BRUCE – ELECTROMAGNETIC ACTUATED PIN PULLER

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ABSTRACT

Pin pullers are used to hold, lock or secure deployable or moving parts on spacecrafts during their launching. These 'one shot' actuators used to be based on explosive charges. Pin pullers important characteristics are their retraction force that needs to be sufficient to pull the pin out of the locking mechanism, their maximum radial force, which limits the size of the secured system, and their dimensions and weight. The possibility of resetting the mechanism is also an appreciated advantage. Upon request of CNES, the French National Space Agency, CEDRAT TECHNOLOGIES has designed a resettable electromagnetic actuated pin puller, called BRUCE (Broche Rétractable Utilisant une Commande Electromagnétique – Fig. 1).

Figure 1. BRUCE

1. INTRODUCTION

There is an increasing need for spatial compatible locking/securing devices. Non explosive actuators based on fusible wires appeared 30 years ago. In 1999, Cedrat Technologies qualified a shape memory alloy (SMA) based latch mechanism that has been mounted on board of ROSETTA satellite [1]. It was using a Tini Aerospace SMA actuator to break a locking rod. Though this technology was reliable, the process of breaking a part induced a risk of pollution Cedrat Technologies had to deal with. This issue is crucial when it comes to securing optical systems or matter analysis instruments. Another drawback of numerous SMA or fusible wire base actuator is that they cannot be reset without replacing the broken part, thought manually resettable SMA pin pullers are now available. Electromagnetic bistable pin pullers have also been designed but they provide lower performances [2].

Cedrat Technologies and the CNES have worked along to design a manually resettable electromagnetic pin puller. The choice of electromagnetic actuation makes the pin puller compatible with PYRO command and usable on pollution sensible systems. Moreover, Cedrat technologies has significant experience in the design of all sorts of electromagnetic actuators [3]. The aim was to provide higher performances than equivalent SMA pin pullers in the same dimensions. Moreover, BRUCE has been designed following the ECSS design rules and margins contrary to some of the competition actuators.

2. DESIGN

BRUCE is based on a two stages architecture patented [4] by the CNES and Cedrat Technologies (Fig. 2).

The first stage uses a compact variable reluctance actuator which unlocks the second stage, a balls mechanism. This mechanism holds the pin out of the pin-puller housing and unlocks it when the electromagnetic actuator is tripped. The pin retraction is obtained using a compression spring. The link between the first stage and the second one is a part called the trigger.

Fig. 2 shows the architecture of the pin puller. When the electromagnetic actuator is powered, a magnetic field is created in the first stage parts that tends to attract the trigger. As a result, the trigger moves down and allows the balls to translate to the centre of the mechanism: the second stage is now unlocked. Driven by the compression spring, the pin is free to move down.

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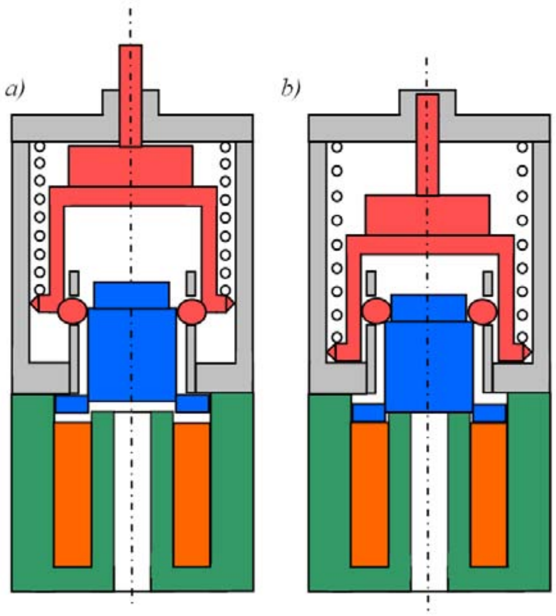

First stage: Electromagnetic actuator
Trigger
Second stage: Balls mechanism

Figure 2. BRUCE simplified architecture:
a) Locked pin configuration
b) Unlocked configuration

The interest in this architecture is that the second stage allows a reduction of the needed actuation force: the actuator force needed to unlock the pin is 8 times smaller than the pin retraction force.

The mechanism can easily be manually armed by pulling the pin to its maximum stroke using a M1.6 threaded hole and a dedicated tool. It can be armed as well by pushing the pin via a hole in the backside of the system. In both cases, the balls translate back to their initial locked position.

Material choice allows the broad service temperature range: BRUCE can be used from -150°C to 150°C under vacuum or in ambient air.

In order to offer the best possible performances as well as to be compliant with ECSS design rules, optimisation work has mainly been carried out on the electromagnetic actuator and the contact pressure between the balls and the mechanism parts.

Pressure:
Contacts between the balls and the surrounding parts have been optimised in order to reduce contact pressures. Indeed, the balls hold the pin in its locked configuration and therefore undertake the driving spring potential force which is as high as 100N. Contact surfaces have been optimised by means of sphere/sphere and sphere/cylinder contacts. Calculations using Hertz theories have been done to ensure that ECSS margins in terms of stress were verified. The machining precision feasibility is very critical considering that the closest the radiuses of the ball and the other part surface are, the lower will be the contact pressure. As a result, contact pressure reductions are limited by machining precision – tolerances as low as 5µm have been specified to the parts suppliers. For a given ball diameter, contact pressures determine the maximum retraction force of the actuator.

The study of the contacts between the balls and the triggers also led to the sizing of the electromagnetic actuator. Indeed, ECSS specifications require the use of a safety factor of 3 on friction forces and 1.2 on spring characteristics. Clearly, the higher the retraction force is, the higher the actuator force must be.

Actuator:
Several electromagnetic actuator shapes have been studied on CEDRAT software FLUX 10.4 in order to find the most suitable one for the pin puller application. As the trigger mass needs to be as low as possible to avoid untimely retraction of the pin, configurations featuring small moving parts (Fig. 4) have been preferred to others (Fig. 3).

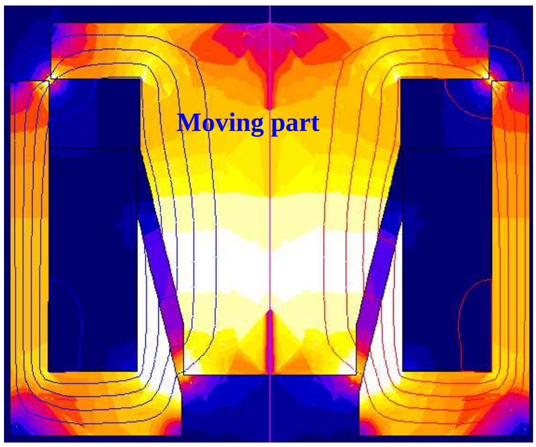

Figure 3. Example of actuator shape that hasn't been chosen: the mobile part is too heavy to suit the application.

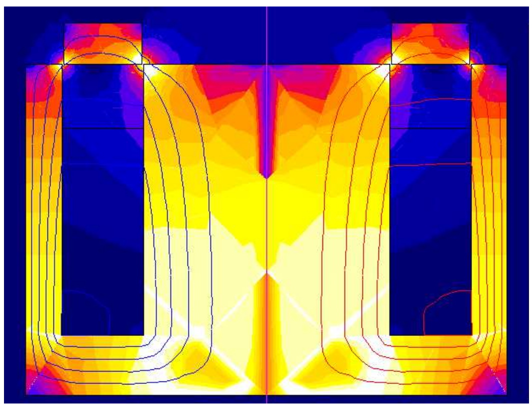

Figure 4. Actuator shape before optimisation

Once its main shape chosen, the actuator has been optimised to:

- Interface properly with the trigger
- Be fixed to the upper part of the mechanism
- Provide enough driving force to comply with demanding ECSS margins
- Have the same diameter as the competition pin puller, or lower.

Studies have been carried out on FLUX 10.4 to evaluate the impact of each modification of the actuator on its force curve. For example, it has been determined that three M2 holes through the outer part of the actuator would have no influence on its performances. Indeed, the electromagnetic saturation takes place in the inside part of the actuator, not in the outer part (Fig. 5). Those three holes are used to screw the actuator to the mechanism housing.

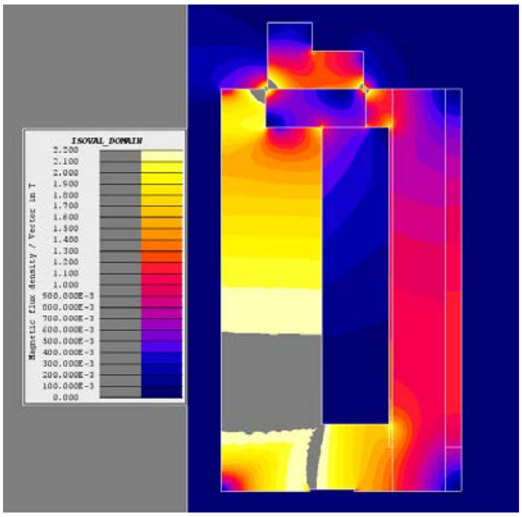

Figure 5. Simulation showing the saturation in the inside part of the actuator (half of the section is shown)

Starting from that observation, we also studied the impact of the coil mean diameter on the actuator performances. The bigger the coil diameter is, the bigger will be the inside part of the actuator, and the less the saturation will be. As a result, performances should be higher when the coil diameter is raised.

The expected reduction of the saturation has been found (Fig. 6). This study allowed us to raise the force provided by the actuator by a third (from 55 to 70N at its maximum).

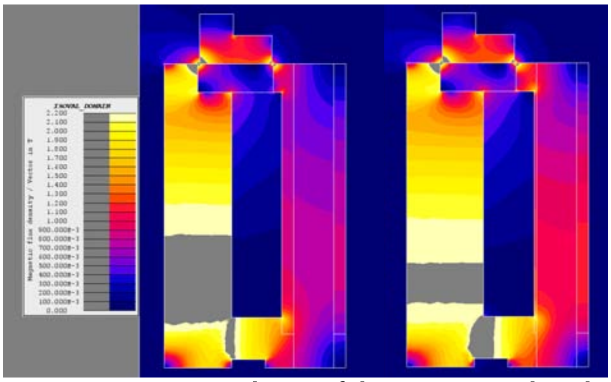

Figure 6. Evolution of the saturation when the coil mean diameter is raised

3. PERFORMANCES

Bruce is compatible with PYRO commands: a 5A and 21mA long current pulse is used to retract the pin. The actuation takes 5ms, which is four time shorter than the command pulse duration.

The following table (Fig. 7) sums up the performances of BRUCE compared to equivalent SMA pin pullers.

	SMA Pin-puller 1	BRUCE	SMA Pin-puller 2	SMA Pin-puller 3
Dimensions (mm)	L:31.75 ∅: 31.8	L:63.7 ∅: 31.8	L:50.8 ∅: 46	L: 70 ∅: 51
Weight (g)	28	125 *85**	74	130
Service temperature (°C)	-60/+70	-150/ +150	-60/+70	-60/+70
Stroke (mm)	6.35	6.3	9.5	12.7
Retraction force (N)	22.24	102 *150**	111	334
Pin maximum axial load (N)	9	390 *1500**	45	112.5
Pin maximum radial load (N)	222	450 *600**	1110	2220

**without ECSS margins*

Figure 7. BRUCE performances compared to equivalent SMA pin pullers.

BRUCE reaches higher performances than equivalent SMA pin pullers. Moreover, its architecture allows the use of various electromagnetic actuator sizes with the same mechanism. This makes BRUCE able to adapt its performance to the application by reducing its weight or raising its performances.

4. TESTS

Cedrat Technologies and the CNES have performed intensive testing of BRUCE EM (Engineering Models). Functional and axial/radial load tests have been first carried out successfully. BRUCE EMs have then been cycled with and without load (Fig. 8).

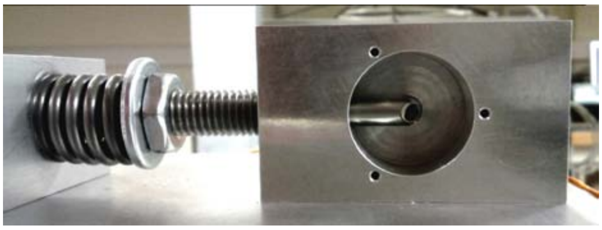

Figure 8. 450N radial loading of the pin

Tests records confirm that the actuation is performed within the first 5ms of the current pulse (Fig. 9). These characteristics are repeatable over 100 cycles.

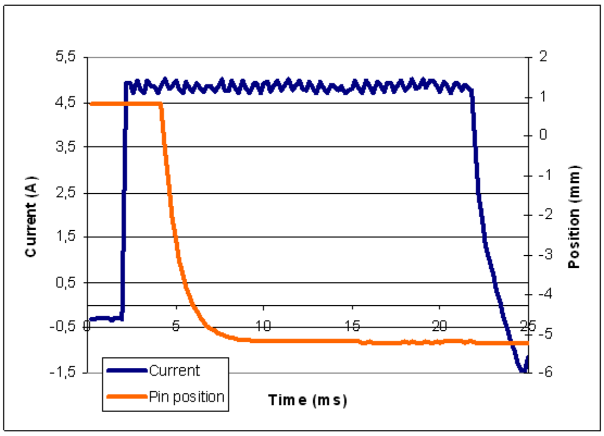

Figure 9. Record of command current and pin position during a typical actuation

Actuations under thermal vacuum at -150°C and 150°C have also been successful. To conclude this campaign, ten actuations in vacuum at ambient temperature and under a 100N radial load have been carried out successfully (Fig. 10).

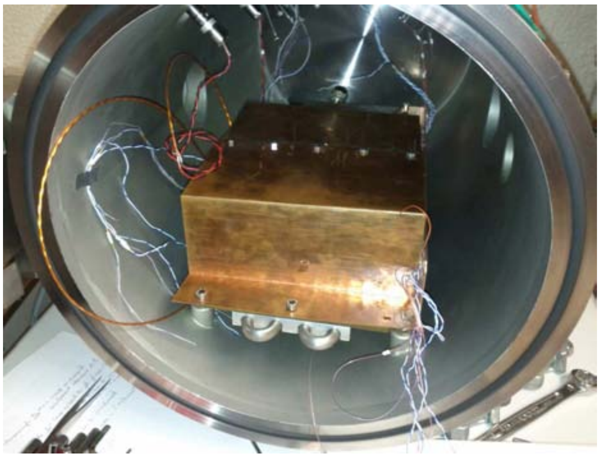

Figure 10. Vacuum tests set up

BRUCE EMs also underwent vibrations and shock tests along axial and radial axes (Fig. 11). Expertise has been performed in order to detect any sign of slipping at parts interfaces and no fault has been found.

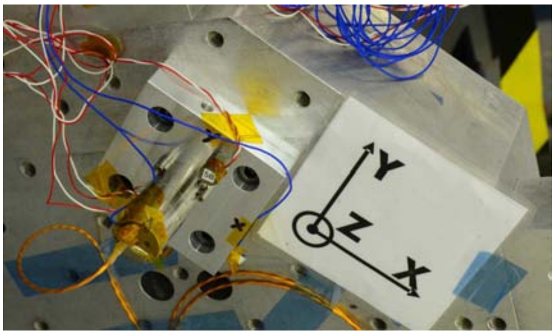

Figure 11. Vibrations and shocks levels

The levels that have been applied are shown in Fig. 12.

SINE SWEEP	
Frequency (Hz)	**Level (0-peak)**
4-20	12.5 mm
20-100	20 g (2 oct/min)

RANDOM VIBRATIONS - 30 gRMS during 2min30sec		
Frequency (Hz)	**PSD (g^2/Hz)**	**Slope (dB/oct)**
20	0.2	-
100	1	3.00
400	1	0.00
800		-3.00
2000	0.0428	-5.00

SHOCK	
Frequency (Hz)	**Level (g)**
100	20 g
100-1000	Linear log-log
1000-10000	1000 g

Figure 12. Vibrations and shocks levels

The same EM has then been integrated to TARANIS IME-HF antenna for more vibration tests (Fig. 13). Here again, BRUCE remained in locked position along the whole campaign despite the amplification of the excitation by the host system. After the exposition to the excitation, an actuation has been performed successfully.

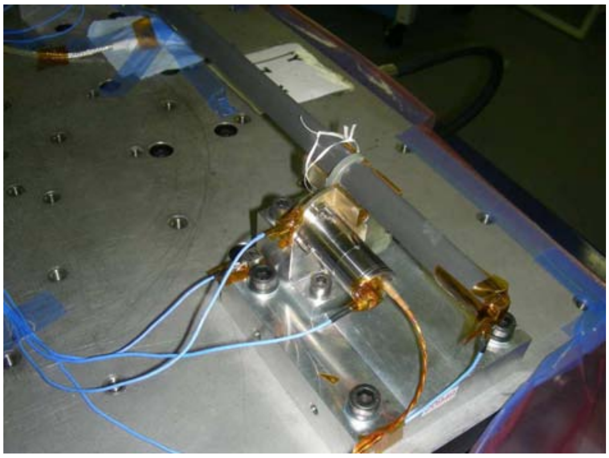

Figure 13. BRUCE integrated to IME-HF antenna for vibration tests

Finally, a last series of tests using statistics software has been performed.

- A first series of actuations has been done with various commend currents bellow the 5A minimum command current, the current pulse duration being fixed to 20ms. The success or non success of each actuation allows obtaining a Gauss curve, ensuring that all actuations will be successful with a 5A command current. The influence of radial load on this Gauss curve has also been studied.
- A second series of actuations have been done using the same principle but changing the pulse current duration under the specified 20ms, the current value being fixed to 5A. Here again, it has been statistically shown that all actuations will be successful (Fig. 14).

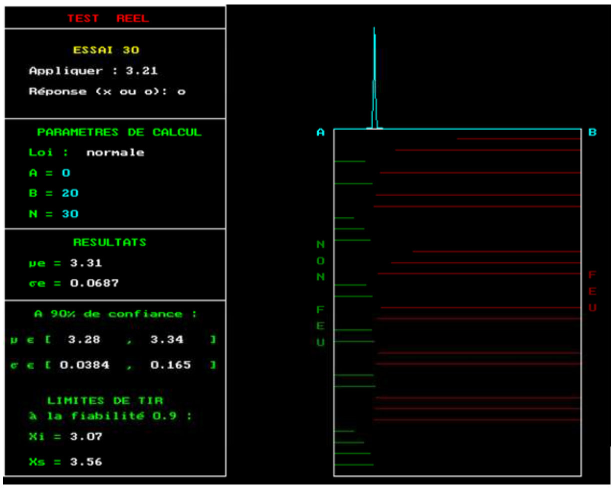

Figure 14. Screenshot showing that all actuations are effective for a 3,5ms long current pulse

At the end of these tests, the two BRUCE EMs had performed around 100 cycles each. One of them has been disassembled and inspected for damages. Chemical analyses have also been carried out on friction interfaces showing normal tribologic behaviour.

Minor design modifications have been done at a non functional parts interface to replace a sintering process by a laser welding process. The reason is that CEDRAT TECHNOLOGIES has heritage on laser welding and that this process is considered as more reliable. A full qualification including EMC tests is foreseen for early 2014. CEDRAT TECHNOLOGIES is actually producing qualification and flight models.

5. CONCLUSION

This paper presents BRUCE, an electromagnetic actuated pin puller entirely designed following ECSS requirements. This actuator is a totally coherent alternative to SMA systems given its better performances, similar dimensions, and its ease of use. The two stage architecture has indeed been optimised in order to provide the best possible performances in a contained volume. Cedrat Technologies would like to thanks the CNES for this fruitful cooperation.

6. REFERENCES

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