SHAPE MEMORY ALLOY ROTARY ACTUATOR FOR OPERATION IN MARS

Collado, M.[(1)], Cabás, R.[(1)], Fernández, D.[(1)], Moreno, L.[(2)], López, F.[(2)], Abderrahim, M.[(2)]

[(1)]Arquimea Ingenieria, S.L., Parque Científico Leganés Tecnológico, Avda. Gregorio Peces Barba, 1 – 28918 Leganes (SPAIN), Email: mcollado@arquimea.com
[(2)]Universidad Carlos III de Madrid, Avda. de la Universidad, 30 – 28911 Leganés (SPAIN), Email:moreno@ing.uc3m.es

ABSTRACT

A rotary actuator based on SMA (Shape Memory Alloy) technology was developed for its operation in Mars as part of the equipment on the MetNet Mars Precursor Mission. The aim of this device is to clean the dust particles deposited on the surface of an optical sensor that measures the rate of dust deposition in the surface of Mars. This rate will be obtained by measuring the amount of light before and after the operation of the wiper at defined time intervals.

One of the most important restrictions in this design is the resistance to an impact of even 2,000 g. For this reason, weight reduction is one of the main requirements. After studying several technological options to develop this actuator, an SMA-based solution was designed and constructed because of its advantages in relation to other existing technologies. The actuator consists on a wiping arm containing both the brush and the moving element which performs its angular strain.

Technology performance, test results and preliminary qualification results are presented in this paper in order to prove the fitness of the designed mechanism as a simple and effective solution for this application and for others that involve the operation in dirty environments with a wide range of temperatures. An Engineering Qualification Model will be presented in this work.

The use of Shape Memory Alloys on the designed dust wiper presents several advantages because of its light weight, high force to weight ratio and low volume. For these reasons, this technology is suitable for several space applications where mass reduction is demanding but movement accuracy is not.

1. INTRODUCTION

The device here presented was developed as part of the equipment on the MEIGA (Mars Environmental Instrumentation for Ground and Atmosphere) project, which is a part of the MetNet (Meteorological Network) Mars Precursor Mission. The aim of this mission is to demonstrate feasibility of a new lander concept that optimizes the ratio of the payload mass to the overall mass, as well as the availability of new high quality and long duration meteorological instruments.

The built actuator is an initial prototype which is intended to be a probe of concept of the final device. The main objectives of the design on this preliminary phase are:

- Make an initial approach to the final model, making possible to have an idea of the size and mass of the final device.
- Make a first design in order to select among several solutions for the main difficulties on the requirements, such as shock resistance, temperature cycles, ...
- Test the performance of the selected design.

The designed actuator was developed to clean surfaces from deposited micron-sized dust particles (aerosols) and it is an evolution of the previous work for the Mars Science Laboratory rover [1]. The device must clean the surface of an optical sensor looking at the Martian sky. This way, the sensor can measure the light intensity before and after the dust cleaning, inferring the amount of deposited dust on its 4 cm^2 surface. The actuator performs an angular movement of 25º, covering the whole sensor area with the brush attached at its end.

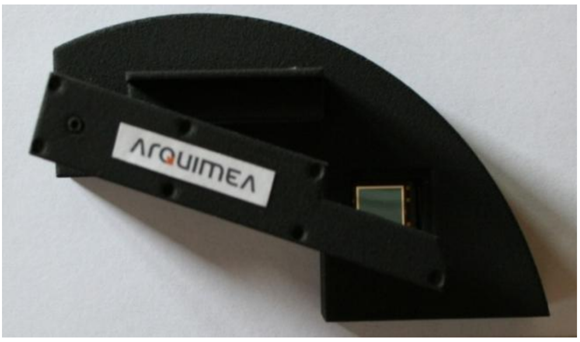

Figure 1. Top view of the SMA Rotary Actuator.

Due to the mission requirements, the actuator was designed to support a shock of 2,000g, which could take place during the landing on the Mars surface. Another important requirement as a result of the mission characteristics is the need to reduce the size and weight of the devices. In addition, there is a restriction in the

Proc. '13th European Space Mechanisms and Tribology Symposium – ESMATS 2009', Vienna, Austria
23–25 September 2009 (ESA SP-670, July 2009)

power consumption of the actuator that demands an optimization of the design.

This device may have further cleaning applications (solar panels, sensors, cameras, windshields etc), and it may be particularly useful whenever a robust and light cleaning mechanism is required to be operated remotely or in human hostile conditions. The actuator technology is extremely light and robust, making it interesting for future Mars operated mechanisms such us valves, openings, or struts demanding minimum mass, great strength to mass ratio and greatest robustness.

2. MARTIAN DUST

The Martian atmosphere contains a significant load of suspended dust. Dust settles out of the atmosphere onto exposed surfaces; the effect of the dust coverage can be directly seen in the output of the rovers' solar arrays [2-4].

It was found that Martian dust settling on MER rovers solar array has different properties from that of atmospheric dust measured from solar scattering properties. Evidence for a three-component particle distribution was observed [5]:

- *Airborne dust:* Primarily particles of ~1-2 μm radius, which stay suspended in the atmosphere for long periods. Airborne dust has magnetic properties, since it is primarily composed by composite silicate particles containing as a minor constituent the mineral magnetite [6].

- *Settled dust:* Particles > 10 μm radius, which are raised into the atmosphere by wind or dust-devil events, but settle out of atmosphere. Deposits on the surface are significantly larger than the particles measured in the atmosphere. This could be either distinct larger particles, or conglomerate particles formed by agglomeration of micron-scale particles.

- *Saltating particles:* Particles > 80 μm, which move primarily by saltation. Note saltating particles are seen to reach MER rovers deck, a meter above the surface.

During previous studies on this topic [1], a passive approach based on magnets was analyzed by testing two type of dust particles deposited on top of a magnet. A highly magnetized dust and an unmagnetized dust were tested. In both cases the dust was electrically charged, simulating Martian airborne dust conditions. The results showed that this passive approach exhibits saturation problems under certain levels of dust deposition.

In this case, an active dust removal technology based on a brush made of microfibers was selected due to the following reasons:

1. Using a brush guarantees a maximum amount of dirt wiped from the surface independently of the environmental conditions.
2. Dust wiping effectiveness does not depend on the type of dust particles (magnetized or unmagnetized), particles size, or deposition rate.
3. Dust wiping also allows the removal of frost [1].

3. TECHNOLOGY DESCRIPTION

In order to fulfill the strong requirement of minimizing mass of the device, an SMA (Shape Memory Alloy) actuator was developed. These materials perform a change of phase in their structure as a consequence of a thermal process, producing a change in their shape that can be used to execute a mechanical work [7-8].

The main advantage of this technology is its great strength in relation to its ultra-low weight, optimizing the mechanical work performed by the device with a minimum mass. Furthermore, this technology has the advantage of being immune to dust and to radiation and that it does not require lubrication to work.

Due to the weather conditions in Mars, the actuator should be able to work in a range of temperatures between -90ºC and 25ºC. Additionally, the device must support temperatures of 70ºC during the mission. Therefore, the design was optimized to satisfy these thermal requirements in addition to the power limitations. The estimated actuation profile for the actuator at different conditions in Mars is shown in Fig. 2. The time to reach the complete strain depends on the ambient temperature, being of 5.3 seconds at -90ºC and 2.2 seconds at 25ºC.

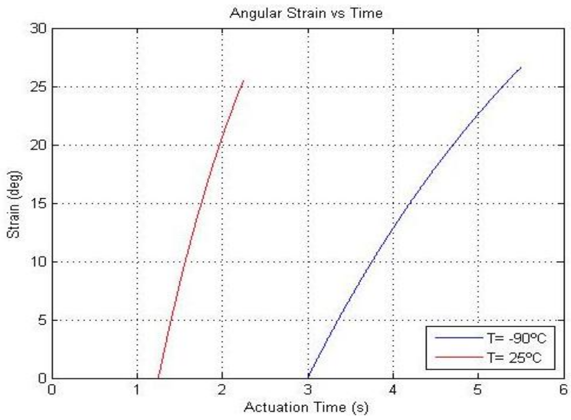

Figure 2. Strain vs. Time at -90ºC and 25ºC.

The actuator only requires two positions, 0º as a rest position and 25º as end of carrier once it has finished the wiping operation (Fig. 3). This makes the control algorithm very simple. A position sensor has been included in order to detect the final position and to acquire information about the strain during the actuation.

Ultra-light structural materials are included in the design resulting in an extremely light but robust actuator. All the elements have been specifically designed to support a high-amplitude impact. For this reason, special attention was paid to the anchorage of both the device structure and the internal elements of the actuator.

For the purpose of achieving the best performance at the wiping procedure, a brush was designed and constructed with Teflon, Titanium, and Kapton. Wiper included multiple fibers arranged in order to wipe submicron particles.

Due to the accumulation of dust in the brush after several wiping operations, brush cleaners were included in the design. Several geometries were tested and optimized to the brush fibers geometry in order to ensure a correct cleaning.

The rotation shaft was optimized for this design, reducing the friction on its movement. It was constructed using shelf-lubricating materials in order to avoid the use of lubricants in the device, reducing the force needed to move the wiper and thus improving the actuator performance.

The optical sensor used to measure the dust deposition in Mars will compare the amount of received light before and after the wiping of its surface. In order to avoid errors in this measurement, it is important to achieve a good wiping performance.

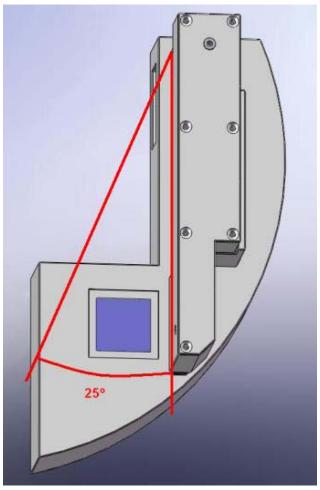

Figure 3. Wiper Movement.

4. TESTS

Preliminary tests over the SMA materials were carried out at the Arquimea Actuator Test Bench (ATB) in order to characterize them and optimize the actuator design, looking for the accomplishment of all the device requirements.

Figure 4. Arquimea Actuator Test Bench

Arquimea Actuator Test Bench, as show in Fig. 4, is a new tool specifically designed to test smart materials and actuators. This tool is able to execute a complete thermo-electro-mechanical characterization of materials. It consists of a collection of high-precision sensors responsible for collecting information about the main parameters involved in the working of these materials, such as strain, force, temperatures, electrical resistance,... These sensors, combined with a high-precision mechanics offer high resolution and accuracy in the measurement of the strain (up to 0.2μm) and the force (0.4mN).

The data collected by the sensors are then stored and processed by an acquisition hardware, in which specific software is running in order to provide a graphical interface to the user and to perform the configuration, storage and processing of the information.

The bench can also control the actuation of the device using an electronic driver designed for this purpose. Additionally, the bench has a furnace that allows heating the sample to a specific temperature, in order to change the ambient conditions.

Other important features of this equipment are its capability to research on different actuator configurations, to test diverse mechanisms solutions and new control strategies for the actuators.

Once the design process was concluded and a prototype actuator constructed, several electro-mechanical tests were made at the Actuator Bench in order to obtain its final performance and features.

Finally, performance tests of the wiper were done at the Martian Dust Simulation Chamber in order to quantify the dust removal achieved by this device.

5. RESULTS

The main features of the device constructed in this prototype phase can be shown in the following summary:

- Device weight: 50gr.
- Actuator weight: 15gr.
- Strain: 25º.
- Wiping Max. Force: 2.3N.
- Power Consumption: 2.5W.
- Operating temperatures: -90ºC ÷ +25ºC.
- Survival temperatures: -120ºC ÷ +120ºC
- Max. Actuation Time (Earth): 9.3s.
- Max. Actuation Expected Time (Mars): 5.5s.

Figure 5: Front view of the SMA Rotary Actuator.

All the tests done in the design phase and with the final prototype were carried out at normal atmospheric conditions, which differ essentially from those of Mars. The most important changes affect to the times needed to complete the movement of the actuator, due to the differences in the thermal conditions. The results achieved in this sense are really similar to those expected in the calculations for Earth conditions. For this purpose, it is necessary to perform special tests in a chamber able to reproduce the Martian atmosphere.

To measure the Cleaning Efficiency, several test were done at the Martian Dust Simulation Chamber, where the amount of light before and after the wiping was compared. After several cycles using different amount of deposited dust, the values achieved were between 94 and 97%, which shows the high efficiency of this device.

6. CONCLUSIONS

In this paper, a new approach for an angular actuator based on SMA technology was presented. The first prototype has accomplished most of the requirements of the device, but still more work is needed to optimize it.

For future works on this design, which are now in progress, a chamber to test the device on real conditions would be interesting, specially to obtain better results for the actuation. More tests will be done to check the shock resistance of the design in future phases. Some design changes will improve the mass of the device and actuator once the final materials will be used.

The selected technology is probed to be a good solution for the problem here presented and it also becomes an interesting technology to develop actuators to be used in several conditions and applications.

7. REFERENCES

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