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EXPERIMENTAL ACOUSTIC MODAL ANALYSIS - A REVIEW

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1. INTRODUCTION

Industry is faced with increased commercial pressure to reduce development lead times and find quicker solutions to noise and vibration problems. This has resulted in the need for an improved experimental method for determining the modal properties of three-dimensional acoustic cavities. Examples of acoustic cavities where noise generation has become a particularly important issue is in the transport industries, e.g. the passenger compartments of automotive and rail vehicles. Experimental modal analysis is a technique which enables the dynamic characteristics such as natural frequencies and mode shapes to be extracted from measured transfer function data. Structural modal analysis is now well established as a method, and the theory for this is adequately covered in the text by Ewins [1]. Acoustic modal analysis, however, does not lend itself so easily to this technique, and presents a number of inherent problems. These need to be overcome if results are to be produced and analysed in a form which is useful to the Noise and Vibration Engineer, and which can be compared with other forms of output.

The first of these problems relates to the extraction of mode shapes from measured data. In the case of structural modal analysis, the measured quantities contain directional information. However, for acoustic modal analysis, the output measurement of sound pressure is a scalar quantity which makes the extraction of mode shapes from this data very difficult for anything other than the low order modes. Whilst frequency and damping information for modes is useful on its own, knowledge of the actual mode shapes is a very powerful design and development tool.

The second problem relates to the measurement of the associated transfer functions for acoustic cavities. For acoustic modal analysis, the two primary variables are the pressure, *p*, and the source volume velocity, *Q*. Pressure can be measured accurately and reliably using either a microphone or a very sensitive pressure transducer. However, a transducer for the direct measurement of volume velocity or particle velocity is not readily available. This problem has forced a number of investigators over the years to devise indirect means of measuring volume velocity or acoustic impedance [2,3]

The experimental technique described here is an alternative method for acoustic modal parameter extraction which has been designed to overcome these problems. It has been developed for use directly with commercially available software for structural modal analysis, in order to present animated mode shapes in a form which corresponds directly with the pressure mode shapes output from numerical methods such as finite element analysis.

A review of earlier work is given, along with a description of this new method which has been developed.

2. PREVIOUS WORK

Early studies of the mode shapes of cavities were limited to plotting the pressure distribution within the cavity for each natural frequency of interest independently [4]. Smith has used pressure transfer function measurements to extract the low order acoustic modes of an automobile cavity in the longitudinal direction [5]. Nieter and Singh [6] used a dual channel FFT analyser to extract global modal properties for a number of configurations of wave tubes. The acoustic system was excited using an electromagnetic shaker driven piston, and measurements were limited to the plane-wave region by imposing an upper frequency limit which only produced longitudinal modes. Work by Kung and Singh [2] extended this to concentrate on three dimensional annular-like cavities. The excitation was by means of a convertible horn driver. Pressure transfer functions were obtained by measuring the pressure in the calibration cavity of the driver.

Byrne [3] used a similar process for the measurement of pressure transfer functions in a small rectangular enclosure. The excitation was provided by a convertible driver with a microphone in the magnet cavity to measure volume velocity. Approximating functions were fitted to the transfer functions spatially using a least-squares approach.

Knittel and Oswald [7] developed a technique for the measurement of acoustic particle acceleration which enabled mode shapes of acoustic particle motion in terms of acceleration to be extracted and plotted. Unfortunately, because of the quadrature relationship between acceleration and pressure at the cavity resonances, it was difficult to compare these with predicted modes from numerical models, particularly for those modes where there was pressure variation in more than one direction.

3. THEORETICAL BACKGROUND

In order to find the spatial variation of pressure along the various axes, and hence directional information, a finite difference approach was used, along the lines of that developed by Knittel and Oswald [7]. Unlike their technique which used two microphones and gave a resulting measurement which was in quadrature with the original pressure distribution at resonance, this technique uses a three in-line microphone probe. This enables a second order finite difference calculation to be carried out, and since the spatial distribution of pressure at resonance is a sinusoidal function, the second derivative exhibits the same nodes and antinodes as the pressure itself. A diagram of the finite difference calculation used is shown in Fig. 1.

Hence, the expression for the second spatial pressure derivative, $\partial^2 p/\partial x^2$, is given by

$$\frac{\partial^2 p}{\partial x^2} = \frac{p_1 - 2p_2 + p_3}{d^2} \quad (1)$$

where p_1, p_2, and p_3, are the pressures measured by the three microphones, and d is the spacing between the microphones. Because this measurement uses the difference in pressure in a particular direction, it enables data which are not relevant to the actual mode shape to be rejected. In addition, since the second derivative exhibits the same nodes and antinodes as the original pressure measurement, this allows direct comparison with other plots of predicted pressure variation to be made.

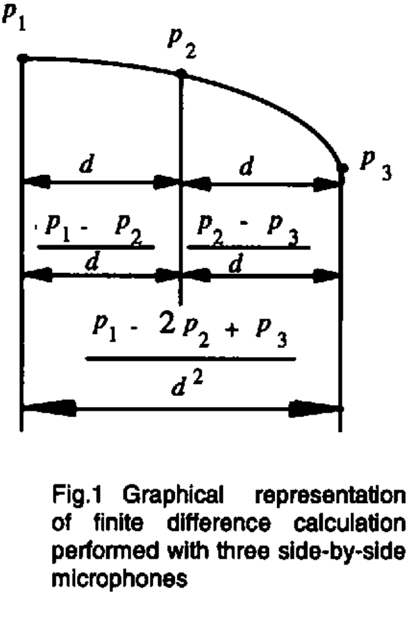

Fig.1 Graphical representation of finite difference calculation performed with three side-by-side microphones

4. EXPERIMENTAL TESTS

In order to verify the technique, it was used to extract the modes of a bare rectangular office. This was chosen because it was a good approximation to a rectangular, rigid, reflective walled cavity.

Measurements were taken in all three orthogonal directions in the office over a rectangular mesh of 26 points. From the transfer function measurements, mode shapes were extracted using the ICATS structural modal analysis software [8]. For comparison, the natural frequencies and mode shapes were also predicted with a finite element model which was generated using ANSYS finite element software [9].

The results obtained for the bare office are given in Table 1. The mode shape indicates the number of half waves in the x, y and z directions respectively. These have been obtained from interpretation of the animated mode shapes achieved using the modal analysis software. These show very good agreement both in terms of natural frequencies and mode shapes between the experimental and finite element techniques. This is true even for those modes where there is pressure variation in more than one direction.

Finite Element	Experimental	Mode Shape
54.0	54.1	1 0 0
61.4	62.6	0 1 0
73.4	71.6	0 0 1
81.7	81.6	1 1 0
90.9	88.5	1 0 1
95.6	93.2	0 1 1

Table 1 Natural frequencies and mode shapes for the bare office

5.CONCLUSIONS

The results obtained show very good agreement with finite element method results, demonstrating the ability of the technique to measure the directional nature of pressure variation in modes and to reject effects in orthogonal directions.

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