CAGING MECHANISMS FOR THE MARS EXPLORATION ROVER INSTRUMENT DEPLOYMENT DEVICE

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Abstract

The Mars Exploration Rover (MER) program will land two rovers on the Martian surface in January 2004. Each will be equipped with a 5 degree-of-freedom, 1-meter long robotic arm known as the Instrument Deployment Device (IDD). The IDD will position instruments mounted to its end effector with greater precision than any previous Martian arm. Two dual-use caging mechanisms were designed for the IDD. The mechanisms are very small in size, and act as launch restraints as well as passive cradling (re-stowing) features during rover excursions on the Martian surface.

The caging mechanisms are designed to use existing structural elements of the IDD to minimize mass and volume. The design also uses the IDD actuators to deploy and re-stow subsequent to the arm's release from the launch locks. Unique design elements are employed because typical release interfaces, such as those using shear-pins in engagement with spherical bearings, could not be utilized due to volume constraints. The final designs, however, do not sacrifice release performance.

A cable-cutter and pin-puller, both with standard NSI pyrotechnic initiators, are used to unlatch the IDD after landing. The cable-cutter is used at the end effector in the area of the IDD instruments, which have the highest susceptibility to pyrotechnic shock.

This paper discusses design tradeoffs and considerations for the two mechanisms, reasons for choosing each pyrotechnic device, lubrication methodology, thermal-vacuum system testing, and lessons learned.

Introduction

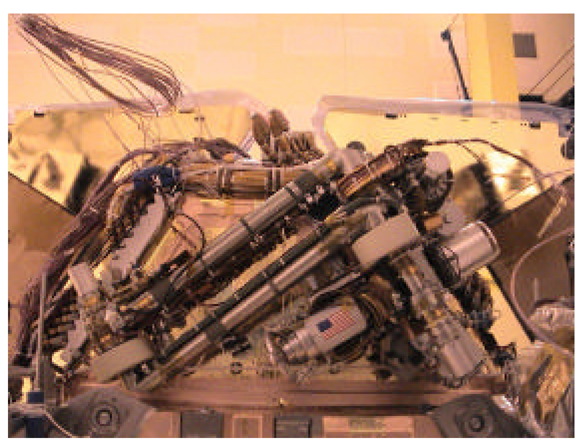
The IDD is mounted on the underside of MER, in an envelope constrained on all sides by the MER chassis, the stowed Mobility system, and the lander chassis below. The height of the envelope was the most difficult to overcome, as the IDD had to maintain this height constraint not only for the stowed launch and rover mobility, but also during the IDD unstowing and restowing maneuvers. This constraint drove the design of both caging mechanisms.

Design Considerations

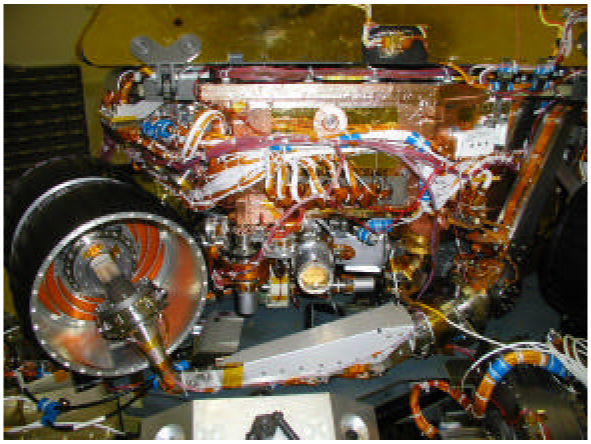
- The launch/landing system must constrain the IDD plus Instruments mass of 5.9 kg
- Designed landing impact of 60 g's.
- Temperature range, Survival: –120°C to +110°C
- Temperature range, operational: –120°C to +45°C
- Maximum of two release circuits available from the flight system specifically configured for a pyrotechnic, burst type signal.
- Must be able to install, align, and arm the pyrotechnic actuators after IDD mounted under Rover in launch configuration.
- Only two specific models of pyrotechnic release devices to choose from: pin-puller or cable cutter
- Limit pyrotechnic shock to all instruments and motor brushes.

Design

The IDD is mounted to the underside of the shelf portion of the MER on a composite honeycomb panel. The flatness and susceptibility of warping under launch/landing/driving loads of this type of composite panel and the operating temperature range necessitated the need for a kinematic type of latching system that was tolerant of this environment.

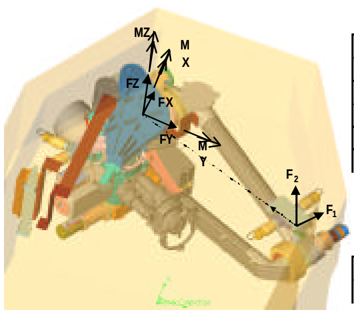


IDD MOUNTED ON MER



IDD MOUNTED ON MER

Reaction forces and moments at rover (limit loads)



SHOULDER (at bolt center)

FX (lb)	457	Landing
FY (lb)	494	Landing
FZ (lb)	427	Landing
MX (in-lb)	1128	Landing
MY (in-lb)	1556	Landing
MZ (in-lb)	756	Launch MMAC

ELBOW (at pin)

F_1 (lb)	97	Launch MMAC
F_2 (lb)	99	Launch Random

FIGURE 1: LOADS ANALYSIS- REACTION FORCES

Figure 1 shows the Loads analysis for reaction forces and moments used for the design. The largest mass on the IDD is the instrument turret at the end of the robotic arm. At this location a six degree of freedom mount was incorporated into the turret structure using three pins engaging bushings as shown in Figure 2.

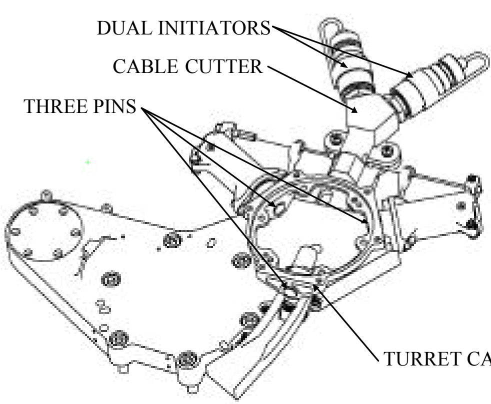


FIGURE 2

The design uses the three pins, oriented to point to the middle of the turret axis at 120 degrees apart. The pins engage bushings in the turret cap, and are shaped at their ends to form a spherical joint. Because of the limited height requirement, bushings were used in place of spherical bearings. This also resulted in a significant mass savings of 21 grams. The contact stress caused by using a radiused ball end pin can be very high. The mating materials were carefully selected and the radius on the pin was made as large as possible to allow for some misalignment and IDD sag. This joint was carefully analyzed to prevent Brinelling the bushings from extreme contact stress from the small pin size. The pins are sized smaller in diameter than the bushings by .076 mm (.003 inch) to .13 mm (.005 inch) to allow for slight misalignment and allow small particles generated during launch and landing not to bind the mechanism. The pin and bushings are dissimilar steels to reduce cold welding and binding. The pin is made from MP35N and the bushings are made from Nitronic 60, 60% cold worked. The Nitronic 60 has been used very effectively in the past to prevent galling in applications with metal-to-metal interfaces.

The locking mechanism, as stated previously, uses three pins inserted into bushings to constrain the turret during launch and landing. To deploy the IDD, two of the pins retract to allow the Turret to move off of the third stationary pin using the Azimuth actuator rotation. Using one of the two available initiator circuits from the Rover system, a cable cutter is used to release the two pins, held in place by a latch at each cable end. Each pin was fitted with a spring of 175 newtons (39 pound) force. An auxiliary push off spring was incorporated to help break any small binding or stiction, using a smaller pin running through the center of the single stationary pin, with a spring with a force of 22 newtons (5 pounds).

The opposite end of the IDD at the Elbow actuator is held to the MER chassis via a pin puller, shown in Figure 3.

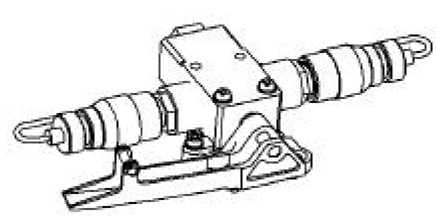


FIGURE 3

To keep the IDD system semi-kinematic, the axis of the pin-puller is aligned with the CTE growth of the IDD, and only constrains the IDD in the Z direction, (up and down), and the X direction, constraining the rotation about the shoulder Azimuth actuator. This arrangement also allows the IDD and MER to flex independently to each other during high g loads. Again, due to the height limitations, there was not room for a spherical bearing in the clevis/pin interface as would have been preferred. This achieved an additional savings of 7 grams. The clevis tang has a "loose" fit of .076 mm (.003 inch) to .13 mm (.005 inch) over the diameter of the pin, 4.88 mm (.192 inch). This loose relationship is to allow rover flex and not bind or cold weld the interface from launch vibration. The cross section of the pin hole in the tang was radiused to allow multi-angle, up to +/-2.5° misalignment from pin-puller as well as rover sag, and mimics a spherical bearing due to the angular misalignment it allows. Dissimilar metals were chosen for the two sides of the interface. The pin of the pin-puller is A286 steel, and the clevis tang is Nitronic 60, 60% cold worked. The clevis is made from 7075-T7351 aluminum. The pin-puller had to be accessible to install and align while the IDD was in the stowed configuration. This was accomplished by mounting the pin-puller to a removable subplate that could be aligned to the pin-puller while mounted on a bench. The subplate has pin features that self align during installation on the MER to the clevis base and tang on the IDD. The pyrotechnic initiator can be loaded at anytime.

Once the IDD is deployed it must be able to re-stow during rover maneuvers on the Martian surface. The IDD must withstand a 6 g load from rover operations. Two areas of the IDD were constrained. The Instrument Turret had to be held in the Z direction, and the X direction but only in the direction toward the Rover chassis. The Elbow is also constrained in the X direction, to eliminate any rotation of the Azimuth actuator, and in the Z direction to keep the Elevation actuator from slowly back driving during long rover maneuvers.

Initially the Turret was only constrained in the Z direction. As the design of the Rover's launch interfaces matured, it became a requirement to keep the Instrument Turret from "flexing" toward the Rover chassis and contacting the new Rover launch restraints with one of the instruments on the Turret. The Turret has a "T" bar feature that interfaces with a channel to constrain the Z direction. There is an X direction stop that releases passively when the Turret is deployed from the launch position. See Figure 4.

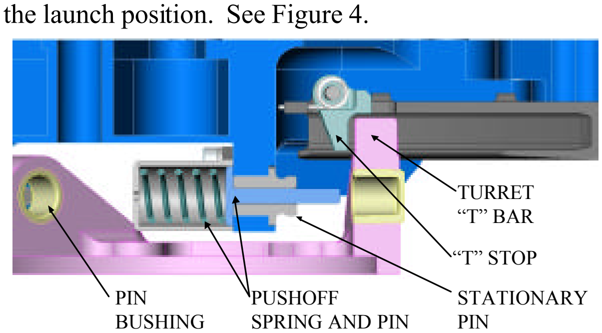


FIGURE 4

This stop in the channel restrains the Turret from swinging too far toward the chassis during the 6 g maneuvers.

The elbow restraint is also passive, and uses the Elevation and Azimuth actuators to latch into place. The clevis tang from the launch lock has a hook on its side that is used to engage a pin.

During the restow procedure, the IDD can use features built into the re-stow locks to help guide it into position. This is especially helpful if the IDD has lost actuator encoder data due to a power loss or other factors, and is nominally not needed. The IDD is able to use current sensing to acknowledge contact. As the IDD rotates the Turret near its restow ramp, it can use the ceiling of the ramp as a Z stop.

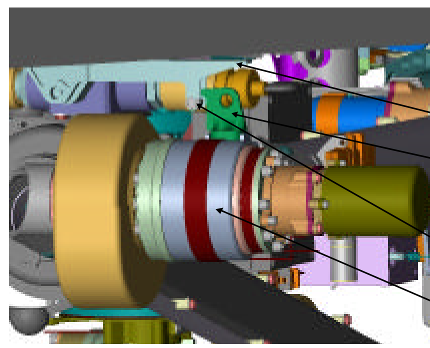


FIGURE 5

There is sufficient width in the ramp to provide some mis-alignment of the turret actuator so that the "T" feature is able to interface with the ramp. There are two features available at the elbow. The first is the Z stop, as shown in Figure 5, and allows the IDD to touch for elevation, and slide into the X stop, which is built into the hook. After the IDD senses both of these features, it lowers the Elevation actuator, and is locked in place for Rover mobility.

Pyrotechnic Shock

The proximity of the instruments at the Turret precipitated the use of the cable cutter device instead of a pin puller. Tests conducted at JPL showed that the recommended cable cutter produces significantly less pyro shock, from approximately 10,000g's to below 2,500 g's, especially when cutting a braided cable rather than a solid cable or rod. The instruments are separated from the cable cutter by at least 4 bolted joints and 1 loose fit pin joint at the turret lock interface, which helps damp the shock. There was also concern of the azimuth actuator that is mounted directly to the same structure as the cable cutter. JPL was experiencing some motor brush failures due to pyro shock. A test was conducted, firing a cable cutter mounted to the

WEB interface structure along with a spare actuator and a test motor to validate the design shown in Figure 6.

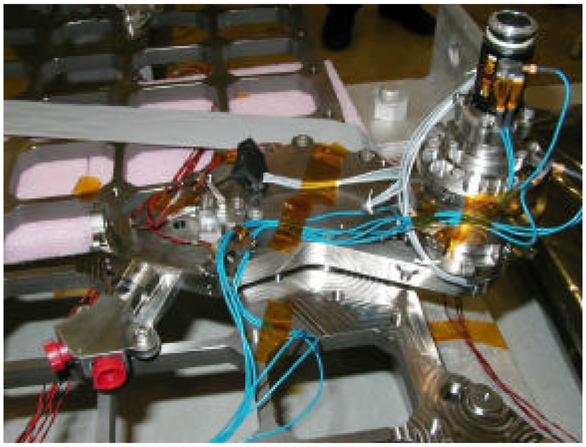


FIGURE 6

Lubrication

All sliding or rotating interfaces received Dicronite dry film lubrication. This durable lubricant can withstand the temperature swing that the design has to undergo, and does not effect mechanical tolerances because of its .001 mm thickness. Additionally, choices of interfacing materials were carefully chosen to lessen the chance of galling or cold welding. A wet lube such as Braycote 600 was not used because of the -120°C operational temperature of the latch and could potentially hinder the release due to the very low viscosity at that temperature.

Lessons Learned

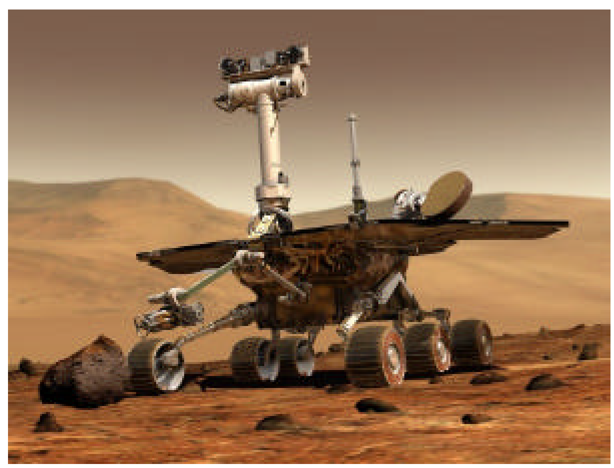
During Environmental testing at cold temperature, the deployment sequence begins with the firing of the pin-puller and cable cutter. As the IDD Azimuth actuator was rotating the Turret out of the turret launch lock pins, the Turret began binding on the single stationary pin. The Azimuth actuator was driven back to the launch position, and during this movement, the Turret released from the stationary pin. Following testing, the stationary pin was redesigned with a smaller diameter, and shortened axially to disengage earlier during deployment. During the previous ambient testing of the IDD deployment, this condition did not ever occur. It was thought that this was possibly due to cold temperature binding caused by the IDD's slightly non-kinematic geometry when stowed for launch. The restow pin location at the Elbow was also redesigned to allow more Azimuth rotation for deployment.

Initially it was thought that any lubrication at the high contact stress areas of the design, such as the ball ends of the pins, and the pins that slide through bushings, would not add to the integrity of the design, and may even hinder in some circumstances as it is known that the Dicronite can flake under extreme contact stress.

After the mechanism was assembled, the sliding friction of the pins through the bushings seemed unreasonably high. After reviewing the design further, it was thought an expectable risk to add the Dicronite Dry lube to all of the sliding and rotating interfaces. The risk seemed low because the design of all the interfaces had enough clearance built in to allow small particles to not buildup and jam the motion, that the addition of the Dicronite could only help, and the very small amount that will flake off will be minimal and within the interface tolerance.

Conclusion

The design of reliable aerospace mechanisms leads to taking conservative approaches. To add the constraints of limited mass, envelope and a very tight schedule adds a degree of risk management. The caging mechanisms designed for the IDD met all constraints of low height, weight, and proved to be a reliable mechanism. Numerous design iterations were used to develop a simple, reliable, and mass efficient design. The use of powerful tools available to the design engineers, such as Solidworks and the integrated FEM tool Cosmos-Works allowed the design to be finely tuned in a relatively short period of time, and with very high precision. Without the help from a great analyst team for accurate loads analysis upfront, and final verification in the end, a design challenge of the IDD could not have been done in such a short time frame.



IDD DEPLOYED ON MARTIAN SURFACE