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MFC 액츄에이터가 부착된 외팔 평판의 능동 진동 제어

Active Vibration Control of Cantilever Plate Equipped with MFC Actuators

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1. Abstract

This paper is concerned with the active vibration control of rectangular plate equipped with MFC actuators. To this end, the dynamic model of the rectangular plate bonded with MFC sensors and actuators was derived by means of the Rayleigh-Ritz method. The MFC actuator and sensor were modeled based on the pin-force assumption. The theoretical model was then validated experimentally. The multi-input and multi-output (MIMO) Positive Position Feedback (PPF) controller was designed based on the natural mode shapes and implemented using dSpace system and Simulink. The proposed control algorithm was applied to the cantilever plate having two MFC wafers having both sensor and actuator. Numerical and experimental investigations were carried out. Both theoretical and experimental result shows that the proposed control algorithm can effectively suppress vibrations of cantilever plate.

2. Dynamic Modeling of Plate

Let us consider a rectangular plate with side lengths a in the X direction and b in the Y direction. By using the assumed mode method, the kinetic and potential energies of the rectangular plate can then be expressed as

$$T_P = \frac{\rho_p hab}{2}\dot{\mathbf{q}}^{\mathrm{T}}\bar{\mathbf{M}}_p\dot{\mathbf{q}}, V_P = \frac{Db}{2a^3}\mathbf{q}^{\mathrm{T}}\bar{\mathbf{K}}_p\mathbf{q} \quad (1)$$

where $\mathbf{q}(t) = [q_1\, q_2 \ldots q_m]^{\mathrm{T}}$ is a $m \times 1$ vector consisting of generalized coordinates, in which m is the number of admissible functions used for the approximation of the deflection, ρ_p the mass density, h the thickness, $D = Eh^3/12(1-v^2)$, E the Young's modulus, and v the Poisson's ratio, $\bar{\mathbf{M}}_p$, $\bar{\mathbf{K}}_p$ are the non-dimensionalized mass and stiffness matrices, respectively. Refer to the reference(Kwak and Han, 2007) for the expression for those matrices.

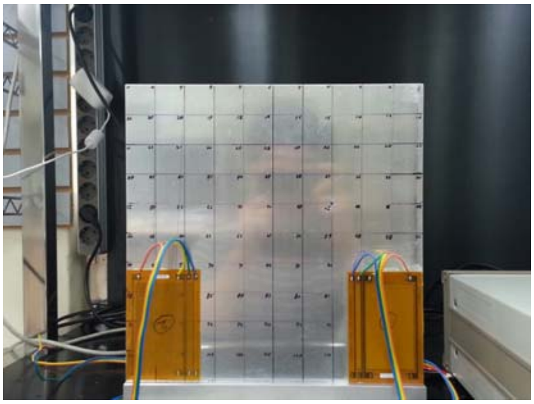

Fig. 1. Cantilever plate with MFC actuators.

3. MFC Actuator Modeling

Let us consider a cantilever rectangular plate partially submerged in a fluid as shown in Fig. 1 and assume that the free end of a plate is close to the bottom so that the effect of the fluid motion between the plate and flat bottom can be neglected. The fluid motion is represented by the fluid's velocity potential function and the fluid is assumed to be inviscid and irrotational. The governing equation for the fluid is the Laplace equation

$$T_Z = \frac{\rho_z h_z a_z b_z}{2}\dot{\mathbf{q}}^{\mathrm{T}}\bar{\mathbf{M}}_z\dot{\mathbf{q}}, V_P = \frac{D_z b_z}{2a_z^3}\mathbf{q}^{\mathrm{T}}\bar{\mathbf{K}}_z\mathbf{q} \quad (2)$$

where ρ_z the mass density, h_z the thickness, $\bar{\mathbf{M}}_z$, $\bar{\mathbf{K}}_z$ are the non-dimensionalized mass and stiffness matrices of MFC actuators, respectively.

Considering the kinetic and potential energy expressions given by Eqs. (1) and (2), the equations of motion for the plate equipped with MFC actuators can be written as:

$$\mathbf{M}_t\ddot{\mathbf{q}} + \mathbf{K}_t\mathbf{q} = \mathbf{B}_a\mathbf{v}_a, \quad \mathbf{v}_s = \mathbf{C}_s\mathbf{q} \qquad (3)$$

The above equations consist of actuator and sensor equations. If we resort to modal transformation, $\mathbf{q} = \mathbf{U}\mathbf{r}$, then we can obtain modal equations of motion.

$$\ddot{\mathbf{r}} + \mathbf{\Lambda}\mathbf{r} = \overline{\mathbf{B}}_a\mathbf{v}_a, \quad \mathbf{v}_s = \overline{\mathbf{C}}_s\mathbf{r} \qquad (4)$$

However, it is impossible to control all modes with the limited number of actuators and sensors.

4. Control Design

It is well known that the damping can be increased because of 90-degree phase shift if we tune the filter frequency of the PPF controller to the target natural frequency of the structure. In this study, we tried to control two lowest natural modes. Their natural frequencies are 18.4 and 45.6 Hz, respectively. Hence, we designed two PPF controllers for each natural frequency. The first natural mode is the bending mode so that its displacement is symmetric about the middle line. The second natural mode is the torsional mode which is axisymmetric about the middle line.

The two-input and two-output positive position feedback (PPF) controller was considered because there two sets of MFC actuator and sensor as shown in Fig. 1. Two lowest modes were chosen to be controlled since they have the largest influence on the vibration response. Since the first natural mode shape is symmetric and the second natural mode shape is axisymmetric about the middle line, the force influence matrix, $\overline{\mathbf{B}}_a$ also reflects the property of the natural mode shapes.

The MFC sensor was connected to the A/D port of the DSP board through the charge amplifier. The D/A port of the DSP board is connected to the MFC actuators through the power amplifier. The damping factor for the PPF controller, ζ_f is set at 0.3, which gives satisfactory robustness to the PPF controller. The digital MIMO PPF controller is downloaded to the DSP board, DS1103 of dSPACE Inc. The filter frequency of each PPF controller was tuned to the first and second natural frequencies. The sampling rate of the digital PPF controller was 10 kHz which is enough for the given problem. Figure 2 shows the Simulink block diagram for the proposed MIMO PPF control algorithm. Figure 3 shows the uncontrolled and controlled frequency response curves of the rectangular cantilever plate. As can be seen in Fig. 3, two lowest natural modes are suppressed.

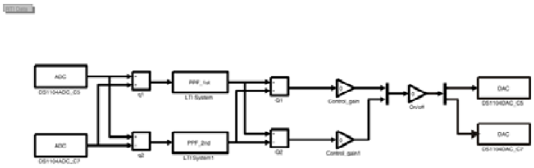

Fig. 2. Simulink block diagram for MIMO PPF control

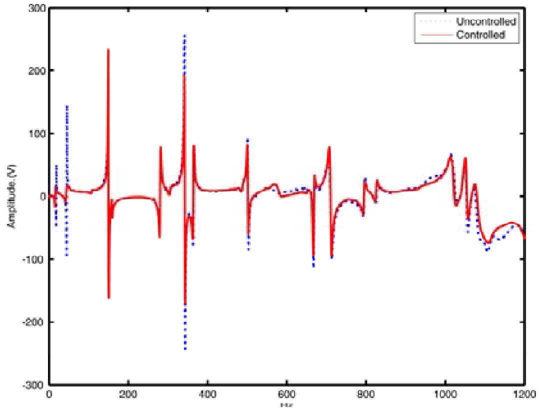

Fig. 3. Uncontrolled and controlled frequency response curves

5. Conclusions

In this study, the dynamic model for the rectangular plate with MFC sensors and actuators was derived using the Rayleigh-Ritz method. The dynamic model was validated experimentally. We also verified the sensor and actuator performance by comparing theoretical results with experimental results. It was found from comparison that the theoretical estimations are close to the experimental results, which validates our modeling approach.

A two-input and two-output Positive Position Feedback controller was designed based on the observation of two lowest natural modes and applied to the cantilever plate. It is found from the experiment that the vibrations can be suppressed successfully by the proposed control algorithm.

Acknowledgement

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