Military Technical College
Kobry Elkobbah,
Cairo, Egypt

8th International Conference
on Aerospace Sciences &
Aviation Technology

EXPERIMENTAL CONTROL OF SOUND RADIATION FROM A PANEL INTO AN ACOUSTIC CAVITY USING ACTIVE COMPRESSION CONSTRAINED LAYER DAMPING.

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Abstract.

The active compression constrained layer damping (ACCLD) is used for the control of sound radiation from a panel coupled with acoustic cavity. The acoustic cavity consists of five rigid walls while the sixth one is flexible aluminum plate. The plate is partially treated with ACCLD, which consists of viscoelastic material sandwiched between a permanent magnet and an electromagnet. Due to the attraction or repulsion forces generated between the two magnets, a compression or expansion of the viscoelastic layer will occur. The energy dissipation in the viscoelastic layer leads to vibration damping and automatically attenuation of sound pressure level inside the cavity. The ACCLD acts as actuator while a microphone used as sensor. The ACCLD is used for controlling the first mode using a single patch at the center of the plate. With these arrangements, good vibration damping and good control of sound pressure level were achieved.

1. Introduction

Recently due to the advent and improving in smart materials, many researchers give a considerable attention for using it in the active control of the sound radiated from vibrating structures. Examples include noise reduction inside aircraft cavity, control of noise in buildings, and control of muffler noise. Particular emphasis has been placed on passively and actively control of the sound radiated from vibrating flexible plates into closed cavity. For example, Alam and Asnani [1], and Lu et. al. [2], utilize the passive constrained layer damping (PCLD), for damping out the vibration of sandwiched plates, as simple and reliable means. The used visco-elastic damping layers are bonded to the vibrating structures in constrained configuration, to improve the damping ratio. Although a good damping ratio was obtained a considerable weight was added to the vibrating plates and that design is limited only for small temperature and frequencies. Fuller [3], and Fuller et. al. [4], utilize the piezoelectric materials as active means for controlling the vibration and sound radiation from flexible plates. The patches of peizo-electric actuator were directly bonded to the plates. For effective attenuation of the sound radiation of plates, such arrangement often requires high control voltage. In another approach for controlling the radiated sound from structures, a number of secondary acoustic sources are arranged around the primary noise source to cancel out the radiated sound. Elliot et. al. [5] actively controlled the in-flight cabin noise induced by the twin turboprops of passenger aircraft. Their controller utilizes 16 loudspeakers, placed

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*Lecturer, Mechanical Engineering Dept., Military Technical College at various positions within the cabin as the secondary acoustic sources and 32 microphone sensors. A reduction of 13 dB at the blade passage was achieved. The control action on their experiment was based on the least mean square (LMS) adaptive algorithm developed by Widraw [6] and Widraw and Stearns [7]. Recently another class of active vibration control using Active Constrained Layer Damping (ACLD) have been recognized as effective means for damping out the vibration of flexible structures. The ACLD treatment combines the attractive attributes of both active and passive damping. Shen [8], developed a distributed parameter model to simulate the dynamics of plates fully ACLD treated to control the bending vibration. In 1996, Baz and Ro [9], presented a theoretical and experimental study for controlling the bending vibration of plates, which are partially treated by patches of ACLD treatment. Accordingly Baz and Ro extended the ACLD treatment for controlling of sound radiated from plates coupled with acoustic cavity. Poh et. al [10], introduced experimental adaptive control of sound radiation from a panel into an acoustic cavity using active constrained layer Damping. The effectiveness of the LMS controller in suppressing sound fields of the cavity at different locations is demonstrated. In 1998 Baz [11] found a new surface treatment, which is called Magnetic Constrained Layer Damping (MCLD), acting as smart damping material which consists of integrated arrays of constrained viscoelastic layer controlled passively by a specially arranged network of permanent magnets. The interaction between the magnets and viscoelastic layers enhance the energy dissipation of damped treatment by the shear strain. Although that arrangement does not need electronics or circuits and have good results with vibration damping, there is still a need for another design for controlling high amplitude vibrations.

In the present paper, a new approach is introduced in which an Active Compressional Constrained Layer Damping (ACCLD) treatment is developed. The ACCLD represents an improvement over the conventional ACLD and MCLD, as it controls the compressional deflection of viscoelastic layer using electromagnetic actuators. The actuators can produce significantly large amount of control force, i.e. it's possible now to control large amplitude of vibration. The ACCLD is a hybrid active and passive controller and ensure fail-safe operation.

2- Concept of ACCLD

The ACCLD consists of a viscoelastic high-density foam sandwiched between an electromagnet and a permanent magnet (Neodymium Blocks) (type NB2518181475-35) as shown in Fig.1. The electromagnetic force of the coil acts along the same line of action as that of the magnetic force of permanent magnet. The operating principle of the actuator depends on the attraction or repulsion forces that exist between the two magnets. For controlling the first mode of vibration, the actuator is placed at the middle of the plate. Hence, as the plate moves up the polarity of the electromagnet is designed to be the same as permanent magnet, north-north, which leads to repulsion force pushing the plate down. But, once the plate starts going down, the polarity changes to be south north and attraction force is generated pulling the plate up. Actually the laser sensor used here is utilized to detect the vibration and provide the negative feedback signal necessary to control the electromagnetic actuator. The viscoelastic rubber-foam is used as passive means for vibration damping.

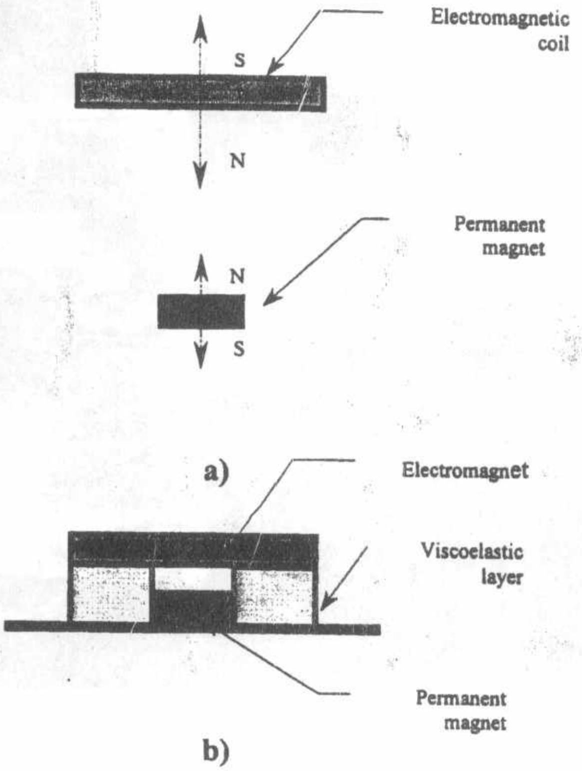


Fig. 1 ACCLD a) before assembly b) after assembly

3 Experimental set-up

The ACCLD is used for controlling the first mode using a single patch at the center of the plate. Figures 2(a) and (b) shows a photograph and schematic drawing of the experimental set-up used to describe the ACCLD plate/cavity system with laser feedback for first mode. The closed cavity used in this study has cuboid shape with dimensions 30.4cmx 30.4cm x 76.2cm. The walls of that cavity are made from acrylic except one made from aluminum with dimensions 30.48cm x 30.8cm x 0.406mm. The aluminum plate is clamped along its four edges and is partially treated by a single patch of ACCLD treatment. Actually ½ inch microphone (type 4165,B&K) located at the center of the plate inside the closed cavity is used as sensor to measure the radiated sound pressure level inside the cavity also, the plate vibration is monitored using laser sensor type (LA40hr). An FFT analyzer is used to excite the plate using the sweep function. The output from the sweep function is magnified using a power amplifier (model 6260, JBL, UREI Electronic Products) which is used to derive the speaker. The output of either the laser sensor or the microphone is used to generate the accessory control action. This action is developed using a filter (WAVEETEK dual Hi / Lo model 432), which is connected to a low noise amplifier (type, AM5), and another power amplifier (Wilcoxon Research type, PA7C), in series.

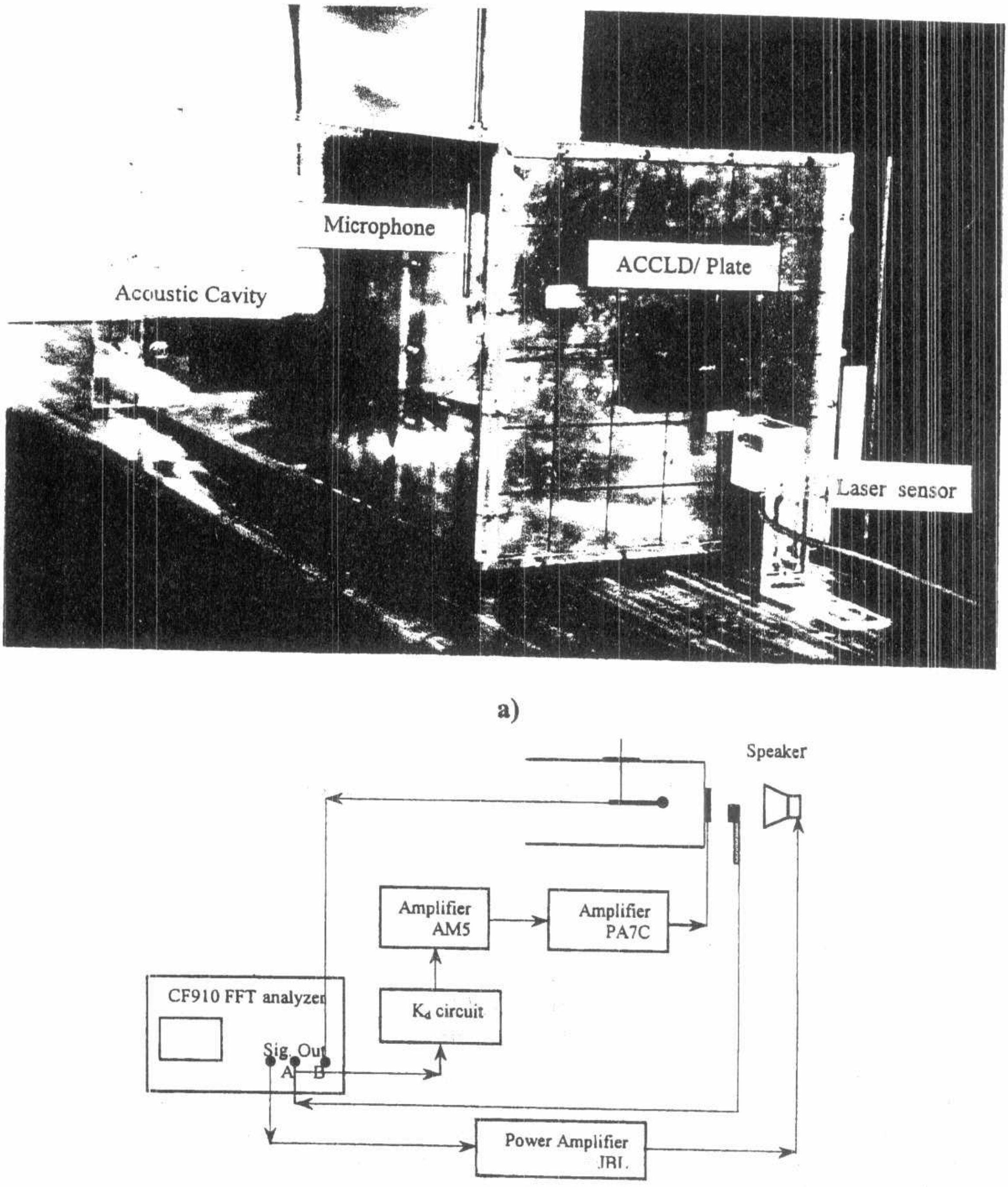


Fig. 2 The magnetic constrained layer damping experiment.
a) photo of the experiment b) schematic drawing

The impact hammer is used to check the first and second modes of vibration of the arrangement as shown in Fig. 3a , for open cavity and Fig.3b , for closed cavity. The mode shapes of vibration are obtained for the plate using cosmosm FEM package as shown in Fig 4. A sine sweep experiment is also carried out to determine the effect of ACCLD on vibration damping of plate. The laser sensor is used to feedback the control voltage. For open cavity Fig. 5 shows the plate vibration with feedback from the laser sensor itself for three different gains. Fig. 6 shows the sound pressure level for the same three gains, with feedback from the laser sensor. While Figs.7-9 shows the plate vibration for closed cavity with feedback from laser sensor, the sound pressure level for the same three gains with feedback from the laser sensor and the microphone respectively. Table 1 shows the modes of vibration of the plate over range from 0 –100 Hz and 0 – 200 Hz. Tables 2 and 3 give the frequency and damping ratio of the first mode of vibration for the plate with a single patch of ACCLD with open cavity while Table 4 and 5 give the frequency and damping ratio of the first mode of vibration for closed cavity. Tables 2 and 4 give the modal parameters using the laser sensor, while Table 3 and 5 gives these parameters using the microphone signal. In these tables as the controller gain increases, the damping ratio increases and the natural frequency decreases.

Table 1 Modes of vibration of plate using impact hammer

	1st	2nd	3rd	4th	5th
Freq. Range 0 –100 Hz	19.0	59.0	59.0	78.75	N/A
Freq. Range 0 –200 Hz	18.5	57.75	57.75	78.0	133.5

Table 2 Effect of gain on fundamental natural frequency and damping ratio using laser sensor output and laser feedback with open cavity

Controller gain , k_d	First mode frequency, Hz	Damping ratio
0	19.18	0.0128
89.44	19.19	0.0179
184.75	18.8	0.0311
362.17	18.52	0.0769

Table 3 Effect of gain on fundamental natural frequency and damping ratio using microphone output and laser feedback with open cavity

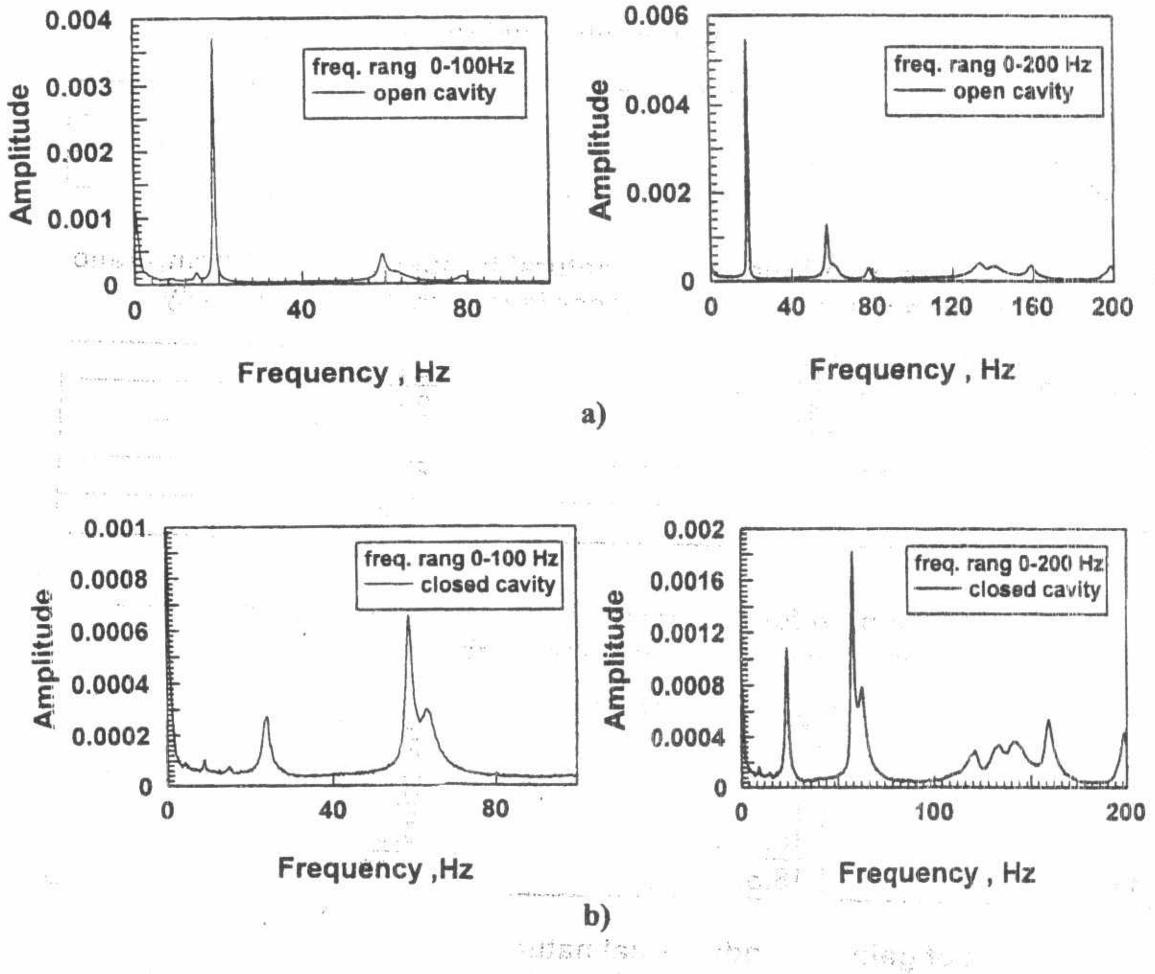
Controller gain , k_d	First mode frequency, Hz	Damping ratio
0	19.19	0.0125
89.44	19.01	0.0181
184.75	18.8	0.0316
362.17	18.57	0.0805

Table 4 Effect of gain on fundamental natural frequency and damping ratio using laser sensor output and laser feedback with closed cavity

Controller gain , k_d	First mode frequency, Hz	Damping ratio
0	23.25	0.0441
49.85	23.03	0.0809
253.67	22.50	0.1268
387.10	22.38	0.1383

Table 5 Effect of gain on fundamental natural frequency and damping ratio using microphone output and laser feedback with closed cavity

Controller gain , k_d	First mode frequency, Hz	Damping ratio
0	23.92	0.0461
49.85	23.75	0.0709
253.67	22.87	0.1118
387.10	22.25	0.1215



a)

b)

Fig. 3 Impact hammer experiment for fixed plate with
(a) open cavity (b) closed cavity

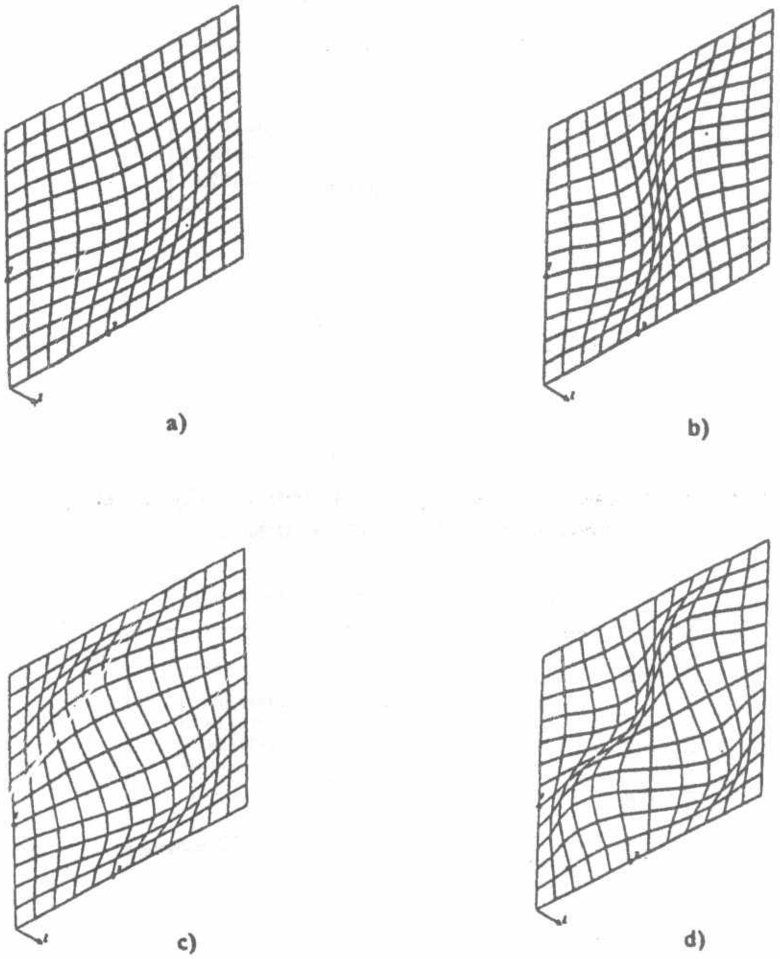

a) b) c) d)

Fig. 4 Mode shapes of vibration for fixed-fixed plate a) 1st mode, b) 2nd mode, c) 3rd mode and d) 4th mode

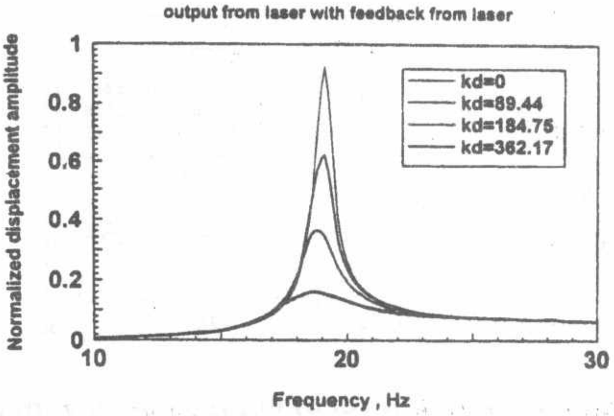


Fig. 5 Normalized vibration amplitude with laser feedback and open cavity .

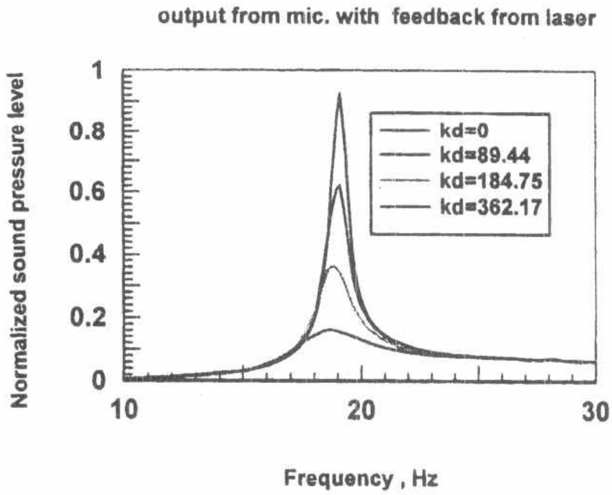

output from mic. with feedback from laser

Fig. 6 Sound pressure level of open cavity with laser feedback at different gains.

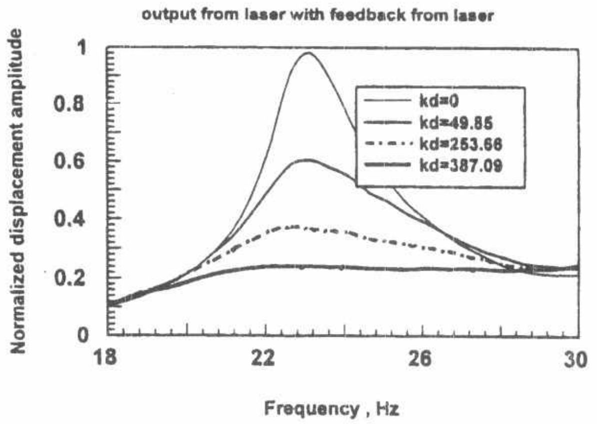

output from laser with feedback from laser

Fig. 7 Normalized vibration amplitude with laser feedback and closed cavity.

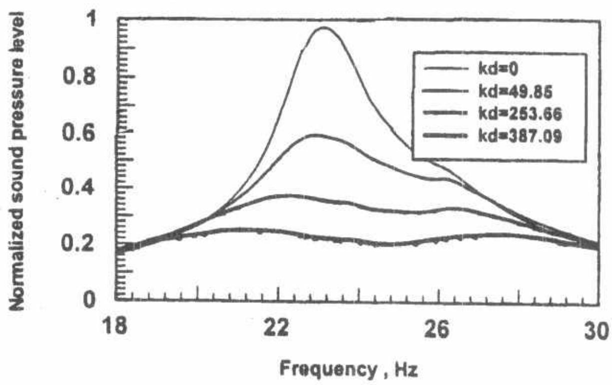

output from mic. with feedback from laser

Fig. 8 Sound pressure level of closed cavity with laser feedback at different gains

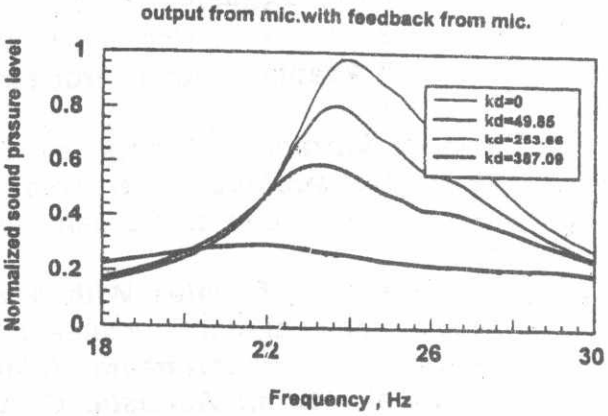


Fig. 9 Sound pressure level of closed cavity with microphone feedback at different gain.

4. Conclusions

This paper has presented an experimental demonstration of the damping characteristics of plates/Acoustic cavity treated with active Compression Constrained Layer damping treatment (ACCLD). The Potential of ACCLD to control the sound radiation from vibrating plates into an acoustic cavity has been also demonstrated. The experimental results illustrate the effectiveness of ACCLD in providing high-energy dissipation through damping the vibration of plates and the sound pressure level inside the closed cavity at different gains

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Appendix A

Calculation of Derivative Gain

The gain of the amplifiers used with the ACCLD, controller, and the filter is determined using the arrangement shown in Fig. 10. The transfer function of these amplifiers is obtained with magnitude (dB) and phase (deg.) for the different gains used in the experiments as shown in Fig.11. From the plot of the transfer function we can calculate the value of gain at each stage. It is clear from the plot, that the gain that makes the phase is the gain of a derivative controller.

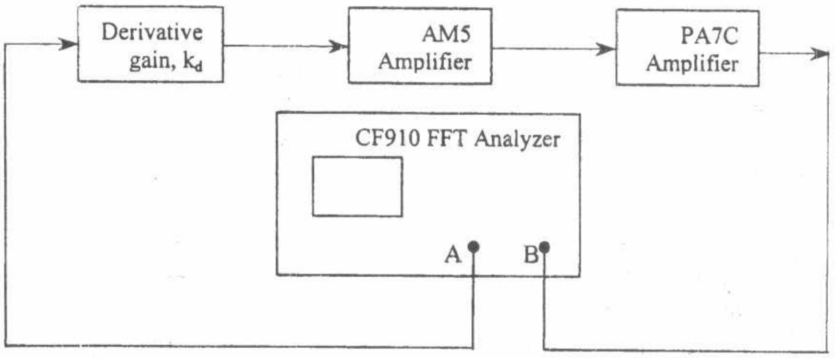
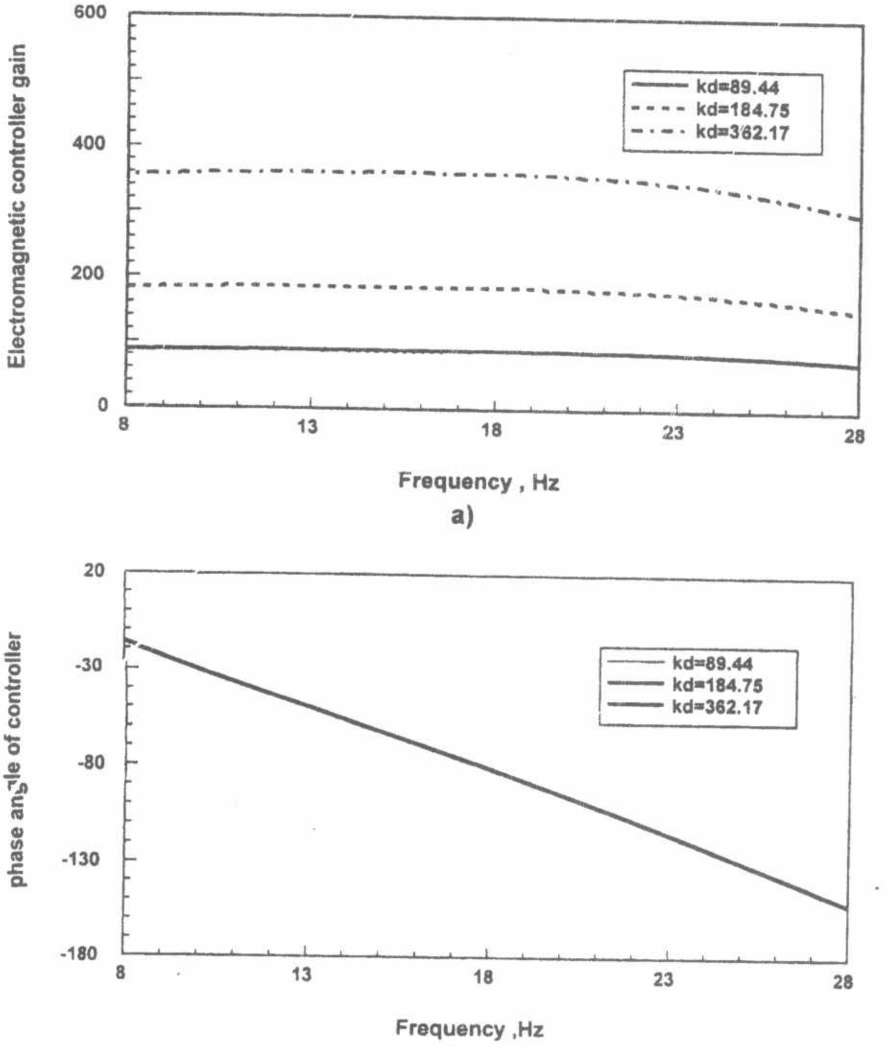


Fig. 10 Schematic drawing for measuring the controller gain



b)

Fig. 11 Transfer function of the controller used
a) magnitude b) phase