Active Control of Enclosed Sound Fields Using Three-axis Energy Density Sensors: Rigid Walled Enclosures

Ben S. Cazzolato[†] **and Colin H. Hansen**[†]

Department of Mechanical Engineering, University of Adelaide, SA, 5005, Australia

(Received 21 April 2000; accepted 4 August 2000)

The use of three-axis energy density sensors for controlling the sound field within a rigid walled enclosure is investigated numerically. It is shown that energy density sensors perform as well as, if not better than, an equivalent number of microphones. The effect on control performance using multiple energy density sensors is also investigated, as is the effect of multiple control sources. The control mechanisms that occur when using energy density sensors with multiple control sources are analysed, and it is shown that the control mechanism moves from modal control to modal rearrangement as the number of control sources is increased. In doing so, the control becomes more local to the sensors. The zone of local control around the energy density sensors is measured, and it is shown that the zone of control is similar in size to that in a diffuse field.

[†] Member of the International Institute of Acoustics and Vibration (IIAV)

1. INTRODUCTION

Global noise reduction is the objective of many active noise control applications in small enclosures such as aircraft cabins and automobiles, and it is widely accepted that the most appropriate quantity to minimise in these cases is the potential energy within the cavity, which provides a measure of the mean square pressure integrated throughout the space. In practice, it is not possible to spatially integrate the pressure field so it is approximated with a number of discrete microphones. For small systems with regular geometries excited at low frequencies, it is often easy to achieve global control with one or two judiciously located microphones. However in most systems where the spatial variation of the pressure field can be difficult to predict, many more microphones may be needed, particularly when the wavelength is small.

It has long been known that the energy density in a one-dimensional sound field is approximately constant throughout the field, and for 3-D systems with high modal densities it has been shown that the spatial variance of energy density (sum of the acoustic potential and kinetic energies) is significantly less than that of the potential energy.[1] Therefore, in order to overcome the observability difficulties that are inherent with microphones as error sensors, such as pressure nodes, Sommerfeldt and Nashif[2] suggested that minimising the energy density at discrete locations can be used as an alternative to measuring the pressure at a point. In a numerical simulation, the authors[2] found that minimisation of the energy density at a discrete location significantly outperformed the minimisation of squared pressures. Subsequent practical studies using the two-microphone technique to estimate the particle velocity in one-dimensional fields[3-6] verified the earlier findings and showed that the location of the energy density sensor makes little difference to the controlled sound pressure levels. Sommerfeldt et al.[7] extended the earlier work to three dimensions and built a three-axis energy density sensor made from six electret microphones mounted in a wooden sphere. Preliminary results indicated that controlling energy density has the potential to achieve greater global control than controlling squared pressures. Park and Sommerfeldt[8] successfully showed that energy density control can also be applied to enclosures excited by broadband noise. Shen and Sun[9] showed that a four-microphone energy density sensor is suitable for active noise control applications and that the global noise reduction offered by a single energy density sensor in a cylindrical shell is comparable with that by 32 microphones uniformly spaced in a ring around the shell.

Energy density control has also been applied to the control of a pure tone in a diffuse sound field.[10,11] It was found that minimising both the pressure and pressure gradient along one axis, rather than simply minimising pressure, resulted in a significant increase in the 10 dB zone of quiet, from a sphere of diameter $\lambda/10$ around the pressure sensor to $\lambda/2$ for an ellipsoid with its longest axis in the direction of the measured pressure gradient.

The work described in this paper aims to explore the effectiveness of using energy density as a cost function for active control of sound in a rigid walled enclosure as compared to cost functions of acoustic potential energy and the sum of the squared pressures at discrete locations.

Numerical simulations were conducted on a finite element (FE) model of a curved panel/cavity system used by the authors previously[12,13] and are discussed in more detail in Section 3.1. For the studies described here the model is uncoupled (purely acoustic) to allow confirmation of previous studies using a single acoustic source. The model is then extended to multiple control sources and error sensors.

2. THEORY: MINIMISATION OF ENERGY DENSITY AT DISCRETE POINTS

To conduct the numerical experiments on the vibro-acoustic model it is necessary to develop a mathematical approach to solving the system of equations for the minimisation of the energy density at discrete points. The derivation in the following section is similar to derivations for minimising the sum of squared pressures at discrete locations.[13,14]