Cost Efficient Space Micro-Switches Based on Contactless Eddy Current Sensors

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Abstract

Micro-switches are frequently used in Space mechanisms to provide telemetry or to provide positive indication of the achievement of a desired position or function such as open, close, ready-to-latch, latched, end of travel, reference position, and for different mechanism applications.
Current switches that rely on electro-mechanical technology are not very reliable and are sensitive to mounting orientation, to thermal gradients, and have a limited number of operating cycles, which is a problem for long life application, launch vibrations and shocks loads.
Micro-switches relying on contact, as well as relay reeds, still provides additional resistive torque that must be overcome by the mechanism actuator, having a negative impact on the motorization margins.
In this paper CEDRAT TECHNOLOGIES presents the design and tests results of contactless micro-switch devices, based on Eddy Current Sensors (ECS) technology, and with embedded space-graded conditioning electronics. This development was achieved under ESA R&D space program, in order to develop Micro-switches devices not affecting reliability of mechanisms, not adding extra mass nor any resistive torque, and with the major objective of achieve very high cost-efficiency for space applications with large quantities, such as for New Space Constellations.
The design has been achieved for two sensing configurations, one for axial motion, and second for tangential motion. The test results of a batch of Engineering Qualification Models are presented for sensing precision, space environmental temperature conditions, launch vibrations and shocks tests, Spacecraft Electro-Magnetic Compatibility (EMC) tests , and radiation environmental tests up to 300krad.

Introduction

Since many years, CEDRAT TECHNOLOGIES (CTEC) is developing and qualifying miniature sensor technologies, in the field of fine space pointing and positioning applications, based either on strain gauges (SG) for piezoelectric mechanism, or Eddy Current Sensors (ECS) for magnetic ones.
ECS sensor technology is currently a major topic of interest, especially in the field of scan mirror mechanisms, fast steering mirrors (FSM), fine pointing mirrors (FPM and PAM), and in the field of reference sensor for proximity detection such as micro-switching and tachometer sensors, for either ambient or cryogenic space temperatures.
A most major topic of interest since few years leading to the increase of ECS technologies development is the field of new space applications such as giant constellations require ring very large quantities, with both high reliability and high cost-efficiency, for proximity detection in deployment mechanism. The maturation of CTEC ECS technology in that field was first started under CNES funding, and is then being continued under ESA funding, for micro-switching applications.

Figure 1. ECS based Micro-Switch sensor

Micro-Switches sensor design description

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Design and integration concept overview

Two Micro-Switches configurations have been designed in order to provide either axial detection or tangential detection, both having same housing and interface design, and each one having a dedicated sensor head configuration.
The sensing head is located at the tip of a cylindrical body which provides M16x1 fastening interface over the complete body length, and which also provides the housing for the embedded conditioning electronics. This design has been proposed in order to provide cost efficiency, as well as simple integration onto structures with precise sensing clearances adjustment, and easy electrical connection to distant power source with without requiring any additional sensor conditioner.

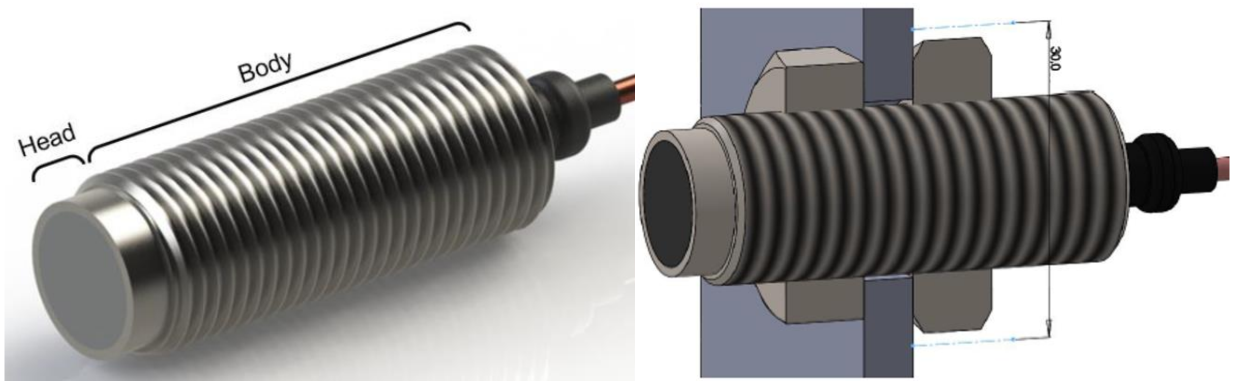

Figure 2. Micro-Switch design and integration concept

The following schemes illustrate the sensing principles for axial and tangential detection.

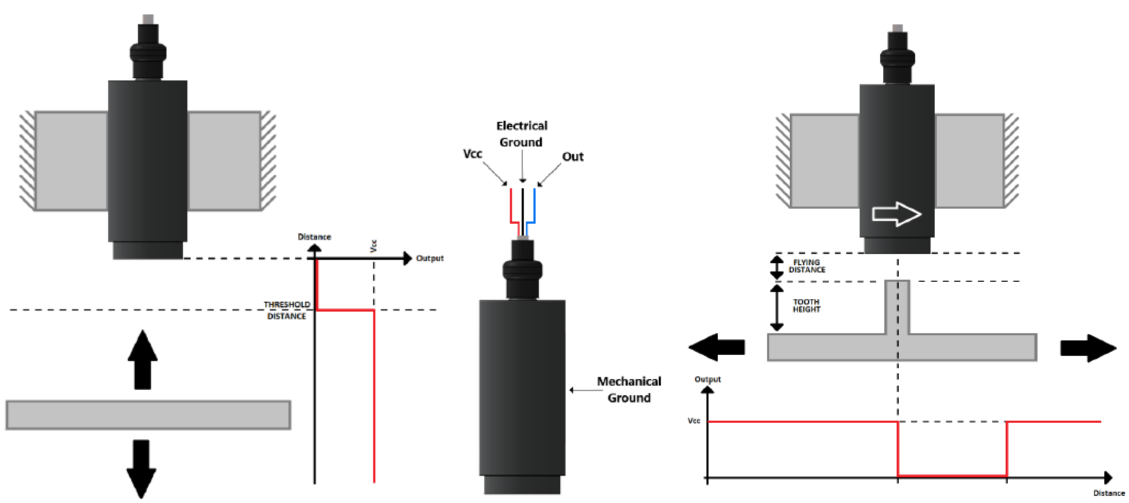

Figure 3. Axial motion Micro-Switch design (left) and tangential motion Micro-Switch design (right)

The sensor operates with a push-pull voltage output, which provides a digital output indicating the proximity of a target located onto a moving part.
In axial configuration, a high level (VOUT = VCC) means that the target is far from the sensor and a low level (VOUT = GND) means that the target is in front of the sensor.
In tangential configuration, the threshold location is in the axis of the sensor. An arrow indicates the target displacement direction to obtain a falling edge of the output. Then, there is a small zone where the output is low. On the opposite direction, this signal behavior can be used as an approach warning before the threshold location.

The figures here under illustrate the clearances without any other conductive parts than the target itself, to be adjusted at integration (red colors), at end of stroke of mechanism i.e. at mechanism motion stopping, thanks to the M16 fastening / positioning interface.

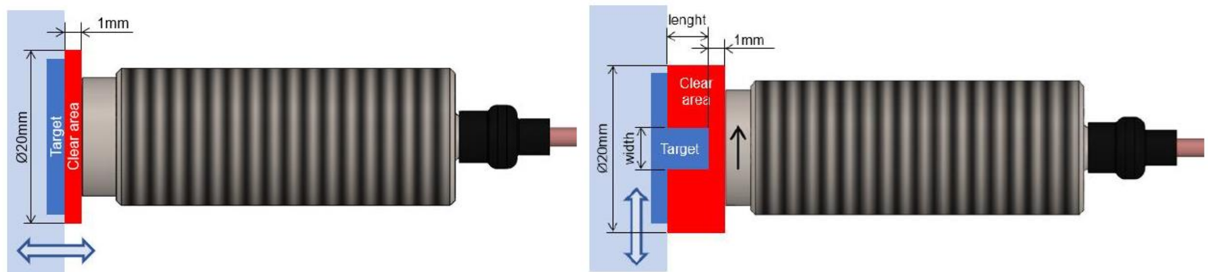

Figure 4. Micro-Switch proximity clearance for Axial motion (left) and tangential motion (right)

The cylindrical body of the sensor which ensures the fastening interface also provides the housing for the conditioning electronics, which will detect and quantify the inductance and resistance variations difference between two measurement coils, based on differential measurement principle. The void volume of the housing all around the electronics PCB is filled with potting, to avoid any air trapping for vacuum, to increase the sensor robustness against vibrations and shocks, and to provide a thermal heat sinking toward mechanical interfaces.
The major advantage of the differential measurement approach between two coils is the insensitivity to thermal variation of the environment, as the thermal drift is applied to the two coils with the same impact cancelled by when subtracted. The figure here under illustrates the architecture of the embedded conditioning electronics.

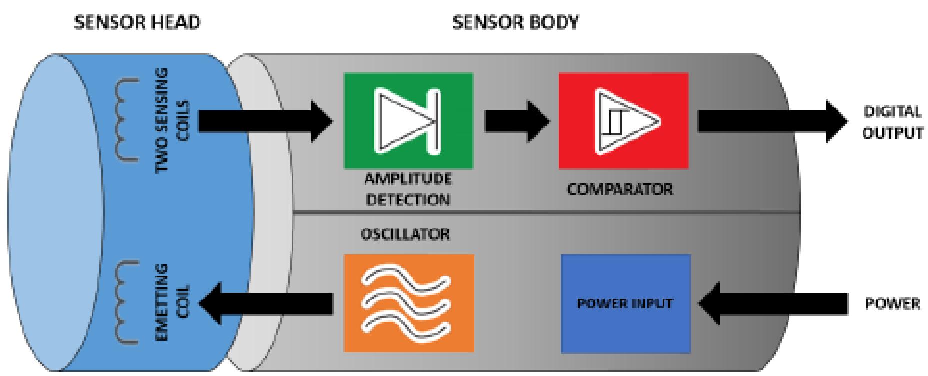

Figure 5. Micro-Switch embedded conditioning electronics

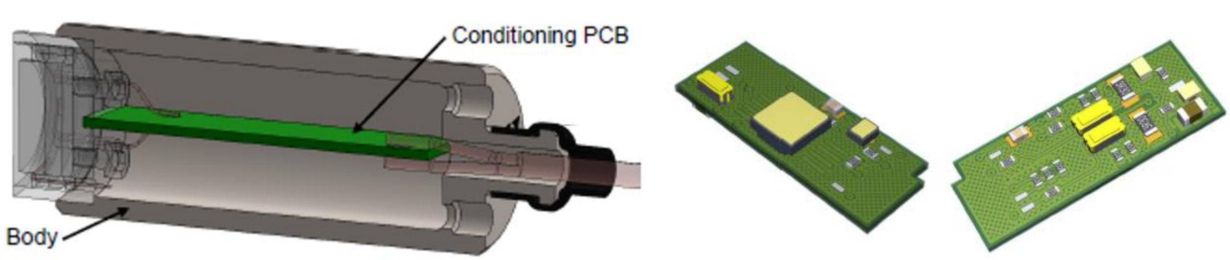

Figure 6. Micro-Switch embedded space grade conditioning PCB design

Both sensor head, sensor body, and conditioning electronics, are independent prior assembly, and can be modified separately. This feature gives the capability to have several configurations of the sensors without

impacting outer design and dimensions, in order to provide either tangential or axial motion detection of a distant target located onto a moving part.
With same overall design configuration, other sensing heads and conditioning electronics, can be re-defined on a custom way to fit with customer requirements, to provide specific threshold distances, and specific operational conditions from high to cryogenic temperatures.

Axial and Tangential sensing heads configurations

The sensing principle of the micro-switches proposed are based on eddy current measurement principle, requiring emitting and sensing coils implemented onto space PCB. The emitting coil generates Eddy currents on a distant target surface, with a small electrical excitation at high frequency, typically adjustable between 500kHz to 5MHz. This signal is based on Colpitts oscillator, the emitting coil being part of the current tank, in such a way that the emitting function requires a very low power to provide the required high frequency magnetic field oscillation.
According to Lenz's law, the direction of the Eddy currents induced on the target conductor by the oscillating magnetic field, generates an opposite magnetic field opposing to the emitted one, in such a way that variations are observed onto the sensing coil inductance values as function of the distance to the target.

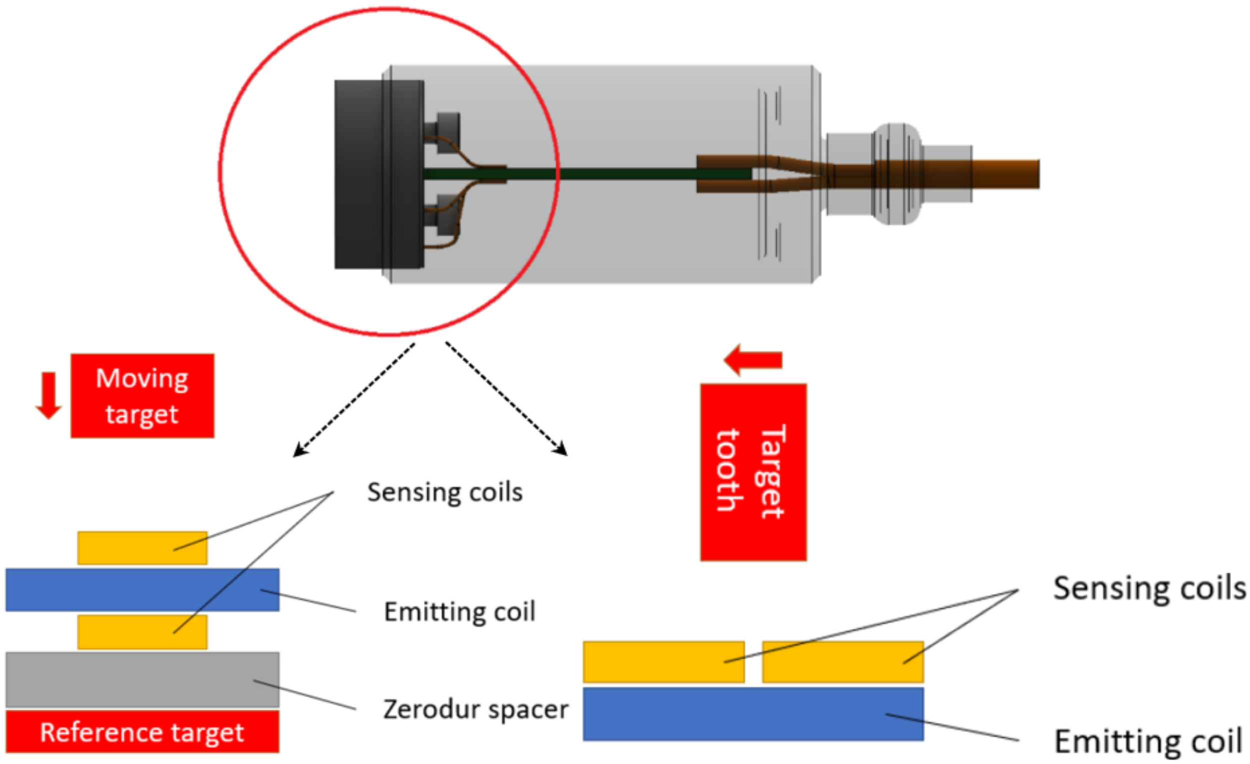

Figure 7. Emitting Sensing & Sensing coils configurations, Axial (left) and tangential (right)

Manufacturing of Engineering Qualification Models (EQM)

The project has allowed the manufacturing of a batch of four Engineering Qualification Models, two in axial motion detection, and two in tangential one. The pictures here under shows the space design achieved, with the space design of embedded conditioning electronics.

Figure 8. Batch of four Engineering Qualification Models

The embedded conditioning electronics has been designed and manufactured according to space grade standards, considering the PCB applicable design rules as well as materials. All active components included in the PCB are space Engineering Models.

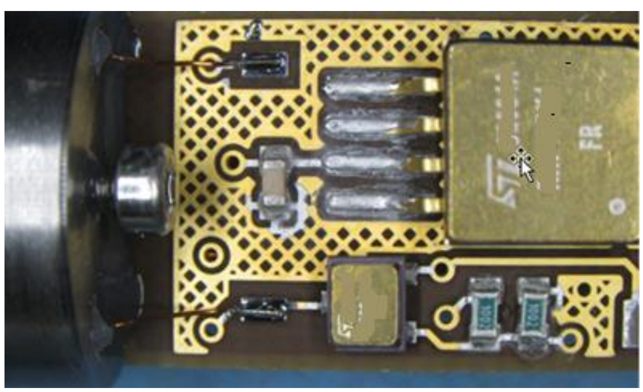

Figure 9. Space grade EQM Embedded Conditioning Electronics

The performance test bench has been realized, based on a commercial reference position sensor, and the use of a voice coil actuator implemented onto flexure bearings, in order to simulate a proximity motion of a moving part without friction.

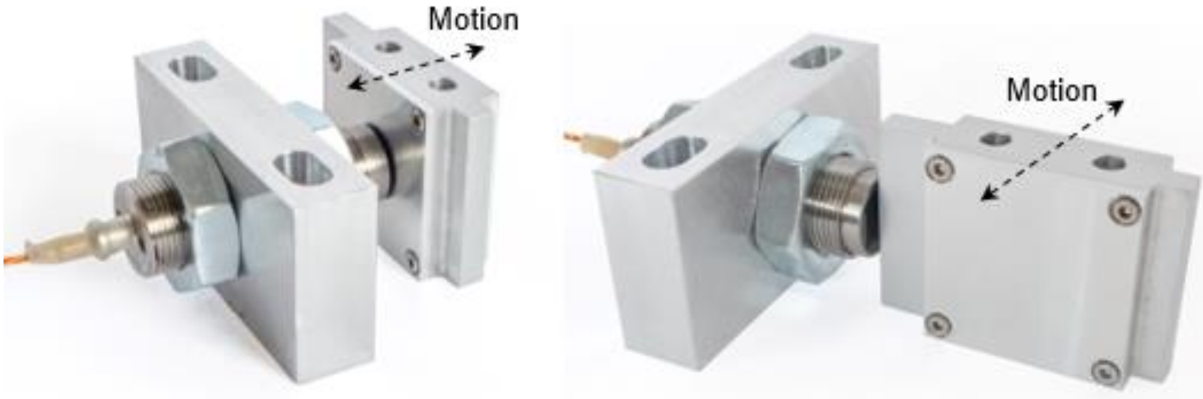

Figure 10. Sensing motion test bench principles, axial (left) and tangential (right)

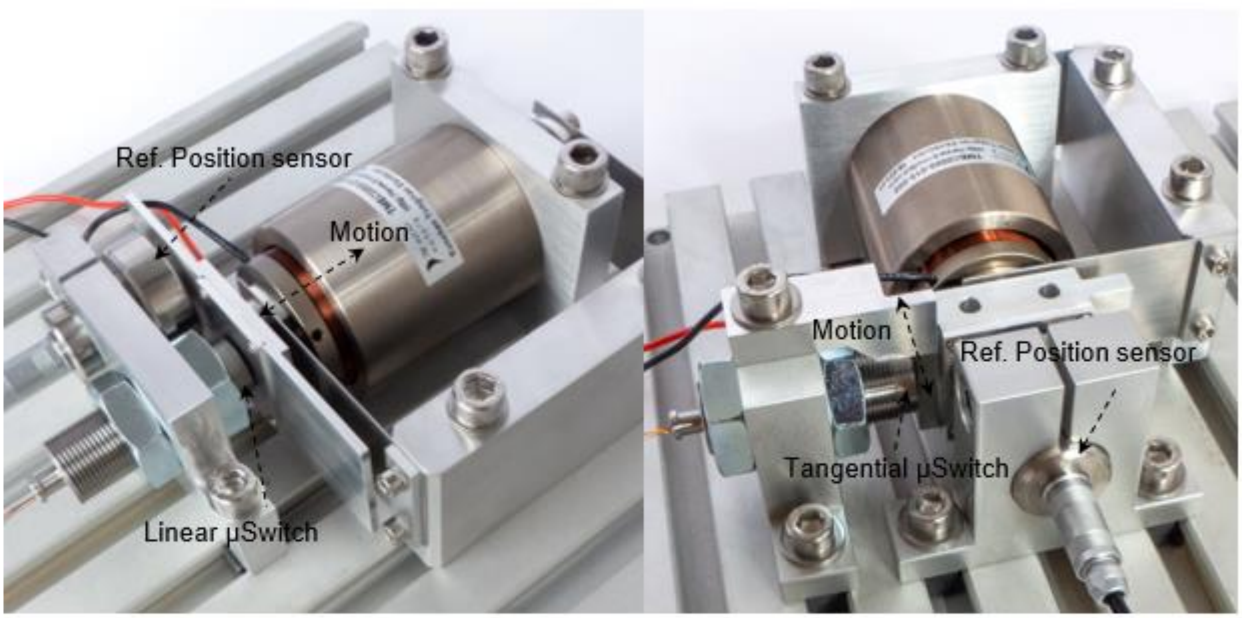

Figure 11. Sensing performance test bench, axial (left) and tangential (right)

The proximity detection principle has been successfully tested, with accuracy demonstrated lower than 100µm. The hysteresis error during cyclic forward and backward motions has also been evaluated to about 10µm, but do not need to be taken in account when using the micro-switch to detect end of stroke such as for deployment mechanism applications.

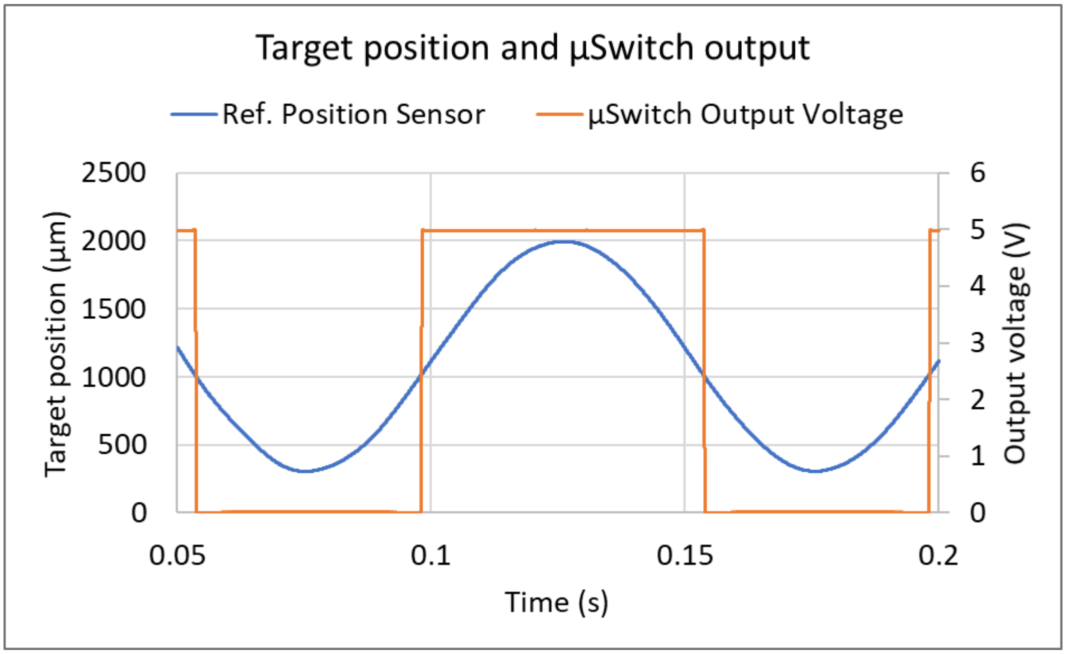

Figure 12. Sensing test results – Proximity detection

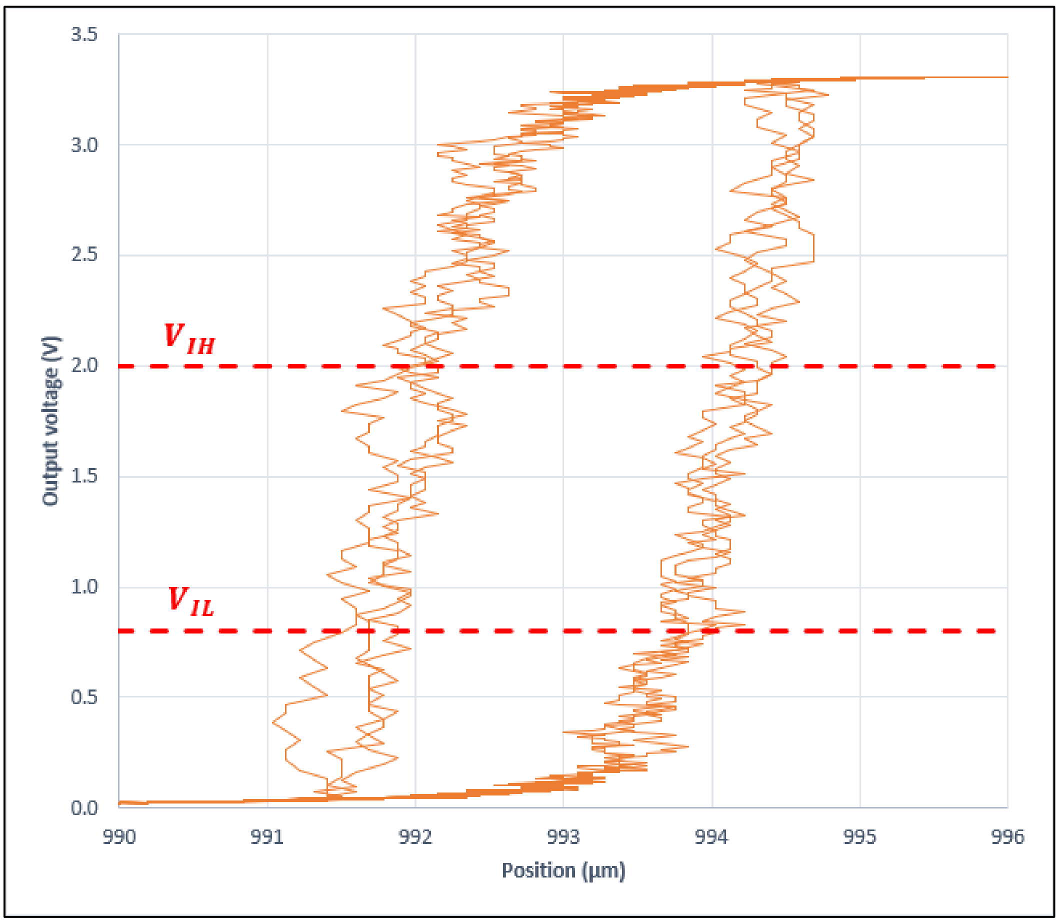

Figure 13. Sensing test results – Forward / backward Hysteresis threshold

The qualification test campaign covered various environmental requirements, such as vibrations, shocks, thermal variations, EMC Emission and Immunity (IEC 61-000), and irradiations up to 300krad.

The following table summarizes the performances of the proposed micro-switch design, as well as expected recurrent cost which is a key driver of this technology for new space applications.

	Axial configuration	Tangential configuration
Contactless Threshold distance (axial)	1mm	NA
Target flying distance (tangential)	NA	<500µm @3.3V <1mm @5V
Switching Function	Push-pull	
Switching level - High	Power supply	
Switching level - low	GND	
Power supply	3.3 or 5V DC	
Power consumption	<100mW	
Electrical interface	Pigtail with leads, up to 5m cable	
Repeatability	≤10µm	
Accuracy	≤100µm	
Response time	<1ms	
Mechanical interface / Overall dimensions	Ø16 x 45mm	
Mass	<50g	
Operating temperature	-50°C to +90°C	
Non-operating temperature	-60°C to +100°C	
Radiative environment	100 - 300 Krad	
Detections cycles	> 500 000	
On / Off cycles	> 1000	
Lifetime	< 22 years	
Outgassing	TML <1%CVCM<0.1%	
1st mechanical resonance	> 2kHz	
Mechanical random vibration	0,5 g²/Hz 60Hz to 400Hz	
Mechanical shock	1500g 1000Hz to 10000Hz	
Reliability	> 0.9999 with a confidence level of 95%	
Recuring cost per unit	< 6k euros for 10 units < 4k euros for 100 units	

Table 1. Micro-Switches functional performances & recurring costs summary tables

Conclusion and acknowledgments

The proposed micro-switch design has shown successful qualification performances, which should ensure a space commercial exploitation after this project. Qualification covers functional tests at ambient and operational temperatures, vibrations and shock environments, EMC and irradiation tests.

The maturation of CTEC space ECS technology was possible thanks to CNES and ESA support fundings, which have allowed the developments of relevant and compact sensing solutions in the field of fine pointing and fine positioning applications, which are currently being launched as off the shelf space product. The reader is invited to evaluate the application of CTEC ECS sensors technologies in the proposed references, especially in the field of new space applications, large size constellations, and pointing mirror mechanisms.

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