NEW DEPLOYMENT MECHANISMS BASED ON SMA TECHNOLOGY FOR SPACE APPLICATIONS

Nestor Nava, Marcelo Collado, Ramiro Cabás

Arquimea Ingeniería, SL. C/ Margarita Salas 16, 28919 – Leganés, Spain. Email: nnava/mcollado/rcabas@arquimea.com

ABSTRACT

New Pin Puller as well as Hold Down and Release Mechanism (HDRM) for space applications have been developed as an alternative to current devices. The temperature restriction is one of their most critical limitations. The new deployment mechanisms are able to work in a wider range of temperatures, such as from -90ºC to +125ºC and under vacuum conditions.
The proposed mechanisms are triggered by an SMA actuator, substituting the pyrotechnic actuators. The use of Shape Memory Alloys (SMA) substituting pyrotechnic elements provides a number of advantages, such as the minimization of shock; reduction of safety measurements; the possibility to perform activation tests repeatedly; and weight reduction.
Two different Pin Pullers will be presented in this work, with different output forces: 100N and 500N. Built models of both mechanisms have been tested. A preliminary design of a new HDRM, called REACT (Resettable ACTuator), and results of analyses will be shown in this paper including a proposal for qualification campaign.

1. INTRODUCTION

Pin Puller is a linear actuator that contains a pin deployed at the unactuated position and withdrawn at the actuated position. A HDRM is a mechanism in charge of holding an element to the spacecraft structure during launch and releasing it under the user demand. These devices have to support high preloads during launch and to be able to release this loads when required.
We present in this paper new Pin Puller and HDRM, based on a new SMA, [1] to [4], technology called SMARQ [5], for holding down and release deployment systems. The use of Shape Memory Alloys in the triggering actuators allows the developed devices to have minimum mass, one of the most critical requirements in space applications [6] and [7]. Two Pin Pullers with different pull forces are reported, such as minimum 100 and 500 N.
Engineering Models of both mechanisms have been built as well as tested and Qualification Models are currently under development and test. Similar, a preliminary design of a HDRM and analyses is reported too with a proposal for qualification tests. The main characteristics of new deployment devices as well as the results of test campaigns will be illustrated.

2. A NEW PIN PULLER

A Pin Puller is an application for SMA based actuators since the mechanism is activated by a SMA actuator [8]. The proposed mechanism will be divided in several sub-systems:

- Structure.
- Pin.
- Retracting elements.
- Moving elements.
- SMA trigger actuator. The SMA actuator can be considered as a unit which is part of the complete mechanism.

Two different versions of the pin puller, Fig. 1, were designed during this activity, such as, one with 100 N and other with 500 N of pull force. The design of both versions is based on spheres which support the pin at the initial position and a compression spring is loaded to perform the driving force once the release takes place. When SMA actuates, a crown rotates allowing the spheres displacement, and thus the pin release and its movement to the actuated position (pin retracted). The reset in both designs is planned to be done by pulling a M4 threaded tool located in the pin tip.
The reset is planned to be automatically by the reverse operation of the trigger mechanism. A flat surface in the pin shaft and frame does not allow the undesired rotation of pin, preventing the mechanism to be accidentally released by an external force
The mechanical design of the Pin Pullers has been conceived in order to optimize the device's weight, reduce the parts complexity and achieve a suitable stiffness. The assembly ensures the alignment of components and compactness of the design. Mechanical parts have been designed to be made of an aluminium alloy. The estimated weights of both models, including commercial components and mechanical parts, are 90grs for the 100 N device and 360.0 grs for the 500 N device.
A monitoring system is included in order to check the successful operation of Pin Puller. The operation principle is based on two PCBs (Printed Circuit Board), one at the pin bottom and other at the housing bottom, which are not in contact in the unactuating position.

'15th European Space Mechanisms & Tribology Symposium – ESMATS 2013'
Noordwijk, The Netherlands, 25–27 September 2013

When the pin is retracted, the pin PCB reaches the brushes of the housing PCB, closing the sensor circuit. The PCBs provide the insulated installation of the sensor to the mechanical structure as well as brushes in the housing PCB.
The mechanism computations has been carried out compliant the ECSS. In fact, the output forces of the stroke springs and SMA actuators have been obtained considering the motorization factor of [9]. Moreover, the mechanism analyses consider the ECSS standard too.

3. QUALIFICATION TEST CAMPAIGN FOR THE NEW PIN PULLER

A qualification test campaign for the Pin Puller with 500 N of pull force has been developed in order to check the success of the proposed mechanism for space applications. The performed tests have been: thermal-vacuum actuation at -90 ºC to 70 ºC, thermal-vacuum cycling in inert atmosphere, sine vibration and random vibration.

Figure 1. New proposed Pin Pullers: 100 N device (left); 500 N device (right)

Fig. 2 shows the setup used for the thermal-vacuum (upper) and environmental (lower) tests. Fig. 3 to 5 show significant plots for the inputs of the above-mentioned tests. In particular, Fig. 3 (upper) shows the time evolution of the temperature during the thermal-vacuum test at 70 ºC. Similar curve has been obtained during the thermal-vacuum test at -90 ºC, as shown in Fig. 3 (middle). The maximum pressure reached during the tests has been 1.33×10^{-5} mbar, as shown in Fig. 3 (lower). Similar, Fig. 4 shows the time evolution of temperature during the thermal cycling in inert atmosphere.
Finally, Fig. 5 shows the input plots of the vibration tests. In particular, Fig. 5 (upper) shows the profile for sine vibration; Fig. 5 (middle) shows the profile for axial random vibration; and Fig. 5 (lower) shows the profile for radial random vibration.
The Pin Puller has presented successful results of actuation during the test campaign. Successful actuations have been obtained after and before the vibration tests and thermal-vacuum cycling. Similar, successful actuations have been obtained at -90 ºC and 70 ºC. These results validate the feasibility of the proposed mechanism based on SMA technology as suitable alternative to the traditional deployment devices.

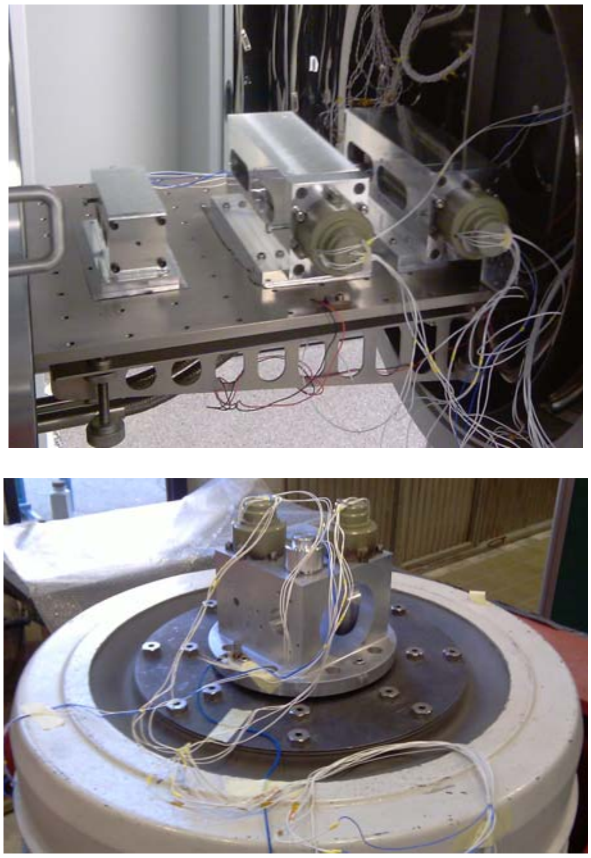

Figure 2. Test setups for the qualification campaign: thermal-vacuum (upper); vibration (lower).

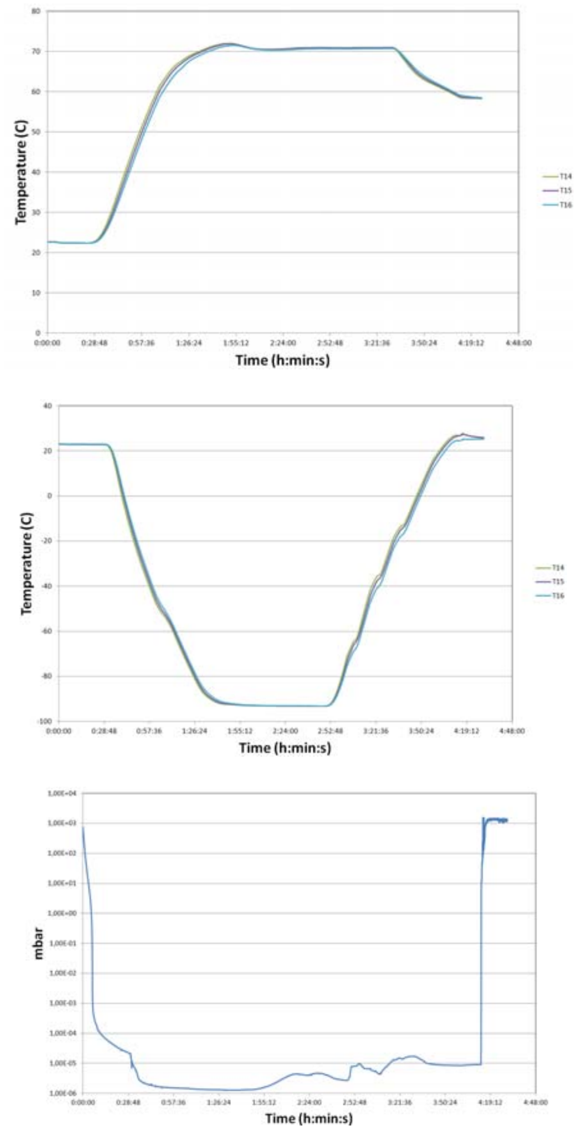

Figure 3. Time evolution of thermal-vacuum inputs: actuation at 70 ºC (upper); actuation at -90ºC (middle); vacuum levels (lower).

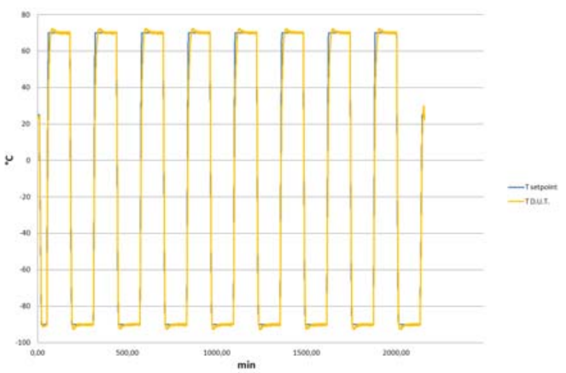

Figure 4. Time evolution of test inputs: thermal-vacuum actuation at 70 ºC (left); sine vibration (right).

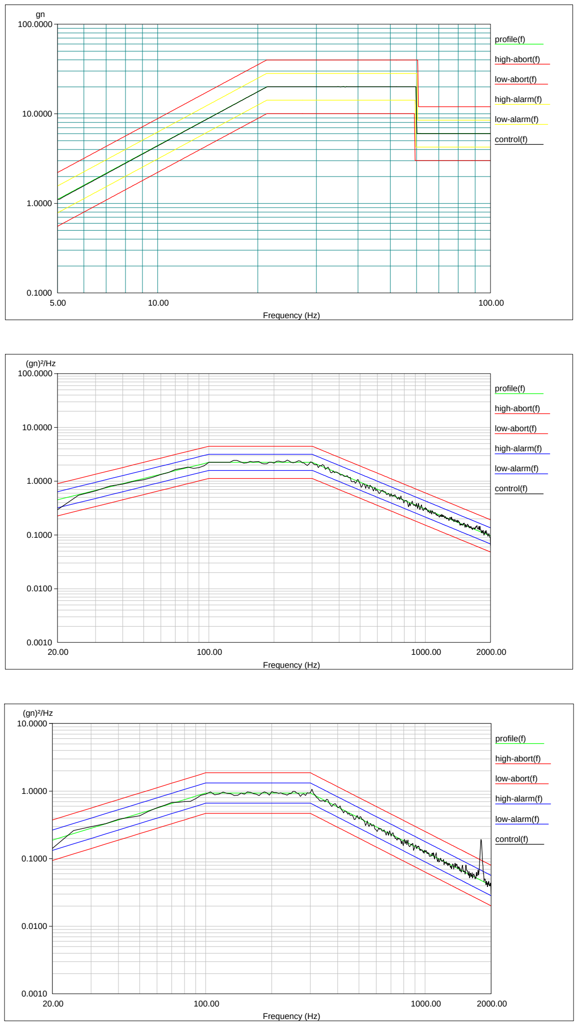

Figure 5. Time evolution of vibration inputs: sine (upper); axial random (middle); radial random (lower).

4. A NEW RESETTABLE HOLD DOWN AND RELEASE ACTUATOR (REACT)

A HDRM is another application for SMA based actuators. In this case, the mechanism and mechanical interfaces are different to Pin Puller as long as SMA material, electrical interface, control, sensor and heating can be the same.

A new HDRM based on SMA technology has been designed for development of loads and appendixes in space applications. Fig. 6 shows an overview of REACT models that can support a preload of 35KN, 15KN and 2.5 KN. This design involves a rod, which can play the role of nut or screw depending of the user requirement, supported by spheres that block the axial movement during a preload application. The rod shape allows misalignment and blocks the rotation around axial axis for a proper installation of the device. When SMA actuates, a crown rotates providing the spheres displacement, thus the system deployment.

Rod and supporting part of REACT are made of stainless steel with high strength. Another option is to build these parts with titanium alloy that provides weight reduction. Other mechanical parts are made of aluminium alloy and then hard anodized as well as coated with solid lubricant based on PTFE. These coatings increase surface hardness and reduce the friction coefficient of moving parts. The estimated weight of the REACT is 287.83 g (provided by CAD tool) without SMA actuator as well as electrical interfaces. The estimated weight has been computed considering above-mentioned parts in titanium.
The reset operation can be carried out automatically by means of the reset spring of SMA actuator and a reset compression spring. When the Rod is placed at the initial position, the reset springs try to set the mechanism to the initial position holding the rod.

Figure 6. The proposed new resettable hold down and release actuator (35 KN, 15KN and 2.5 KN).

Table 1. Family of actuators proposed by Arquimea.

PIN PULLER				
Description	**Pull Force (N)**	**Mass (g)**	**Ø (mm)**	**L (mm)**
Pin Puller 25N	25	45	50	33.3
Pin Puller 50N	50	79	58	38.2
Pin Puller 100N	100	100	60.4	47.4
Pin Puller 250N	250	194	81	56.6
Pin Puller 500N	500	312	87.5	67.4
REACT				
Description	**Preload (KN)**	**Mass (g)**	**Ø (mm)**	**L (mm)**
REACT 2.5KN	2.5	91	64	29
REACT 5KN	5	109	72	29
REACT 10KN	10	114	52	54.1
REACT 15KN	15	171	58	62.7
REACT 25KN	25	243	62	77.8
REACT 35KN	35	354	78	78.5

The monitoring system of REACT is composed of a sensor, so called release switch, which indicates through a signal when the operation is completed. The release switch is composed of two PCBs: one has two separated brushes and the other has a pad for current conduction. The functional principle of the sensor is to connect the brushes through the electrical pad closing the circuit. In fact, when the REACT is unactuated the circuit is open. During actuation, the mechanism provides the PCB contact with brushes closing the electrical circuit.
Since the high preload requirements for this type of actuators, Finite Element Analyses (FEA) have been developed in order to check the structure resistance. The rod has been recognized as the most required part. The obtained values are below the strength limits of the proposed materials for the rod, considering the factor of security from [9]. The results of the FEA have constrained the REACT design, in term of dimensions, materials and shape of the mechanical parts.
Now, Pin Puller and REACT actuators type are under development at Arquimea. These actuators are composed of the same mechanism of the above-reported devices, but they provide different output force capabilities. Table 1 lists the proposed devices that form a family of deployment mechanism.

5. QUALIFICATION TEST CAMPAIGN FOR REACT

Fig. 7 shows a proposal of a complete test campaign for qualification of REACT. The proposal includes pre and post tests; physical inspection; functional tests; environmental tests; thermal vacuum tests; and lifetime. Before and after test campaign, pre and post tests will be developed in order to figure out the degradation in sensitive elements of the mechanisms. In particular, the output force of SMA actuator will be measured in order to check degradations after tests. Output force of reset springs will be verified for the same aim. Similar, the operation of the secondary SMA actuator will be check.

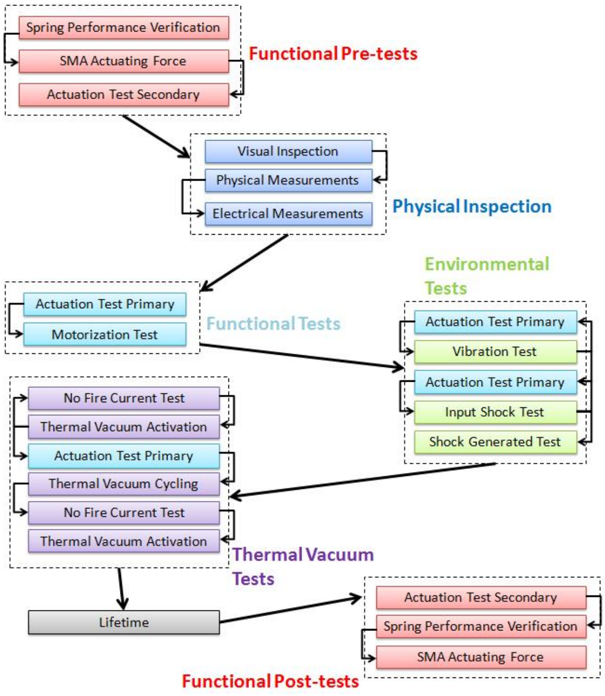

Figure 7. A proposal of qualification test campaign for REACT device.

A physical inspection of the REACT will be carried out at the beginning of the test campaign in order to check the good external appearance, robustness and compactness of the device. Moreover, workmanship will be checked that it shall be in accordance with the manufacturing and process standards, procedures and product specifications. The equipments to be used during these tests have a complete set of safety measures. The qualification will be carried out under the supervision of the Arquimea stuff.

Functional, environmental and thermal vacuum tests will be done in order to validate the REACT operation under space mission conditions. In particular, the performance of the SMA actuators will be checked during the functional test. Since the proposed actuator is low shock, the shock generated level will be measured. The thermal vacuum tests will be developed in a range of temperature from -90 to 125 ºC. Finally, reliability will be verified during the lifetime tests in ambient conditions. The number total cycles of lifetime will be 50, considering the ECSS (European Commission for Space Standardization) margins.

Three qualification models (QM) are intended to be built. Therefore, a way to demonstrate margins would be to perform the qualification on all units in parallel which would allow getting some statistics.

6. CONCLUSIONS

Arquimea proposed a new pin puller mechanism for space application. Two complete Pin Puller devices were design and built and the results of the qualification test campaign have demonstrated the capabilities to be used as space mechanisms.

We also proposed a new non-explosive and resettable hold down and release mechanism for space application. The design has been constrained by the FEA results since the high preload requirement during the device operation. Proper features with suitable dimensions and materials have been selected for the mechanical parts in order to obtain a compact and robust solution. A complete test campaign has been proposed for the space qualification of REACT.

Future applications of this technology are actuators for Hold-Down and Release, such as Frangiblot, NEHRA and so on.

7. ACKNOWLEDGEMENT

An acknowledgement is for ESA that supports the development of the projects 4000103964-11-NL-RA (Development and Qualification of a European Pin Puller) and 4000106611-12-NL-CBi (Resettable SMA Hold Down and Release Actuator for General Use in Satellite System). Moreover, special acknowledgements are for the ESA technical officers Sandro Patti and Massimo Palladino for their important help in these projects development.

8. REFERENCES

1. Duerig, T. W. et al. (1990). *Engineering Aspects of Shape Memory Alloys,* Butterworth-Heineman, London.
2. Otsuka, K. & Wayman, C.M. (1998). *Shape Memory Materials*, Cambridge University Press, UK.
3. Delaey, L. (1991). Diffusionless Transformations. Proceedings of Materials Science and Technology. **5**, 339-404.
4. Jenkins, P.P., Landis, A.G. & Oberle L.G. (1997). Materials Adherence experiment: Technology IECEC- 97339. Proceedings of 32nd Intersociety Energy Conversion Engineering Conference.
5. Collado, M *et al.* (2011). Characterization Results of a novel Shape Memory Alloy and Pin Puller mechanisms based on this technology. *ESMATS 2011*, Constance-Germany, 289-296.
6. Fernández, D., Cabás, R. & Moreno, L. (2007). Dust Wiper Mechanism for Operation in Mars. Proceedings of 12th European Space Mechanisms & Tribology Symposium (ESMATS).
7. Collado, M., Martínez, D., Álvarez, F., Cabás, R., Moreno, L. & López, F. (2010). Evolution of SMA Rotary Actuators for Space Applications in Mars Environment. Proceedings of Actuator 10 – International Conference and Exhibition on New Actuators and Drive Systems.

8. Nava Rodríguez N. E., Collado, M., Cabás, R., San Juan, J. M., Patti, S. & Lautier, J. M. (2012). A Pin Puller Development Based on a New SMA Technology. International Conference and Exhibition on New Actuators and Drive Systems, ACTUATOR 2012, Bremen – Germany, 482 - 485.
9. Mechanism (Functional dimensioning: motorization factors), ECSS-E-ST-33-01C.