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THE VIEWING OF LOUDSPEAKER MODES BY LASER SPECKLE

M Brooke

Department of Physics, University of Wales College of Cardiff
PO Box 913, Cardiff CF1 3TH
(Work carried out as an undergraduate at the University of Surrey)

INTRODUCTION

Loudspeakers have resonances which occur as natural frequencies of the cone and surround materials. Of these, only the axisymmetric modes are significant in producing audible colourations in a speaker's response [1].

Holographic techniques are well established in viewing vibrational modes, but are prone to many experimental restrictions. Laser speckle techniques are less sensitive to these restrictions and therefore much simpler to utilize. Speckle shearing interferometry can be employed to record detailed information about both in-plane and out-of-plane displacements [2]. Here its use has been extended to vibration analysis by recording loudspeaker mode shapes.

LOUDSPEAKER CONE RESONANCE

Mode Shapes

A loudspeaker cone only vibrates as a rigid body at lower frequencies. Its stiffness is not sufficient to withstand the inertial forces occurring at higher frequencies, resulting in bending. This bending leads to higher order resonances at which the radiation impedance decreases and the output level of the speaker increases.

The modes of vibration of the cone may have both radial and circumferential nodal lines but it is only the purely axisymmetric mode shapes, occurring at higher frequencies, which affect the speaker's frequency response [3]. Three regions can be distinguished within the axisymmetric vibration pattern: an inner region where only longitudinal waves exist, a transitional region where longitudinal and transverse waves interact, and an outer region containing only transverse waves. Generally, the higher the frequency of a cone resonance, the nearer the centre the transitional region moves, thus filling the cone with bending waves [1].

Detection

Two methods of finding possible resonances were used:

i) The frequency response of the speaker was measured using a microphone held 20 mm away from various points on the cone.

ii) A close microphone was used to record the speaker's impulse response and subsequently a fast Fourier transform was carried out on the data obtained. An impulse contains components of all frequencies so all the speaker's resonances should be excited.

Once possible resonance frequencies were located, the existence of modes was verified by driving the speaker at large amplitude enabling the mode shapes to be directly viewed in laser light. Large amplitudes are necessary only for direct viewing of the modes; the speckle shearing technique subsequently used to record information is very sensitive and only requires small amplitudes.

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LASER SPECKLE

Each point on an optically rough surface scatters some light to an observer. This light interferes with light scattered from other points on the object, giving a randomly distributed interference pattern in all space. This is perceived as a random speckle pattern which does not change if the object moves parallel to the line of sight, but moves with the object if it tilts or translates. When viewing speaker modes, therefore, the speckle is clear at antinodes and "blurs out" at nodes [4].

Misfocusing Method of Interferometry

The object is illuminated by an expanded laser beam and is imaged by a large-aperture lens which is misfocused as in Figure 1.

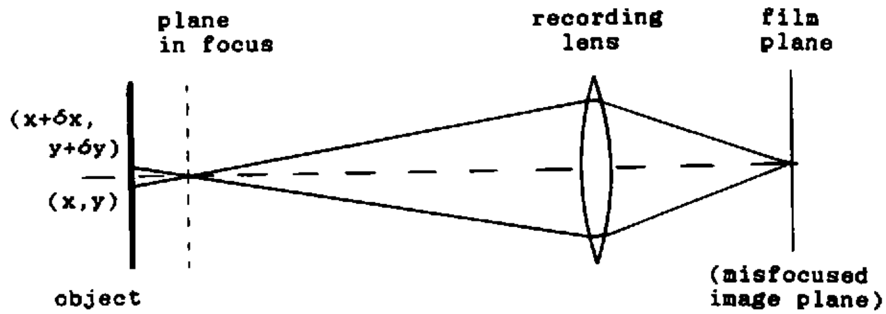

Figure 1. Experimental arrangement for the misfocusing speckle shearing camera.

Misfocusing causes the lens to focus on a plane either in front of or behind the object's surface. This means that a *patch* of light on the object will be imaged as a *single point* in the film plane. Consequently, within this patch, the light from any point (x,y) will interfere with light from all its neighbouring points $(x+\delta x, y+\delta y)$ for all values of δx and δy within the patch. As a result of this interference, each pair of points will produce a speckled fringe pattern with a certain orientation and frequency of ruling in the film plane. Thus the interference between all points and all their neighbours produces a superposition of an infinite number of fringe patterns with all orientations and all frequencies of ruling up to the limit imposed by the recording lens. When viewed, this superposition just appears to be a random speckle pattern.

When the object is deformed, points (x,y) and neighbouring points $(x+\delta x, y+\delta y)$ are displaced by (u,v,w) and $(u+\delta u, v+\delta v, w+\delta w)$ respectively. Since there is a relative displacement between the points, there is a relative change in the optical path lengths and therefore a shift in the speckle rulings. Hence, making exposures before and after deformation gives a superposition of the two sets of fringes. When these are viewed they give rise to a multiplicity of families of Moiré fringe patterns depicting the derivatives of surface displacement [5].The angle at which the resulting picture is observed determines the direction of resolution of the derivatives.

In vibration analysis, many images are formed, but time-averaging occurs so that the most influential positions are the two extremes of vibration and the speckle contrast distribution is proportional to the Bessel function J_o^2 [6].

FINITE ELEMENT ANALYSIS

A finite element analysis program forms and solves the set of linear algebraic equations required to describe the system in question. This is done by dividing the object up into small elements and applying the equations to each element.

It was sufficient to model the loudspeaker cone in radial cross-section only. The entire mode shapes can be found by rotating the finite element results about the speaker's axis of symmetry [7].

LUSAS 7 was the FE package used. Its accuracy was confirmed by using the same axisymmetric thin shell elements to model a circular aluminium plate. From classical theory, the first three modes of the disc have resonance frequencies of 225·6, 881·9 and 1970·4 Hz respectively. The FE analysis gave values of 226·6, 822·3 and 1976·7 Hz - all having accuracy better than $\pm$ 0·5 % .

RESULTS

The loudspeaker was a B&W bass driver which was 380 mm in diameter. The cone was made of cobex and was lightly sprayed with matt white paint for improved reflectivity.

A normal 35 mm SLR camera was used to produce the misfocused speckle shearing interferograms.

Figures 2 and 3 show examples of interferograms with their corresponding FE predictions.

The interferograms had to be photographed in front of a point source of white light for presentation here. Hence, the only fringes visible are the first-order bright fringes corresponding to the antinodes of the modal pattern. The technique requires monochromatic lighting in order to give better fringe quality.

The photograph in Figure 2 shows the mode at 1873 Hz. Three bright concentric fringes can be seen which correspond to the three distinct antinodes in the FE prediction. The central region is mottled and unclear, possibly due to the resolution of in-plane motion here. It is interesting to note that the FE prediction of the resonance frequency of this mode is 1835 Hz; an error which is possibly due to slight inaccuracies in the original FE modelling of the cone.

The photograph in Figure 3 shows the mode at 2459 Hz Five bright fringes corresponding to the antinodes in the FE prediction can be distinguished. The centre is again unclear. The FE analysis determined this mode's resonance frequency almost exactly.

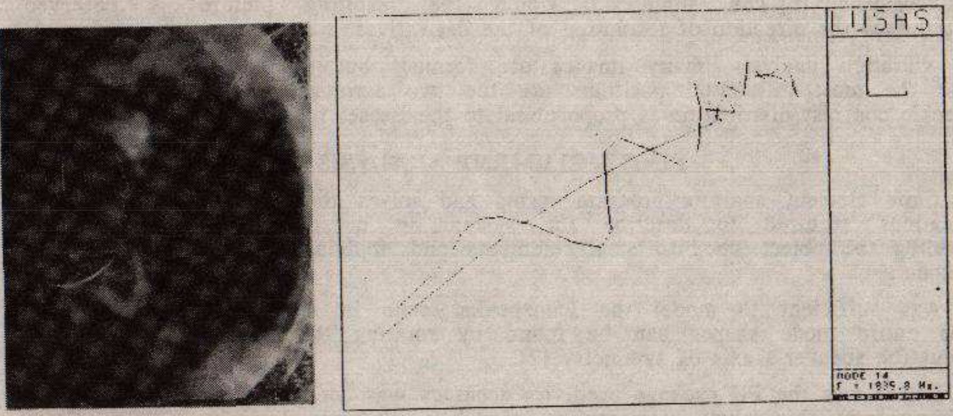

Figure 2. (Left) The 1873 Hz mode with its predicted shape from FE analysis (right) at 1835 Hz. The photograph depicts nearly half of the loudspeaker cone area. The apex of the cone is at the centre of the left-hand side of the picture.

Figure 3. (Left) The 2459 Hz mode with its predicted shape from FE analysis (right) at 2459 Hz.

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SUMMARY

The time available for this research was rather limited. If more time was spent on refinement of the method it could undoubtedly be improved to give more quantitative results. However, the work presented here shows that speckle shearing interferometry provides a much more straightforward means of viewing modes than does holography, and a much less expensive means than the newer Electronic Speckle Pattern Interfrometers. It does not require the accurate alignment, absolute vibration isolation, large coherence lengths or high-resolution photographic media of holographic techniques.

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