DEVELOPMENT OF THE MEDA INSTRUMENT WIND SENSOR DEPLOYMENT MECHANISMS FOR THE M2020 MISSION

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ABSTRACT

One of the seven Scientific Instruments on board M2020 rover is MEDA, Mars Environmental Dynamics Analyzer. MEDA will help prepare for human exploration by providing daily weather report and information on the IR-UV-Vis radiation and wind patterns on Mars. It makes weather measurements including wind speed and direction, pressure, temperature and relative humidity, and also characterize the amount and size of dust particles in the Martian atmosphere near the rover.

The paper describes the development of the MEDA Wind Sensors and the solution developed to comply with the functions under the cruise, landing and Mars operation environmental conditions. It also describes the test campaigns done during qualification and acceptance tests. Special focus is in problems encountered during the qualification test. In particular, the issues related to the Hold Down & Release Mechanism resettable actuator and the Latch Mechanism lubrication degradation are covered, including the investigation to determine the root causes as well as lessons learned.

INTRODUCTION

The NASA JPL M2020 rover will investigate a region of Mars where the ancient environment may have been favourable for microbial life, probing the Martian rocks for evidence of past life. The mission also provides opportunities to gather knowledge and demonstrate technologies that address the challenges of future human expeditions to Mars. Another goal of the mission is to characterize the climate of Mars.

One of the seven scientific instruments on board the M2020 rover is MEDA, Mars Environmental Dynamics Analyzer. MEDA, led by the Instituto Nacional de Técnica Aeroespacial – Centro de Astrobiología in Spain (CAB-INTA) will help prepare for human exploration by providing daily weather report and information on the radiation and wind patterns on Mars. It makes weather measurements including wind speed and direction, pressure, temperature and relative humidity, and characterize the amount and size of dust particles in the Martian atmosphere near the rover.

Under INTA-CAB’s overall responsibility and being CRISA responsible of the electronics, AVS has been the responsible for developing, manufacturing and verifying the structure and mechanism of the MEDA Wind Sensors. The two Wind Sensors are housed in two structures, one static called WS1 and other deployable called WS2, mounted orthogonally to the RSM, Remote Sensing Mast, of the M2020 Rover, Fig. 1. The WS2 Deployment Mechanism includes a Hold Down & Release Mechanism (HDMR) and a Latch Mechanisms. This paper focuses on the development of those mechanisms.

Figure 1. MEDA WS2 and WS1 location at the M2020 RSM; Credits NASA.

DESIGN JUSTIFICATION

MEDA is a contributed legacy of the Mars Science Laboratory’s REMS, Rover Environmental Monitoring Station. REMS [2], also led by INTA-CAB, is an instrument composed of six sensors designed to measure the wind direction and magnitude, pressure, relative humidity, ground temperature, air temperature...
and ultraviolet radiation. It is currently recording all those parameters around the clock and at a programmable cadence on-board Curiosity.

As an unfortunate and remarkable event, REMS lost one of the wind sensors during the landing on the surface of Mars in August 2012. The pebbles ejected from the ground by the thrusters struck the sensors causing the failure of part of the wind sensor.

It is also important to note that, during Curiosity’s Martian exploration carried out over these more than 7 years, an important activity has been to decorrelate and eliminate, as far as possible, the aerodynamic disturbance caused by the Rover in the logged wind measures.

So, from the moment of proposing MEDA as one of the scientific instruments of M2020’s payload, several improvements (in particular, concerning the wind sensors) were clearly identified: self-protecting the sensors (specially for the landing event), increasing the number of detectors to provide redundancy, and separating the detectors as much as possible from the Rover’s aerodynamic disturbance area. Additionally, a better-performance electronics was also proposed, although it is out of the scope of this paper.

After being selected, AVS started working on those premises, by defining several design solutions for a deployable WS2 that could meet those goals, while WS1 remained static (due to limitations on its expandable workspace).

So several mechanisms were conceptually designed for WS2: ejected cap, telescopic mechanism, etc. Finally, the deployment mechanism known at JPL as “the navaja” (Spanish word for switchblade) was selected for its development. Its proven deployment concept allows also customizing the structure design to maximise the protection of the sensors against pebbles impacts during landing.

The deployment mechanism has these main functions: to maintain the boom in stowed position during launch, cruise and landing in the Mars surface, to protect the wind sensors against impact of pebbles during landing, to deploy WS2 boom in order to position the sensors as far as possible from the rover aerodynamic influence and to lock the boom position so as to provide stable sensors nominal positioning during traverse on Mars.

WS2 DESIGN DESCRIPTION

The WS2 deploying mechanism consists of a deployable arm (which includes the wind transducers) fixed to the static boom by means of a hinge. The arm deployment (180° angular stroke) is carried out by the force exerted by two torsion springs located in the hinge shaft, which provide the required motorisation torque for the instrument (both under Mars & terrestrial tests orientations).

In stowed configuration a Hold Down and Release Mechanism, HDRM, keeps the arm in position until it is activated and the deployment occurs. The HDRM that releases of the deployable part is accomplished by means of a Frangibolt actuator provided by TiNi Aerospace. The Frangibolt (FB) is based in a Shape Memory Alloy (SMA) cylinder compressed during its assembly process and which elongates to its original size once it reaches its actuation temperature (approx. 80°C) by the power supplied by its internal heaters. The elongation of the FB causes the fracture of a preloaded bolt (Frangibolt Fastener) featuring a notched section. When this fastener is broken, the interface part between the deployable arm and the static boom is released and the deployment of the Arm is achieved driven by the springs force.

A pair of ball plungers were placed in the interface between static and dynamic part to use them as “kick-off” springs and aid in the initial separation of the joints but also to reduce the risk of a failed deployment due to cold welding between the contact surfaces of the deployable interface in case of unexpected issues with the already applied solid lubrication performance.

A Switch Washer (SW), also provided by TiNi Aerospace, is used as an electrical switch and opens the electric circuit feeding the FB once the Frangibolt Fastener is broken (and the WS2 deployed). This device is used to cut off the current to the FB internal heaters once the deployment has occurred and avoid overheating the actuator. It is worth to mention that the HDRM is actuated by a redundant electric circuit and that the SW is only present in the main power circuit. This design allows to bypass the Switch Washer by using the redundant circuit and hence reducing the risk of not being able to heat the FB actuator in the event of a SW failure.
Once deployed, the remaining torsion spring torque keeps the WS2 Arm in the deployed position. However, a latching system consisting on a pair of spring plungers has also been included as a latching mechanism. The aim of this latching is not to keep the arm in position but to avoid it rebound after the deployment or during the Rover movements on the Martian soil. Each of these plungers is mounted on the deployable arm and its nose is compressed against a static part (so-called, latch track) placed in the static part of the hinge. The latch tracks feature a small drill matching the position of each arm plunger in the deployed state. These features allow the insertion of the compressed plunger tips inside the drills once the arm reaches the deployed position and prevent bending it back. A dedicated tool was required to unlatch and allow the stowing of the arm for future deployments.

**WS2 DEVELOPMENT**

The WS2 structure and mechanism and the electronics development had very different schedules, so a decoupled approach had to be taken, leading to a model philosophy that tried to compensate this constraint i.e. the unavailability of electronics during the qualification of the structure and mechanism.

The following models have been developed along the project:
- DM, Demonstration Model, for the mechanism conceptual design validation.
- Structural Model 3D printed model to be delivered to JPL only for implementation on the RSM as part of the MEDA EM.
- MP EQM, Mechanical Part Engineering Qualification Model, representative in form, fit and function for the qualification of the structural parts and the mechanisms.
- MP EQM+, same as the MP EQM but including electronics for electrical validation.
- PFM, Protoflight Model.
- CM Calibration Model.

The most remarkable aspects of these models along with the problems and solutions found during their development are discussed in the subsequent paragraphs.

**WS2 DEMO NSTRATION MODEL, DM**

A demonstration model was designed, manufactured and assembled in order to demonstrate the design concept functionality before the Preliminary Design Review (PDR). It included the structure, the deployment mechanism and the Hold Down Release Mechanism (HDRM). A total number of 18 deployments were carried out with this model, 6 of them were conducted at CAB-INTA’s MARTE Chamber [1] which is an advanced vacuum vessel designed to simulate the Mars environment by regulating its surface and environment temperatures, solar radiation, total pressure and atmospheric composition. The DM deployments carried out inside MARTE aimed to be representative of the Martian CO₂ environment and were performed at different representative pressure and temperature values (3 atm and 16 atm pressure and -63°C, -14°C and 25°C temperature).

One of the objectives of testing the DM was to decrease the risk of the new design in comparison with the proven static concept already flown in REMS. Therefore, 2 of the deployments were done with some REMS spare sensors installed in the tip. The sensor ‘dices’ survived the deployments. Although not being a complete validation, these deployments contributed to gain confidence in the new design and its capability to safely store and deploy the wind transducers along the mission. Self-induced shock measurements were also taken during this test.
WS2 MECHANICAL PARTS ENGINEERING QUALIFICATION MODEL, MP EQM

The WS2 MP EQM was fully representative of the flight mechanical parts and mechanisms, including coatings, paint & HDRM actuator, but it did not implement actual electronics and sensors (dummy PCB parts were used instead).

The WS2 qualification campaign comprised the habitual set of mechanical tests (random & quasi-static vibration, pyroshock and thermal-vacuum), with functional (deployment) tests intercalated before & after each environmental test.

A 6-DoF load cell was used during the ambient temperature functional tests to measure the deployment efforts exported to the interface.

The measurements show the initial shock from the Frangibolt release and the later impact against the end stop:

The impact against the hard stop drives the response below 1000 Hz, so a low-band filter was applied to the time histories (orange curves) in order to determine the values to be compared with the quasi-static limit values defined in the requirements for the induced forces and torques.

The time between the release and the impact with the end stop was monitored as an indication of the stability of the mechanism.

MP EQM issues with the Frangibolt

During the functional test just before the Thermal and Vacuum test (TVT) i.e. after successfully performing the vibration and pyroshock tests, an issue was detected regarding the HDRM Frangibolt actuator: the main (primary) circuit showed no electrical continuity.
One of the ways to search for the root cause was doing several computed tomography (CT) to the failed actuator. As can be seen in Fig 8, one of the main circuit cables was broken. The tomographies helped to identify some other anomalies as birdcages on the twisted cables in the area of the welding. However, these findings did not fully explain the failure itself.

In parallel, all the possible causes were identified and mitigation actions were taken addressing all of them to decrease the risk of further failure as much as possible:
- The design was slightly changed in order to decrease as much as possible the shock imparted to the cables during the activation of the actuator.
- CT scan of all the procured actuators
- Maximise the precautions during Frangibolt handling; and special tool was designed and manufactured for the Frangibolt refurbishing that would reduce the bending cycles of the wires
- Reduce the number of firings of the flight model and perform CT scans after every deployment on ground.
- A destructive test was conducted at JPL searching for evidences of the failure root cause. No conclusive evidence was found.

A Delta-qualification was needed to qualify the WS2 design.

MP EQM tribological issues

Given the relatively low number of deployment cycles required and taking into account time availability restrictions, Dicronite DL-5 (thin film tungsten disulphide impingement coating) was initially selected to lubricate both the Latch track and the HDRM separation surfaces.

The qualification test of the mechanical parts and mechanism of the WS2 included 14 deployments as part of the functional and life tests: 6 of them were carried out at CAB-INTA’s laboratory at ambient temperature (24°C) and the 8 deployments left were performed at CAB-INTA’s Thermal Vacuum chamber at different combinations of temperatures (-50°C, -10°C and +25°C) and pressures (6mbar, 7mbar and 9mbar).

The WS2 design requires full disassembly of the hinge to allow the inspection of the latch tracks (along which the locking plungers slide during the deployment); this aspect was considered during the design development, but several factors (mainly the small size, limited space and assembly & adjusting required features) lead to this configuration.

This circumstance, coupled to the tight programmatic constraints, prevented the performance of a full tribological assessment of these parts between the qualification campaign and the Delta-qualification campaign that was performed due to the Frangibolt issue (only visual inspection was performed, and although there were indications of wear, they were inconclusive about the compliance with the post-test inspection success criteria). Hence, the mechanical parts underwent another 14 additional deployment functional tests as part of the Delta-qualification test.

The post-Delta qualification test inspection revealed excessive tribological degradation of the latch track surfaces, but it was not possible to determine at which point it had occurred (i.e. after the fulfilment of the qualification tests or before). Therefore, additional dedicated tests were performed on a dedicated test tool to validate its use on these parts.

For the HDRM separation surface, it was possible to perform qualification post-test inspections. The analysis, carried out by ESTL, showed excessive wear of the HDRM contact surfaces. Decision was made to switch from the use of Dicronite DL-5 to the more robust Tiodize IV treatment (proprietary anodizing coating with TIOلون X40 PTFE impregnation), widely used by JPL in other M2020 components. This coating was tested successfully during the delta-qualification tests.

The QM+ issues with the Frangibolt preload

Measurement of the preload of the HDRM bolt was not possible in the case of the WS2 deployment mechanism.
Several methods were considered during the preliminary design, direct measurement by a load cell, ultrasonic measurement or the use of a sensorised bolt. However, none of them was compatible with the limited space available, the accommodation constraints and with the size of the bolt used.

The change in preload for the same torque applied during the re-setting of the Frangibolt was detected indirectly and due to the large number of deployments performed as part of the extended test campaign.

Right after the Delta qualification campaign performed due to the Frangibolt issue, the qualification model MP EQM was converted to MP EQM+ by the addition of the electronics. The need to perform additional deployments to verify the electronics with the same hardware that had already passed two qualification campaigns (WS2 MP EQM qualification and Delta qualification) lead to more issues:

After both campaigns, the model had undergone 29 deployments instead of the originally planned 15: an initial functional test at AVS’ premises, 14 more deployments during the WS2 MP EQM qualification campaign and 14 more deployments for the MP EQM Delta qualification campaign. Note that the FM has only to perform four deployments.

During the MP EQM+ campaign, a latch plunger broke in a functional test (Deployment No. 32).

A thorough study was performed to determine the root cause. Several factors complicated the comparison, such as the modifications on the HDRM stack configuration after the initial Frangibolt failure and the change of lubrication between the qualification and the delta-qualification. However, an increasing trend on the deployment forces and torques imparted at the interface was detected.

Since the actuator remained the same, the additional energy impact energy had to be related with an increase of the elastic energy stored by the preload force. Note that, as a rough estimation, 10% of increment of preload would cause an increment of 20% of impact energy, which is in line with the results observed. This increase was attributed to the accumulated burnishing effect of the wear at the Helicoil insert of the HDRM interface part, which affects the actual nut-factor leading to higher preload for the same preloading torque applied.

Similar previous experiences had been reported by JPL during the InSight development, which helped to confirm this hypothesis. Potential refurbishment of the corresponding interface part had been considered during the design phase but it was finally disregarded due to the relatively reduced number of re-tightening cycles initially expected. However, the need of a Deltaqualification campaign and the re-use of the hardware for different models due to the time and budget constraints, increased significantly the number of cycles.

For the flight models instead, the limited number of deployments, only four, lead to the decision not to refurbish this part.

WS2 PROTO-FLIGHT MODEL, PFM

The Proto-flight Model and its spare unit passed successfully the acceptance campaign at Crisa.
The number of deployments was reduced as far as possible, down to four, in order to avoid over stress on the Frangibolt wires, degradation of the lubrication and modification of the preload at the HDRM. None of these issues occurred during the acceptance campaign.

LESSONS LEARNED

The following lessons learned have been gathered during the development of the mechanical parts and mechanism of the MEDA Wind Sensors:

- In addition to the standard quality assurance processes, it was necessary to perform additional test as CT Scans to the HDRM actuator after an issue occurred during the qualification campaign. This has been the method to ensure that the welding of the wires in a very small actuator as the Frangibolt FD04 do not suffer any damage during the operation as part of a HDRM. It is an affordable inspection test and allows the inspection of the part lowering the risk of having a failure during the operation of the flight model.

- In addition to the usual information gathered from the literature and from the lubrication suppliers, it was necessary to perform a dedicated campaign on the lubricated parts of the latch track. In the case of the WS2, it was necessary to do a Delta qualification campaign that lead to more deployments that initially expected. These circumstances, combined with the impossibility to perform intermediate inspection test, caused the need to perform a dedicated test after the two campaign to complete the validation of the design and the selected processes adding cost and time to an already tight schedule.

- It is not always possible to measure the preload torque on the HDRM assembly. This was the case of the HDRM of the WS2 due to its small size and accommodations constraints on the volume available. The change in the preload due to the accumulated burnishing effect of the wear at the Helicoil insert of the HDRM interface part, which affects the actual nut-factor leading to higher preload for the same preloading torque applied, can cause unexpected deployment or issues on other parts of the mechanism that is advisable to consider at the very beginning of the activity.

CONCLUSIONS

The Wind Sensors of the MEDA instrument have been designed, manufactured and qualified. As part of the qualification of the structure and mechanism performed by AVS, several issues were encountered with the HDRM Frangibolt actuator, the lubrication of the latch track surface and the HDRM separation interface and the variation in the HDRM bolt preload. All those issues were studied and corrective and mitigation actions were taken. Finally it was demonstrated that the design met the mission requirements. The proto-flight models were successfully tested before the final integration in the M2020 rover at JPL. Launch is scheduled on July 2020.

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