Aerospace Science and Technology 45 (2015) 1–9

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Experimental study on on-orbit and launch environment vibration isolation performance of a vibration isolator using bellows and viscous fluid

Dae-Oen Lee, Geeyong Park, Jae-Hung Han *

Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, 291 Daekah-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form 2 April 2015
Accepted 18 April 2015
Available online 22 April 2015

Keywords:
On-orbit vibration isolation
Launch vibration isolation
Three parameter isolator
Transmissibility

ABSTRACT

Operation of various actuators on a satellite such as reaction wheels, cryocoolers, etc. produces micro-vibration which may have adverse effects on the performance of high precision payloads. In order to protect the high precision payloads from the vibration disturbances, vibration isolators are often applied in the vibration propagation path. Vibration isolators developed for on-orbit space application should be able to isolate micro-vibration when in orbit, and also withstand severe launch vibration environment. In this paper, on-orbit and launch environment isolation performance of a vibration isolator using bellows and viscous fluid is evaluated. For the on-orbit environment test, a test setup was prepared inside a thermal-vacuum chamber and the transmissibility of the vibration isolator was measured to examine the effects of on-orbit space environment on the isolation performance of the developed isolator. The isolation test performed in a vacuum condition revealed problems caused by the elongation of the bellows due to the pressure difference which were addressed by sealing the viscous fluid inside the bellows at a vacuum condition. The effect of temperature variation on the isolation performance was found to be confined to the narrow frequency region around the isolator's resonant frequency due to the isolator's three parameter configuration. This result implies that the isolation performance of a vibration isolator having temperature dependent damping can be made less sensitive to the temperature variation by implementing three parameter configuration. The developed vibration isolator is designed to survive large deformation without being permanently deformed to guarantee the structural safety of the isolator in the launch environment. The structural safety of the isolation system is evaluated through sine and random vibration and shock tests. The on-orbit and launch environment test results indicate that the developed isolator can provide effective isolation for the small amplitude vibration disturbances on-orbit and also survive the large amplitude vibration during launch without any damage.

1. Introduction

High precision payloads on board a satellite are exposed to vibration disturbances induced by the operation of various actuating components including reaction wheels, control moment gyroscope, thrusters, cryocoolers, solar array drives and other scanning components [1,11,14]. Although the vibration induced by the aforementioned sources is usually very small, even a micro-level vibration or jitter may cause serious degradation in the performance of high precision payloads [12,15,16]. In order to protect the high precision payloads from the vibration disturbances, vibration isolators are often applied in the vibration propagation path. Several vibration isolators utilizing viscoelastic materials have been developed for space application including advanced X-ray Astro-Physics Facility (AXAF [18]), James Webb Space Telescope (JWST [4]) and satellite ultraquiet isolation technology experiment (SUITE [1]). Viscous isolator called D-strut [7,9,20] has been developed and applied in various space programs including isolation of reaction wheel assembly in Hubble Space Telescope (HST [8]), vibration isolation and suppression system (VISS [5]) and miniature vibration isolation system (MVIS [17]).

Vibration isolators developed for on-orbit space application should be able to isolate micro-vibration when in orbit and also withstand the severe launch vibration environment. Because the space environment is very different from the environment where the ground tests are performed, on-orbit isolation performance could be significantly different from those evaluated through the ground tests. The material properties of commonly used viscoelas-

* Corresponding author. Tel.: +82 42 350 3723; fax: +82 42 350 3710.
E-mail address: jaehunghan@kaist.ac.kr (J.-H. Han).

http://dx.doi.org/10.1016/j.ast.2015.04.012
1270-9638/

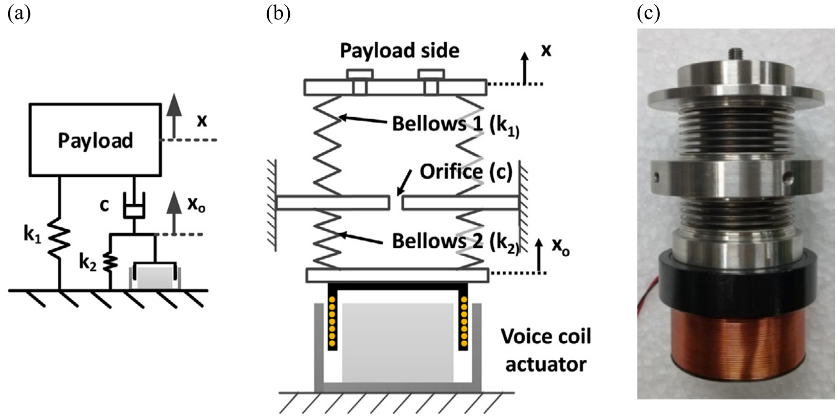

Fig. 1. Schematic of the vibration isolator.

tic materials and viscous fluids are heavily dependent on temperature, and vacuum environment can also cause changes in the material properties through outgassing. Although flight qualification tests have been performed on previously developed vibration isolators, the effect of space environment on the isolation performance is usually stated in changes of material properties and more complete information such as measured transmissibility has not been presented.

In this paper, the effects of thermal-vacuum environment on the isolation performance of vibration isolator using bellows and viscous fluid are examined experimentally in terms of the measured transmissibility. A test setup is prepared inside a thermal-vacuum chamber which allows the measurement of transmissibility of the isolator in thermal-vacuum environment. By using the test setup, problems caused by the elongation of the bellows due to the pressure difference in vacuum environment were observed. This problem was addressed by sealing the viscous fluid inside the bellows at a vacuum condition. The effect of temperature variation on the isolation performance was also observed and the test results show that the changes in isolation performance are confined to the narrow frequency region around the isolator's resonant frequency which is due to the isolator's three parameter configuration.

In addition to the on-orbit environment test, launch environment test is also conducted to check the structural safety of the isolator under the launch loads. Some modifications are made to the bellows to reduce the maximum induced stress and to increase the yield strength of the bellows. With these modifications, the isolator can undergo large deformation without being permanently deformed. The on-orbit and launch environment test results indicate that the developed isolator can provide effective isolation for the small amplitude vibration disturbances on-orbit and also survive the large amplitude vibration during the launch without any damage.

The organization of this paper is as follows. In Section 2, a description of the developed vibration isolator is given including modifications made to the isolator so that the isolator may withstand large deformation without being damaged and maintain its isolation performance in a vacuum environment. In Section 3, on-orbit vibration isolation performance is analyzed experimentally in a thermal-vacuum chamber and the effect of temperature variation on the isolation performance is discussed. Section 4 deals with launch environment test, and summary and concluding remarks are given in Section 5.

2. Development of vibration isolator

A vibration isolation platform for reducing on-orbit micro-vibration developed by the author's research group includes passive three parameter isolator [3,6] made using bellows and viscous fluid (similar to D-strut) and the active components (voice coil actuators and force sensors). Because the vibration disturbances generated on-orbit are very small in amplitude, the isolator is designed to be sensitive to small motion. Bellows are used as a spring element and a fluid chamber which allows the sealing of viscous fluid at non-moving point thereby eliminating problems related to high friction between the o-rings used for sealing and the moving parts. The two bellows are connected using an orifice so that damping is induced as the fluid passes from one chamber to the other. One side of bellows 1 is fixed to the foundation through the housing and the other side is connected to the payload, while one side of bellows 2 is fixed to the ground and the other side is connected to the voice coil actuator. The passive components of this isolator can be represented by a spring and elastically supported viscous damper in parallel as shown in Fig. 1. By tuning the passive parameters (stiffness of the bellows and damping by the orifice), both the low resonance peak and the high roll-off rate can be achieved passively [3]. The transmissibility of the isolator without considering the active component is given in Eq. (1) where F_d is the disturbance vibration on the payload side, F_{tr} is the transmitted vibration to the foundation, m is the mass of the payload and s is the Laplace variable.

$$\frac{F_{tr}(s)}{F_d(s)} = \frac{c(k_1+k_2)s + k_1k_2}{mcs^3 + mk_2s^2 + c(k_1+k_2)s + k_1k_2} \tag{1}$$

The requirements for the isolation performance of single-axis passive isolator are: isolation cutoff frequency lower than 20 Hz (assuming 5 kg dummy mass) and the maximum amplification less than six. The isolator should not have any local mode below 200 Hz and should provide vibration isolation in frequency ranges starting from the isolation cutoff frequency and 200 Hz. The requirements for the multi-axis isolator is identical to the single-axis case except that the isolation cutoff frequency is increased to 30 Hz. This is because the stiffness of cubic hexapod in translational directions is $\sqrt{2}$ times larger than the stiffness of the strut used to form the hexapod [10]. Due to the three parameter configuration, isolator is expected to have a roll-off rate of −40 dB/dec.

Single-axis isolation performance evaluation test showed that the developed isolator possesses low amplification factor (about 2.11) and high roll-off rate (about −40 dB/dec) and the isolation frequency is around 20 Hz with a 5 kg dummy mass (the passive single-axis isolation test is more thoroughly discussed in Ref. [13]). Fig. 2 compares the measured transmissibility and modeled transmissibility of Eq. (1) where the parameter values have been determined from the experiment. The stiffness of the isolator is found to be larger than the stiffness of the bellows due to the presence of viscous fluid in between the diaphragms of the bellows.