Circular robotics connectors for the ExoMars program

Space Passive Component Days, 1st International Symposium

24-26 September 2013
ESA/ESTEC, Noordwijk, The Netherlands

D. Delaude[(1)], H. Demailly[(2)], G. Bottaro[(1)], C. Groeppelin[(2)], B. Couvel[(2)], M. Capuano[(1)] , A. Cecchetti[(1)]

[(1)]Thales Alenia Space Italia
Strada Antica di Collegno 253
10146, Torino – Italia
Email: debora.delaude@thalesaleniaspace.com

[(2)] Souriau SAS
Etablissement de Marolles-en-Brie
Z.A.C. 3, rue du vallon
94440 Marolles-en-Brie - France
Email: HDemailly@souriau.com

ABSTRACT

ExoMars, led by the European Space Agency, is the first mission of the European Aurora program.
ExoMars is designed to demonstrate key flight and in situ enabling technologies, including Entry Descent and Landing (EDL) capability. The ExoMars program combines two missions planned respectively on 2016 and 2018. For the 2016 mission, the spacecraft is composed by the TGO (Trace Gas Orbiter) and the EDM (Entry, Descent and Landing Demonstrator Module).
The ExoMars Mission 2016 architecture and design will be subjected to the System CDR in November 2013 with Thales Alenia Space Italy (TAS-I) as Industrial Prime Contractor. TAS-I is also responsible of the Entry Descent Landing Demonstrator Module (EDM), including its Guidance Navigation & Control (GNC) system and its Functional EDL End-to-End (FE2E) Simulator.
The EDM constitutes primarily a technological development to demonstrate the European capabilities to safe landing on Mars surface.
As for any stages of the launchers and satellites composed by several modules, each separation is a critical step of the mission and all the mechanisms and parts involved has to precisely work for a successful result. The role of the separation mechanisms is primary for this purpose and specific connectors have been used to allow power, data and UHF signal transmission without prejudicing the harness electrical continuity and affecting the separation devices' performances.
This paper describes the selection and validation of one of the key element of the ExoMars EDM separation devices: the separation connectors 8977 Series Connectors produced by Souriau (France).

INTRODUCTION

After approximately 9 months of cruise in the cold interplanetary space the EDM will be separated from the TGO and will autonomously enter in the Martian atmosphere after three days of coasting. During the entry and descent phases, the EDM will deploy a supersonic parachute and release the Surface Platform that will finally touch the surface and communicate to the Earth its successful arrival (see Fig.1and [1] for more details).

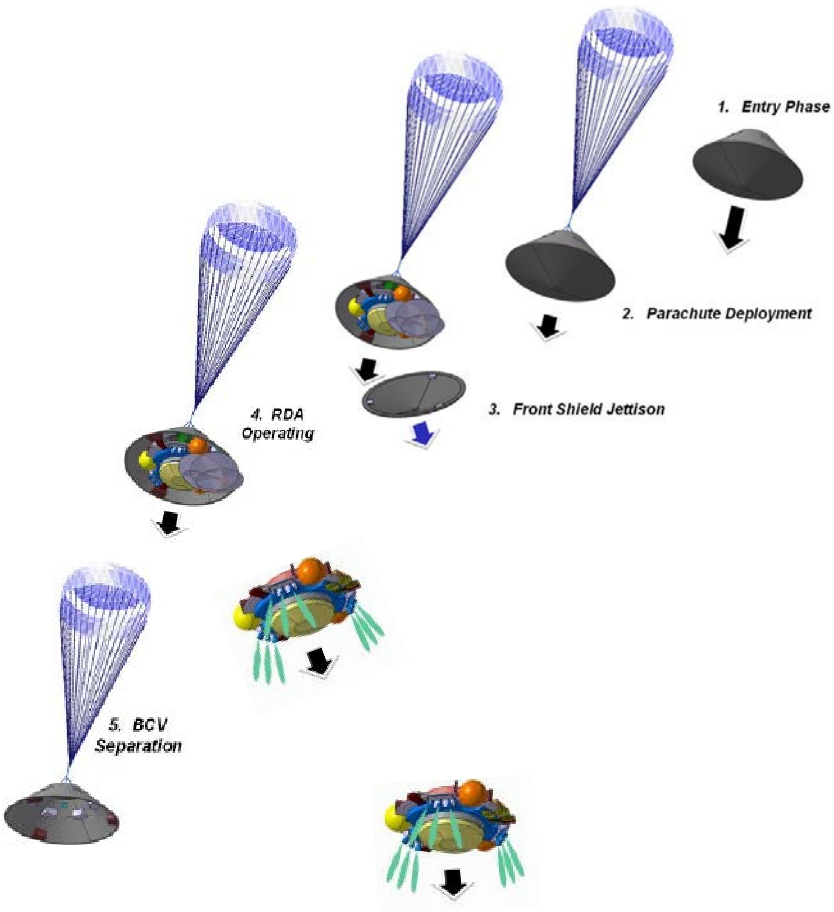

Fig. 1. ExoMars EDM Entry Descent & Landing phases

Harness is routed through from/to the EDM and TGO and between the EDM sub modules. . The connection between the separable elements is obtained by using special connectors that can be automatically un-mated by the separation mechanisms. Three separation devices are implemented in the EXOMARS 2016 mission:

- Main Separation Mechanism between the TGO and the EDM. This separation device provides also the needed spinning to the EDM at separation via a calibrated spring system.
- Front Shield Separation System to eject the EDM Front Shield from the rest of the probe (Fig. 2). The Front Shield Separation Mechanism provides minimum release energy and a guidance for the ejection path for a Front Shield linear separation.
- Surface Platform Separation System to release the EDM Back-shell with the parachute from the lander.

Driver of these separation mechanisms is the fine balancing between the spring repulsive forces and the friction of the parts involved as well as the activation timing. The 12 pairs of connectors with 3 different contact arrangement distributed on the three mechanisms contribute to the separation by transmitting the signals between the different section of the structures and with their un-mating energy.

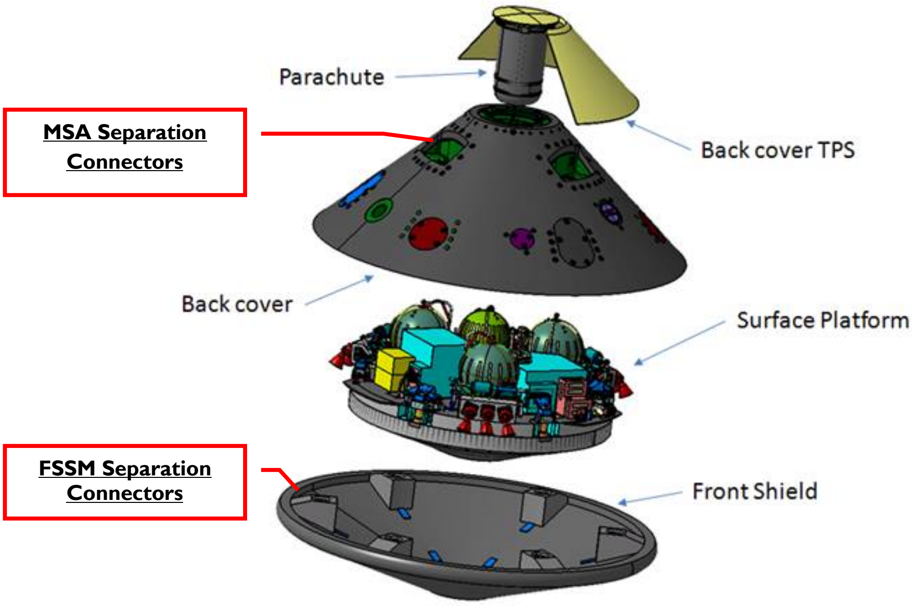

Fig. 2. ExoMars EDM sub-module

These connectors are required to:

- do not hamper the separation with their retention force
- guarantee the stable electrical connection until the separation is achieved
- allow small misalignment during on ground mating and in-flight un-mating to compensate tolerances and movement of the modules
- behave homogeneously and not induce rotational moment on the modules
- be able to operate properly at the different temperatures foreseen during the mission
- withstand the shocks of the separation without loosing parts that could damage other equipments
- meet the quality requirements for space application
- be compatible with the bioburden reduction methods imposed by the Mars Planetary Protection policy adopted by ExoMars

In addition to the technical performances of the connectors the selection of 8977 Series Connectors produced by Souriau was driven by the fact that Souriau is an ESCC qualified manufacturer for other series of connectors and has therefore familiarity with the ESA requirements concerning materials, quality and test approach. Moreover Souriau achieved an important heritage on separation connectors in the frame of the Huygens mission.

THE 8977 SERIES CIRCULAR ROBOTIC CONNECTORS

Souriau has developed a circular connector range dedicated to robotic extra-vehicular activities. The 8977 series have been first used as ORU interface on the JEM (Japanese Experimental Module) exposed facility, which is a part of the Japanese contribution to ISS.
This connector range integrates a compliance mechanism to ease robotic activities, able to catch misalignments in the connector axis as follow:

Table 1. 8977 compliance mechanism performance

ORU plug misalignments	
Movement around the X axis	± 0,9°
Angle authorized between the panels	± 0,9°
Plane movement according to Y and Z requirements	1,95mm
ORU receptacle overstroke	
ΔX overstroke	≥1,5mm

They can be mounted with Low Insertion Force (L.I.F.) contacts, limiting the force needed for mating and unmating, which is a prime parameter in the case of ExoMars mission. As 8977 connectors have been designed to integrate the MIL-DTL-38999 inserts, they can also be mounted with the 38999 contacts: from #22 to #4, signal and power, coax and triax contacts. Thus 8977 series also benefits from MIL-DTL-38999 layouts.
The design of the shells prevents the bending of the contacts.

Fig. 3. Souriau 8977 connectors couple

8977 connectors feature also high EMI shielding efficiency, and are designed to work in deep space environment (low susceptibility to atomic oxygen effects).
Since then, 8977 series have been used on other projects as the ESA/NASA mission to Saturn and Titan called Cassini-Huygens, while providing the umbilical harnesses (designed on the 8977 technology, using L.I.F. contacts) for the separation of the Huygens probe from the Cassini spacecraft. After 7 years of cruise the harnesses successfully fulfilled their mission, allowing the probe to land on Titan.
The 8977 series has been selected also for use on Bepicolombo that will be launched in 2016 toward Mercury.

QUALIFICATION OT THE SEPARATION CONNECTORS FOR THE EXOMARS PROGRAM

Although the heritage of the 8977 separation connectors in several space applications the available data do not cover the full requirement of the Exomars application.
In particular the following properties were not covered by previous heritage and are the cornerstones of the extended qualification campaign undertaken by ExoMars:

- values and dispersion of the un-mating force and energy at the ExoMars worst case conditions expected at separation:
- effect of the cold welding at T_{min}=-60°C in vacuum condition on the un-mating force
- capability to maintain electrical continuity during sine and random vibration at the mission levels with maximum contact disturbance time of 1µs
- capability to maintain electrical continuity during shock up to a peak acceleration of 3000g SRS with maximum contact disturbance time of 1µs

The qualification covers the ESCC3401 and ESCC3402 test tailored at the level applicable to the ExoMars mission 2016, with the addition of the specific mating/un-mating forces and cold welding tests. The complete list of test is reported in Fig 4.

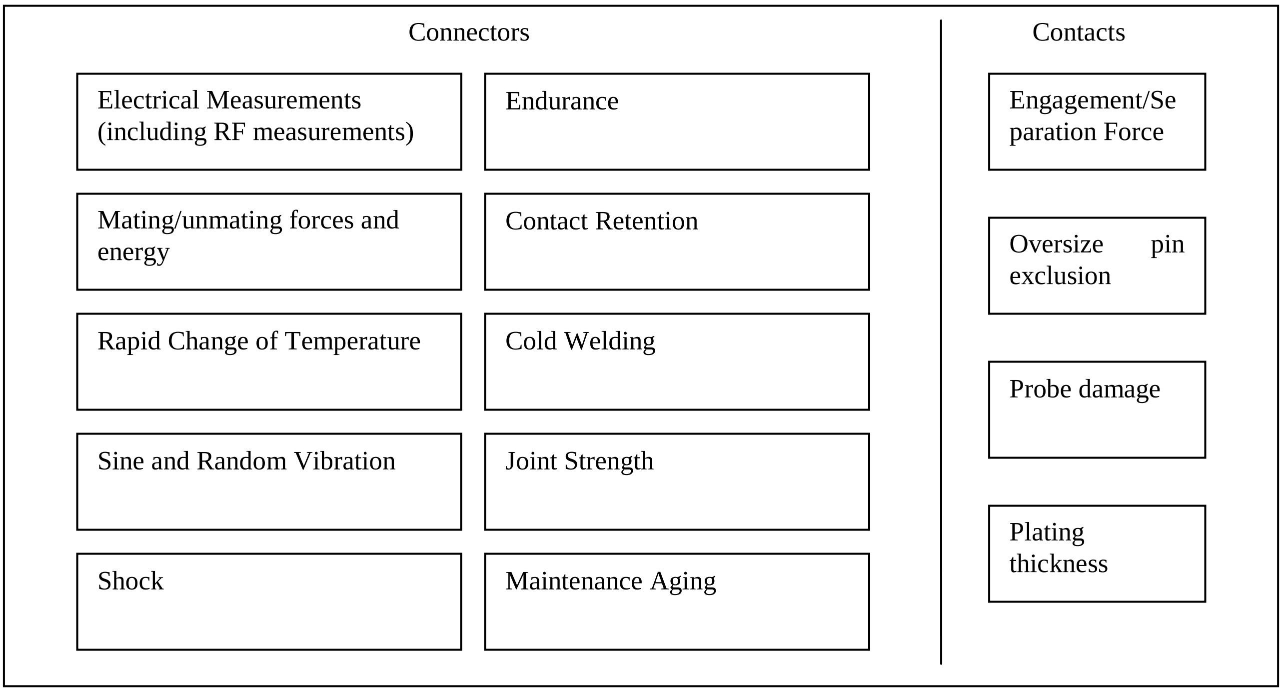

Fig. 4. List of Qualification Test

ExoMars EDM Harness will use different contact arrangements and different contact types, LIF, Coaxial and Thermocouples contacts. The test samples have been selected to be representative of all the arrangements.

The test campaign has been optimised to have an effective coordination between the development of the Separation Mechanisms and the connectors qualification. One of the drivers of the test flow has been the necessity to have a set of fully characterized connectors to be mounted on the Qualification Models of the Separation Mechanisms in advance with respect to the conclusion of the full connectors test campaign. With this purpose the connectors have been produced in two batches, the first batch includes the test samples and the connectors that are used in the Separation Mechanisms qualification models. The flight parts have been produced in a second batch together with some test samples to be submitted to a reduced lot acceptance flow for the validation of the FM parts.

Fig. 5 shows the test philosophy adopted.

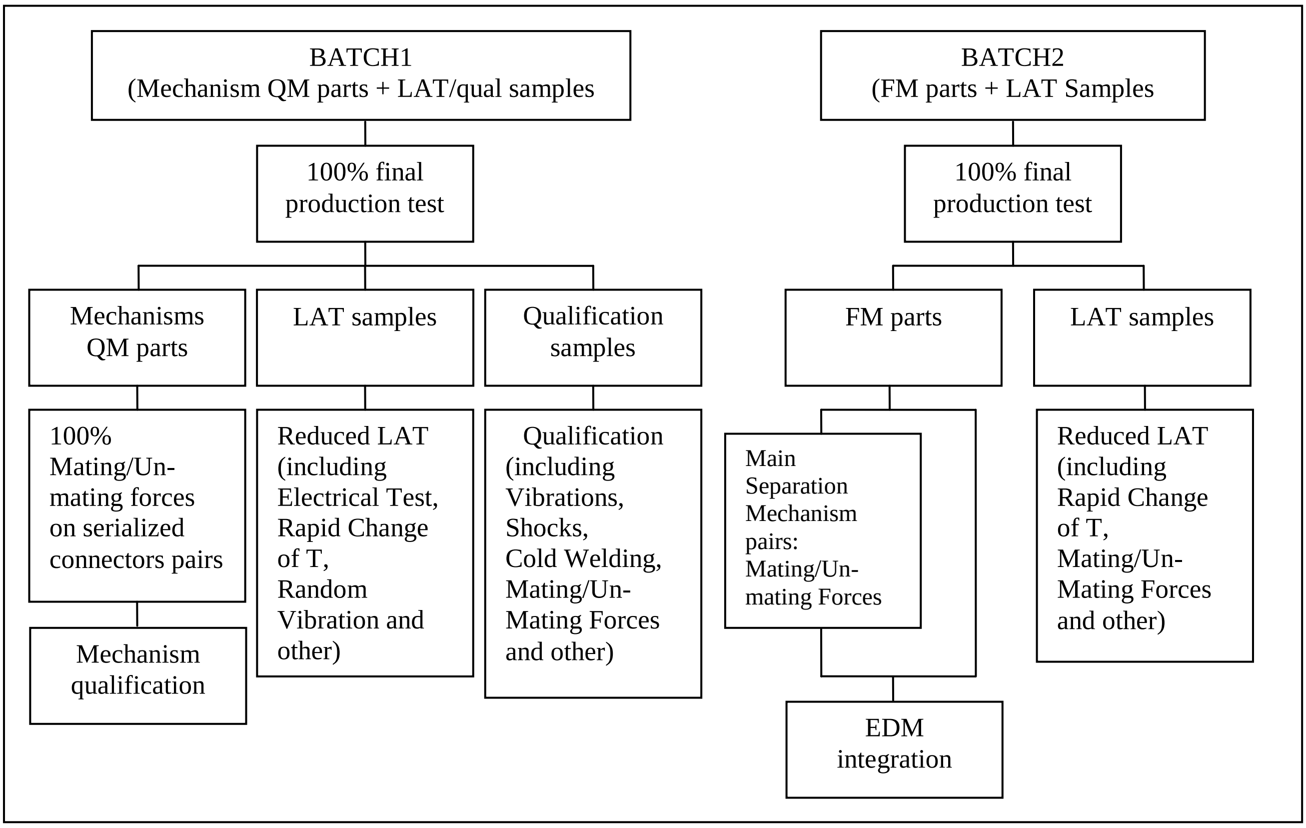

Fig. 5. Test flow

The qualification campaign has not been completed yet but the LAT on Batch 1 is successfully concluded and the results of the mating/un-mating tests on the pairs intended for the mechanism qualification are available.

Mating/Un-mating Forces

The connectors allocated to the qualification of the Separation Mechanisms have been wired and equipped with backshells in order to reproduce as far as possible the flight configuration. These connector pairs have been individually tested for mating/un-mating forces.
The connectors pairs have been tested in vacuum at the worst-case temperatures expected at separation: T_{min}=-60°C, T_{MAX}=+70°C.
The tests have been done at different misalignment conditions up to the maximum angular and in-plane misalignment described in Table 1.
Figure 6 show the test bench used for this purpose.
In addition Souriau decided to perform some measurements at room temperature on a different test bench to validate the test setup. The review of the available results shows that:

- The behaviour of each connector pair is repeatable on subsequent mating/un-mating cycles (repeatable force vs stroke profile)
- The wiring has no effect on the un-mating forces and energy (as expected)
- The separation force depends on the contact arrangements and is lower for connectors fully equipped with LIF contacts (as expected) but the use of thermocouples contacts and coaxial contacts does not jeopardize the separation
- The un-mating force at -60°C is on average 45% greater then the un-mating force at +70°C
- When the same connector pair is tested in aligned and misalignment condition the un-mating force does not significantly change, as far as the maximum misalignment is not exceeded. The same behaviour is observed for the mating force
- For connectors with same size and contact arrangement fully equipped with LIF contacts the forces of each pair may differ about ±25% with respect to the average.

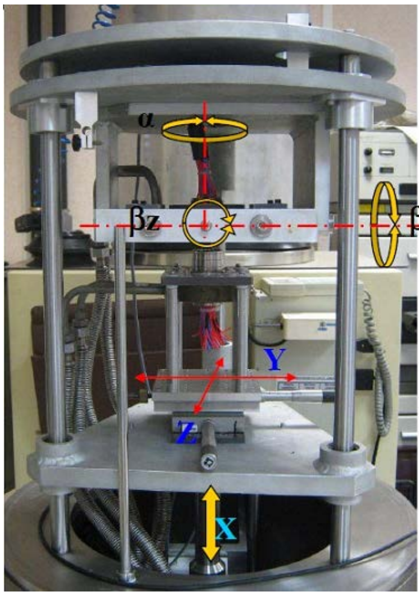

Fig. 6. Mating/un-mating forces test bench

It should be noted that the Mating /Un-mating forces are mainly due to the contacts insertion/removal force, therefore the forces cannot be measured unless the connectors are wired. The test will be repeated during qualification and on the Batch 2 LAT samples. In addition the pairs of FM connectors to be mounted on the Main Separation Mechanism will be submitted to the mating/un-mating test before integration on the EDM in order to select the most appropriate pair for each position.

Vibration

As explained in the previous section the EDM will experience shocks and vibrations induced by the separation and by the Martian atmosphere in the entry phase and the connectors shall maintain the electrical functionality. With this purpose both the vibration and the shock tests of the qualification campaign are done on electrically monitored connectors to detect any signal interruption >1µs.

The connectors successfully passed the vibration test of the LAT maintaining the electrical continuity and without any mechanical damage.

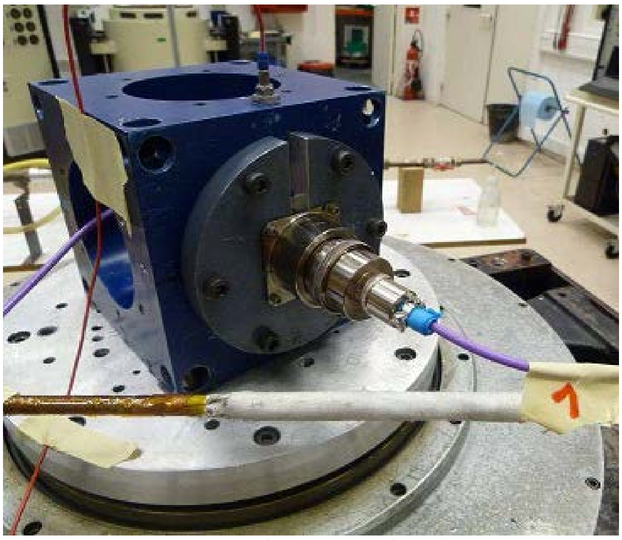

Fig. 7. Vibration test bench

OUTCOME OF THE INITIAL TEST RESULTS AND CONCLUSION

The extended characterization tests on the connectors in the ExoMars condition play an important role to Souriau for further improving the performance of its product by adjusting the tolerances of their connectors.
The measurements so far obtained have been used to tune the qualification test of the three EDM Separation Mechanisms and to refine their design.
The un-mating force and energy of the connectors that will be mounted on the Flight Model of the Main Separation Assembly will be measured before integration on the EDM and will be used as input for the final calibration of the mechanisms.
The results obtained by the LAT vibration test are successful and this is promising also on the results of the forthcoming shock test.
The qualification campaign will be concluded in the next months and the ExoMars team attention if focused in particular on the Shock and Cold Welding test results. Nevertheless the initial results are encouraging on the suitability of the 8977connectors for the ExoMars 2016 mission and confirm the maturity of the European space technology.

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