CLAMP BAND ASSEMBLY FOR THE BEAGLE 2 LANDER

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ABSTRACT

The Beagle2 probe was launched upon the European Space Agency's (ESA's) Mars Express spacecraft in June this year, destined for the Red Planet. Beagle2 was a particularly demanding programme due to the extremely tight constraints on mass, volume, power consumption and environmental conditions. This paper describes the solution, against these constraints, for the Clamp Band and Release mechanism. The design constraints are explained, followed by a detailed design, calibration and test description of the Clamp Band Assembly (CBA).

Keywords: **Astrium, Beagle2, Clamp Band, Frangi-bolt**

1 INTRODUCTION

1.1 The Beagle 2 mission

The primary aim of Beagle2 is to search for evidence of life, past or present on Mars. Beagle2 was launched on ESA's Mars Express orbiter on a Soyuz-Fregat launch vehicle in June 2003. After a seven-month cruise to Mars, the complete probe will be ejected from Mars Express, see *Figure 1–1*. During this 5-day coast phase, Beagle2 will be totally passive, spinning slowly about its axis in order to minimise thermal gradients and to provide stability at the point of entry into the Martian atmosphere.

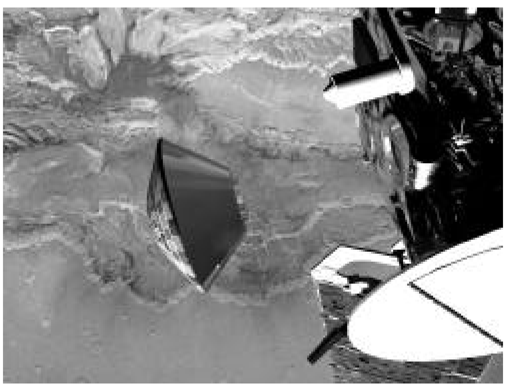

Figure 1–1Beagle2 leaving Mars Express

Once atmospheric entry is commenced, the lander is decelerated from 5.75km/s (20,000kph) to zero in just five minutes. This function is carried out by the Entry Descent and Landing System (EDLS), which involves aerodynamic braking, followed by parachutes and finally airbags for the impact with the surface. This impact occurs at 20m/s and can generate an initial shock as high as 200g despite the protection of airbags. In fact the second impact can be just as severe as the first. The final 1m drop from the airbags (see *Figure 1–2*), when they are released, results in another impact with the surface at 3.1m/s (11kph). This gives rise to shocks of up to 400g within the lander.

Having settled on the surface, the clamp band is released, the lid is opened and the solar arrays are deployed. Finally after confirmation that there are no obstacles to arm deployment, the hold-downs on the PAW (multi-functional end tool) and robot arm are released. The robot arm/PAW subsystem will then be ready to survey the landing site, examine rocks and finally take samples for on-board analysis. The targeted operational life is 180 Martian sols (days)

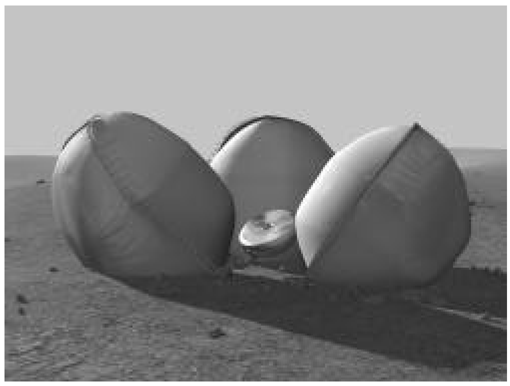

Figure 1–2 Beagle2 dropping from airbags

1.2 The Beagle2 Clamp Band Assembly

The Clamp Band Assembly (CBA) shown in *Figure 1–3*, is required to secure the lid to the base of the Beagle2 lander throughout the initial phases of the mission from build, integration to Mars Express, launch, cruise to Mars, ejection from Mars Express, cruise towards Mars, entry into the Martian atmosphere and landing.

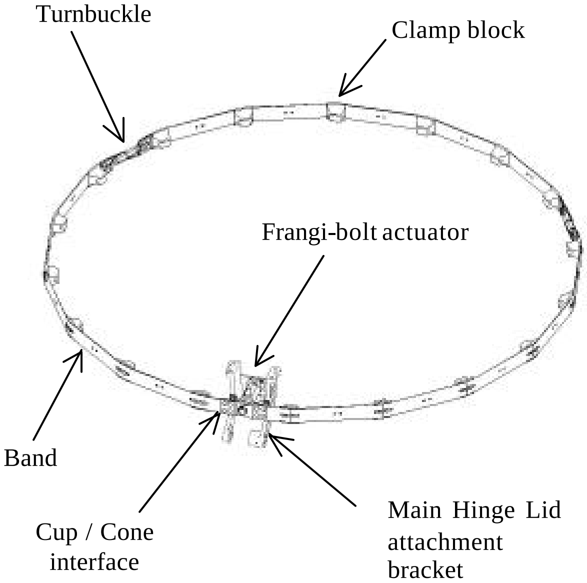

Figure 1–3 Beagle2 - Clamp Band Assembly (CBA)

Once the Beagle2 lander has settled on the Martian surface the clamp band will be released allowing the lander to open and the solar array panels to be deployed.

2 DESIGN CONSTRAINTS

2.1 General

- Design

The function of the CBA is to ensure that the lid and base of the lander remain securely clamped together until commanded to operate, releasing the lid from the base allowing the lander to open and the remainder of the mission to continue. After release the clamp band is redundant.

After dropping from the airbags the lander can be in any orientation when the CBA is operated, it is important that once released the band does not impede further operations on the lander, mainly lander opening. For this reason the point of release was carefully chosen to avoid possible interference with the Main Hinge Mechanism (MHM) that opens the lander.

There is no ejection system due to the size and mass constraints. The system therefore relies solely on the tension and strain energy stored in the band to clear the lander once released.

There was also no space or mass for a clamp band catcher system.

- Mass:

The mass of the entire Beagle2 probe is limited to 72Kg by Mars Express. The clamp band like all other equipment has tight mass targets to be as light as possible. The target mass of the CBA was < 525 grams, the actual Flight Model (FM) CBA weighed 456 grams.

- Power:

Power is limited to 1.2 Ah due to size of the battery and when Beagle2 lands, the probe will have been coasting for 5 days following ejection from Mars Express and battery power will therefore be low.

- Deployment / release:

The time window for the CBA release mechanism actuation is 3 minutes. On actuation the clamp band must instantly release removing all clamping force and drop away from the lander.

- Envelope:

The envelope of the clamp band is fixed by the diameter of the lander at (620mm). Out side that diameter there is very little space as the airbags pack around the lander and the clamp band volume has to be minimised.

2.2 Environmental

- Temperature:

The CBA has to survive a relatively benign temperature environment during the mission apart from the sterilisation process which involves high temperatures.

Cases	Temperature Limits
Operational	-20 ^{o}C to + 20 ^{o}C
Survival	-23 ^{o}C to + 23 ^{o}C
Sterilisation - Survival	+ 125 ^{o}C
Failure Case – Survival (Heater Failure)	-58 ^{o}C

- Random Vibration:

The dominant cases for random vibration are during launch in the z-axis.

Z Axis **Qualification Level**	
Frequency	Input (Qual. level)
20 – 40 Hz	+18 dB/oct
40 – 100 Hz	+6 dB/oct
100 – 140 Hz	3.0 g^2/Hz
140 – 2000 Hz	-6 dB/oct

X & Y Axis **Qualification Level**	
Frequency	Input (Qual. level)
20 – 40 Hz	+24 dB/oct
40 – 50 Hz	1.5 g^2/Hz
100 – 150 Hz	0.5 g^2/Hz
200 – 800 Hz	0.08 g^2/Hz
950 – 1150 Hz	0.5 g^2/Hz
1150 – 2000 Hz	-12 dB/oct

- Shock:

The final stages of landing are the dominant design cases for shock, occurring either for the airbag impact on the Martian surface or from the final drop when the airbags detach allowing the lander to fall to the surface.

Medium Duration Shock (for surface impact)	
Qualification Level SRS	
Frequency	Input (Qual. level)
10 – 100 Hz	+6 dB/oct
100 – 1000 Hz	400g
1000 – 4000 Hz	-3 dB/oct
4000 – 10000 Hz	200g

- Martian Atmosphere:

The break down voltage of the atmosphere is 100V, which must not affect the release device causing premature release of the clamp band.

- Vacuum:

The Beagle2 probe is subject to a deep space vacuum for the 7-month journey to Mars.

- Sterilisation

The CBA has to be sterilised is accordance with interplanetary requirements for micro organisms. The method for all parts except the frangi-bolt actuator was dry heat sterilisation by heating to 125°C for 48 hours. The frangi-bolt actuator is a Shape Memory Alloy (SMA) and was sterilised by Plasma sterilisation, as dry heat sterilisation would take the actuator above its transition point of 80°C causing a risk that the actuator could relax.

3 DETAILED DESIGN

3.1 General

The CBA comprises of 3 band sections which each have 6 clamp blocks attached to them that interface to the lander holding it together when the band is tensioned. The 3 band sections are joined together in 2 locations by screw turnbuckles that allow the band to be tightened and a separation interface that is held in place by a special bolt that interfaces with the frangi-bolt release device

The point of separation of the band has been selected to be adjacent to the MHM to ensure that upon release the clamp band does not impede movement of the MHM, preventing the lander from opening.

In a full tension release where the clamp band has maximum energy the clamp band is designed to be ejected totally clear of the hinge line and land on the Martian surface in either landing orientation, lid up or down.

The turnbuckle positions have been carefully selected for 2 reasons. Firstly to allow even tensioning of the clamp band and secondly to aid a tensioned release by increasing the weight at the furthest point from the release point, thus increasing the inertia so that upon release the middle of the band is forced clear of the lander.

In a worst-case scenario, where the clamp band has lost all its tension causing a minimum energy release, the band has been designed to drop away from the lander upon release. If the lander lands lid down upon release the band will clear the lid, landing on the Martian surface totally clear of the lander. If the lander is base down the band will fall onto the Aero-shell Release Mechanism (ARM) lugs clear of the hinge line and will not prevent lid deployment.

Due to the tight requirements on the electrical design there is only 1 firing circuit supplied to the release device and there is no telemetry available to detect a release.

3.2 Mechanical

Figure 1–3 shows the main components that make up the CBA.

- Band Sections:

The Band consists of 3 titanium straps that are each formed into an arc that in total has a larger natural diameter than the lander, so when the band is released it will form a bigger diameter than the lander thus giving a clearance to fall away from the hinge line in case of a minimum energy release.

Each band segment has 6 slots in it to accommodate the attachment of the clamp blocks allowing some movement for location of the clamp blocks to the interface brackets on the lander and to help even tension distribution around the band.

- Base and Lid Brackets:

The lid and the base have 18 mating brackets bonded into their corresponding halves to transfer shear loads between the structure lid and the base, see *Figure 3–1*. The brackets form a wedge shape that interfaces with the clamp blocks mounted around the band. The brackets are manufactured from titanium and are both treated to prevent cold welding between the surfaces of the brackets and the clamp blocks.

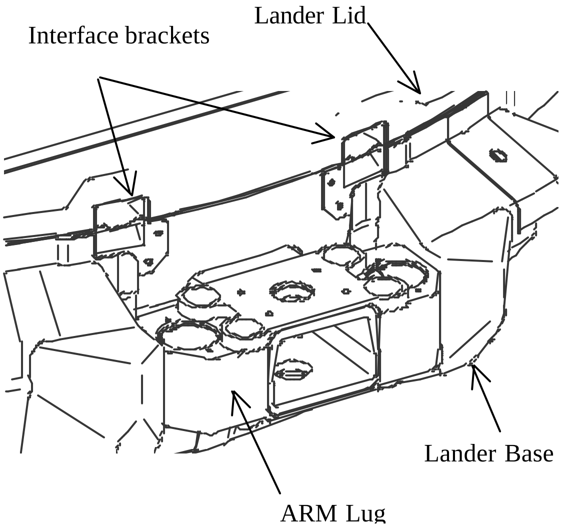

Figure 3–1 Lid / Base clamp block interface

- Clamp Blocks:

The clamp blocks provide the means of transferring the tension in the band into a clamping force at the lid / base interfaces due to their V-shape design, see *Figure 3–2*. The rear profile of the clamp blocks has a radius that forms a tangent line between the clamp blocks to allow for straightening of the band between the blocks due to the tension. The clamp blocks are machined from a high-grade aluminium alloy and are treated with a low friction coating.

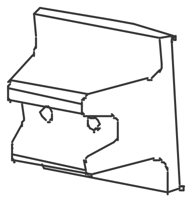

Figure 3–2 Clamp Block

- Frangi-bolt interface:

The CBA release point consists of 2 end fittings machined from titanium to form a cup / cone interface to transfer the loads in the tensioned band and prevent bending in the frangi-bolt. The interface is clamped together by the frangi-bolt arrangement, concealed in the lid attachment bracket of the MHM. One half of the interface is coated in an anti friction coating to prevent cold welding of the two surfaces. The end-fittings are riveted to the band sections in single shear using Monel rivets.

- Turnbuckle:

In addition to the frangi-bolt there are 2 turnbuckles between the 3 sections of the band that are used to apply a balanced tension around the band. Each turnbuckle consists of 2 stainless steel silver coated band end fittings, one with a left hand thread (LH) and one with a right hand thread (RH). The end fittings are held together with a special nut containing the reciprocal LH and RH thread, see *Figure 3–3*. Rotating the nut between the end fittings pulls the bands together thus increasing the tension in the band. The turnbuckle end fittings are riveted to the clamp band sections in a double shear configuration due to the strength of the material using Monel rivets.

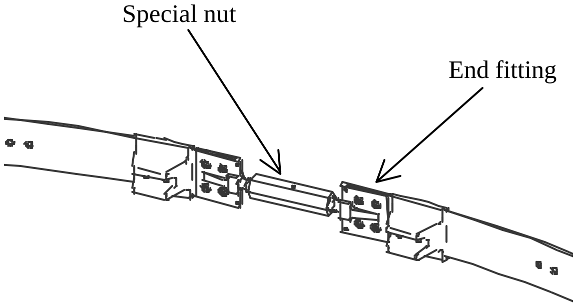

Figure 3–3 Turnbuckle tensioning section

- Wire Locking:

The turnbuckle nuts are wire locked in place to the end-fittings to prevent the nut from unscrewing thus relieving the band tension, see *Figure 3–4*.

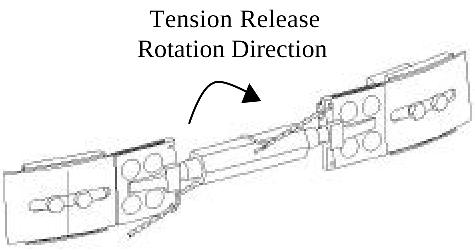

Figure 3–4 Wire locking of the Turnbuckles

3.3 Electrical:

- Release Device:

The release device is a frangi-bolt design, which uses a SMA actuator, which is compressed before installation. A 24V nominal voltage is passed through the actuator, which causes the actuator to heat up and the SMA to return to its original 'bigger' size thus fracturing a specially notched titanium bolt.

The frangi-bolt that holds the cup / cone interface together is notched just below the bolt head to allow a clean separation of the cup / cone interface.

- Interface to Beagle 2:

As only one firing circuit is provided from the electronics the redundant circuit is not used. The frangi-bolt is hard wired directly into the electronics.

3.4 Tribology:

- *Base / Lid brackets:*

The base / lid brackets are treated with Apticote 100T 'Hard-Chrome' to provide a hard wearing resistant coating that will prevent cold welding between the brackets / clamp blocks.

- *Clamp Blocks:*

The clamp blocks are coated all over with Apticote 350D to provide a smooth surface finish that will allow motion between the clamp blocks band and the base / lid brackets as the tension is increased around the band.

- *Cup / Cone end fitting interface:*

The separating interface of the cup is coated in Apticote100T to provide a hard smooth surface, which will prevent surface adhesion allowing separation of the cup / cone at the moment of fracture of the frangi-bolt.

- *Frangi-bolt / Washers:*

The frangi-bolt thread and washers are coated in spray Molykote D321 to aid the tensioning of the frangi-bolts.

- *Band sections:*

The band sections are coated with spray Molykote D321 around the sliding interface of the clamp blocks to aid the distribution of tension around the band during tensioning.

3.5 Calibration

A calibration sequence was developed with the Development Model (DM) CBA by attaching a number of strain gauges around the inside and outside of the band sections. The tension was then monitored in the band during tensioning, thus allowing confirmation of an even tension being achieved around the band. Using this data strain gauge positions where selected for the Flight Model (FM) clamp band sections.

Figure 3–5 shows a band section on the calibration rig with two hydraulic rams attached at either end of the band section. A force was applied to the rams simultaneously and the strain gauge readings taken, up to a proof load of 4000N to give some margin over the desired tension around the lander.

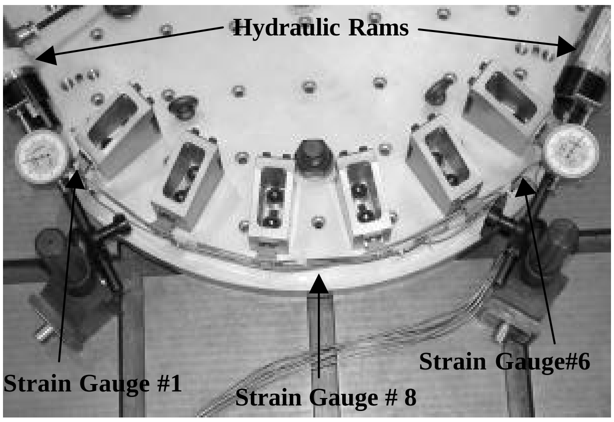

Figure 3–5 Band section strain gauge calibration

Around the clamp blocks bending occurs due to the band sections being 'formed' around the rear surface of the clamp-blocks causing a positive micro strain ($\mu\varepsilon$) offset compared to the pure tension applied.

On the band section between clamp blocks the natural curved form of the band is pulled in to a straight line causing a negative (compression) $\mu\varepsilon$ offset compared to the pure tension.

From the load / micro strain graphs *Figure 3–6*, an estimate can be made of the point that the initial bending of the band is complete and thereafter a pure tension is being applied to the band. This is judged to be the point at which the slope of the curve changes, around 500N.

At this load, the με reading is zeroed and the theoretical με value at that load added. From this corrected με value, the estimated pure tension load in the clamp-band section is calculated.

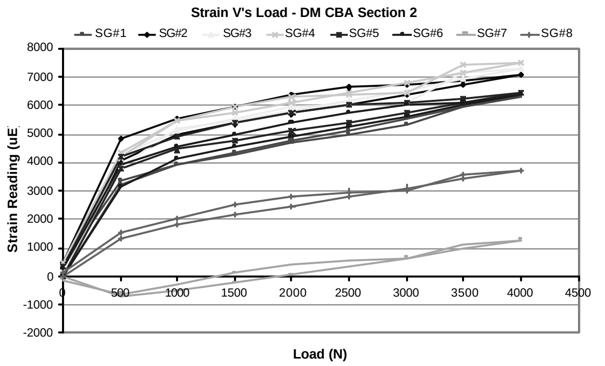

Figure 3–6 Strain V's Load

From the above calculation, the graph of applied load to corrected με can be plotted (*Figure 3–7* shows 3 strain gauges, indicated in *Figure 3–5*) and a formula for an estimate of the pure tension for a given measure με value can be obtained. This conversion formula can then be used to estimate the apparent pure tension in the band during the operations of the tensioning procedure.

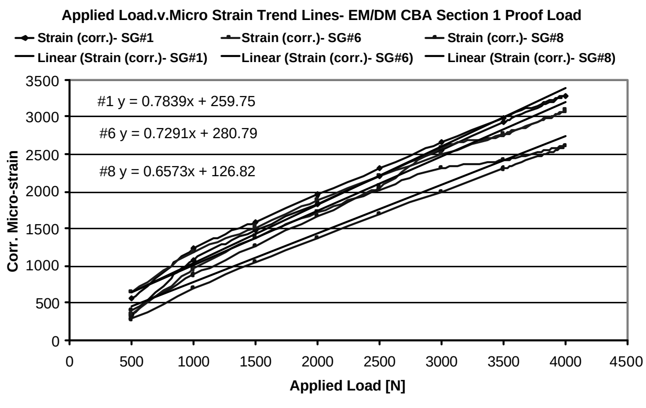

Figure 3–7Force V's Micro-strain calibration graph

3.6 Tensioning:

The strain gauges are monitored and recorded throughout the tensioning procedure. The monitoring and recording is performed using PC based software called Orchestrator.

The tension is applied by tensioning / tightening the turnbuckles in a controlled manner and balancing the tension around the clamp band by tapping the clamp blocks from side to side.

The sequence of turn-buckle tightening is dependant upon the tension characteristic in the clamp-band after the previous steps. The following tension and torque data is applicable to the clamp band,

- Frangi-bolt torque = 3.5 Nm Nominal
- Clamp-band Tension = 2300 N Nominal*

*- The clamp-band required tension shall be taken as the average tension level around the circumference of the clamp-band. *Figure 3-8* shows a typical tension distribution around the clamp band assembled onto the lander structure.

The frangibolt interface and turn buckle positions are shown on the graph.

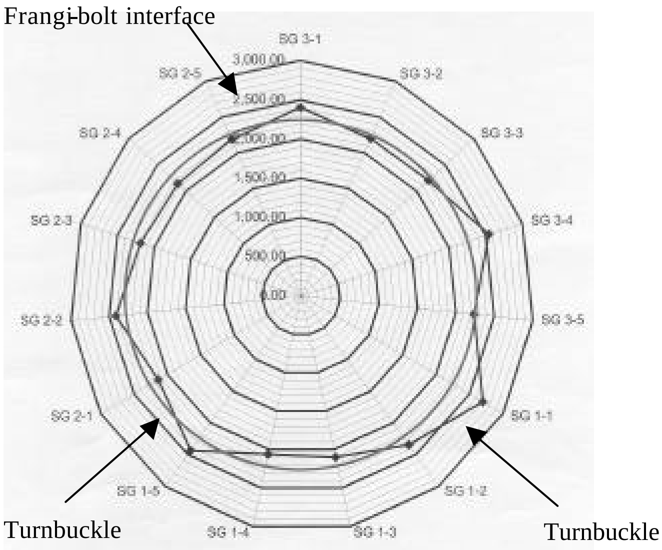

Figure 3–8 Typical clamp band tension around lander

3.7 Test:

- Proof Loading:

To verify the structural integrity of each band section by applying a tension into the individual Clamp band assembly sections up to 4000N.

- Vibration:

The CBA was subject to unit level vibration on a test fixture (see *Figure 3-9* of the DM clamp band in vibration) and probe level vibration where the CBA was assembled around the lander structure and the lander then assembled into the aero shell configuration forming the probe.

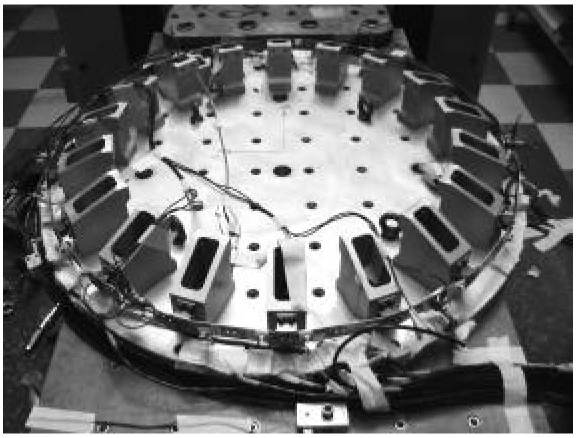

Figure 3–9 DM - CBA in vibration

Figure 3–10 shows a Pre / Post vibration comparison of the strain gauges around the clamp band. The vibration sequence had little effect on the CBA overall tension level. A slight decrease in tension can be observed on some strain gauges, however this is not judged to be critical.

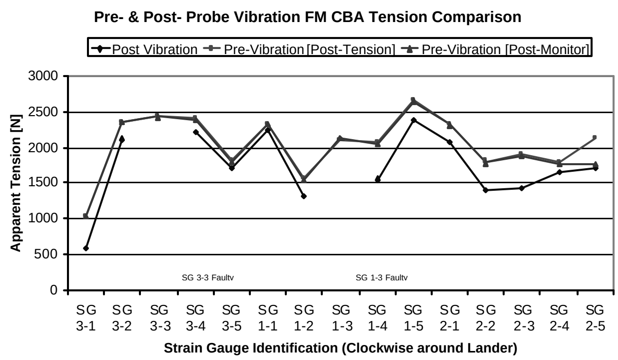

Figure 3–10 Pre–Post comparison of Probe Vibration

- Frangi-bolt:

The frangi-bolt actuation time at room temperature, with a supply voltage of 20V is approximately 1 minute.

Frangi-bolt actuator testing was conducted at temperatures down to -50^{o}C, with a worst-case supply voltage of 18V. All Frangi-bolts fractured within the 3 minute requirement, *Figure 3-11* shows frangi-bolt actuator external temperature V's time for 2 frangi-bolt actuators. The bolt fracture time at $-20\ ^{o}$C can be seen to be 140 seconds.

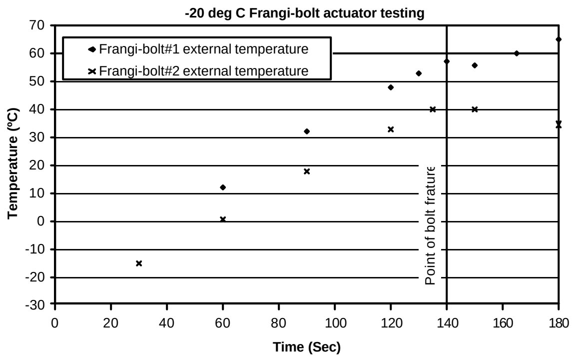

Figure 3-11 Frangi-Bolt testing at -20^{o}C

- Clamp Band Release:

The clamp band was tensioned and released several times on a test fixture and also on the DM and FM lander structure. *Figure 3-12* shows the successful deployment of the DM clamp band post vibration clearing the test fixture by a considerable margin.

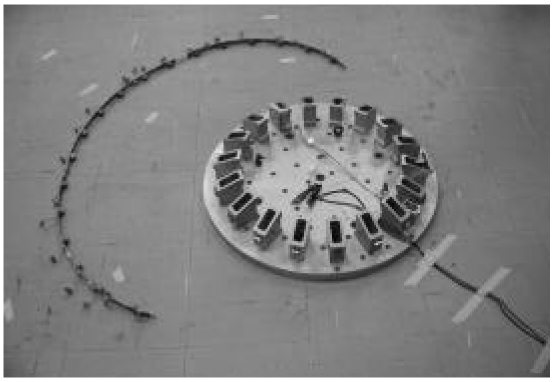

Figure 3-12 DM – Clamp Band release after vibration

Upon frangi-bolt fracture the clamp band release is almost instantaneous with the clamp band totally clearing the hinge line of the structure within 0.2 seconds.

Figure 3-13 shows the successful FM clamp band release after probe level vibration, with the clamp band clearing the hinge line allowing the lander to open.

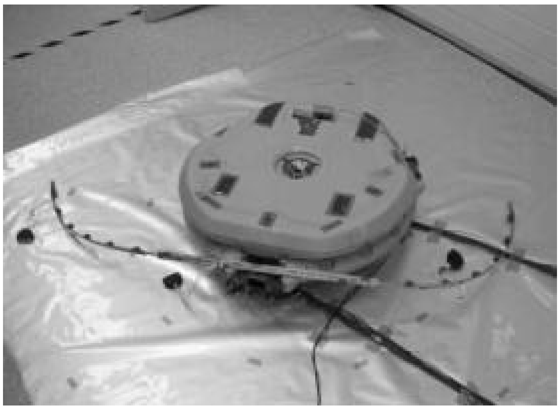

Figure 3–13 FM - Clamp Band release after vibration

The clamp band is shown to be resting on one of the ARM lugs directly opposite the MHM. This is because of the increased weight of the clamp band due to the strain gauge D-connectors that are used to connect the strain gauges to the test equipment for tensioning of the clamp band. The strain gauges cannot be removed before final integration, as the band sections would have to be recalibrated.

Figure 3-14 shows frames from a high-speed video taken of a DM clamp band release. At initial release, all the clamp blocks move clear of their interface brackets relieving any surface adhesion. The band then forms a wave like kick as both ends move away causing the middle of the band to re-contact with the test fixture before springing away as the clamp band falls free.

At varying clamp band tensions the same release wave profile was seen as the band sprung away from its interface.

4 SUMMARY AND CONCLUSION

The Beagle2 program was a very challenging and demanding program with an emphasis put on hardware development pushing design and materials to their limits.

The Clamp Band Assembly for Beagle2 has proven repeated successful deployments and has the potential for further development for use on future planetary missions, where mass and volume are particular design drivers.

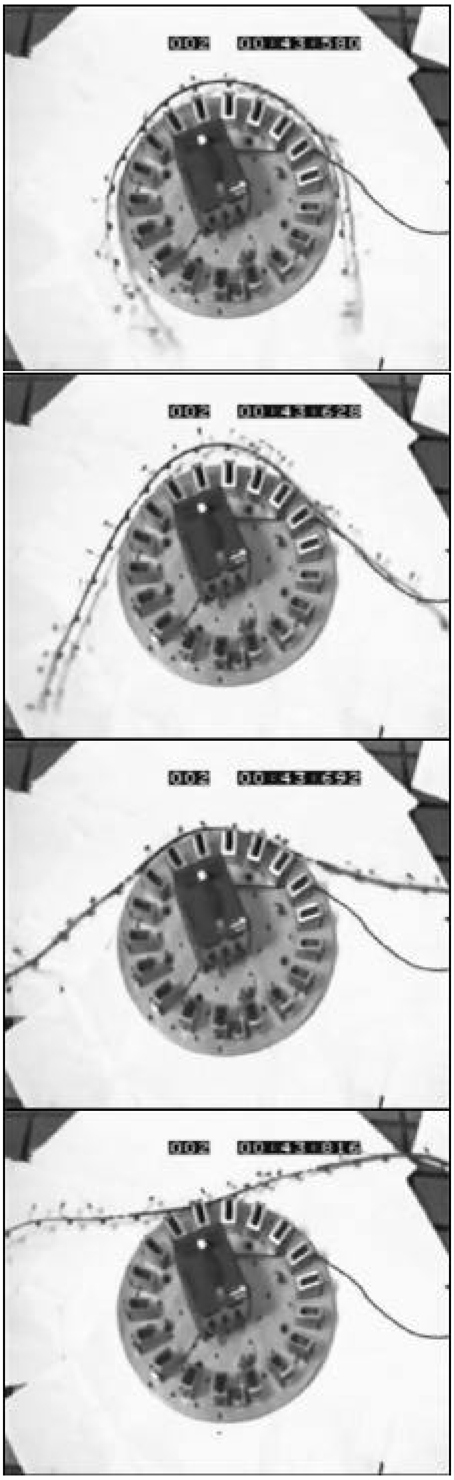

Figure 3-14 DM – Clamp Band Release

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