OSCILLATION AMPLITUDE REDUCTION OF A HIGH-TC SUPERCONDUCTING LEVITATION SYSTEM BY AN ELECTROMAGNETIC SHUNT DAMPER COUPLED NONLINEARLY

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Abstract. An electromagnetic shunt damper, consisting of an electric circuit, can work as a kind of dynamic vibration absorber for a mechanical system. It can convert a portion of mechanical vibration energy into electricity, and the vibration amplitude of the main system can be reduced as a result. This energy conversion can be achieved by electromagnetic coupling and no mechanical contact is required. Thus, this damper is convenient for a superconducting levitation system where a magnet, the target of damping, levitates with no contact support. However, since the natural frequency of such a levitation system is commonly much lower than that of an electric circuit, it is difficult to tune the parameter values of both systems. In this research, we introduced a different type of electromagnetic shunt damper, which is nonlinearly coupled with a high-Tc superconducting levitation system. Our experimental results, showing successful suppression of vibration, verified the effectiveness of this type for reducing the required value of the circuit to one fourth of the conventional one through internal resonance.

1. Introduction

A high-Tc superconducting levitation system can levitate a magnet stably with no control and has the advantage that its energy loss is extremely small and there is no deterioration due to friction because there is no mechanical contact. On the other hand, since the damping of such a levitation system is small, the vibration amplitude of a levitated body tends to increase. As a result, there is a risk of vibration beyond the pinning limit of the superconductor, and of the quenching phenomenon in which the superconducting state is broken by heat generation. One of the ways of avoiding such risks is to use an electromagnetic shunt damper. It can reduce the amplitude of a levitated body by converting its mechanical vibration to the electric vibration of a circuit coupled with the main system electromagnetically. With this damper, the non-contacting characteristics of the levitation system can be maintained, because it can damp the vibrations of the target body in a non-contacting manner by means of electromagnetic force. However, the required values for the circuit elements become so large that it is difficult to realize them. Therefore, instead of such dampers, control is often utilized in many studies [1]. In this research, in order to operate the electromagnetic shunt damper with the advantage of non-control, we focus on the mechanism that can relax the conditions required for the circuit elements by using the internal resonance phenomenon caused by nonlinear coupling [2], We experimentally verify the amplitude reduction.

2. Analysis model with nonlinear coupling

In our analysis model, a magnet is levitated over a high-Tc superconducting bulk placed on a shaking table. A coil is attached to the levitated magnet so that they can vibrate together, while this coil is connected to a capacitor and a resistance, forming an electric circuit. When the superconducting bulk excited vertically, with the vibration of the levitated magnet, the coil moves in the static magnetic field generated by magnets with an iron yoke fixed around the coil. The electric circuit and the fixed magnets with the yoke stated above can work as an electromagnetic shunt damper suppressing vibration of the main system.

With this setup, there exists coupling between motion of the levitated magnet and fluctuation of the electric charge in the circuit. The electromotive force is induced in the coil during vibration, while the electromagnetic force is exerted on the electric current in the coil by the static magnetic field. Let x be the displacement of the levitated magnet seen from the shaking table, and q be the electric charge of the capacitor. The induced voltage in the coil is proportional to both the velocity of the magnet dx/dt and the magnetic flux density B, while the electromagnetic force is proportional to both the electric current dq/dt and the magnetic flux density B. These are coupling terms in the governing equations describing this electromagneto-mechanical problem. This coupling is linear with respect to x and q if the magnetic field is uniform in the moving region of the coil. However, in our analysis we assume the magnetic flux density B varies linearly with x, which can be given by arranging the opposite magnetic poles along x. With this gradient magnetic field, the coupling terms become quadratic, and thus the governing equations for x and q can be coupled through these nonlinear terms.

Now we consider that the natural frequency of the subsystem for q is close to twice that of the main system for x. According to the governing equations, once x starts to vibrate with its natural frequency, q also starts to oscillate with its natural frequency through the nonlinear coupling between them. This is called an internal resonance. In such a system, the vibration energy of the main system can be converted to the electrical energy of the subsystem, so the subsystem can work as a damper. The optimal design value for the product of the inductance L and the capacitance C can be reduced to one fourth of that for the linear coupling type.

3. Numerical calculation

Numerical calculations were carried out for the governing equations by using the fourth-order Runge-Kutta method. Obtained frequency response curves show that the amplitude of the main system is successfully reduced in the vicinity of primary resonance region, while the current oscillating at a frequency twice the excitation frequency is induced in the circuit. These results, indicating occurrence of internal resonance and conversion of the vibration energy to the electrical energy, predict effectiveness of the electromagnetic shunt damper using internal resonance.

4. Experiment

We carried out experiments by using a setup corresponding to the above model and by measuring the displacement and the electric current. Fig. 1 shows frequency response curves in a nondimensional manner. Fig. 1 (a) plots the amplitude of the excitation frequency component of the magnet vibration. It can be clearly found that the maximum amplitude near the primary resonance is reduced by 25.4% by using the electromagnetic shunt damper. It can be further confirmed from Fig. 1 (b) that the current oscillating at a frequency twice the excitation frequency is induced in the circuit when the excitation frequency is close to the natural frequency of the main system.

Conclusions

For the purpose of suppressing vibration of a levitated body in the high-Tc superconducting levitation system, this research focused on a method of using an electromagnetic shunt damper coupled nonlinearly with the main system. Our numerical calculations show occurrence of internal resonance and conversion of the vibration energy to the electrical energy, leading to effective reduction of the vibration amplitude. This numerical prediction was verified by our experiments using this type of electromagnetic shunt damper with reducing the required value of the circuit.

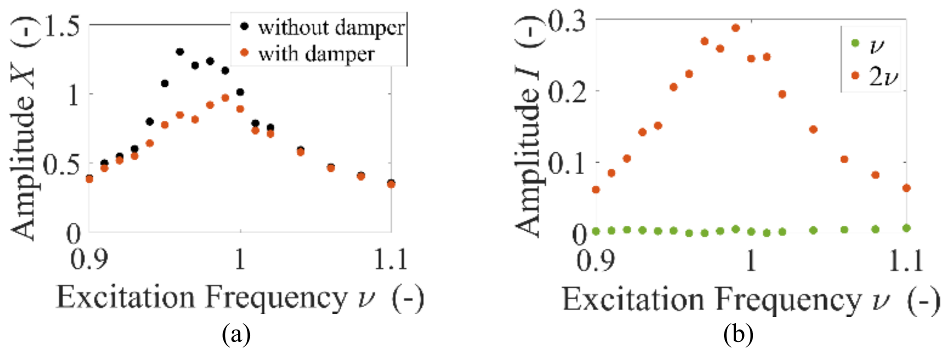

Fig. 1 Experimental results of nondimensional frequency responses: (a) levitated magnet; (b) electric current

References

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