the FDMs subsystem (Feedthroughs, Door & Mechanisms, and electronic unit).

This subsystem consists on several through-wall filters (located on the Heat Shield) that provide the satellite with non-hermetic protective covering for its remote detection instruments.

Some of these feedthroughs (6) need a door cover to protect the instruments in some operational conditions.

With the aim of optimizing the performance and to save costs, spares, interchangeability, materials, motors, qualification and design & analysis, a single door shaft and mechanism is implemented, dimensioned for the biggest door.

Figure 1. FDMs assembled at HS STM (ESA courtesy).

INTRODUCTION

The door is the component that prevents sun incidence from going into the feedthrough. It is located at the sun entrance side of the feedthrough. Each door provides identical interface to the mechanism rotating shaft interface.

The design of the door is based on a reduced mass and high bending stiffness because the inertia of the door has a big impact in the Eigen frequency of the assembly.

GENERAL SPECIFICATIONS

Each door is actuated by a mechanism where its major requirements are:

- High temperature working conditions till 500^{o}C.

- High random vibration levels: 73grms (out of plane axis) and 52grms (in plane axes). Structural and electronic components designed and chosen specifically for such demanding dynamic environment.

- High emissivity and absortance properties for compatibility with the instruments.

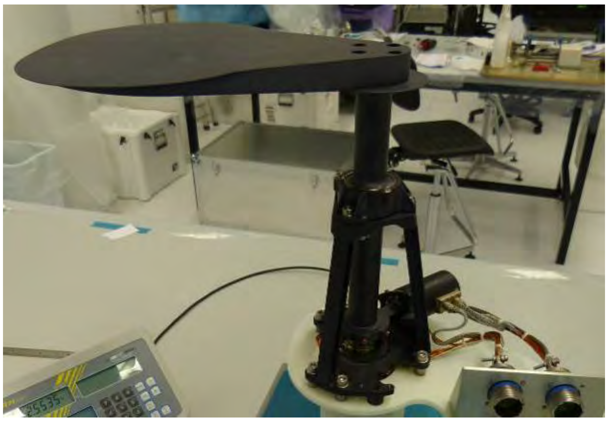

Figure 2. Door & Mechanism EQM configuration.

MECHANISM DESIGN

The mechanism is designed to rotate the door from closed to open positions and from the open to closed positions.

Proc. '16th European Space Mechanisms and Tribology Symposium 2015',
Bilbao, Spain, 23–25 September 2015 (ESA SP-737, September 2015)

The door is externally coated with a special developed coating on the face looking at the sun. In the inner face, no coating is applied.

The mechanism has the following elements:

- Housing/support: Monolithic piece that provides structural connection to the support panel.

  It consists of two flanges structurally connected by three legs. The lower flange provides I/F to the support panel, supports the lower bearing, the switches assembly and the launch locking device.

  The upper flange supports the upper bearing support.

  It also includes mechanical end stops for the mechanism. It is externally coated with PVD.

- Rotating shaft: It is used to operate the doors. Titanium machined hollow shaft connected to the door at its upper part, and the gear-motor on its lower part, supported by lower and upper bearing.

  It consists of a tube with the door I/F flange in the upper part, the journal bearing shaft in the middle and the motor coupling I/F shaft, the lower bearing support shaft and the rotating arm support shaft in the lower part.

  The journal bearing shaft contact surface is barrel shaped and polished.

  The rest of the piece is externally coated with PVD.

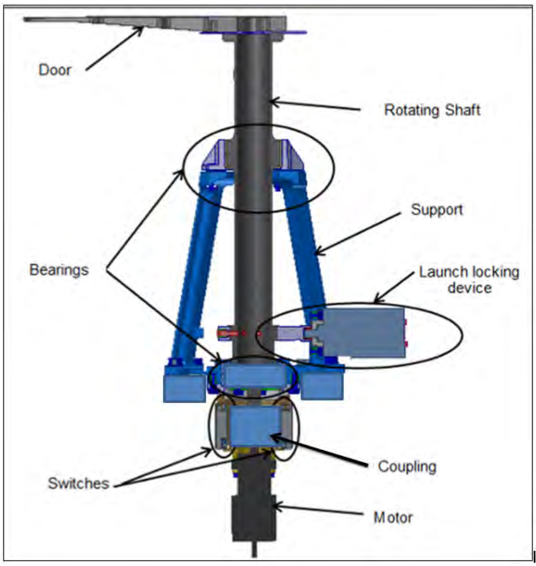

Figure 3. Door & Mechanism section view.

- Bearings
  The bearings allow rotation of the door shaft with respect to the housing and are compatible with a life of at least 500 cycles:

  - Upper bearing: Journal Bearing designed to work at temperatures higher than 300 degrees and to allow gradients of temperature of ~80ºC between the shaft and the housing without interference. It is also designed to withstand the very high rattling and fretting forces induced in vibrations without suffering damage or affecting the friction torque of the mechanism.

  - Lower bearing (ADR): Two paired angular contact ball bearings selected to withstand the demanding thermal and structural environments.

- Motor and reed switches housing:
  Titanium machined conical hollow piece with two flanges at both ends and two rectangular flanged holes in the conical part to provide structural link between Housing and motor and between Housing and Reed Switches Support.

- Motor (CDA): The motor moves the door between two fixed positions in orbit (closed/open) under control of an electrical signal from spacecraft.

- Switches: Redundant reed-switches are included to feature an electrical signal feedback enabling unambiguous determination of its open or closed position.

- Coupling: The coupling transmits torque from the motor shaft to the rotating shaft absorbing misalignments due to manufacturing tolerances and thermal distortion (rotating shaft and motor shaft are of dissimilar materials).

- Launch locking device: Single shot electrical actuator is implemented to avoid rotation of the rotating shaft due to launch loads and to release the mechanism for operation.

  The electrical actuator withstands rotation forces and maintains the door & mechanism in closed position during launch and retracts the mentioned pin to leave the door & mechanism free, ready to be moved by the motor.

  The locking actuator capability of withstanding lateral loads is very low compared to the door rotation forces induced by the dynamic environment. To solve this problem the support structure of the locking actuator is designed to withstand these loads without transmitting them to the device. The coupling between the locking actuator and the rotating shaft is designed to allow the thermal distortion between the two pieces (made of dissimilar materials), to withstand the high contact forces that appear during vibrations and to allow the actuator performance.

- Harness (including connectors and connector supports) from Doors operating mechanism and thermal hardware to an interface connector bracket.

Figure 4. FDMs assembled at HS STM (ESA courtesy), left; Example of FT that is covered by a door (right).

STRUCTURAL ANALYSIS

Structural analysis has been performed for the 6 mechanisms that are part of the FDM subsystem.

Although all of the mechanisms are identical, the doors are different sizes for the different feedthroughs.

The extremely high random levels specified (73 and 52 grms) required a thorough structural optimization in order to design a mechanism able to withstand such loads. Minimize mass and maximize the stiffness of all the structural components, especially the doors, was key in the design process of the mechanism.

Figure 5. PHI HRT DM Von Misses stresses. Random Y.

THERMAL ANALYSIS

Thermal analysis is presented as a challenge due to the proximity of the Spacecraft to the Sun, the closest ever (0.28AU). This leads to high working temperature requirements for the critical elements that will be submitted to a wide temperature range throughout the different phases of the mission.

The highest temperatures, at around 500ºC, are obtained at the door, therefore the thermal design is intended to minimize conduction heat fluxes along the length of the mechanism, in order to ensure that temperatures of the critical items remain within their allowable operative temperature limits. This involves important thermal gradients (more than 400ºC) between the upper and lower parts of the mechanism.

Door & Mechanism thermal mathematical models have been generated to carry out the analysis to obtain temperatures and heat fluxes.

In addition, a complete S/C thermal model including the integrated HS, supplied by prime contractor, has been considered to allow the thermal calculations, as well as several disc shape shells to represent the effect of the instruments on the FTs, that have been added to the complete model.

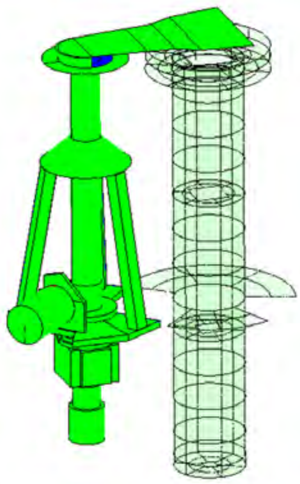

Figure 6. EUI – FSI. FT Door Mechanism mathematical model for the thermal analysis

COATING

Coating aspect was declared as a critical technology process for the instrument needs. An exhaustive coating trade-off was performed in Phase 1 prior to the official project launch. This trade-off included different coating technologies and processes, focused on the thermo-optical, working temperatures, adhesion and electrical conductivity requirements, these requirements are sometimes contradictories in terms to fulfil all of them at the same level.

After Phase 1, PVD technology was defined as the baseline technology for coating:

- Application: Thermo optical protection
- Emissivity (ε): 0.72 – 0.76
- Absortance (α): 0.88 – 0.90
- α/ε ratio: 1.18 – 1.20
- Use Temperature Range (° C): -180 to 500
- TIS (%): 10 – 14
- Appearance: Black-violet, homogeneous and even appearance
- Typical Thickness (µm): 3 – 8
- Coatable substrates: Titanium, super alloys, steels. Aluminum (restrictions apply)

A confidence test has been performed successfully, and now a complete qualification test is on-going.

The PVD coating technology is a process highly compatible with the requirements for space applications. It guarantees, in addition of thermal properties, extreme adhesion levels, cleanliness and minimum outgassing levels. The PVD (Astro Black® registered mark by Metalestalki) coating is a thin dark highly adherent film deposited by Physical Vapour Deposition. It is a stable ceramic coating that won't be affected by the extreme conditions and vacuum of space, as it can withstand temperatures as high as 500 ºC or as low as -180 ºC and Sun's radiation.

Its high emissivity and absortance values guarantee an appropriate thermal control of the coated parts, allowing a high fraction of the heat of the coated parts to be radiated back to space. Door and Mechanisms are externally coated with PVD as can be seen in Figures 1 and 3. FTs are coated internally and externally.

This coating has been successfully developed and is going to be used in components of Solar Orbiter as in the Antennas Subsystem by SENER.

EQM TESTING

Following tests have been performed at qualification phase:

- EQM vibration:
    - Sine: 20 g (out of plane axis) and 15 g (in plane axes)
    - Random: 25 grms (out of plane axis) and 18 grms (in plane axes). The original random requirements were relaxed for the EQM testing due to the limitation of the facilities in reaching to such levels and due to a relaxation in the mechanisms mounting panel requirements.

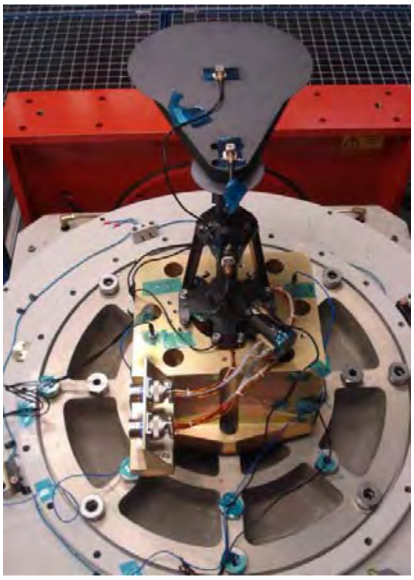

Figure 7. EQM Vibration test

- EQM shock

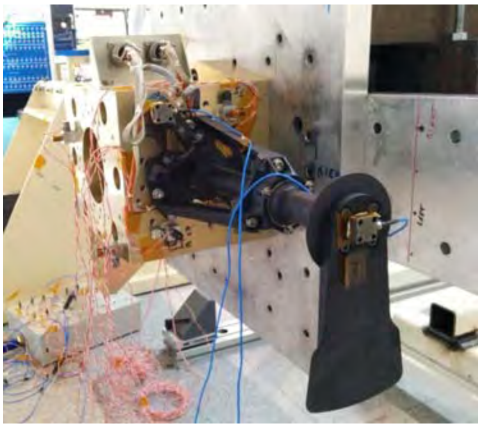

Figure 8. EQM Shock test Z Axis test set up

- EQM life & extended life: 4000 cycles

- EQM Thermal Vacuum Test

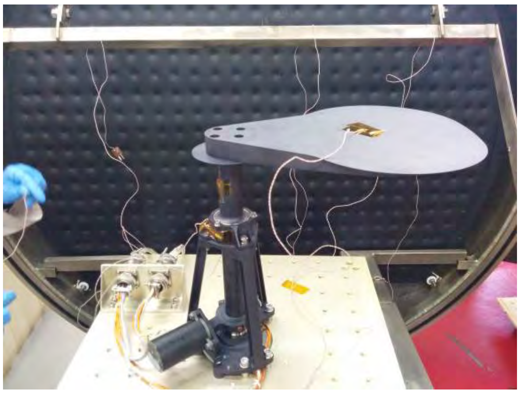

Figure 9. EQM Thermal Vacuum Test

- EQM Functional Performance Test

- EQM Solar Simulation
The test was performed in the thermal vacuum chamber at the University of Padua in June 2014.

  The test included two cases (closed door and open door) and the main objective is to provide inputs to validate the Thermal Mathematical Models used to perform the analyses.

  Both FT and Door & Mechanism were submitted to 7 SC sun beam, that is, a heat flux of 9100 W/m2. This allowed reaching during the test, up to 300ºC at the door of the mechanism, with a temperature gradient of 250ºC between the door and the actuator located at the bottom part.

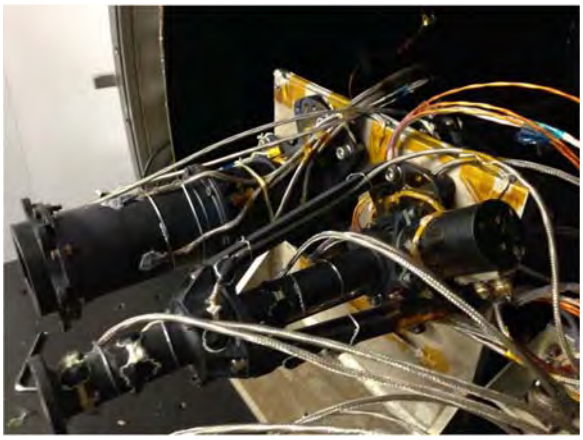

Figure 10. EQM SOLAR SIMULATION TEST (DM&FT)

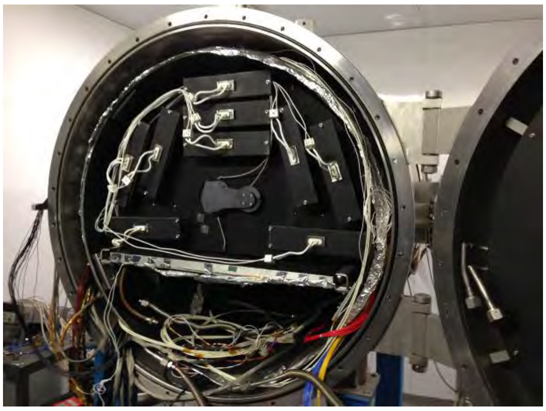

Figure 11. EQM SOLAR SIMULATION TEST (DM&FT) in chamber

CONCLUSIONS

Main aspects of the mechanism developed are:

- High range of temperature working conditions from 200ºC to 500ºC that implies some components are close to the current state of art:

  For the upper part bearing, the criterion to design has been a compromise between minimum friction and behavior with dynamic loads, thermal behavior to avoid the possibility of seizure, stiffness of the mechanism, friction to torque budget, loads on contact surfaces. No commercial solutions available.

  Motor temperature range: -100ºC to 220ºC.

  Due to extreme temperature range, a switch trade-off was performed at the initial phases. Selected one has previous heritage from BepiColombo, although specific up-screening is being performed to take into account the proper Solar Orbiter requirements.

- High vibration level for a door in cantilever disposition with high displacement in the door.

- Locking actuator with high precision and optimized for supporting the high vibration loads but with a design that allows the door operation once the vibration stage is finished.

- Design to mass optimization, with very small Ti thickness.

EQM campaign finished in 2014, now the FM is in progress.

All the mechanism design, assembly, integration and testing has been performed by SENER. Door & Mechanism manufacturing has been done by Goimek (local manufacturing workshop), coating by METALESTALKI (local facility), and main supplies are gearmotor from CDA, bearing from ADR and locking actuator from TiNi.

ABBREVIATIONS AND ACRONYMS

AU	Astronomical Units
EQM	Engineering Qualification Model
FDM	Feedthroughs, Door and Mechanism
FM	Flight Model
FT	Feedthrough
HS	Heat Shield
I/F	Interface
S/C	Spacecraft
SC	Solar Constants
SMA	Shape Memory Alloy
STM	Structural Thermal Model
PVD	Physical Vapour Deposition
TIS	Total Integrated Scattering