INNOVATIVE PROCESSES AND COMPONENTS USING SHAPE MEMORY ALLOYS FOR SPACE APPLICATIONS

F.Fouché (1), F.Leproux (2), K.Elghalmi (3)

(1) NIMESIS TECHNOLOGY, 4, Rue des artisans – 57245 Mécleuves – France, Email : f.fouche@nimesis.com
(2) NIMESIS TECHNOLOGY, 4, Rue des artisans – 57245 Mécleuves – France, Email : f.leproux@nimesis.com
(3) NIMESIS TECHNOLOGY, 4, Rue des artisans – 57245 Mécleuves – France, Email : k.elghalmi@nimesis.com

ABSTRACT

Engineering disciplines concerned with the space sector are always looking for breakthrough technologies, that will meet their needs in terms of efficiency of design, development, assembly, integration, and verification.

NIMESIS TECHNOLOGY has been developing the technology of shape memory alloys for over 20 years, The exceptional properties of these smart materials (memory effect and superelasticity) prompted the founders to use the characteristics of these alloys for industrial and development applications, especially in the Space sector.

Shape Memory Alloys (SMA) are often proposed as a non-explosive solution to provide a simple, safe, and reliable means of anchoring spacecraft appendages during launch. SMAs can be triggered by heating to return to its initial shape. Such devices based on the more well-known SMA, NiTi, were developed and used, but were limited by their low actuation temperature (about 100°C). [1]

In fact, shape Memory Alloys are materials capable of regaining their initial shape, by remembering the thermomechanical treatments that they are subjected to.

CONTEXT

The development of the small satellite industry and the new variety of on-board instruments are increasingly leading to the miniaturization of space mechanisms. In addition to size reduction, cost reduction and time-to-market have become key objectives for recurring components used in space systems. With this variety of new applications, actuators are also more widely used as they provide key functionalities such as opening appendages like solar panels drastically reducing system complexity and cost. [2]

HIGH PERFORMANCE SHAPE MEMORY ALLOYS

Shape memory alloys (SMAs) are recognized as reliable and efficient materials for actuators' design. The major drawback of these shape memory actuators is the triggering temperature which is below 100°C with standard Ni-Ti alloys. Nimesis' CN-250X exhibits a transformation temperature which can be adjusted between -200°C and +250° and is available in round cross-section with a diameter of 0.5 mm to 35 mm. The state of the art and detailed characterization work carried out for several recent CNES R&T programs have demonstrated that Cu-Al-Ni single crystal wire is a very good candidate for space applications that require triggering temperatures between 100°C and 200°C.

A dedicated alloy has been manufactured during this program. The casting shows transformations temperature at 155°C ± 5°C. After casting, the alloy is transformed into semi-finished products and then NIMESIS performs its patented single crystallization process to obtain a high performances SMA component.

CN-250X (Copper-Aluminium-Nickel single crystal) alloy is an SMA that shows two desirable properties compared to NiTi for space applications. On one hand, the actuation temperature of this copper based SMA can be set between -200 and 250°C; typically, it can be adjusted around 155°C, meaning a margin of 30°C compared to the maximum temperature encountered in Orbit. On the other hand, CN-250X provides higher elongation during its martensitic transformation than NiTi, reducing the volume and weight of the actuator. The small hysteresis of the material also makes it popular for space application. [3]

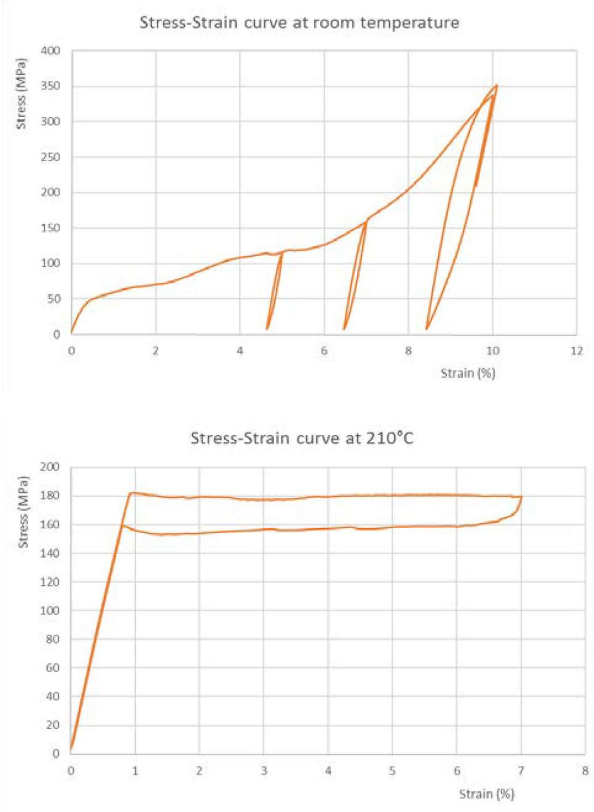

Figure 1: Tensile tests of Cu-Al-Ni single crystal samples at room temperature (martensitic state) and at 210°C (austenitic state)

NIMESIS TECHNOLOGY is also involved in the development of more complex SMAs, including high temperature and very low temperature variation of NiTi such as NiTiCo, NiTiHf, NiTiCu or NiTiNb. Those alloys will allow to take advantage of some properties of NiTi, such as its high resistivity (beneficial for heating through Joule effect) on a larger range of temperature, for application such as cryogenic actuators.

NIMESIS TECHNOLOGY masters the shaping of SMAs as bars, wires, plates, and springs.

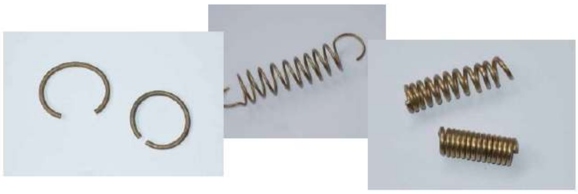

Figure 2: Examples of actuators made with Cu-Al-Ni single crystal wire

HIGH PERFORMANCE HOLD DOWN RELEASE ACTUATORS

Many space applications such as satellite solar panels deployment require a Hold Down and Release device. However, with the emergence of Newspace and the reduction of satellite's sizes, prime manufacturers need increasingly smaller mechanisms.

In 2021, Nimesis and CNES finalized the full specification and definition and are now focusing on the qualification of smart actuators for HDRM. Called TRIGGYS and dedicated to space applications, this high-tech product is adapted from largest to smallest satellites as well as other spacecrafts – as rovers for example.

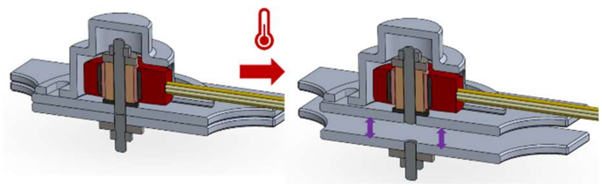

Figure 3: Principle of use of TRIGGYS

Through its simple configuration and use, TRIGGY is very reliable. Indeed, this Launch Lock Device (LLD) is mainly made of a compressed SMA component, a pre-notched stainless-steel bolt – or fastener, a heater and temperature sensors. The high-power density heater allows the shape recovery of the SMA when heated, with a 155°±5°C transition temperature. As a result, the fastener stretches until it fails at the notch, providing controlled fracture and so enabling the release of the mechanism. Triggys are able to sustain a preload from 1 350 N to 57 550 N. [4]

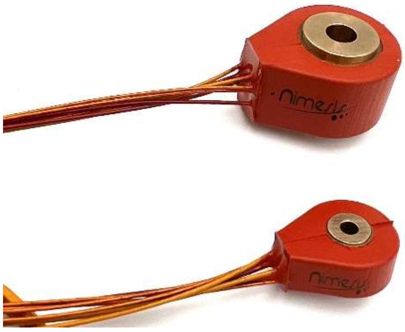

Figure 4: TRIGGYS TRHT02 and TRHT06

The development and qualification of TRIGGYS results from a work done within CNES R&T program. The qualification process aims to demonstrate and validate the design of the TRIGGY actuators and the use of CN-250X as an approved material for space through:

- Functional tests, in the air and under vacuum, at low and high temperature
- Thermal and functional cycling tests
- Vibration tests
- Generated Shock measurement

The qualification of TRIGGYS will be completed in Q3 2022. Other HDRAs (Hold Down Release Actuator) have already been developed and tested by NIMESIS TECHNOLOGY with the help of CNES, including the Pin-loader.

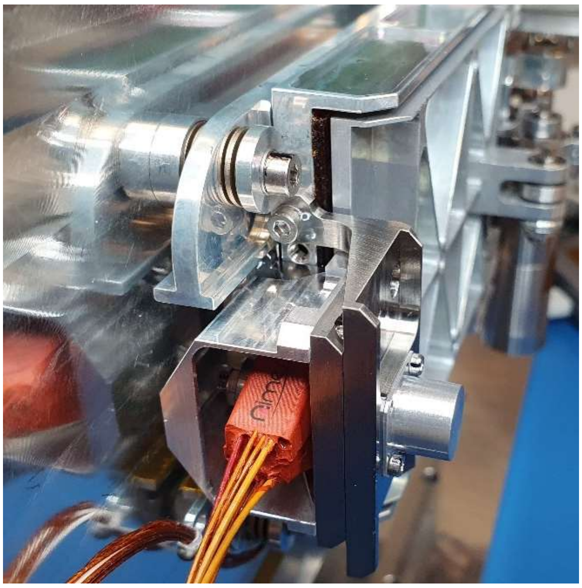

Figure 5: Engineering model of TRIGGY TRHT04 mounted on the dust cover HDRM of the MIRS instrument

Similar to the Pinpuller developed in the 1990s, the PinLoader. It differs from the Pinpuller in its ability to apply a significant force of 1000 N. It is based on a copper-based high temperature SMA. Moreover, this actuator remains very compact, with a diameter of 30 mm, a length of 37 mm and a weight of 130 g.

This actuator is an auto-resettable device, also based on high temperature CN-250X.

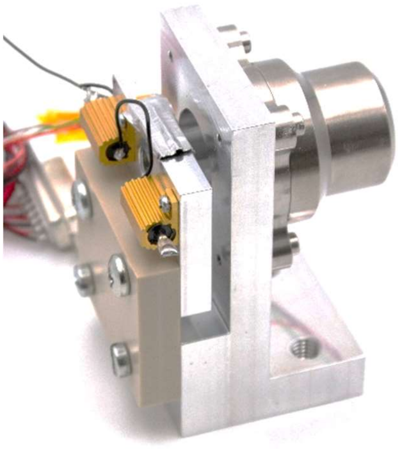

Figure 6: Pin Loader

A complete catalog of actuators is in development to answer all the needs of the market, including:

- Low shock actuators
- Rapid actuators
- Flat actuators

As SMAs react to the increase of heat, suitable to the temperature within the atmospheric re-entry. We offer to use such components to deorbit and demise a satellite or launcher in a passive way. A dedicated range of passive actuators called Murphy is proposed for the dismantlement of satellites structures. These last are designed to sustain 30 years on orbit, and upon thermal initiation during re-entry, triggering the fragmentation of spacecrafts. It will be implemented as a passive system that will be activated just as the temperature rises. So that the system will only be activated due to an atmospheric re-entry.

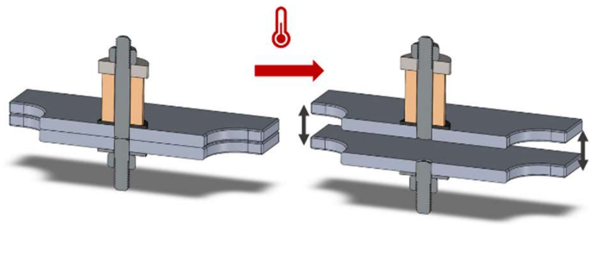

Figure 7: concept of a Murphy actuator for the dismantlement of a structure

The strategy is to be executed at the end of the satellite's life and, depending on the speed and angle of re-entry, the temperature of the satellite will be set according to the altitude, so that the activation can be adjusted to match this last. Its function will be to separate the structural elements. [5]

ADVANCED MECHANISMS BASED ON SHAPE MEMORY ALLOYS

NIMESIS TECHNOLOGY is involved since 2018 in the MMX (Mars Moon Exploration) project. This mission, involving CNES, DLR and JAXA, is dedicated to the exploration of the surface of Phobos, a moon of Mars with, among other, a small rover. [6]

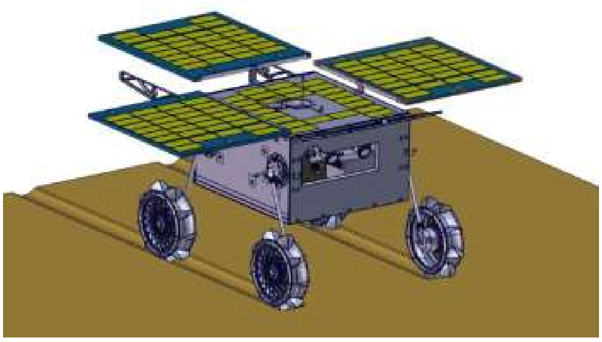

Figure 8: MMX rover with deployed solar generator - CNES/JAXA

NIMESIS TECHNOLOGY supplies the Solar generator deployment system. This system consists of a torsion rod, made of NiTi and actuated by an integrated heater. This system has the advantage of a smooth deployment, very well adapted for the low gravity environment of Phobos and of a dust resistant architecture.

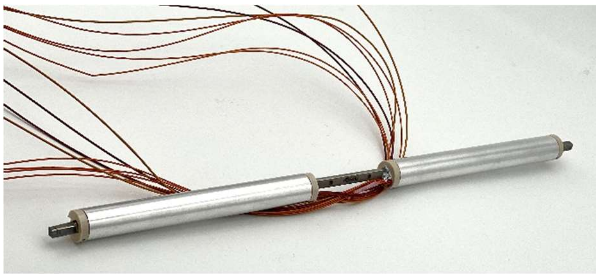

Figure 9: SMA based torsion rod for the MMX rover

TRIGGYS actuators will also be used for the opening of Hatches and Dust covers mechanisms on the rover.

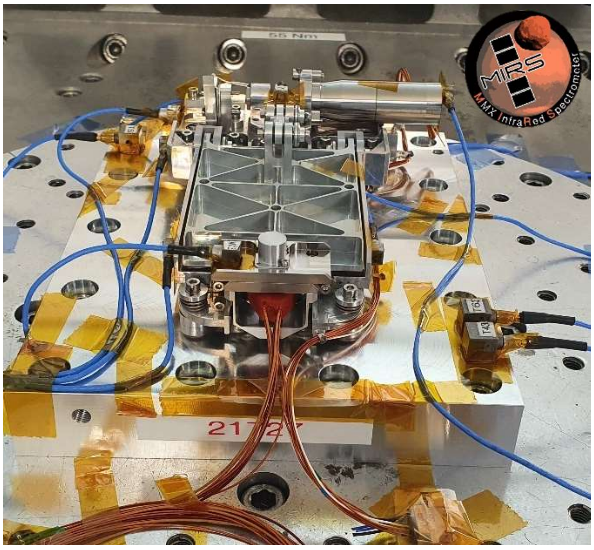

Figure 10: dust cover HDRM of the MIRS instrument with a Triggy EM – MMX CNES/JAXA

Based on this technology, NIMESIS TECHNOLOGY proposes a rotary actuator family called HECTOR. HECTOR consists of a range of torsion rod, from length of 70mm to 270 mm and able to provide minimum rotation of 90° to 200° for application such as solar generator, antennas, or mast deployment. They are adapted from 3U CubeSats to Geostationary Satellites. The HECTOR family will be qualified in Q4 2022.

Also used for the deployment of solar panels, a joint developed by the company MECANO ID is based on the coupling of a Carpenter hinge and an AMF hinge. The carpenter joint is an actuator that allows a self-deployment at 180°C with two stable positions. It has the advantage that it can be locked in the open position, however its release can be too rough. Therefore, this release step can be regulated by coupling with a shape memory hinge which allows a controlled opening during heating.

Figure 11: SMA hinge

ADDITIVE MANUFACTURING OF SHAPE MEMORY ALLOYS

Current SMA technology is currently limited by the possible shapes of the manufactured parts – i.e., mostly restricted to cylinders and wires – and by the achievable sizes. These limitations in manufacturability result, among other factors, from the difficulty in machining SMA alloys, such as Copper.

The emergence of additive manufacturing makes it possible to rethink the design of mechanical parts with an extended freedom of shape. Current mechanisms and actuators can be redesigned with the aim of saving weight, simplifying the mechanism, or increasing performance. New mechanisms can also be envisaged to meet specific functions.

The capacity to combine innovative materials (shape memory alloys), topological designs, and additive processes, all under the name of 4D printing, to create new or improved functionalities in structures and parts for transportation applications, such as actuators, deployment devices, morphing elements...

This technology refers to the process by which a 3D printed object can modify its own structure and change shape with the impulse of heat.

Nimesis has run since 2018 a project with the European space agency and Thales Alenia Space, that aims the development of a powder-based 4D printing process for NiTi shape memory alloys and the associated modelling.

We have succeeded to print our first prototype: a rotating actuator that can change its form with the impulse of heat for which we are currently testing its capacities with thermo-mechanical tests.

Compared to the existing ones, the objective is to provide a torque and a degree of rotation defined while limiting the size of the actuator in length. The defined Specs are as follows:

- Maximum diameter: 60 mm
- Maximum length: 160 mm
- Minimum torque: 13 Nm
- Minimum rotation: 90°

Figure 12: 4D printed rotary actuator

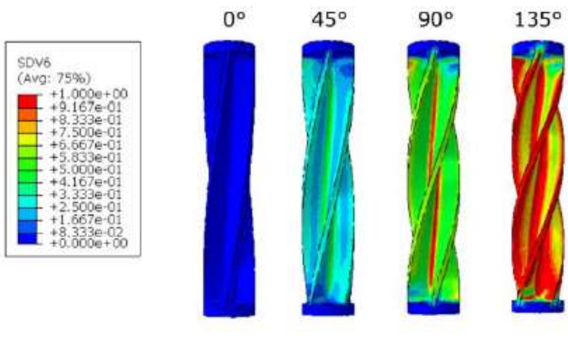

Figure 13: 4D printed rotary actuator performances

To meet the needs of industrials, this technology is continuing to be developed as a new line of activity at Nimesis, by studying other alloys combinations to derive functional components from it. The aim for us is to combine superelasticity, memory effect within the same component, based on the final use of the printed product or/and its environment.

This specific process, conducted by an SLM machine, can optimize the products specifications and functionalities, allowing the printing of parts with complex shapes, the ability to enhance features and reduce weight, all within a short production cycle.

SUMMARY AND OUTLOOK

Shape memory alloys (SMAs) are materials for which the reputation and confidence has continued to grow in recent decades, especially since their classification among the smart materials. SMAs owe their properties to a well-known phase transformation of metallurgists who is martensitic transformation. The latter appears as a shear causing a change in structure without any displacement relative of atoms. This transformation, generated in the material, can under the effect of temperature variation (or stress) lead to memorized shapes of the material at high or low temperature.

NIMESIS TECHNOLOGY has gained a great expertise in this technology allowing it to meet the needs of the space industry in terms of reliability, performance, and market-costs.

In fact, the paradigm shift that the space industry is experiencing is turning the needs towards disruptive technologies. The developments that Nimesis is undergoing represent a line towards this quest.

Bringing together the multiple functions of SMAs (not limited to the list above), as well the optimization allowed by additive manufacturing to the space sector will maximize the opportunity to create advanced and efficient products and processes, offering by that an innovative line of functionalities.

ACKNOWLEDGMENTS

TRIGGY is developed as a cooperative effort between NIMESIS TECHNOLOGY and the CNES (Centre National d'Etudes Spatiales)

4D printing is developed as a cooperative effort with ESA (European Space Agency), Thales Alenia Space, LEM3 and Pint.

The authors would like to address a special thank the teams of CNES who support the development, qualification, and commercialization of NIMESIS TECHNOLOGY's actuators.

REFERENCES

[1] Busch D. J, Purdy W. E, Johnson A. David, development of a non-explosive release device for aerospace application, 26thAerospace Mechanism Symposium

[2] California Polytechnic State University. Cubesat design specification rev. 13. Technical report, 2014

[3] Development and Testing of a High-Temperature Shape Memory Actuator Using CN-250X for Hold Down and Release Mechanisms (HRM), ESMATS paper 2017 Florian FOUCHE

[4] Development and qualification of a High-Temperature Shape Memory Alloys based Actuator for Hold Down and Release Mechanisms (HDRM), Florian FOUCHE, François LEPROUX

[5] ESA CLEANSAT_SMA Dismantlement Mechanisms, Stéphane HEINRICH, Florian FOUCHE, Alain HAUTCOEUR

[6] Roving on phobos: challenges of the MMX rover for space robotics, Jean Bertrand, Simon Tardivel, Frans Ijpelaan et al.