Comprehensive Evaluation of Vibration Characteristics of A Micro Vibration Suppression Mechanism Using Magnetic Flux Pinning Effect

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Abstract

In recent years, image resolution required for space missions has increased dramatically. To achieve the resolution, it is necessary to prevent the transfer of vibration and heat generated from disturbance sources to observation equipment. To solve this problem, this paper proposes a mechanism that separates a mission part and a bus part, and passively controls the relative position using magnetic flux pinning. Authors construct a system that simulates the proposed mechanism, conduct experiments to apply small vibration disturbances to the joints due to flux pinning and discuss the effectiveness of the proposed mechanism from the obtained vibration transfer characteristics.

磁束ピンニング効果を用いた非接触微少擾乱抑制機構における振動伝搬特性の総合評価

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摘要

次世代宇宙望遠鏡で要求される高い画像分解能の実現には、観測装置への微小振動擾乱と熱の伝播が問題となる。これに対し筆者らのグループでは、熱と振動の伝播を同時に抑制できる「磁束ピンニング効果を用いた非接触微小擾乱抑制機構」を提案している。今回の講演では、垂直・水平方向振動のそれぞれに対する振動伝播特性と，金属ダンパの導入による振動抑制効果について、実験により評価した結果を報告する。

1. Introduction

In recent years, image resolution required for space missions has dramatically increased. To acquire high resolution data, internal disturbances should be suppressed. Especially, internal vibration and heat isolation system is important for space observation missions. Conventional vibration suppression mechanisms such as Stewart Gough Platform (SGP) [1] have been researched so far. However, these methods have a problem to prevent from heat transfer. These mechanisms connect bus and mission parts with a structural material. Therefore, heat can propagate through these mechanisms. For future space observation missions, a mechanism that simultaneously suppresses vibration and heat transfer is proposed in this paper.

In this study, a "micro-vibration disturbance suppression mechanism using superconducting flux pinning effect" is proposed. The mechanism can separate mission and bus parts electromagnetically and passively control the relative position. For the mechanism, to "estimate feasibility", "suggest a design approach for a parametric study", and "verify the performance of the proposed mechanism" are important. The estimation and design approach have already been examined.[2] Therefore, vibration characteristics are evaluated experimentally in this paper. For simplification of the experiment, vibration transfer characteristics are measured for a pair of superconductor and permanent magnet. Moreover, although the actual internal vibration is a three-dimensional random vibration, the vibration in the experiment is divided into vertical and horizontal directions. The vertical vibration characteristics have already been

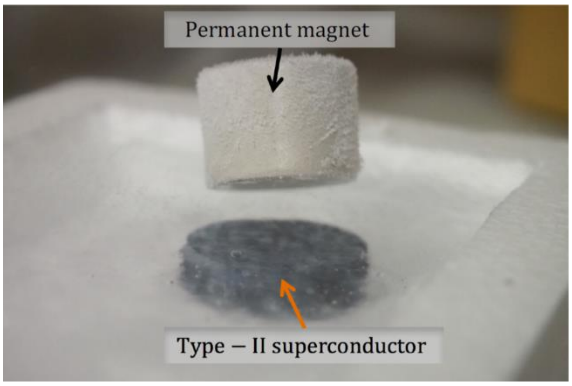


Fig.1 Magnetic flux pinning effect

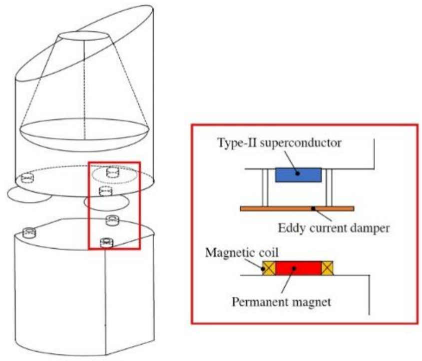


Fig.2 Micro Vibration Disturbance Suppression Mechanism

measured, and it was found that a model of the spring mass damper system can sufficiently characterize vibration characteristics of the proposed mechanism. Therefore, in this paper the vibration characteristics in the horizontal direction for the proposed mechanism were measured. In addition, the proposed mechanism is considering the introduction of an eddy current damper to enhance the damping force. Vibration transfer characteristics were measured with copper and aluminum dampers respectively attached, and the damper coefficient of the damper used in the experiment was numerically calculated.

2. Proposed mechanism

The proposed mechanism is composed of multiple type II superconductors, permanent magnets, eddy current dampers, and magnetic coils. It is a mechanism that separates the space telescope into a mission part equipped with a lens and a bus part equipped with various devices such as a cooling device. It controls their relative positions without a contact by the superconducting magnetic flux pinning effect. As shown in Fig. 2, the proposed mechanism mounts a superconductor in the mission part and mounts a permanent magnet and an electromagnetic coil in the bus part. The superconducting state is maintained by cooling the type II superconductor accompanying the cooling of the mission part.

The superconducting flux pinning effect is a characteristic phenomenon of the type II superconductor. When this phenomenon occurs, the permanent magnet is pinned in its initial position on the cooled superconductor, as shown in Fig1. The magnetic field lines of the permanent magnet are quantized and bound in the normal conducting part of the type II superconductor. As a result, the magnetic flux pinning force works so as to maintain the initial position with respect to the disturbance. It is considered that the mechanism has spring damper characteristics. The transfer function is calculated for this model, and an approximate curve is drawn along the measurement point. The experimental performance confirmation of the proposed mechanism has already been measured for vertical vibration. It can be seen the measurement points can be sufficiently approximated by the approximation curve of the model.

3. Research

Numerical analysis and simulations such as "mechanical modeling", "estimation of pinning force", and "case study for parametric study" have already been conducted. However, it has not been clarified how accurately these analysis results are compared with the actual measurement. Therefore, the purpose of this paper is to measure the vibration transfer characteristics of the proposed mechanism in an environment simulating zero gravity environment and compare the vibration transfer characteristics estimated using the analysis method of the previous study to evaluate the validity of the analysis method. Therefore, the analysis method used for the estimation will be described first, and then the details of the actual experiment will be described.

3.1 Analytical method

The motion of the proposed mechanism was modeled as a spring mass damper system. The motion of the mechanism was analyzed assuming that the pinning force is the spring force and the damper force is generated by the eddy current damper. The following explains the estimation of the spring constant and damping coefficient.

The pinning force was estimated using the mirror image method [3)]. The mirror image method is a method in which the SC surface in the superconducting state is estimated as a mirror surface and the pinning force is calculated by the interaction between the magnetic moment of the magnet and the magnetic moments of the Frozen image and Mobile image reflected in the mirror. The force calculated by this method was converted to the spring constant by differentiating the direction. And the eddy current damper force was estimated numerically. The magnetic field that penetrates the damper was calculated [4)] by simulating the PM as a solenoid coil with 100 turns and the damper coefficient was obtained.

3.2 Experimental system

In a simulated 0 gravity environment, a horizontal micro-vibration is applied and the vibration propagation characteristics were measured. A box with four neodymium magnets was hung with a fishing line like a pendulum. The box weights 0.124 kg. The box can be weighted up to 1.21 kg by attaching aluminum rods (Fig. 4). The length of the pendulum is 1.3 m. The magnet plays the role of the bus part in the proposed mechanism. The magnetic moment of the permanent magnet used is 0.6784 Am [2)]. The modal shaker was m060 and MA1 of IMV Co., Ltd., and a tank for liquid nitrogen was attached to it. The material of this box was a polycarbonate plate that can withstand the temperature of liquid nitrogen. The YBaCuO type-II superconductor is attached in this box and cooled by pouring liquid nitrogen into the tank. The type-II superconductor side corresponds to the mission part in the proposed mechanism. Displacements of the permanent magnet box and the tank were measured using laser rangefinders (KEYENCE LK-G405 and LK-G3000). Fig.3 shows the actual experimental equipment.

The experimental procedure is shown below. At first the initial relative positions of the permanent magnet box and the type-II superconductor was fixed at 6.5 mm. A 1.5 mm thick aluminum plate was inserted between them to fix their positions. After liquid nitrogen was poured into the tank and field cooling was performed for 1 minuet, the aluminum plate was removed. Horizontal vibration of a specific frequency was applied by the modal shaker and vibration states of the tank and PM box were measured by laser range finders. The above operation was repeated 3 times for each frequency.

In addition, vibration transfer characteristics with a metal damper installed between the superconductor and the magnet was also measured. In this experiment, a 0.5 mm thick copper plate and aluminum plate were used. Experiments were performed by applying vibrations of the frequencies shown in Table2 when the PM box was heavy.

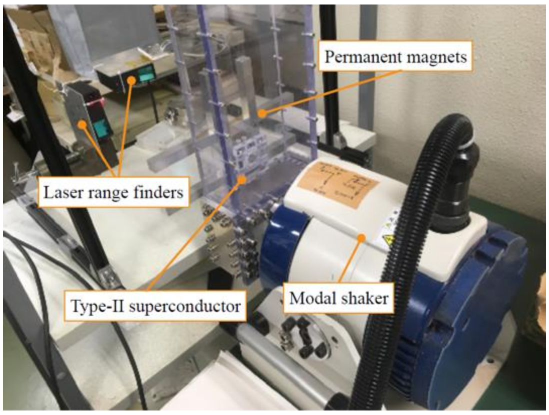


Fig. 3 Experimental equipment

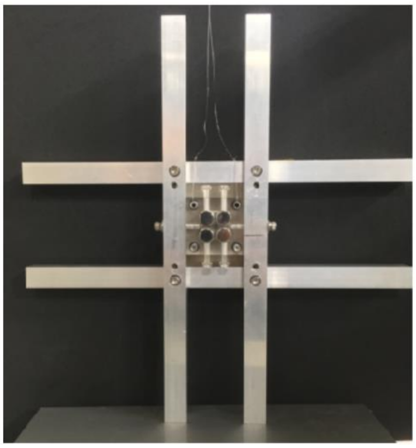


Fig.4 Permanent magnets box

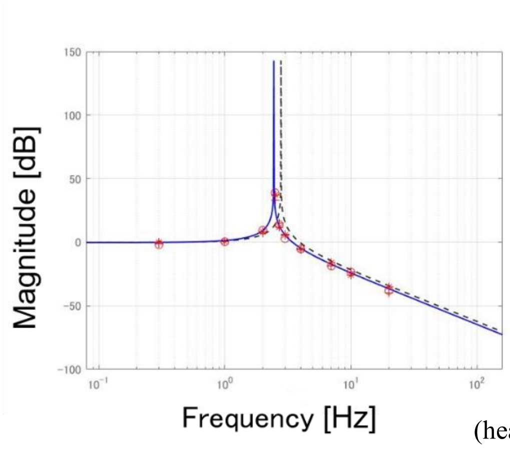
4. Results and Discussions

4. 1 Vertical and Horizontal vibration transfer characteristics

An approximated curve was drawn for the measured values and compared with the estimated vibration characteristic curve by modeling. Since the damper force in the flux pinning state is smaller than the spring force, it was assumed that the damper coefficient was 0 in the estimation. Fig. 5 and 6 show the horizontal vibration transfer characteristics. In both cases, a vibration suppression effect was observed for high-frequency vibrations above 10 Hz. In addition, a comparison of the estimated and measured Bode plots showed a deviation in the resonance frequency. This deviation has a relative error of almost 10%, and a rough estimation could be made by the mirror image method. Also, as the cause of the deviation, when the distance between SC and PM was changed by 0.5 mm and re-estimation was performed, the relative error was greatly reduced. Since the error in the 0.5 mm interval can occur sufficiently due to the distortion of the experimental device that occurs during cooling in this experimental system, it is considered that the cause of the deviation is the error in the SC and PM interval.

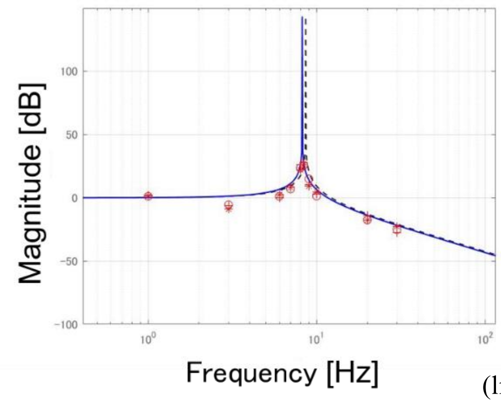
4. 2 Influence on vibration characteristics by introducing metal damper

Figures 7 to 10 show the results of the vibration characteristics with a 0.5 mm thick copper plate (Cu) and aluminum plate (Al) between the superconductor and the permanent magnet. It was found that the resonance intensity was reduced by introducing a metal damper in both Cu and Al. Also, since the outline of the Bode diagram did not change significantly with or without the damper, it was found that the pinning state was not affected by the metal damper. Therefore, It is considered that the eddy current damper is effective in the proposed mechanism. In addition, since the relative error due to the comparison of the resonance strength between the estimation and the actual measurement was 10%, it is considered that the estimation can be roughly achieved considering the measurement error. In order to evaluate the estimated damper force more accurately, it is necessary to measure the vicinity of the resonance point with high accuracy, and this is a future subject.



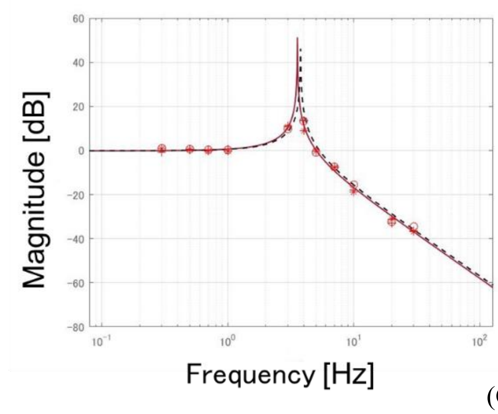
(heavy)

Fig.5 Horizontal vibration transfer characteristics



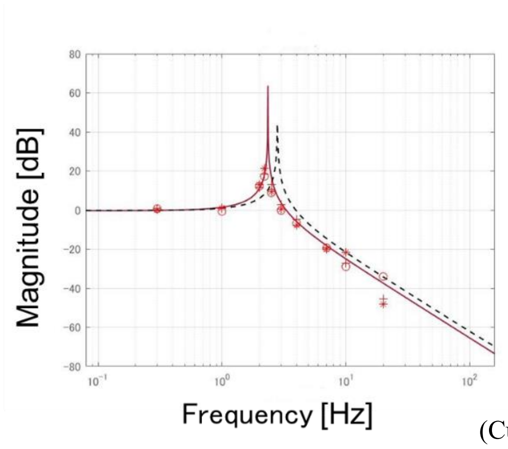
(light)

Fig.6 Horizontal vibration transfer characteristics



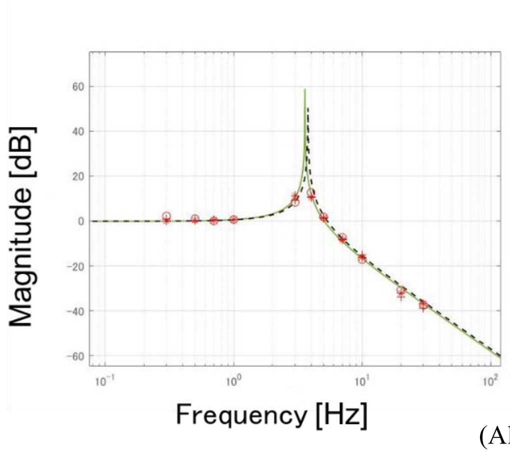
(Cu)

Fig.7 Vertical vibration transfer characteristics



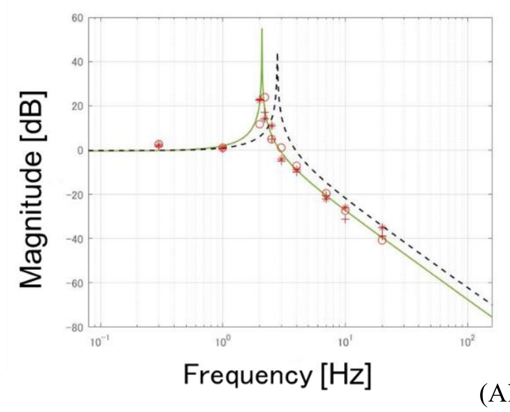
(Cu)

Fig.8 Horizontal vibration transfer characteristics



(Al)

Fig.9 Vertical vibration transfer characteristics



(Al)

Fig.10 Horizontal vibration transfer characteristics

5. Future works

In this paper, the fundamental vibration transfer characteristics of the proposed mechanism were clarified experimentally. As the future work, I will introduce pointing control by adding a "magnetic coil (MC)". I plan to conduct an experiment in three steps with the goal of verifying whether vibration can be suppressed while tilting the magnet box in the pointing direction.

First, the control force is measured. Since the repulsive force generated by diamagnetism in the superconducting state is used as the control force, it is verified whether the repulsive force is generated as expected by applying the external magnetic field in the pinning state. Moreover, since it is assumed that not only repulsive force but also attractive force is generated depending on the magnetic field direction of MC, the direction of the current is changed to verify experimentally. Secondly, the spacing between the superconductor and the permanent magnet is controlled using the repulsive force. I verify what kind of change in vibration characteristics will occur due to the interval control. Thirdly, two sets of "SC/PM/MC" are used to measure the vibration transfer characteristics while tilting in the pointing direction. I will demonstrate the feasibility of measuring the vibration characteristics and controlling the pointing direction for the future work.

6. Conclusion

In this paper, the basic performance of the proposed mechanism was evaluated by measuring the vibration transfer characteristics. From the measurement, it was found that the estimation methods and modeling by the spring-mass damper system that have been studied can express the vibration suppression performance of the proposed mechanism. It was also found that vibration suppression actually occurs in the high frequency band, and the resonance intensity can be improved by introducing a metal damper.

In the future, I will investigate the introduction of control using a magnetic coil and its effect on vibration transfer characteristics. A verification experiment will be conducted in three steps, and a demonstration experiment of pointing control using two sets of "superconductor, permanent magnet, magnetic coil" is performed.

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