Development of a compact active vibration isolator for cryogenic conditions

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Abstract

One of the key challenges for the Einstein Telescope, which is the targeted underground infrastructure to host a third-generation gravitational wave observatory [1], is the greatly improved sensitivity. In addition to an increased interferometer arm length of 10 km, a cryogenic system to cool the main optics down to 10-20 K and an advanced vibration isolation system are required to achieve this sensitivity. JPE and the Eindhoven University of Technology have jointly designed and developed an innovative cryogenic active vibration isolator (CAVI). The development is part of the Einstein Telescope Technologies (ETT) project, a public-private partnership of institutes and companies.

The concept is based on an inertial mass (seismometer) mounted on top of the isolated mass, which was earlier proposed and investigated by the Joint Institute for Laboratory Astrophysics for a single Degree of Freedom (DoF) [2]. Instead of using helicoil springs with inherent low-frequency internal mode shapes, and accurate temperature control for obtaining constant shear modulus at room temperature, a novel monolithic flexure-based straight guide mechanism is proposed for cryogenic conditions [3]. An adjustable gravity compensation mechanism is integrated for both the isolated and inertial mass, where the mechanism for the latter serves as stiffness compensation as well. By accurately measuring relative displacement between the two masses with a laser interferometer, an estimation is obtained for the absolute acceleration (at low frequencies), and the absolute displacement of the isolated mass (for frequencies above the decoupling frequency of the seismometer). By using this relative displacement and a cryogenic voice coil actuator in a feedback loop, the effective isolation frequency can be improved to 0.2 Hz compared to 6.7 Hz for an equivalent passive isolation system with similar parameters and an isolated mass of less than 1 kg. Both the attenuation of floor vibrations and the rejection of direct disturbances are significantly improved, and sub-Herz isolation is achieved.

The proposed compact and light weight design serves as a modular foundation for application in any orientation as part of a 6 DoF vibration isolation system that can be deployed in cryogenic and Ultra-

High Vacuum (UHV) conditions. A functional demonstrator has been realized and the experimental validation is going to start shortly to evaluate the ultimately achievable isolation performance. This paper elaborates on the working principle, design choices and initial results.

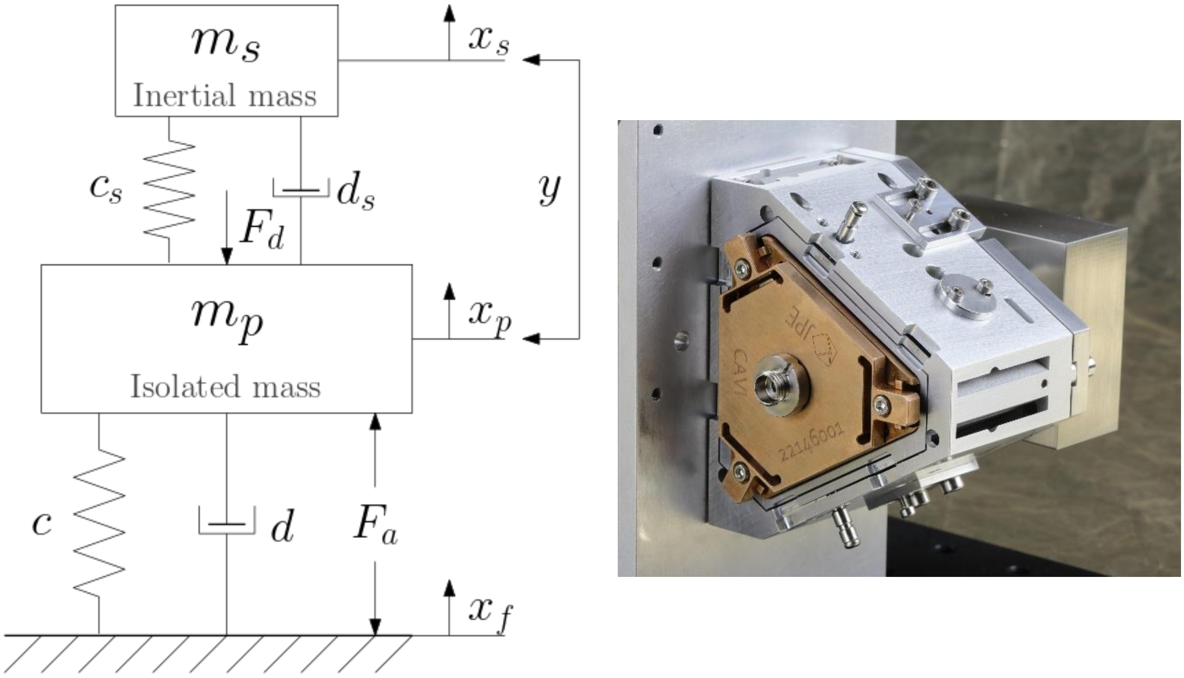

Figure 1. Schematic representation and realization of the cryogenic active vibration isolator (CAVI).

[1] http://www.et-gw.eu/ET (et-gw.eu)
[2] Nelson, P.G., An active vibration isolation system for inertial reference and precision measurement, *Review of Scientific Instruments*, vol. 62, no. 9, pp. 2069-2075, 1991.
[3] Struver, D.P.P., Design of a voice coil actuated active vibration isolator for cryogenic conditions, Master thesis, Eindhoven University of Technology, Netherlands, 2022.