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Micromechanisms for Optimism Seismometer

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Abstract

Within the framework of the Mars 94 mission, it was decided to design and build a new vertical axis seismometer in order to continuously record the seismic events occurring on the Mars planet. The mission requirements lead to very stringent constraints on power, volume, mass and shock resistance at the landing. The seismometer must be able of automatic leveling and automatic fitting to the local gravity. This paper deals with the mechanisms designed for this seismometer. Due to the short allotted time for its development and low cost, the baseline was to apply the rules of spatial tribology and, when it was possible, to customize existing components for space applications.

Introduction

Seismology is a powerful method to determine the inner structure of a planet, including its crust, mantle and core. As the internal structure of Mars is rather poorly known, it was decided in the framework of the Mars 94 mission to design and build a new vertical axis seismometer in order to record the first observation of marsquake and to get information about the internal structure of the planet. The work was supported by the CNES and the prime contractor was "Institut National des Sciences de l'Univers." SODERN was in charge of the seismometer sensor head.

The main functions of the seismic sensor head are:
- Continuous recording of the seismic events
- Automatic fitting to the local gravity of the landing spot by mass centering
- Automatic leveling in a half cone angle of 40 degrees

The main constraints were:
- Size: <1 dm^3
- Mass: ≤350 g
- Low power consumption
- Shock resistance: 200 g 10 ms
- Able to be sterilized

Seismometer description

The seismometer sensor head (Figure 1) is shared in two parts: the packaging and a seismic sensor. The packaging must protect the seismic sensor from shock during landing and a caging mechanism was designed to do this.

The seismic sensor is a leaf spring sensor. It uses an inertial mass of 50 g suspended like a pendulum by a leaf spring at one end and pivoting with respect to the mainframe at the other end.

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The displacement of the seismic mass is recorded by two transducers. The first transducer is a low-power differential capacitive transducer, and in order to keep the mass in mid position between the two electrodes, a feedback is produced by a coil moving through a magnetic field. The second transducer is a velocity transducer based on the coil magnet principle.

In order to fit the local gravity of the landing spot, or to adjust the system after thermoelastic distortion, a movable mass fitted on the boom can be recentered by a micromotor. The sensitivity of the seismometer is expected to be 10^{-8} ms^{-2} in the period range from 0.2 s to 30 s. The seismic sensor is enclosed under vacuum to obtain the best sensitivity. As the small station could land on soil with a tilt of 40 degrees, a leveling mechanism is needed. When vertical is reached by the seismic sensor, it is clamped in position.

Mechanisms requirements, description and tests :

Motor

For development time and money savings, it was decided to use the same motor for several mechanisms. The main requirements for the motor were:

- Torque: up to 50 mN•m
- Mass: less than 10 g
- Size: less than 5 cm^3
- Able to work in vacuum environment
- Able to be sterilized
- Low cost
- Temperature range -30 °C to +50 °C in operating mode
  -50 °C to +80 °C in non operating mode

The PORTESCAP micro-motor was chosen because of its very low mass (5 g with a 1/1700 gear box) and its very small size. The most difficult problem was for this motor to be able to work in high vacuum, within a large range of temperature, and with very low outgassing. The main difficulties lie with the lubrication of the collector, of the bearing, and of the gear box:

- For the collector, it was decided to avoid any fluid lubricant and to use gold as a solid lubricant.
- For the bearing, the first criterion was to use an oil with a very low outgassing. Two families of oil were selected: a perfluoropolyether (Fomblin Z25 and Krytox) and a hydrocarbon (Pennzane SHF X2000) [1]. Figure 2 gives an idea of the elastohydrodynamic film thickness versus temperature. It appears that Krytox 143AD does not work at low temperature and that Fomblin Z25 has the curve with the lowest slope. The drawback of the PFPE oil (Fomblin Z25) is that it reacts with clean freshly worn steel surfaces. In our case, the operating time is very short, of the order of about ten minutes for the total lifetime, so it appears that Fomblin Z25 could be used and was the best candidate.
- For the gear box, the same basic oil was used, but to be sure that the lubricant will stay in contact, we used the Braycote 601 grease, which is a mixture of Fomblin Z25 oil and polytetrafluoroethylene (PTFE) particules.

A remaining problem was the outgassing of the motor, which was too high even with the new lubricants. To reduce the outgassing, it was decided to bake all the parts at 80 °C under primary vacuum before assembling and to cable with wires insulated with PTFE instead of PVC. Figure 3 gives the torque of the motor at different temperatures.

Caging mechanisms

To withstand shock and vibration during transportation, launching and landing, the seismic sensor needs a caging mechanism. This mechanism is a one shot mechanism.

After leveling on Mars, the seismic sensor must be caged and eventually uncaged for re-leveling if the station moves (e.g., by wind). For mass and space savings, it was decided to use the same motor for the two caging mechanisms. As the motor has a low torque (50 mN•m), great care was taken to reduce parasitic torque due to friction. An elastic linking was done between the motor shaft and the crank arm to avoid flexure on the shaft. A rotative potentiometer was used, and this potentiometer is mounted on a ball bearing to reduce friction torque. Friction compatible couples of materials were selected and solid lubrication based on molybdenum disulphide was used.

Leveling mechanism

Its principle is based on gravity forces. The trade off leads to a double-axis gimbal equipped with unlubricated ball bearings. The ball bearings are preloaded through Belleville spring washers. To reduce the friction on the ball, the bearings have a loose crimped ribbon retainer. The ball bearings were designed in order to avoid false brinelling between the ball and the track under the 200 g shock. Great care was taken to reduce any parasitic torque due to the electrical connections, which are made of very thin flexible printed circuits, the thickness of the tracks is around 7 μm. Figure 4 gives the result of the leveling before and after mechanical tests done on Earth and extrapolated to Mars gravity.

Seismometer sensor

It is designed with a pivot, a seismic mass and a leaf spring. To obtain a high sensitivity, it is necessary to reduce the noise of the seismometer. Even if the seismometer has no mechanical imperfection, different sources of intrinsic noise must be considered.

One of these noise sources is the Brownian motion of the mass. This noise with an inertial mass M, an angular frequency w_0 and a mechanical quality factor Q corresponds to an acceleration power density [2] of:

$$PSD = \frac{4\,k\,T\,w_0}{MQ}$$

T: absolute temperature
k: Boltzmann's constant

To reach the required sensitivity, a quality factor of 100 is required. This was obtained by taking great care with the clamping at both ends of the leaf spring and to select a pivot with a very low torque and a low structural damping.

The pivot is of the crossed spring type in order to determine the rotation axis with precision. The low torque is obtained by using very thin leaves (25 μm). The low damping is achieved by clamping the leaves with brazing instead of another mechanical fastening, by screws for example. To avoid mechanical damping due to the electrical connections between the seismic mass and the fixed mainframe, it was decided to use the leaves of the pivot as electrical connections. This imposed brazing the leaves on a ceramic. To withstand the shock at 200 g, the trade-off leads to a pivot flexible enough to be able to down on stops under the constraints.

Recentering mechanism

This mechanism compensates the difference between the theoretical gravity of Mars and the gravity at the landing spot, by moving the location of the center of gravity of the seismic mass. This mechanism used the same motor as the caging mechanism. The motor assembly moves along an Archimedes' screw. The lubrication is a solid lubrication based on compatible materials (polyimide reinforced with graphite on copper alloy). During the outgassing of the seismometer in vacuum at 80 °C, the polyimide part bent, and it was necessary to loosen up a bit this part with the Archimedes' screw.

Velocity sensor

It works on the coil magnet principle. It was designed with a generator constant of 140 $ms^{-1}v^{-1}$, which gives a resolution of 1 nms^{-1} at the resonance frequency. To achieve this generator constant in a small volume, it is necessary to have very efficient magnets. The trade off leads to using samarium cobalt magnets. The coil is made of a 20-μm-diameter wire. The coil is wound without a shell to save space. Particular care was taken to shield efficiently the velocity sensor for two reasons: the seismometer is located in the vicinity of a very sensitive magnetometer, and the temperature-compensated spring material is ferromagnetic.

Capacitive displacement transducer

It has a very low power consumption. The resolution is about 1 nm. For signal cleanliness, the electronics are hybrided on the transducer.

Electromagnetic actuator

It is built on the same principle as the velocity transducer. This actuator holds a double coil. The first one is used as a feedback actuator for the capacitive displacement transducer and the second one allows testing the seismometer on Earth by balancing the difference of gravity between Mars and Earth with an offset DC current.

Seismometer development and performances

Within two years, this seismometer head was developed and four models manufactured: an engineering model with a leaf spring designed for Earth gravity, two flight models with leaf springs for Mars gravity, and a spare model. The engineering model has operated since January, 1994, and two days after its starting it recorded in Paris the Los Angeles (Northridge) Earthquake. Despite its small size, OPTIMISM's performance is similar with other good seismometers, and Figure 5 compares its performances with an STS seismometer [3].

Conclusion

A new vertical axis seismometer was designed to record the marsquake in order to get information about the internal structure. This seismometer will continuously record the seismic events, it will be capable of automatic leveling in a half cone tilt of 40 degrees, and will adjust automatically to the local gravity of the landing spot by mass centering.

This seismometer has a very low volume, low mass, and low power consumption.

Computer-aided design was a powerful tool during this development because of the small size and complexity of the parts.

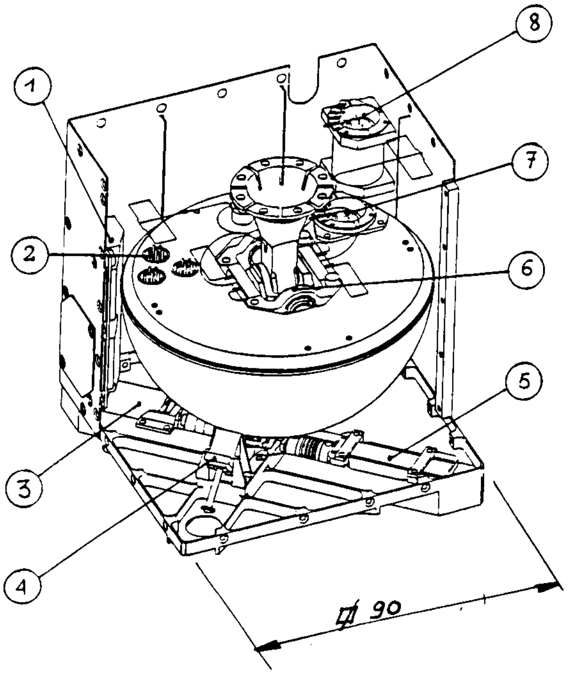
This seismometer needs a number of mechanisms. Because of the short development duration, the design of the mechanisms was based on applying the rules of spatial tribology and, when it was possible, in customizing existing components for space applications.

References

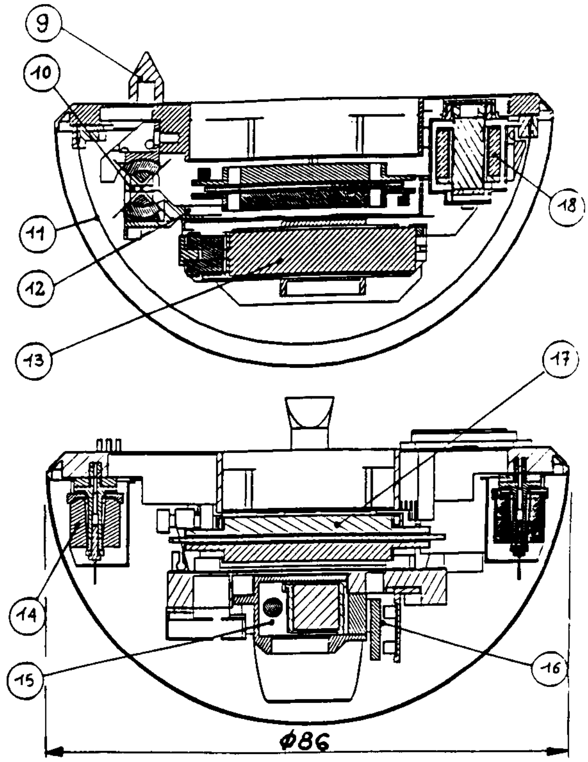
[1] Caractérisation triboligique de lubrifiants pour applications sous vide Laboratoire de mécanique des contacts. R et T CNES (1992)

[2] Usher, et al. The design of miniature wideband seismometers. Geophys. J 55, 605 613 (1978)

[3] E. Wielandt, G. Streckeisen. The leaf spring seismometer: design and performance. Bulletin of the Seismological Society of America, Vol.72 N.6, pp 2349-2367 (Dec 1982)



Seismometer head



Seismic sensor

1. Front end electronics
2. Sealed hermetic connector
3. Rotative potentiometer
4. Caging mechanism
5. Motor
6. Double gimbal
7. Mobile tiltmeter
8. Fixed tiltmeter
9. Pip
10. Pivot
11. Leaf spring
12. Boom
13. Motor
14. Getter
15. Recentering mechanism
16. Linear potentiometer
17. Capacitive displacement transducer with hybrided electronic
18. Velocity transducer and feed back actuator

Figure 1 - Optimism seismometer

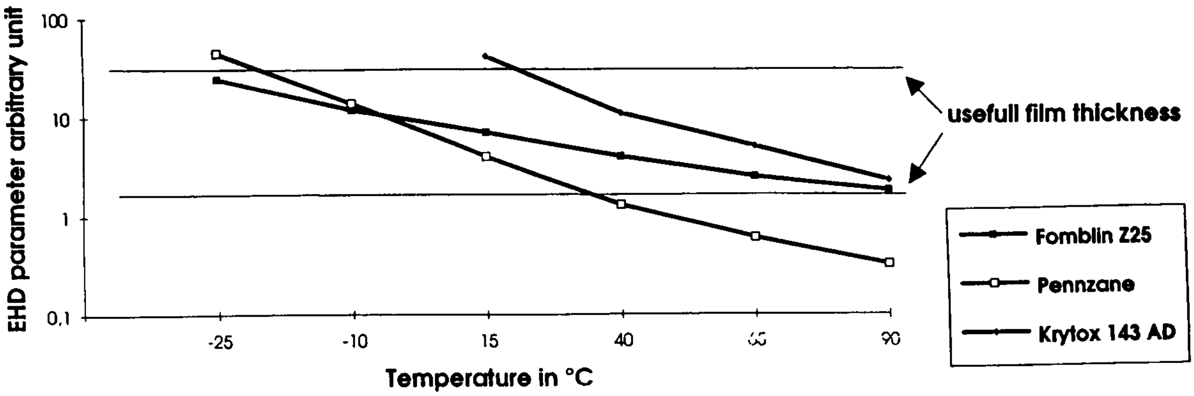


Figure 2 - Behavior of some "space" oils

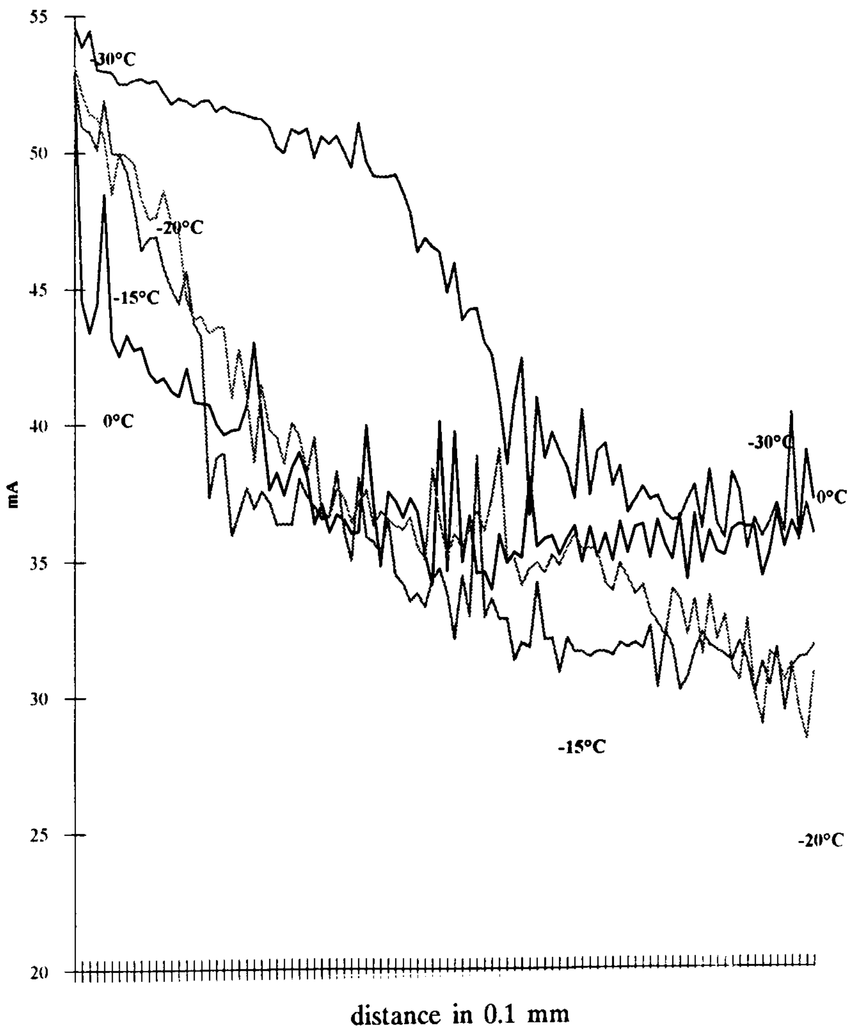


Figure 3 - Motor torque at different temperatures

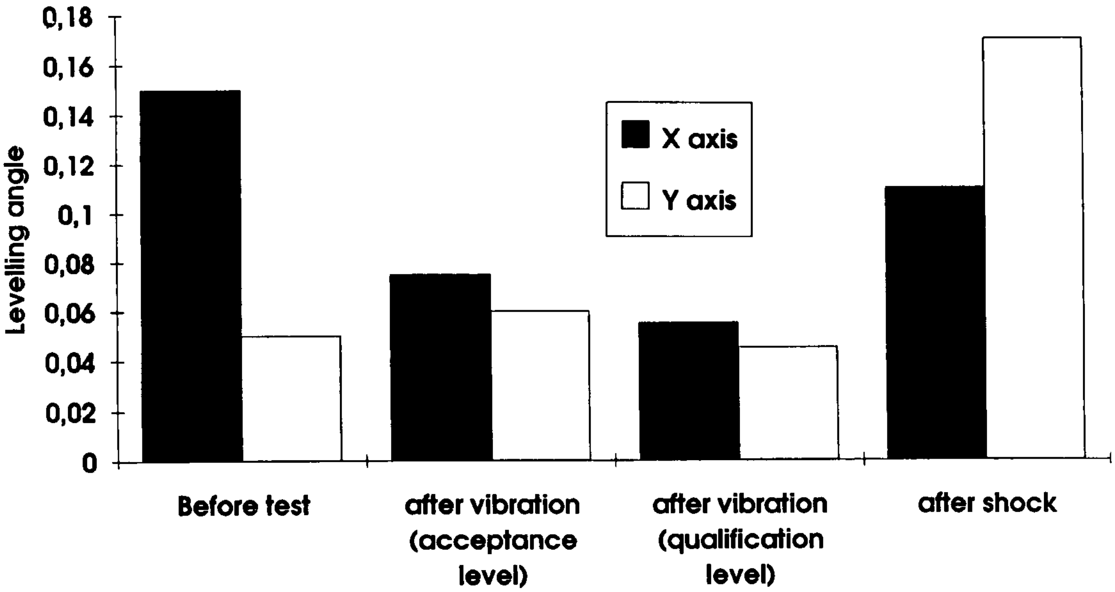


Figure 4 - Leveling accuracy

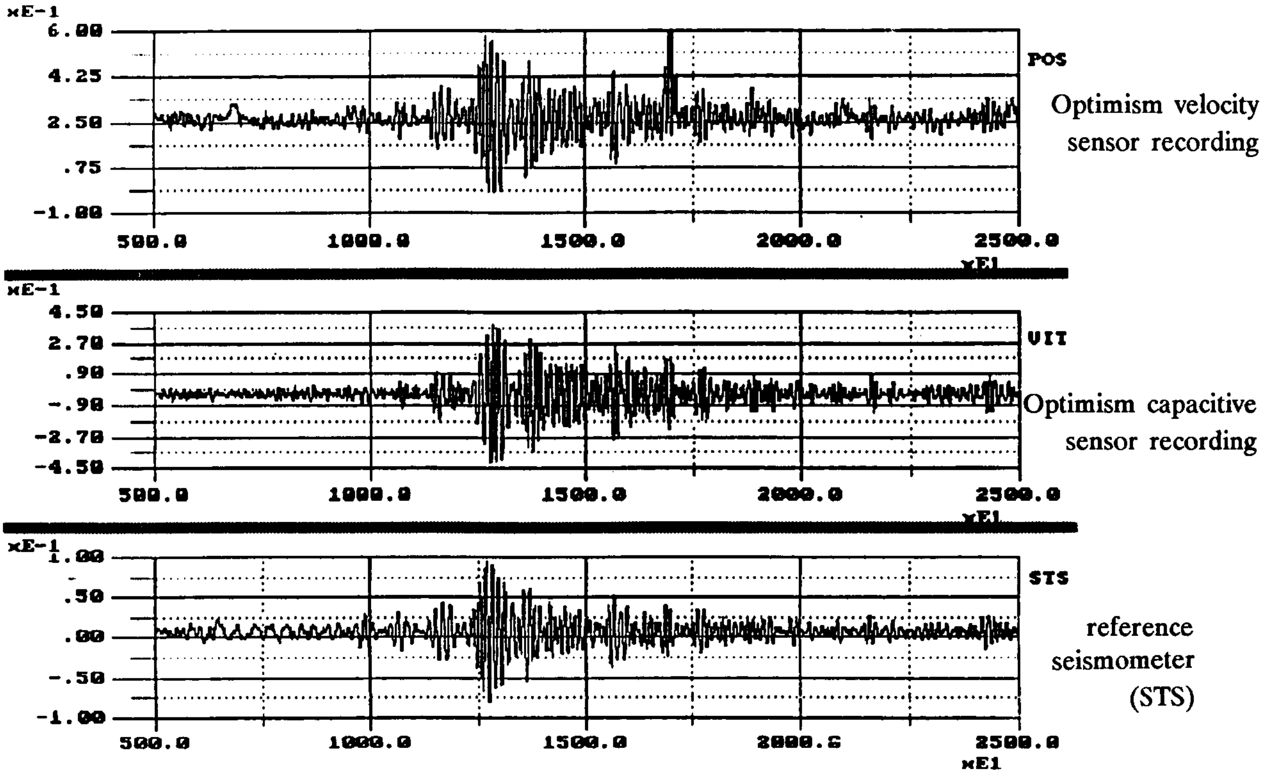


Figure 5 - 1994 Los Angeles (Northridge) earthquake recorded in Paris by Optimism