Development of Active Vibration Isolation System for Display Equipments

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초록

최근 반도체 및 디스플레이 산업 등에서 초정밀 가공, 측정 등이 필요함에 따라, 외란과 내부 진동을 차단하는 방진 시스템에 대한 연구가 활성화 되고 있다. 기존에 소개된 여러 방진 시스템 중에서 가장 많이 연구되는 공기스프링은 압축 공기를 이용하여 큰 하중을 지지할 수 있으면서 상대적으로 낮은 강성으로 낮은 고유진동수를 유지할 수 있다. 본 연구는 기존의 레벨링밸브를 이용한 수동 방진 시스템을 분석하여 이를 개선하고 디스플레이장비용 능동 방진 시스템을 설계하였다. 공기의 비선형 특성에 기인하는 복잡한 비선형 시스템 제어에 PID 제어기 보다 유리한 퍼지 제어기를 설계하였고, 실험과 해석을 비교하였다.

--------------------------------NOMENCLATURE--------------------------------

A effective area

C_r flow restriction constant

m_b mass flow rate of air into bottom chamber

m_p payload mass

m_t mass flow rate of air into top chamber

n polytropic exponent

P_b bottom chamber pressure

P_t top chamber pressure

Q_b volume flow rate of air into bottom chamber

Q_t volume flow rate of air into top chamber

V_b bottom chamber volume

V_t top chamber volume

x_b base displacement

ω_0 natural frequency

x_p payload displacement

1. Introduction

Vibration isolation system is mostly required to reduce vibration due to external disturbances and internal actuators in super-precision measurement and manufacturing system for semiconductor and display industry as shown in Fig. 1. In this paper, active vibration isolation system is developed using air-spring, both passive control and active control method are used. Fuzzy control method to be good at controlling complex and non-linear system is designed especially. [1) 2)]

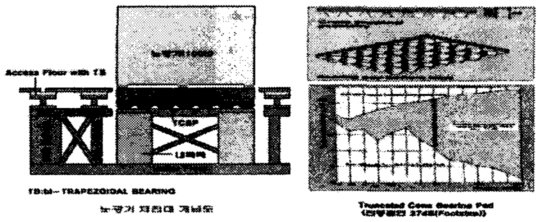


Fig. 1. Display equipment

2. Numerical simulation

2.1 Modeling of air-spring isolator

The modeling of air-spring isolator is shown in Fig.2 which uses two air chambers connected by a small orifice.[7) 8)] As the load-plate moves up and down, air is forced to move through this orifice, producing a damping to bevery strong for large displacement, while be weak for small displacement. This allows for fast settling of the payload, without compromising small amplitude vibration isolation performance. A payload which receives the load straightly and a diaphragm are also included in this modeling.

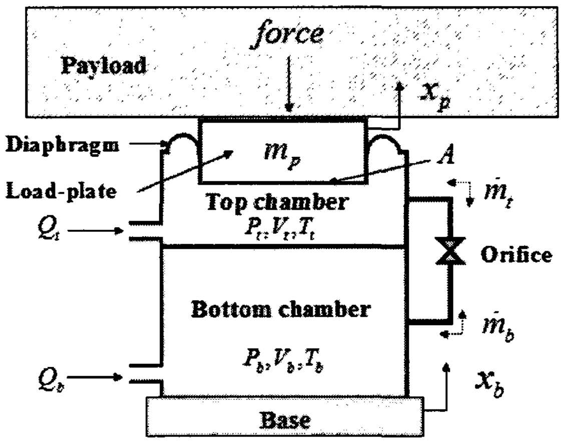


Fig. 2. Schematic diagram of air-spring

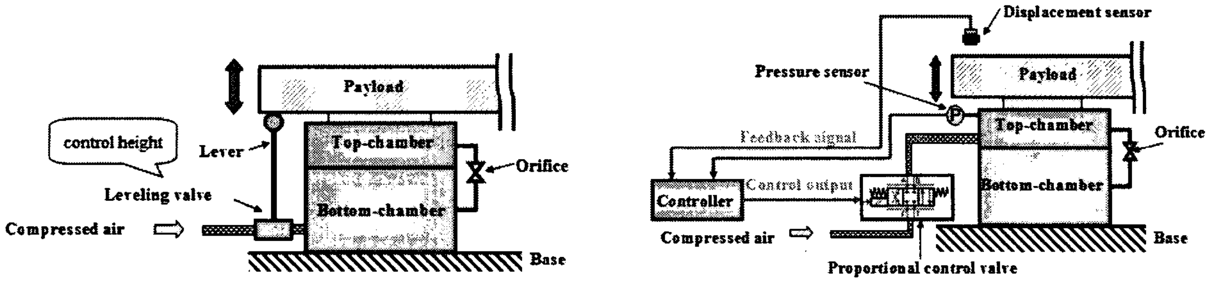
The natural frequency of air-spring isolator is given by

$$\omega_0 = \sqrt{\frac{nAg}{V}} \tag{1}$$

From Equation (1)[5)], we can conclude that the stiffness of the spring (and hence the natural frequency of a mass supported on the spring) is dependent upon the height of the spring (volume of air), but unlike steel coil spring, its natural frequency is nearly independent of the mass of the payload. Consequently, if the load is changed but the pressure is adjusted to bring the payload back to the same operating height, then the naturalfrequency remains constant which is highly desirable for vibration isolation table.

2.2 Passive and active control method

Vibration isolation control method can be divided into two kinds, passive control method and active control method. Both of the methods have been studied in using for controlling the vibration isolation table using air-spring.



(a) Passive control method (b) Active control method

Fig. 3. Schematic diagram of air-spring control system

(1) Passive control method

The schematic diagram of air-spring vibration control system using passive control method is shown in Fig. 3(a). The pressure in the isolator is controlled by a height control valve which senses the height of the payload, then always brings the payload back to the same operating height. But, because this method is dependent on the mechanical characteristic of leveling valve, it has some limitation such as large non-linearity of air-spring and being sensitive to disturbances which will cause various natural frequencies. Due to the four actuators of the vibration isolation table not moving together since no equipments to harmonize their motion, it could cause coupling problem for this system.

(2) Active control method

The schematic diagram of air-spring vibration control system using active control method is shown in Fig. 3(b). In the developed system, according to the large non-linear characteristics of air-spring, a feedback system with two loops is designed. Eddy current displacement sensor is used to measure the displacement of payload while pressure sensor is used to measure the pressure of the top chamber. All the feedback signals are introducedinto the controller and then the output signal is imported to the proportional control valve that could control the pressure of chambers because the top and bottom are connected by the orifice. A proportional control valve is a signal proportional to import and export volume of the pneumatic valves. It can be given for the importation of electrical signal proportional to the control pressure, flow and direction.

2.3 Fuzzy logic control

Fuzzy logic is much closer n spirit to human thinking and natural language than the traditional logical systems. Basically, it provides an effective means of capturing the approximate, inexact nature of the real word. Therefore, the essential part of the fuzzy logic control (FLC) is a set of linguistic control strategy based on expert knowledge into an automatic control strategy.

The advantage of fuzzy logic control can be summarized as follows. First, the control strategy is represented by multiple fuzzy rules, and thus it is easy to represent complex systems and non-linear systems. Second, the control strategy is modeled by linguistic terms and thus it is easy to represent the human knowledge. Lastly, fuzzy control is a kind of robust control that more than one control rule can be used.

Linguistic variables, such as small, medium, and big are used to represent the domain knowledge, with their membership values lying between 0 and 1. Basically, a fuzzy logic controller has the following components, and you can see the relation in Fig. 4.[6)]

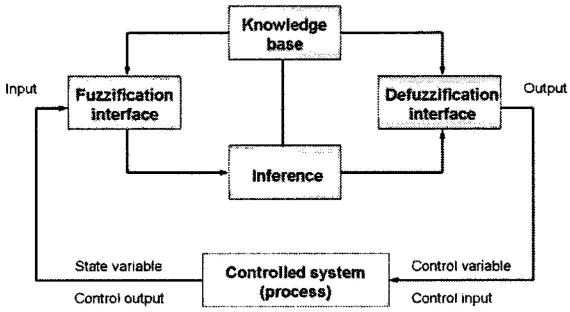


Fig. 4. Configuration of fuzzy control

Although fuzzy logic control is widely used for complex system and non-linear system, it is difficult to make the fuzzy control rules because it is dependent on expert experiences and engineering knowledge. And if you use too many fuzzy logic controllers, it will need expensive high capability signal processors. So in our study, in order to weaken the non-liner effect of air-spring, fuzzy controller is designed for controlling the pressure feedback loop, where the differenceof controlled displacement output and pressure output is defined as error, then both the error and the derivative of error are chosen as input variables while the input voltage of proportionalcontrol valve is its output. And MATLAB simulation with fuzzy toolbox is used. Table 1 shows the rule base for our fuzzy logic controller. NB, NM, NS, ZO, PB, PM, PS represent negative big, negative medium, negative small, zero, positive big, positive medium and positive small, respectively.

The air-spring modeling is made in AMESim software shown as Fig. 5 and then use the MATLAB S-Function to simulate the pressure control part of the system. We both use the PID controller and fuzzy controller in this part, and compare the results with that of no-control system shown in Fig. 6. We can see that although the fuzzy controller has big steady error which is not very important in air-spring, it could get better settling time.

Table 1. Rule base for fuzzy controller

e \ $\dot{e}$	NB	NM	NS	ZO	PS	PM	PB
NB	ZO	ZO	NS	NM	NM	NB	NB
NM	ZO	ZO	NS	NM	NM	NB	NB
NS	PM	PM	ZO	NS	NM	NB	NB
ZO	PB	PB	PM	ZO	NM	NB	NB
PS	PB	PB	PM	PS	ZO	NM	NM
PM	PB	PB	PM	PM	PS	ZO	ZO
PB	PB	PB	PM	PM	PS	ZO	ZO

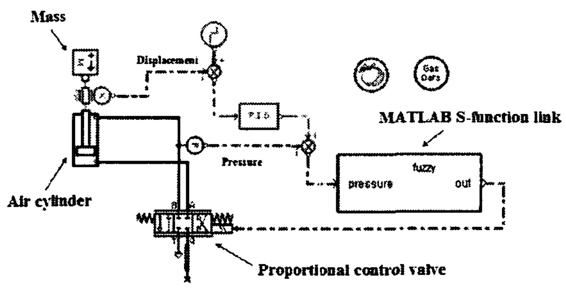


Fig. 5. Block diagram of air-spring control system using AMESim

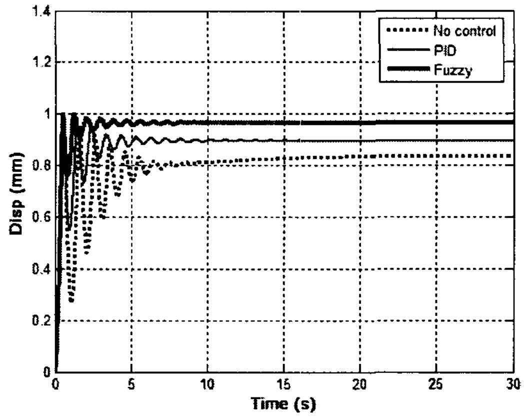


Fig. 6. Comparison among no, PID and fuzzy control results using AMESim

2.4 Active vibration isolation system

(1) Active vibration isolation modeling

In order to simulate the action of vibration system, we use the rigid body analysis Visual Nastran software to make a 3 degree of freedom modeling including z-dir, roll(θ_x) and pitch (θ_y), which is shown in Fig. 7. We use four actuators to drive the corresponding air-spring, but because this is a 3 degree of freedom system, two actuators should be made moving together as one.

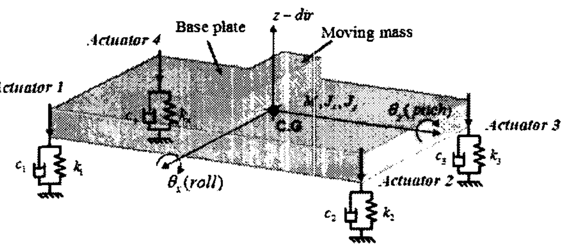


Fig. 7. Vibration isolation system modeling

(2) Active control system

According to the active vibration isolationsystem model, we use the interface between Visual Nastran and Matlab to make the control system. With four air springs involved, there are several vertical vibration modes of the table on the support system. But we consider the motions including vertical motion, pitch and roll. We should make the made-based control system shown as Fig. 8 according to the motion equations of three degree of freedom.[3] We first use the PID controller to control the displacement of each degree of freedom, and then both use the PID controller and fuzzy controller to control the pressure which is shown in the figure as air-spring controller. Let the moving mass which is 10% of the whole mass moving quickly, then we could simulate the active vibration isolation system and get the results that is shown in Fig. 9.

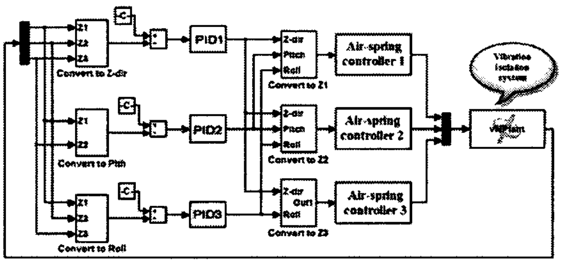


Fig. 8. Mode-based control system

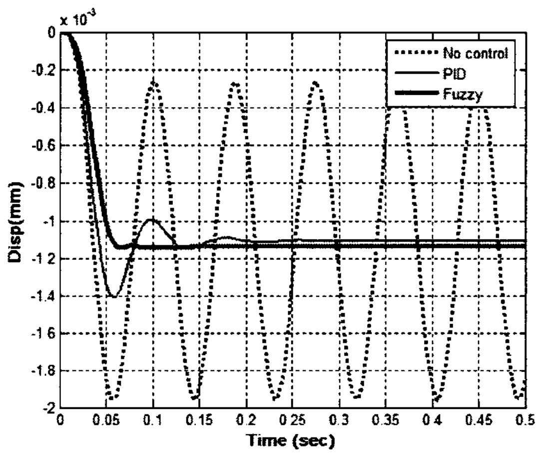


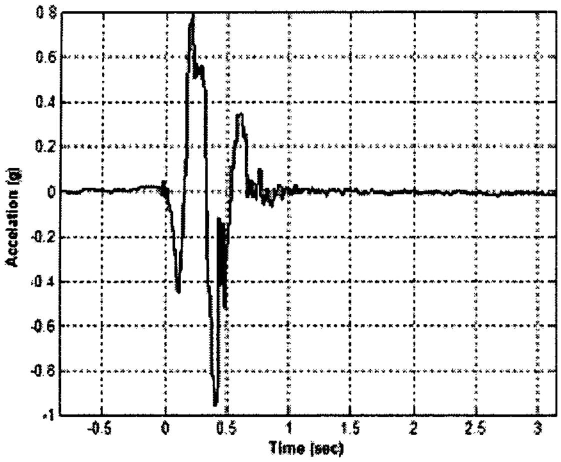
Fig. 9. Comparison among no, PID and fuzzy control results with moving mass

3. Experiment

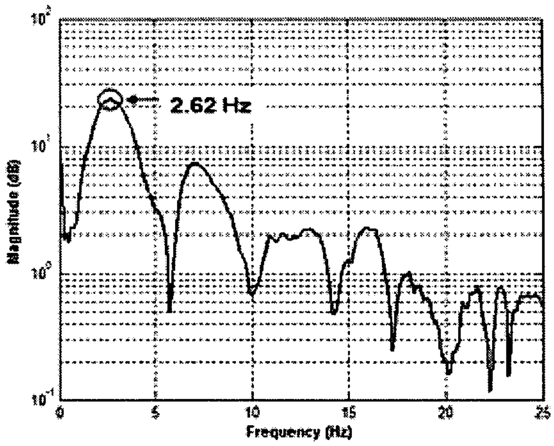
For each controller, after giving an impulse to the vibration isolation table on z-dir, we could get the impulse responses and power spectrum of the system. Table 2 shows comparison results of vibration isolation table, and Fig. 10shows the response of fuzzy control system. The developed vibration isolation using fuzzy controller is found to be very effective in view of natural frequencyand settling time.

Table 2. Vibration isolation table results

Control Method	Natural frequency		Settling time	
	(Hz)	effect (%)	(Hz)	effect (%)
Passive control	4.00	0.0	1.7	0.0
PID control (gain tuning 1)	2.38	-40.5	2.0	+17.6
PID control (gain tuning 2)	3.10	-25.5	0.9	-47.5
Fuzzy control	2.62	-34.5	0.9	-47.5



(a) Impulse response (z-dir)



(b) Power spectrum

Fig. 10. Response using fuzzy controller

4. Conclusions

In this paper, we have developed a vibration isolation system using for display and equipments, with good vibration isolation efficiency and effective position balance. Through numerical and experimental results, the developed control method using fuzzy controller has been verified to be the better effective.

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