PASSIVE LEVITATING SUSPENSION FOR CRYOGENIC INSTRUMENTS

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ABSTRACT

A new cryogenic vibration isolator and thermal disconnect based on superconducting levitation is presented. A prototype has been designed, manufactured and tested for its potential implementation on a space instrument.

Cryogenic suspensions are usually made of bipods structure or tensioned straps. Therefore, through these suspensions, heat is easily conducted and microvibrations are gently transmitted. To overcome the limitation inherent to existing cryogenic isolators, a consortium led by MAG SOAR (LEVISOLATOR project under ESA contract number 4000115328/15/NL/HB) has designed and manufactured a contactless Superconducting Magnetic Suspension (SMS). This suspension is mainly composed of YBaCuO high critical temperature superconductors and a SmCo permanent magnet array. The lack of contact between parts makes this device to have zero thermal conductivity between ground and the suspended equipment. Additionally, a great vibration isolator is provided, damping can be customized and mechanical vibration power is dissipated exclusively in outer part – preventing heating of the Focal Plane Array (FPA). This contactless feature makes the SMS the perfect solution when heat plays an important role in, for instance, optical or electronic devices.

Component test results have showed that the technology is a promising candidate to hold future cryogenic space instruments. The results of the preliminary test at component level were according to expectations. The know-how acquired so far in the passive levitation technology could be applied to the design of suspension systems for cryogenic Focal Plane Array (FPA). An example of a mission utilizing a cryogenic FPA would be the planned X-ray observatory ATHENA

INTRODUCTION

High Temperature Superconductors in the mixed state are used to design mechanical devices such as journal bearings [1], linear bearings [2] and positioning mechanisms for cryogenic environments [3]. The superconducting magnetic suspension (SMS) described in this paper is mainly composed of a set of polycrystalline melt textured YBa2Cu3O7 disks manufactured by CAN SUPERCONDUCTORS. The envelope of each SMS component has a maximum diameter of 25 mm and a length of 60 mm.

In this paper, we present the results of the component test campaign in a relevant cryogenic environment which demonstrate compliance with the requirement specifications for vibration isolation (10% vibration transmissibility above 30 Hz) and thermal disconnect (<1mW). The component developed is going to be implemented to isolate input vibrations in a 12 kg FPA by considering four SMSs. Due to the lack of contact, magnetic mechanisms present several potential advantages for operation in cryogenic and space environments: no lubrication is required and there is lack of wear, no debris is generated, and they provide inherent overload protection among others [4-10]. In this case, tunable damping coefficient and the ability to prevent power dissipation in the core are worth it as well.

OBJECTIVE OF THE PROJECT

To develop a cryogenic vibrations isolator to minimize the sensitivity of a 12 kg Focal Plane Array (FPA) to external vibrations.

The vibration isolator and thermal disconnect can be scaled up and re-designed depending on the customer needs. The prototypes have been tested demonstrating compliance with vibration and thermal isolation requirements.

There are two important features of the proposed technology:

1) Isolate vibrations by a factor of 10 at 30 Hz. The expected transmissibility curve on radial direction for the 6 DOF system is depicted on the following figure (see black solid line). In this direction, there are three peaks which corresponds with the different modes of the suspended mass in that excitation direction. There are several modes that are not observed e.g. mode 2. This is justified due to the null mass participation of this mode in the radial direction. Additionally, it is observed the transmissibility curve for a single component by considering a 3% damping ratio (green line on Fig. 1).

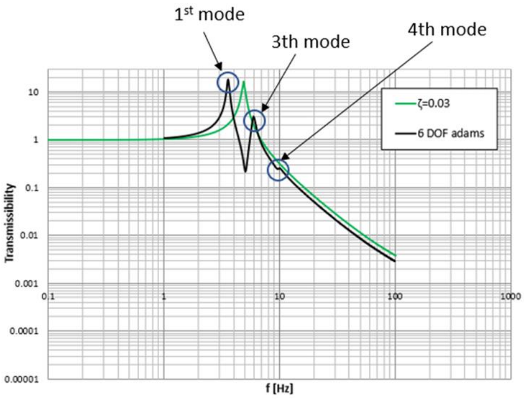

Figure 1: Expected transmissibility curve of the vibration's isolator for a 12 kg FPA

2) The proposed solution eliminates thermal conductivity between ground and the suspended equipment i.e. FPA. This contactless feature makes the SMS the perfect solution when heat plays an important role in, for instance, optical or electronic devices. In Fig. 2 it is observed the temperatures of the PMs shaft (blue solid line) and superconductors (orange line). It is observed that while the PMs remains at room temperature, the superconductors are cooled down up to 10.78 K. Hence, due to the lack of contact, thermal conductivity between ground and the suspended mass is zero.

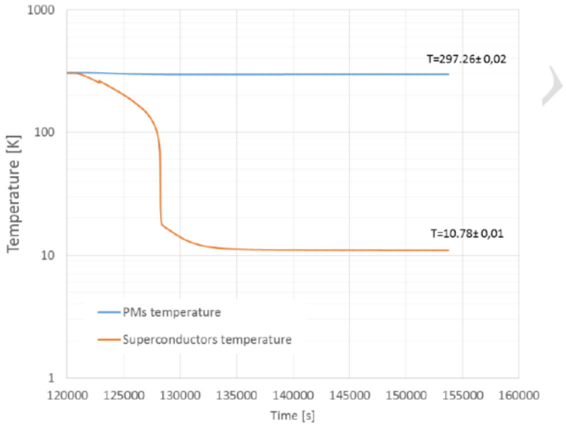

Figure 2: Thermal disconnect feature (zero thermal conductivity)

EXPERIMENTAL SET UP

In Fig. 3 it is presented the cryostat property of MAG SOAR used for component tests. Each component has been tested under high vacuum conditions (10-7mbar) and cryogenic temperatures. A thermal vacuum chamber equipped with a Cold Head model SRDK-4082D2-F50H, a scroll pump from Edwards model nXDS12i and a turbomolecular pump from Leybold model TurboVac 450i provides the cryogenic conditions for the breadboard tests. Inside the thermal vacuum chamber, a Voice Coil actuator from H2W technologies model VCS06-500-CR-01-MC with 1 micron resolution and 16 mm stroke is installed inside the vacuum chamber and moves the permanent magnets of the SMS. The actuator is equipped with a linear magnetic encoder from Renishaw with the same accuracy.

Figure 3: High Vacuum Chamber with 4 K Cryohead

A specifically designed magnetic shielding is installed minimizing the magnetic contamination of the Voice Coil Actuator and any kind of interaction with the bearing. To characterize the axial and radial forces a traction compression load cell with a measurement range of 50 N and 0.1% linearity error is rigidly connected to the Voice coil actuator on one side and to the permanent magnet arrangement on the other.
A PT100 sensor is mounted on the permanent magnet arrangement shaft and a silicon diode from Lakeshore model DT-760 is used to measure the temperature of the superconductor continuously. In Fig. 4 it is presented the main parts that form the testbench used for component test characterization.

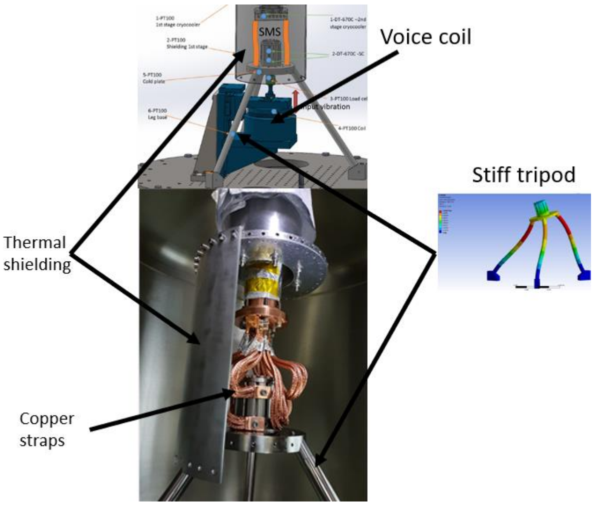

Figure 4: Test bench for axial characterization at 15 K

COMPONENT EXPERIMENTAL RESULTS

Four SMS specimens have been manufactured and tested (see Fig. 5). These specimens are responsible for vibration isolation and thermal disconnect of the 12 kg FPA.

Figure 5: Four SMS specimens that will be combined to support the 12 kg FPA

The experimental characterization campaign is based on the quasi-static motion of the permanent magnet arrangement in the axial and radial direction of the SMS keeping the superconductors rigidly connected to the ground. In a first step, the superconducting bearing is assembled and the superconductors are field cooled in position. Once the process has been completed, a new temperature is set up and established and the whole process repeated.

AXIAL CHARACTERIZATION TESTS

The SMS have been designed for working in two different scenarios:

1) Orbit scenario: The FPA is located in its orbit position i.e. $Z_{min} = 0$ mm.
2) Ground scenario: The displacement of the 12 Kg FPA due to gravity shall be less than Z_{max} =3.5 mm in axial direction.

Taking these two scenarios into account, the load capacity (LC) of the superconductivity bearing has been defined as:

$$LC = \frac{F_{max} - F_{min}}{2} \qquad (1)$$

being F_{max} the force corresponding with Z_{max} and F_{min} the force corresponding with $Z_{min.}$ The equivalent stiffness (K_{eq}) of the component is defined as:

$$K_{eq} = -\frac{F_{max} - F_{min}}{Z_{max} - Z_{min}} \qquad (2)$$

Hence, in Fig. 7, force and stiffness vs. temperature from 90 K to 12K is depicted. When decreasing the temperature, it is observed that the force increases from 90 K to 30 K. Below 30 K, the force and stiffness remains constant. Therefore, the component reaches a stationary state of force and stiffness at temperatures below 30 K.

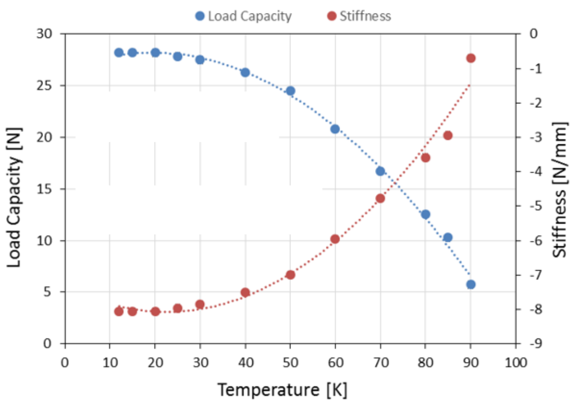

Figure 6: Axial load capacity and stiffness vs. temperature. Red dots- Stiffness variation vs. temperature. Blue dots- Force variation vs. temperature.

DAMPING

To characterize the damping ratio of each component, a free oscillation test was carried out. For doing so, a new test set up was designed, manufactured and tested in order to characterize the behaviour of the SMS (see Fig. 8).

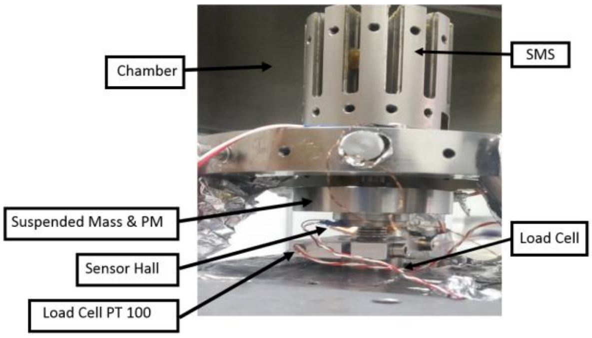

Figure 7: Free oscillation test for damping ratio characterization.

Initially, the suspended mass attached to the PMs was positioned by using a voice coil actuator. Once the SMS reaches the target temperature of 15 K, the voice coil actuator was switched off, therefore the suspended mass was free to move and to position (after stabilization) in the static position of equilibrium. In the following figure it is observed the displacement variation of the suspended mass vs time.

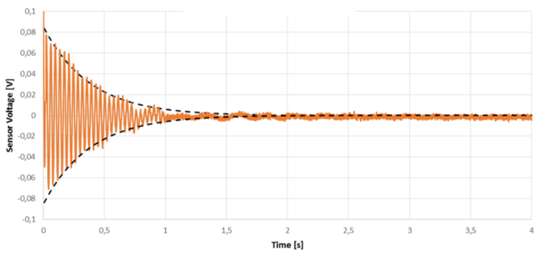

Figure 8: Displacement vs time of the suspended mass. It is observed that after a sudden event the system is stabilized in its equilibrium position.

CONCLUSIONS

In this paper a contactless Superconducting Magnetic Suspension (SMS) has been presented. The lack of contact between parts makes this product to have zero thermal conductivity between ground and the suspended equipment.

The SMSs presents constant load and stiffness capabilities below 30 K. Damping can be customized and mechanical vibration power is dissipated exclusively in outer part– preventing heating of the suspended equipment.

MAG SOAR know-how and previous heritage allow to design a device capable of isolate vibration by a factor of 10 at 30 Hz and to eliminate thermal conductivity between ground and the suspended equipment such as FPA. The vibration isolator and thermal disconnect can be scale up and re-design depending of the desired suspended mass.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J. R. Hull, “Superconducting bearings,” Supercond. Sci. Technol., vol. 13, no. 2, 1999.

[2] J. L. Perez-Diaz, J. C. García-Prada, E. Diez-Jimenez, I. Valiente-blanco, B. Sander, L. Timm, J. Sanchez-Garcia-Casarrubios, F. Romera, and Heribert Argelaguet-Vilaseca, “Non-contact linear slider for cryogenic environment,” Mech. Mach. Theory, vol. 49, no. 7, pp. 308–314, 2012.

[3] J. Serrano-Tellez, F. Romera, D. Gonzalez-de-Maria, M. Lamensans, Heribert Argelaguet-Vilaseca, J. L. Perez-Diaz, J. Sanchez-Garcia-Casarrubios, E. Diez-jimenez, and I. Valiente-blanco, “Experience on a cryogenic linear mechanism based on superconducting levitation,” Mod. Technol. Space- Ground-based Telesc. Instrum., vol. II, 2012.

[4] Pérez-Díaz, J. L., García-Prada, J. C., Díez-Jiménez, E., Valiente-Blanco, I., Sander, B., Timm, L & González-de-María, D. (2012). “Non-contact linear slider for cryogenic environment”. Mechanism and Machine Theory, 49, 308-314.

[5] Pérez-Díaz, J.L., Diez-Jimenez, E., Valiente-Blanco, I., Cristache, C., Alvarez-Valenzuela, M.-A.,Sanchez-Garcia-Casarrubios, J., Ferdeghini, C., Canepa, F., Hornig,W., Carbone, G., et al. “Performance of Magnetic-Superconductor Non-Contact Harmonic Drive

for Cryogenic Space Applications". Machines 2015, 3, 138–156.

[6] Pérez-Diaz, J.L., Garcia-Prada, J.C., Valiente-Blanco, I., Diez-Jimenez, E. "Magnetic-Superconductor Cryogenic Non-contact Harmonic Drive: Performance and Dynamical Behavior". New Trends Mech. Mach. Sci. 2013, 7, 357–364.

[8] Pérez-Díaz, J. L., Valiente-Blanco, I., Cristache, C. (2016), "Z-Damper: A New Paradigm for Attenuation of Vibrations". Machines, 4,12.

[9] Perez-Diaz, J. L., Diez-Jimenez, E., Alvarez-Valenzuela, M. A., Sanchez-García-Casarrubios, J., Cristache, C., & Valiente-Blanco, I. (2014). "Magnetic Gearboxes for Aerospace Applications".

[10] J. Esnoz-Larraya, I. Valiente-Blanco, C. Cristache, J. Sanchez-García-Casarrubios, F. Rodriguez-Celis, E. Diez-Jimenez, J.L. Perez-Díaz,(2017), "Optimadrive: High-performance gears development for space aplications", Proc. ESMATS