EMERGENCY POINTING ACTUATOR (EPA) RELEASE MECHANISM OF THE POINTING UNIT IN THE MERTIS BEPI COLOMBO EXPERIMENT

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ABSTRACT

The paper presents Emergency Pointing Actuator (EPA) of the Pointing Unit (MPOI) as a part of the Mercury Radiometer and Thermal Imaging Spectrometer (MERTIS) used in the Bepi Colombo mission. EPA shall be used in case of MPOI electronics failure. It can rotate the motor shaft with pointing mirror to the Mercury view position and keep this position all the time. The mechanism is based on a spiral spring which will be released on command. The reverse rotation of the spiral spring is blocked by a special fiber and it can be released by burning the fiber.
The EPA mechanism was verified in different modes of operation and demanding environmental conditions. The tests included: thermal analysis for different modes, estimating time of fiber burning in variable temperatures.

1. INTRODUCTION

The Pointing Unit (MPOI) is situated in front of the MERTIS instrument. The main objective of the Pointing Unit is to orient the entrance of the instrument to 4 different targets sequentially (the Mercury surface, deep space, 300K black body, 700K black body). This is realized by implementing a single rotary mechanism with a 45° tilted mirror. The MPOI consists of: counter bearing assembly (1), pointing mirror assembly including screen tube (2), stepper motor (3), magnetic sensors with electronics (4), drive power electronics (5), cross pointing structure including 4 target ports (6), emergency pointing actuator (7) (see Figure 1-1).

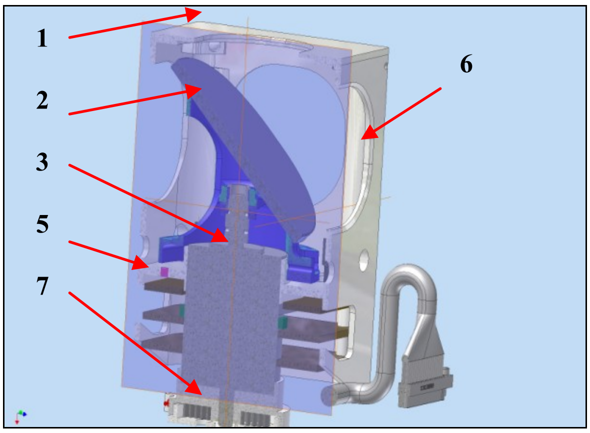

Figure1-1 MPOI cross section

The Emergency Pointing Actuator is a mechanical system of the MPOI unit and is released in case of MPOI electrical and mechanical failure.

The EPA module was investigated at the unit and component levels. The unit levels refer to EPA interfacing with the MPOI unit, however component level was considered as a single test of EPA components with the EPA system working independently.
At the unit and component level the EPA mechanism was investigated in different modes and variable temperature conditions. The tests included: fiber elongation at fixed temperature (cycle's life tests), measuring time of the fiber burn in variable temperatures and analysis of short electrical control rectangular pulses.
The Emergency Pointing Actuator environment conditions of tests are very demanding; moreover the mechanism should have high reliability.

2. EPA DESIGN AND REQUIREMENTS

Emergency pointing actuator (EPA) was designed for a case of electronic or mechanical failure which could block the rotation of the mirror.
EPA system is fixed to the motor enclosure and is connected to the motor shaft.

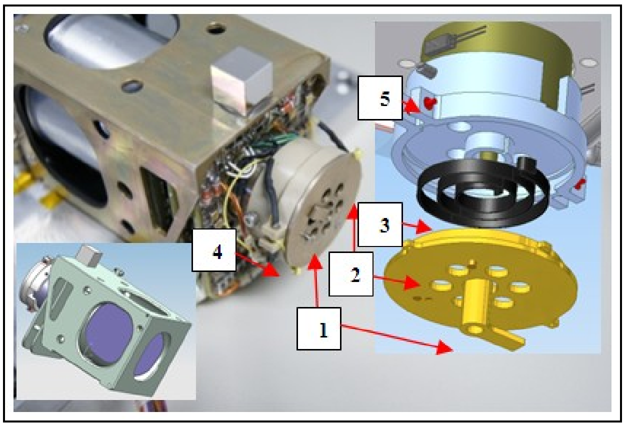

Figure 2-1 The MPOI and EPA Module.

The mechanism consists of four mechanical elements, fiber and two resistors. The idea of operation is based on a spiral spring (Figure 2-1, point 3), whose reverse

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rotation is blocked by special fiber Dyneema SK65 Φ 0.3mm (Figure 2-1, point 4). One end of the fibers is fixed in the hole of the top cover, then it embraces the resistor, it passes under the spring box to reach the second resistor (Figure 2-1, point 5) and finally is fixed using second hole in top cover.
In case of failure, the fiber is burn and spring torque is transmitted by a bumper (Figure 2-1, point 1) on the motor shaft where the mirror is fixed.
It can rotate the motor shaft to the Mercury view position and keep this position all the time. Further rotation is blocked by a mechanical limiter which can precisely fix the Planet view position. The maximum torque of the spiral spring is 130Nmm. The value of torque securing the Planet View mirror position depends on the rate of spring winding.
The mechanism is released by command from the Instrument Control Unit of MERTIS.
The commands from the ICU switch on the power in the EPA resistor system. Resistors need 3.2W (28V) to burn fibers during a few seconds. Every resistor can burn the fiber and thus activate the run release mechanism. They work in cold redundancy.
It is assumed that the EPA should be operational in the thermal range from -50ºC to +85ºC. Random vibration load for the MPOI was estimated at the 40G rms level. The hard radiation has no influence on the proper operation of the EPA. Additional requirements were imposed by mass and current level limits. These assumptions had a strong influence on the design and the selection of components and their parameters.
The minimum limits defined for: the spiral spring, the fiber and the resistor are shown in the Table 1-1.

EPA Components	Limits
Fiber	Fiber Temperature Operating Range: [-50ºC – 85ºC]
	Melting Point >120ºC
	Fiber Strength > 260Nmm
	Fiber Elongation in Operating Temperature Range ± 2mm
Spring	Spring Torque Tolerance 130 ± 10%Nmm.
Resistor	Tolerance of Resistance in Operating Temperature Range ± 5%.

Table 1-1 The EPA Components Limit.

The success of the EPA design requires testing of all EPA components separately and the EPA module for the operating MPOI conditions.
In the next sections, the following EPA tests are described: fiber strength analysis as a function of fiber length, fiber time burn in various temperatures, and fiber strength analysis during short resistor control rectangular pulses.
The EPA procedure test was divided for unit and component tests level. The main goal of EPA unit level test is to show a proper work of EPA together with other MPOI modules in required conditions.
The EPA component level tests (CLT) showed the behaviour of each EPA component (SK65 Dyneema fiber, resistor, spring made of 17-7 PHSS material) separately and it gave the possibility to check the parameters of delivered components in the requested conditions. The material of the spring was covered by a thin layer of Teflon to avoid vacuum welding of the rolled spring. The EPA CLT confirmed proper selection of the components and validity of the design.

3. FIBER DYNEEMA SK65 ELONGATION

The Dyneema fiber was analysed before the EPA design and tests started. The fiber was analysed only at high temperatures due to close the fiber melting point compare to fiber operating conditions.
The fiber simulation is shown on Figure 3-1.

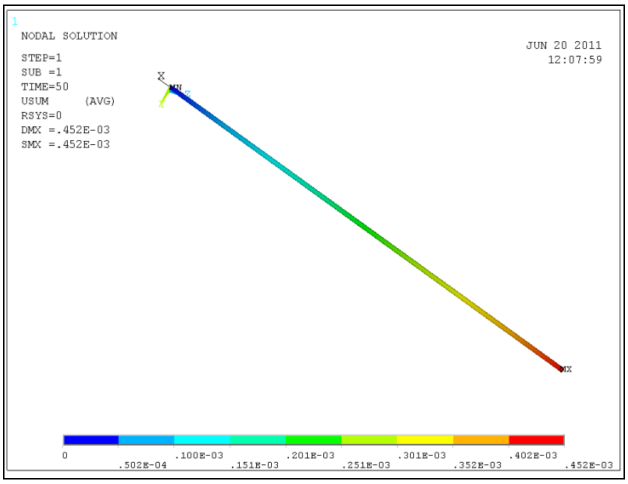

Figure 3-1 Thermo - Structure Fiber Calculations.

The fiber was underwent thermal and structural transient analysis with the following conditions: temperature +85°C, initial load: 7.6N (130Nmm), operating time: 8h.
The analysis showed that maximum fiber elongation for specified operating conditions are about 0.5mm. It is about 0.5% of whole fiber length used in the EPA module. Theoretical results will be verified during the test (see paragraph 3.1).

4. EMERGENCY POINTING ACTUATOR TESTS

The EPA components test was divided into three independent parts: time of the fiber burn test, electric and spiral spring tests.

4.1 Time of the fiber burn

4.1.1 Test set up

The main goal of this topic is the thermal investigation of Dyneema fiber.
The change of the fiber length in time at different temperatures and repeatability time of the fiber burn were determined.
Test was performed in the temperature range between -30°C and +80°C (for this test the maximum temperature was reduced down to 80 °C), fiber tension: ~130Nmm.
The simple test set up is shown on the Figure 4-1.

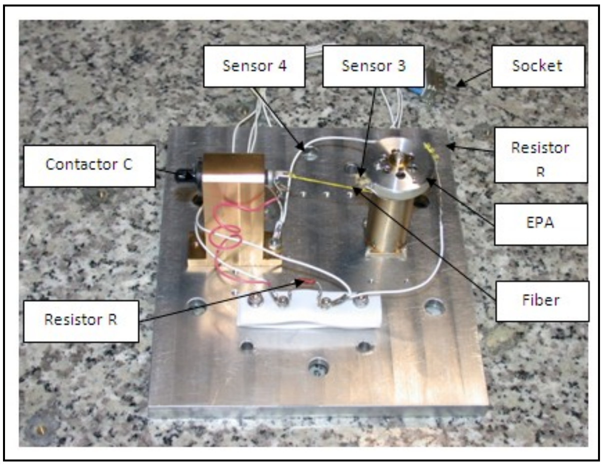

Figure 4-1 Measurement System.

The presented elements of the set up were placed on a mechanical plate which was subsequently fixed to the table of the vacuum chamber. EPA was mounted on a dummy of the stepper motor. Fiber was placed as described in section 2, but one of end of the fiber was connected to the contactor. The idea of the measurement is a simple and presented in the electrical schematic in Figure 4-2. In the initial state, contactor C is compacted (Figure 4-2). When DC Power Supply E is connected, oscilloscope channels: V_1, V_2 record voltages equal to 28V. The time needed for burning fiber is recorded by channel V_1. The channel V_2 is the reference channel and records voltage equal to 28V, when DC Power Supply is switched on. After the fiber has been burnt, by resistor R_M (250Ω), the contactor C is disconnected and the voltage is as follows: $V_1 = 0$ and $V_2 = 28$V.
The period of time after which the fiber will have burnt is measured as the time when the voltage on channel V_1 is equal 28V.

During the tests (before burn) the fiber is stretched by a spring and initial tension is about 130 N mm.

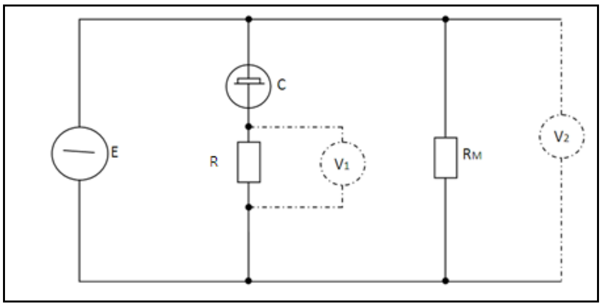

Figure 4-2 Electrical Scheme.

4.1.2 Fiber test at temperature + 80°C.

The EPA test was done at temperature +80°C. The blue curve (Figure 4-3) is a voltage from channel V_1 (see Figure 3.2). The fiber was burnt during the period of time defined as the time when V_1 equals to 28V (for curve blue) - t_1, whereas green curve shows voltage from V_2. The voltage on V_2 is equal to 28V when the power supply is switched on – t_2. The results of test are presented in Figure 4-3and Figure 4-4.
Time needed for the fiber to burn (from Figure 4-3) is equal to **1.45s** (t_1).
Figure 4-4 shows temperatures on sensors no # 3, 4 (see Figure 4-1). Temperature on sensor # 3 (T_1) is constant and approximately equals +78°C, while temperature on sensor # 4 (sensor close to burn resistor, T_2) is variable.
The fiber was burnt at temperature around 140°C, but close surrounding of the resistor had temperature T_2 = 95°C. Temperature T_3 = 112 °C is the temperature when power supply was switched off and voltage on resistor R is equals to 0.

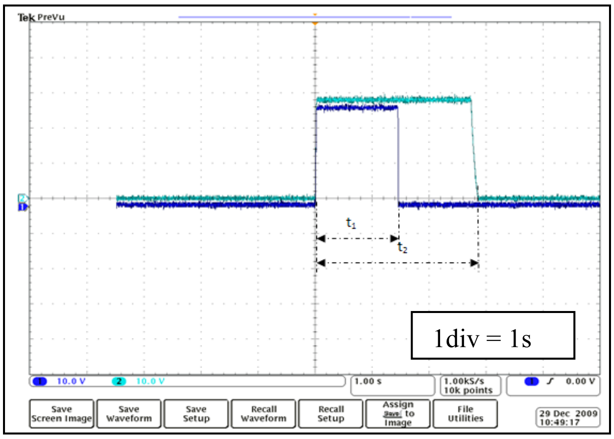

Figure 4-3 Fiber time burn at +80°C.

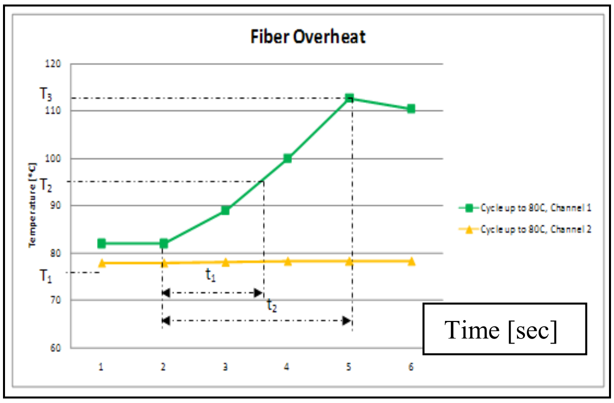

Figure 4-4 Temperatures on the 3 and 4 sensors at +80°C.

4.1.3 Fiber test at temperature - 30°C.

Figure 4.5 shows time needed for the fiber to burn at temperature -30°C. The time is equal to **5.1s** (blue curve – t_1).

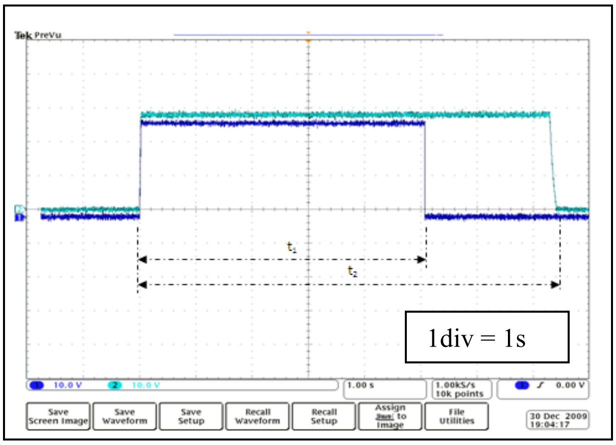

Figure 4-5 Fiber time burn at -30°C.

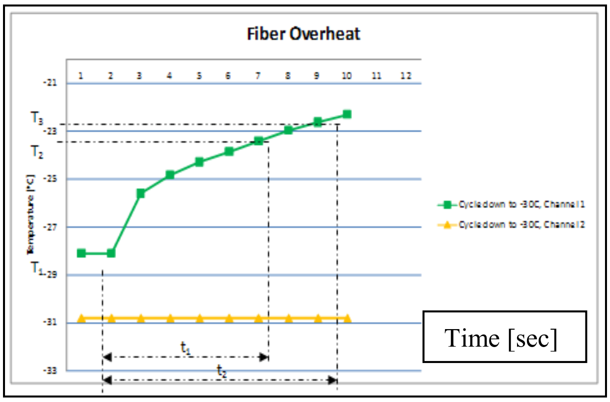

Figure 4-6 Temperatures on the 3 and 4 sensors at: -30°C.

The temperature on R_M (see Figure 4-1) increased from -27.5°C up to -23°C when the fiber was overheating (Figure 4-6). Time t_2 is the time after which the power supply was switched off. The temperature increased up to $T_3 \sim$ -22°C.

4.1.4 Test at temperature +80°C, for extended time.

The EPA structure was also checked during an extended time of keeping power on the resistors responsible for burning the fiber. After the fiber was burnt the voltage at resistor R_M was constantly switched on, by about 2 time of normal period time required to burn the fiber (10s). The process of applying the voltage is shown in Figure 4-7.

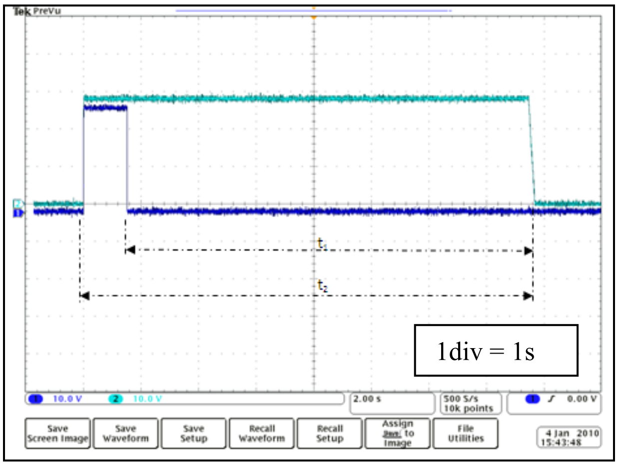

Figure 4-7 Plot with burn time for extended time.

The high temperature of the resistor did not cause any damages and EPA successfully passed the 10 sec. test of powering the resistors. It was confirmed that quite big margins of time exist to switch off power from the EPA resistors.

The repeatability of resistor R_M was checked after each thermal test. The tolerance of the resistance was about ± 5%.

4.2 Fiber Elongation at +85°C

The goal of the test was to determinate a relative value of fiber elongation at the defined range of temperatures in vacuum conditions.

The MPOI temperature range extends from -50ºC to +85ºC; therefore the test was performed for a long period time at the maximum temperature. The change of length of the fiber was measured at fixed 85ºC temperature under load 7.6N.

The initial fiber length was 100mm.

The fiber melting range is 144ºC – 152ºC [1]. Linear thermal coefficient of SK65 fiber is very low (-12E-6 1/K), but fiber thermal behaviour close to the melting

point and under load has not been specified by the supplier.
The simple measuring system which transfers elongation of the fiber to an angular position of an arrow is shown on Figure 4-8.
Elongation is observed by angle arrow position changes observed on the markings. The accuracy scale of the measuring system is 0.1mm.
The test results contain measuring errors connected with fiber steady tension which have not been identified in the simulation.

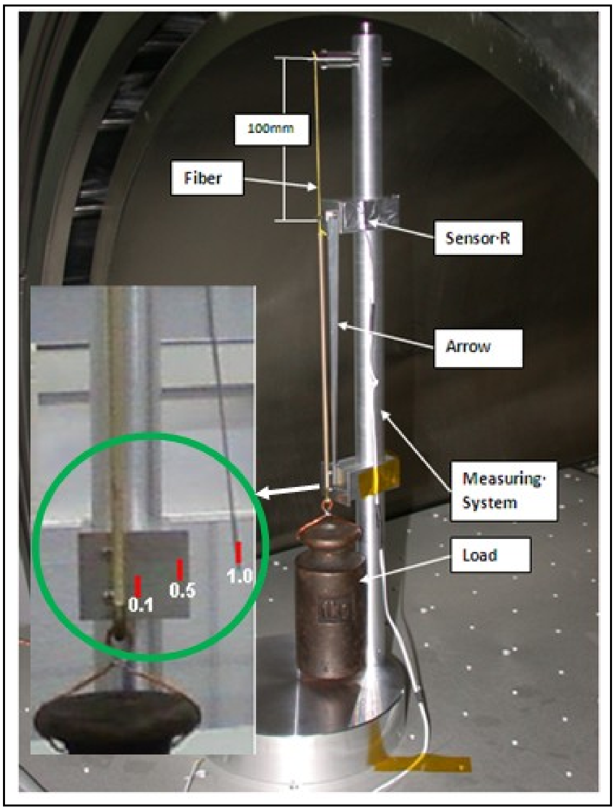

Figure 4-8 Measuring System.

The temperature of fiber was detected by resistor "R". The temperature diagram is shown on Figure 4-9.

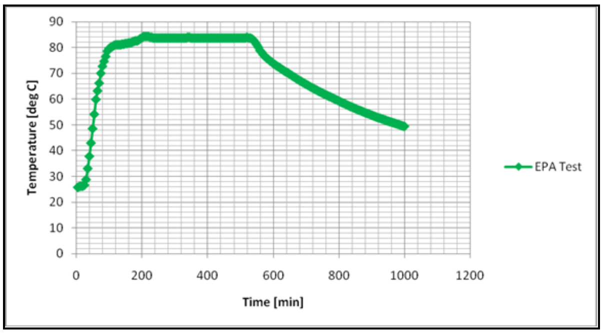

Figure 4-9 Thermo Balance Shape.

After eight hours at +85ºC (non-operational condition of MPOI) the fiber elongation was about 1mm (elongation is 1% of initial fiber length: 100mm) and during the test fiber presented a very stable behaviour.
The fiber elongation was also predicted by the simulation (see paragraph 3). The elongation result obtained from the simulation was equal to 0.5mm. It is comparable to test data (1mm) and insignificant compared to the fiber length used in the EPA module (100mm).

5 Short Electrical Control Pulses

The MPOI and EPA should be resistant to any accidental electrical loads during ground and space operation. The accidental electrical pulses should not trigger the release mechanism and it should not change significantly the time of the fiber burn. From this reason below described tests were carried out.
The MPOI-EPA requirements impose the need for the following electrical tests: The first part of the test was performed with regular pulses (with filling pulse equal to 50%, test time = 10s, impulse time = 20ms). The second part was performed with the irregular driver signal (test time equal to 5min, filling pulse changes from 0.99% to 13%, signal period equal to 10.1 – 11.5s). Tests should be done at the temperature 85º C and meet the following criteria: resistance changes of resistor ≤ 2Ω, the fiber damage should not be observed for 10s during the first test, fiber damage should not be observed for pulse time ≤ 0.5s at the second test. The measuring system is shown on Figure 5-1.

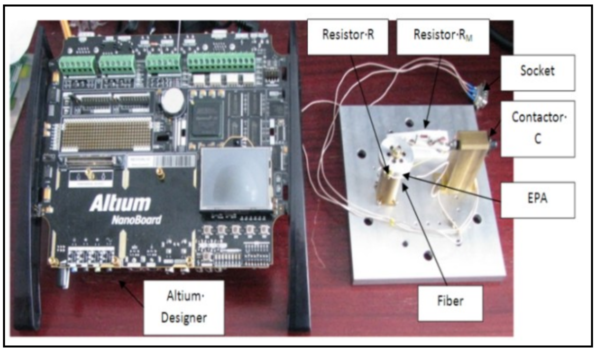

Figure 5-1 Measuring System.

The voltage time period on resistor "R" is controlled by Altium design system. The period of time when the fiber is under load or being burnt is observed by the oscilloscope. Furthermore fiber is loaded by force 7.6N. Description of the measurement set up is shown in section 4.1.1.

5.1 Regular Driver Signal Pulses

The fiber was heated by means of regular pulses equal to 20ms by 10s. The Figure 5-2 and Figure 5-3 have shown input and driver signals.

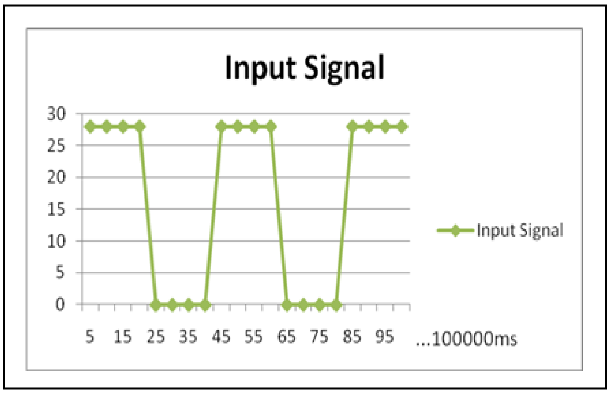

Figure 5-2 Input Signal.

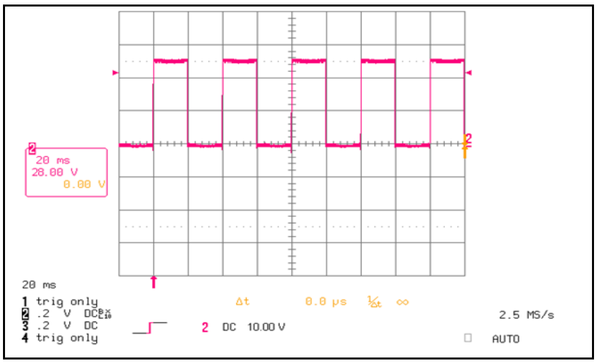

Figure 5-3 Driver Signal Pulses.

The fiber changes have not observed after the test.

5.2 Irregular Driver Signal Pulses

The fiber was heated by irregular pulses during the 5min time cycle. The shortest pulse lasted 10.1s (fill pulse: 0.99%) but the longest 11.5s (fill pulse: 13%). The results of the tests are shown on Figure 5-4 and Figure 5-5.

Test results for irregular driver signal pulses are summarized on table 5-7:

The fiber burst for pulse equals to 1.5s. The resistance of the resistor changed about 0.8% during all tests. The damages of the fiber or EPA module have not been observed during the test.

Figure 5-4 The Pulse Time 0.1s.

Figure 5-5 The Pulse Time 1.5.

Impulse Time [s]	0.1	0.3	0.9	1.5
Resistor Resistance Before Test [Ohm]	250	250	249	248
Resistor Resistance After Test [Ohm]	250	249	248	248
Fiber Before Test	√	√	√	√
Fiber After Test	√	√	√	x

Figure 5-6 Irregular Fiber Test Results.

6 Spring measurement

The load of the EPA spiral spring was verified to determine the load on the fiber and mirror during the fiber burn. The spring measuring system is shown on the Figure 3.15.

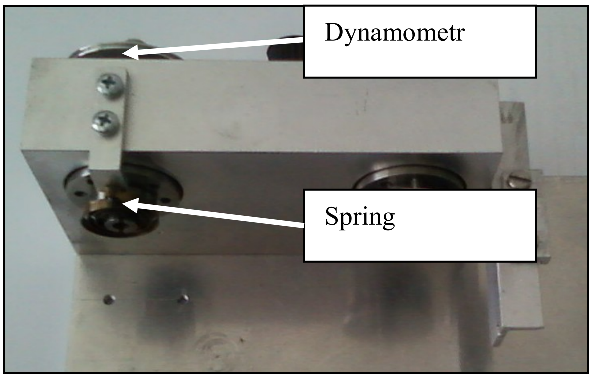

Figure 5-7 The spring measurement system.

The load from the dynamometer after winding of the spring is about 7.6 N. It produced the torque on the fiber of about **130Nmm.**

5. CONCLUSIONS

The EPA is devised as an emergency module in case of MPOI electrical and mechanical failure.
Long tests described in the paper were mainly dedicated to thermal aspects of the EPA behaviour.
The EPA passed successfully 5 vibration tests at the qualification levels and 2 shock tests according to the specification for MERTIS. During these tests EPA was placed in different models of MPOI. No damages and no self-release of mechanism were observed. Tests have shown that EPA is a resistant to vibration. The performed tests confirmed proper design and usefulness for of the EPA for the MPOI.

6. ABBREVIATIONS AND ACRONYMS

E (28V) – is a DC Power Supply,
V_1, V_2 – Channel V_1, V_2,
R_M (250Ω) – resistor,
R – is a resistor,
C – is a connected contactor.

7. REFERENCES

[1] Dyneema high – Strength, High Modulus Polyethylene Fiber, Supplier document, Issue 01-01-2008.