DESIGN, TESTS AND LESSONS LEARNED OF A LOW SHOCK, LOW MASS AND LOW COST PIN PULLER

K. Zajac, C. Raum, A. Alegre Cubillo, A. Geißler, M. Oswald
HTS GmbH, Am Glaswerk 6, 01640 Coswig, Germany

Abstract

This paper gives details of the development and verification of a breadboard model of a pin puller for application in a hold down and release mechanism (HDRM). During the project, which is still ongoing, a compact, low weight, low shock and cost-efficient release device based on thermo-mechanical release mechanism has been developed, manufactured and tested. On top, this release device allows multiple resets with a minimum effort.

Up to now the pin puller did undergo different tests and analysis in order to elaborate the maximum force and temperatures endured by the mechanism components of the device. Test conduction and results will be presented with focus on deviations from the expected behaviour and on lessons learned. The next activities are focused on the optimization of the device. Especially investigations to improve the material combination as well as component design to enhance the reliability and reduce manufacturing costs are ongoing.

1. INTRODUCTION

Hold down and release mechanisms (HDRM) are established in spacecrafts to hold, lock or secure large deployable structures like antennas, solar arrays or moveable parts like instrument or cover mechanism during launch phase. The prime component of such a HDRM is a reliable release actuator. Typical non explosive actuators are actuators to break a locking bolt, separation nuts and pin pullers. The process of breaking a part or release of bolt induces a risk of particle contamination, even though that this technology is reliable. For debris and fragment-free operation pin pullers are used typically. For securing optical instruments this issue is critical. Another drawback of numerous release devices is that they cannot be reset without replacing a part or even to replace the whole device. In addition shocks emitted by the release device are critical with a look to the functional integrity of the fixed components and mechanisms. Furthermore frequently used devices are disposed by US American enterprise with strong International Traffic in Arms Regulations (ITAR) and long lead times.

To be independent of non European release devices HTS GmbH, located in Coswig, Germany specializing in the development and manufacturing of mechanisms for spacecrafts, started to design an easy resettable, fully European pin puller following the ECSS design rules and margins [1]. The objective is to develop a low shock, low mass and cost-efficient release device based on a proven principle which is able to provide equal or higher performances than equivalent non European pin pullers available on the market. The current activity is supported by Germany's national Space Program under the German "Komponenteninitiative" with administrative management of the DLR Space Administration.

2. REQUIREMENTS

As a baseline for the design of the pin puller, a dedicated pilot application was selected, and the technical requirements were derived. A selection of the baseline requirements which have driven the development and verification effort is given in TAB 1.

Requirement	Quantity
Lateral Load (Actuation)	≥ 500 N
Pull stroke	≥ 8 mm
Separation time	25 ± 5 msec
Mass	≤ 100 g
Life	50 Cycles MIN
Operational temperature range	-70°C / +80°C
Non-operational temperature range	-100°C / +100°C

TAB 1. Baseline requirements for the pin puller

An important design requirement was to avoid electro explosive devices for actuation due to creation of high mechanical shock. As non explosive pin pullers can be actuated electromagnetic, mechanical or by shape memory alloy (SMA), the decision at HTS was made for mechanical actuation. Another important design requirement was addressed to the refurbishment after actuation. In general pin pullers can be reset without replacing parts but it is often necessary to dismount the whole device for the refurbishment. The approach at HTS was to design a pin puller which is resettable after use, e.g. on-ground testing, without the need of dismounting.

3. BREADBOARD DESIGN

The design for breadboard (BB) testing consisted of the housing, two covers and the pin. The pin puller is characterized by its compact design, low shock and a low mass. The design is described in FIGURE 1. The thermo-mechanical release mechanism allocated inside the housing causes the pin to retract into the housing. The pin remains locked in this position until the mechanism will be reset by the reset screw allocated inside the lower cover according to the reset procedure.

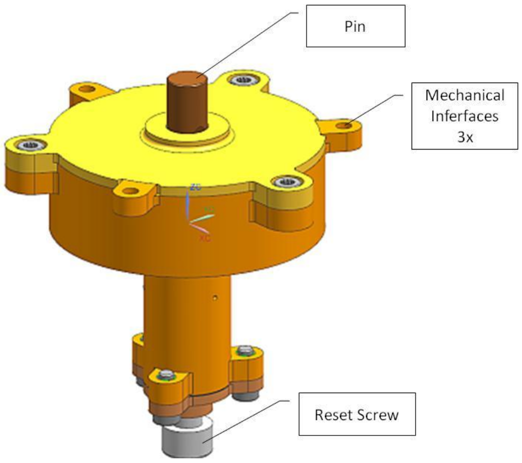


FIGURE 1. Breadboard design of pin puller

The mechanical interface is established by means of three bores in the housing of the pin puller where the mechanism can be fixed by three screws. The electrical and data interface is established by means of a pig tail wire where a bundle of two wires is used for the heater power supply and a bundle of four wires for the thermal sensor system.

The pin puller function is based on a thermo-mechanical principle where the temperature of the mechanical parts is triggering the pin pulling function. Therefore, a power supply is necessary to achieve the correct triggering temperature. In order to avoid defects as a result of overheat, a thermal sensor system is installed. This system will be used to monitor the heating system temperature and to cut the power supply in case of achieving the safety temperature.

4. TESTS AND RESULTS

Before finalizing the design for the Engineering Qualification Model (EQM) of the pin puller, an extensive test campaign on component and breadboard level was carried out to proof the functional concept, detect possible design issues and develop the necessary test equipment in parallel. Some of the major results will be presented in the following.

4.1. Functional Test

The assembly and integration of the pin puller BB model was performed under laboratory conditions. All steps were noted in the as-run assembly and integration procedure. The resulting hardware was photographic documented and all functional and test steps are recorded at the pin puller log card.

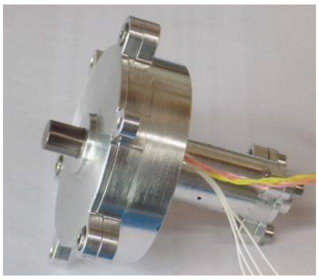


FIGURE 2. Pin puller BB after final assembly

After successfully performing the physical properties tests with mass, mechanical interface and electrical parameter measurement, the BB test campaign started with performance and functional testing focused in verifying the functionality of the pin puller. During the first actuations no lateral load was applied to the pin to prevent damage of mechanism or heater. After successful verification of the working principle, a stepwise increase of lateral load was applied to the pin puller. By means of a lever ground support equipment a maximum lateral load of about 500 N was identified to allow correct functioning of the mounted pin puller.

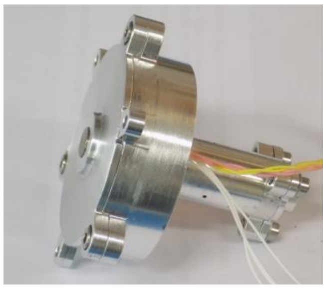


FIGURE 3. Pin puller BB after actuation

TAB 2 summarizes the main results of the performance and functional tests achieved during BB test.

Requirement	BB Test Result
Mass	99 g
Box shape	Ø 70.5 x 57.8 mm³
Heat up sequence	60 ± 15 s @ 25W
Pull stroke	8.2 mm
Separation time	20 msec
Lateral Load (Actuation)	490 N

TAB 2. Pin puller BB test results

4.2. Characterization Tests

Different characterization tests were performed improving the understanding of the pin puller BB. Some of the major tests are summarized below.

The thermo-mechanical release mechanism will be heated by an attached heating device. The heater is designed as a flexible PCB which combines two heaters on one board. The board will then bend around the release device so that one heater is positioned on each side of the release device. The heating test was performed alone, without the pin puller and split in two parts. First the influence of the heater was checked.

Therefore the release device was tested without the heater and then equipped with the heater. The heating was done both times in the oven. The tests showed that the heater application has no influence of the actuation temperature of the release device.
In the second part of heater test the release device was equipped with heaters on both sides. In this test the behaviour of the release device was evaluated depending on which heater was operated. The tests revealed that the actuation temperature of the release device doesn't depend on the heating side. If the electrical power is the same, the actuation temperature will be nearly the same. Also the test revealed that the actuation temperature depends on the heating rate. With increasing heating rate the actuation temperature will decrease.

To achieve a low shock device according ESA classification [2], an appropriate damping concept and material is necessary to reduce the release shock of the pin puller during pin stroke. As the first concept of V-shape damper was withdrawn due to particle contamination a more detailed investigation was performed. During this damper test different rubber, silicone and fluoropolymer elastomer were screened. After the identification of suitable materials regarding temperature, outgassing and damping characteristic representative samples were manufactured. The experimental investigations were executed with a drop test setup including shock sensors and characterization of different impact energies. The test revealed that viton fluoroelastomer complies with the given requirements and will be used for the pin puller. More detailed investigations on device level shall be done within the emitted shock test campaign.

4.3. Vibration Test

In order to simulate the launch environment a sinus and random vibration test has been performed. These tests of the pin puller as part of an HDRM were performed in the frame of the test campaign of an advanced de-orbiting subsystem [3] at DLR test facility, Institute of Space Systems Department Mechanics & Thermal Systems in Bremen. The vibration test was done axis by axis in the sequence sine sweep, sine vibration, random vibration, sine sweep. During sweep the natural frequencies were determined and compared to test prediction values. The functional integrity of the pin puller was tested by means of short electrical test between, before and after every vibration direction in order to detect failures. An actuation of the pin puller was performed after passing the vibration test successfully.

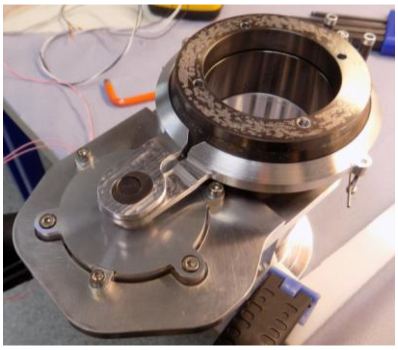


FIGURE 4. Pin puller mounted in the HDRM of the de-orbiting subsystem

The pin puller was tested successively in test directions x, y and z. No significant changes of the main resonance frequencies were detected. No damage or other failures appeared at all inspection points of the pin puller during and after the vibration tests.

4.4. Thermal Test

In order to simulate the thermal environment during a mission, the pin puller was exposed to thermal cycling's followed by visual inspection and functional test. These tests of the pin puller as part of an HDRM were performed in the frame of the test campaign of an advanced de-orbiting subsystem [3] at DLR test facility, Institute of Space Systems Department Mechanics & Thermal Systems in Bremen. The temperature has been measured and monitored on different positions inside and outside the de-orbiting subsystem including the pin puller.

The general conditions of the thermal cycling test were normal pressure, maximum temperature gradient dT/dt of 2 K/min and dwell time of minimum 1 hour. The temperature regime consists of 8 cycles starting at room temperature (RT) then rise to +40°C and drop to -30°C, ending at RT due to HDRM requirements.

There were no visible changes before and after the thermal cylling test. Furthermore the hot case and cold case firing was performed succesfully. Based on the test results, the pin puller is able to withstand the temperatures between -30°C to +40°C without significant changes or failures.

5. LESSONS LEARNED FROM BB TESTING

The BB testing campaign delivered valuable inputs into the engineering model (EM) design. Problematic areas are for instance the tolerances of the manufactured parts, the assembly duration and the refurbishment.

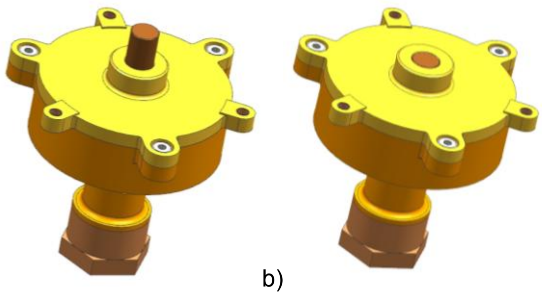
The general tolerances of all built in parts can vary, resulting in different clamping conditions of the thermo-mechanical release mechanism. This tolerance adjustment is a critical item for the pin puller affecting the release temperature. Therefore a tolerance adjustment shall be included by the use of two peelable shims.

In term of the assembly and integration the housing and cover concept of the BB was found adverse for rapid assembly. To reduce the assembly duration the screws located at the lower cover shall be replaced by a thread on the housing and the lower cover. For an improved mechanical interface to the spacecraft structure the top cover shall have a cylindrical fit in the middle.

To reduce the efforts during test campaigns, the pin puller is designed to be easily resettable without dismounting. The reset is done in two steps. The first step is to screw in a reset screw to push back the pin and preload the spring. In the second step the pin puller will be cooled down to the reset temperature of the thermo-mechanical release mechanism. During the characterisation test of the BB model the measured temperature was too low, demanding a long resetting time. This temperature shall be aligned to room temperature resulting in reduced refurbishment effort and time.

6. PIN PULLER EM DESIGN

Based on the elaborated requirement specification and the lessons learned of the BB phase, in particular peelable shims and room temperature refurbishment, an EM pin puller design has been developed. In the cold position (see FIGURE 5a) the pin is locked by the thermo-mechanical release mechanism and preloaded by a spring. When the heater is powered the thermo-mechanical release mechanism will unlock the pin (see FIGURE 5b). Driven by the spring preload, the pin will move and impact into the damper to reduce emitted shock of the device.



a) b)

FIGURE 5. EM Design of the pin puller, a) locked position, b) unlocked position

As the thermo-mechanical release mechanism will be heated by an attached heating device, its fixation in the housing is done by thermal insulation parts to reduce heat dissipation. On the one hand this is done to reduce the power consumption and to reduce time to heat the thermo-mechanical release mechanism and on the other hand to reduce the temperature increase of the surrounding parts to minimize the effects of different coefficient of thermal expansion and heat conduction towards the HDRM or payload.

7. SUMMARY AND OUTLOOK

The objective of this project is to develop and verify a pin puller based on thermo-mechanical release mechanism. The technical requirement specification has been consolidated and will be finalized with the EM.

As a result of the project a well working pin puller was developed and successful BB tests including vibration and thermal cycling tests were performed. However, some possible design and handling improvements were identified and included in the EM design of the pin puller.

The next activities are focused on the further optimization and test of the device. Especially investigations to improve the material combination as well as component design to enhance the reliability and reduce manufacturing costs are ongoing. As the EM of the pin puller shall reach TRL 5 it is planned to build and test the corresponding hardware in the next project phase. The qualification tests on this level include functional and performance tests at ambient and thermal vacuum, vibrations and shock test. To minimize the test period the ground support equipment presented in FIGURE 6 was designed, allowing for a simultaneous or non-simultaneous operation of four pin pullers.

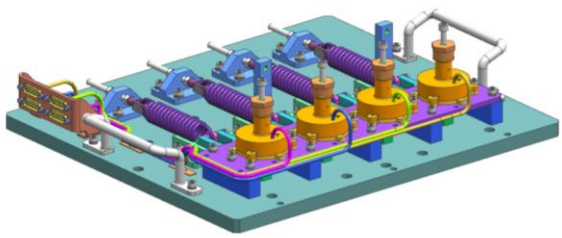


FIGURE 6. Pin puller test equipment

8. ACKNOWLEDGEMENT

The authors would like to thank the involved team of HTS GmbH and the diploma students for their contributions during the implementation of this project and their continuous support. Additionally we thank T. Sinn and L. Tiedemann from HPS GmbH for the vibration and thermal test in the frame of the test campaign of an advanced de-orbiting subsystem. Financial support by the German Federal Ministry of Economic Affairs and Energy (BMWi), represented by the German Aerospace Center (DLR) under contract 50 RM 1611 is gratefully acknowledged.

9. REFERENCES

[1] K. Zajac, T. Endler, C. Raum, T. Schmidt, Entwicklung, Test und Lessons Learned des Multiaxialen Entfaltungs- und Positionier-mechanismus MEP, 5. Nationale Konferenz Satellitenkommunikation in Deutschland, 2017

[2] EUROPEAN SPACE COMPONENTS COORDINATION: Hold-Down And Separation, Systems. ESA, 2014

[3] T. Sinn, L. Tiedemann, A. Riemer, R. Hahn et al., Results of the Deployable Membrane & ADEO Passive De-Orbit Subsystem Activities Leading to a Dragsail Demonstrator, 7th European Conference on Space Debris, 2017