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Optimal design and control of 6 degrees of freedom active vibration isolation system using voice coil motor

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Abstract
This paper represents a design and control of an Active Vibration Isolation System (AVIS). AVIS is widely used to isolate disturbance for precision measuring instruments like an AFM, STP and interferometer. These instruments are sensitive to disturbances that transmitted from ground and direct disturbance caused by environments in all six degree of freedom. The amplitude of vibration in low frequency region with micro-meter level hinders precision and accuracy of instruments. AVIS needs an actuator in order to actively isolate a 6 D.O.F vibration such as a VCM. The proposed VCM actuator is composed of permanent magnet array and coils. The permanent magnet array produces magnetic flux which can generate actuating force to isolate disturbances. Firstly, the proposed VCM actuator is designed and modelled. It uses back steel yoke and the Halbach magnet array to reinforce magnetic flux density. The Halbach magnet array has been developed in order to increase a flux density comparing with conventional NS magnet array. Secondly, in case of AVIS, payload is changed according to the types of instruments which can be isolated from other disturbance. Therefore, actuator should maintain uniform performance through payload change. The proposed AVIS is satisfied this condition through relative relation between the Halbach magnet array and coils in the VCM actuator. The length of coils is longer than magnet array so that VCM actuator handles different coil position according to payload variation. The optimal design procedure, to accomplish maximum force density, is performed considering constraints and cost function. It can generate uniform force for variable payloads. The AVIS needs two types of the proposed actuator, which are classified as direction of generated force like a horizontal and vertical actuator. Depending on actuator type, each of optimal procedures has different design variables. Finally, the proposed AVIS is manufactured and controlled. The manufactured AVIS is evaluated the isolation performance at 20Kg mass payload.

Active vibration isolation, AVI, Voice coil motor, VCM

1. Introduction

Precision equipment is required nano-meter level accuracy and used for measurement, examination, and manufacturing industries. For improving these machines, vibration control technology is one of the most important issues. Mechanical vibration, acoustic noise and ground vibration are major disturbances of hindering machine performance. Therefore, it is essential to develop an actuator for AVIS which can actively isolate disturbances.

2. Design of AVIS

Figure 1 shows the schematic of the proposed AVIS. The proposed AVIS is constructed of 4 passive isolators and 8 active isolators. Voice coil motor is designed for the proposed AVIS and used as active isolators.

VCM actuator which consists of magnets and coils is based on the Lorentz forces which take a role to isolating vibrations. For 6 degree of freedom AVIS, 2 types of actuators are needed through horizontal and vertical force generation direction. As shown in the figure 2 and 3, the proposed actuator structure is possible for various payloads. When upper payload is applied, magnet array is descended; however, coil length is longer than magnet array length. Thus, the proposed actuator can make uniform performances through various payloads. When magnet length is longer than coil length, similar effects can be obtained. However, the proposed AVIS is moving magnet type. The less moving mass weights, the less current needed. It is more efficient way for improving system performance.

The Halbach magnet array has been developed, in order to increase a force density than conventional magnet array [1].

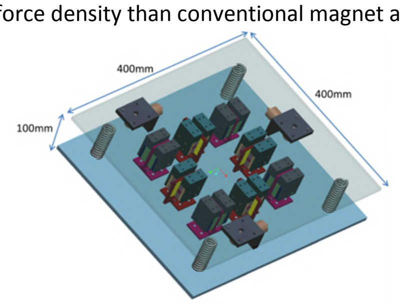

Figure 1. The proposed AVIS

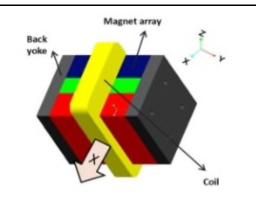

Figure 2. Horizontal actuator

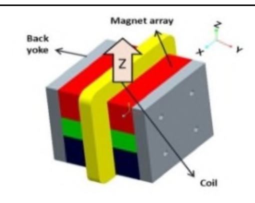

Figure 3. Vertical actuator

2.1. Modelling of Actuators

For optimizing the active isolator, we need to design the accurate model. Since the proposed actuator is structurally simple and only a few magnets are used, we choose the analytic model – surface current model is applied for modelling the system [2]. After the modelling of surface current, we can obtain its modified magnetic field by transforming of coordinates and superposition flux fields for applying the Halbach magnet array. We use iron back steel yoke behind magnet array and apply image methods to analyse yoke and magnet mutual reaction [3].

2.2. Optimization of Actuators

The proposed actuator design was targeted to maximize force density. Therefore, cost function of optimization is maximizing force. Main variables are magnet width, coil width, coil thickness and coil space. The main constraint is limitation for heat generation from coils. The total size is also constrained. Optimization was used for sequential quadratic programming (SQP) method in MATLAB. Figure 4 shows results of convergence of cost function. Figure 5 and 6 represent convergence of each actuator design variables.

By the results of optimization, total actuators size becomes 40×40×66mm (horizontal actuator) and 38×55×55mm (vertical actuator). The force constant of horizontal actuator is 15N/A and vertical one is 17.78N/A. These results were verified by FEM analysis.

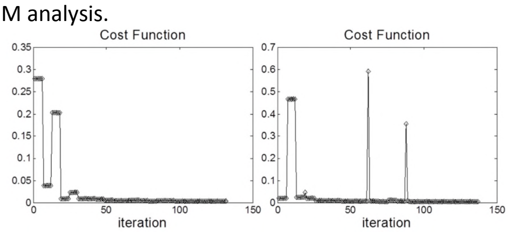

Figure 4. Convergence of cost function

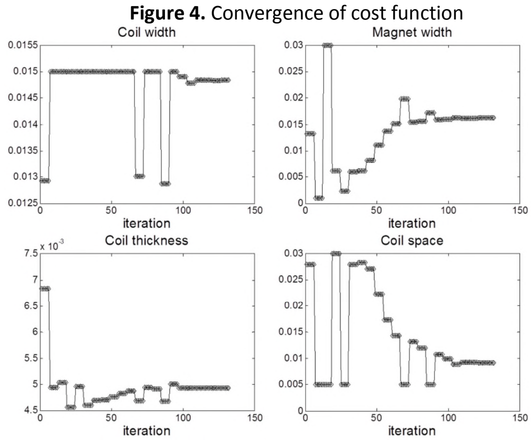

Figure 5. Convergence of design variables (Vertical)

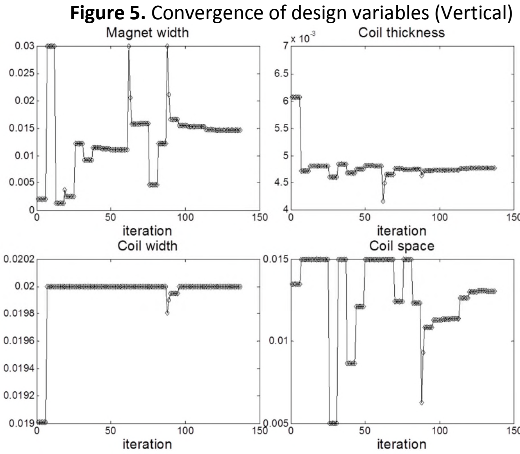

Figure 6. Convergence of design variables (Horizontal)

3. Manufacturing of proposed AVIS

The proposed AVIS was manufactured using the optimized VCM actuator and passive isolators. The dimension of total system is 400X400X100mm. The passive isolator is steel spring which has specific stiffness to maintain loads. The upper and lower plates were made of aluminium and other jigs were also aluminium. As mentioned before, the manufactured AVIS can produce uniform performance at the change of preloads. The manufactured AVIS could assure the performance when ±4mm vertical moves. Figure 7 represents manufactured whole system.

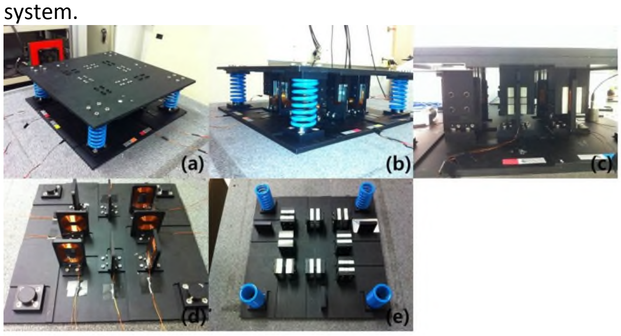

Figure 7. (a) view of system (b) side view (c) assembled voice coil actuator (d) coil assemble (e) magnet and spring assemble

4. Evaluating of manufactured AVIS

In order to evaluate the manufactured AVIS, 20Kg payload was applied on the upper plate. Through velocity feedback, PID controller was installed. Experimental setup was constructed by real time controller dSpace, linear current amplifier TA115, and accelerometer PCB393.

Figure 8 shows transmissibility of the manufactured AVIS. Compared with passive isolation, active isolation was operated well.

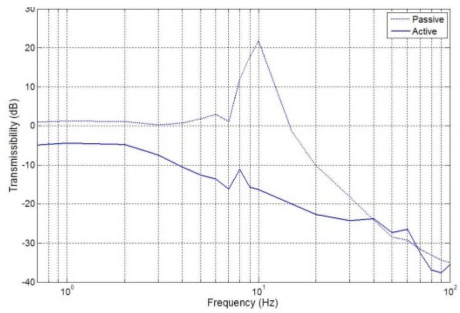

Figure 8. Transmissibility of AVIS @20Kg

5. Conclusion

In this paper, we designed novel type voice coil actuator for active vibration isolation system. The designed actuator has been modelled for obtain magnetic flux and optimized for maximizing force to control vibration. Finally, the AVIS was manufactured and basically evaluated at 20Kg. In the future, we evaluate the system performance with variable payloads and obtain the transmissibility for vibration isolating.

References

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