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TITLE: ACOUSTIC DEVICE

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DESCRIPTION

15 The invention relates to an acoustic device, and particularly to a distributed mode device.

 Flat panel bending wave mode loudspeakers are known, for example from WO97/09842. This document discloses loudspeakers having a radiator member and an exciter which
20 excites bending waves in the radiator member.

 The shape of the radiator member and its material properties determine a number of resonant bending wave modes of the radiator member each with a particular mode shape and frequency. These parameters may be chosen so
25 that the resonant bending wave modes of the radiator member are distributed in frequency over the operative frequency range. By distributing the resonant bending wave modes as evenly as possible in frequency it is possible to make the acoustic response of the acoustic

device as even as possible in frequency and to avoid excessive dips and peaks in the response.

WO97/09842 teaches placing the exciter at a location at which the modes are evenly excited, i.e. at an exciter position that as far as possible couples evenly to all the modes.

The modes are sparsest in frequency at the lower end of the operative frequency range, so it is in this frequency region that it is most important to excite the modes evenly. Thus, the exciter may be located to couple evenly to all the resonant bending wave modes at the lower end of the operative frequency range.

There are often a number of locations on a panel that are good compromises for coupling evenly to a number of modes and WO97/09842 also teaches place a plurality of exciters at a plurality of such locations.

According to the invention there is provided an acoustic device comprising a panel supporting a plurality of resonant bending wave modes each having a resonant frequency, the resonant bending wave modes being divided into a plurality of groups of modes of overlapping resonant frequencies, and a transducer located so as to couple preferentially with one of the said groups of modes.

In accordance with the invention, it is not necessary to place the exciter at a location or locations that couple as evenly as possible to all the resonant bending wave modes, or even all the lower resonant bending wave

modes. Such exciter locations are inevitably a compromise. Rather, it is only necessary to find exciter positions that couple evenly to a group, i.e. a subset, of the resonant bending wave modes.

5 The groups of modes are not simply split into groups in different frequency ranges. Rather, the groups of modes have overlapping resonant frequencies. Of course, the exact frequencies of the individual modes will not, except by chance, be identical, but taken as a whole the
10 groups of modes may cover roughly the same frequency range.

Preferably, the modes of each group are substantially orthogonal to the modes not in that group.

The groups of bending wave modes may be odd modes and
15 even modes. One way of dividing the modes into odd and even is to number the modes in order of increasing frequency; the odd modes are then those with odd numbers and the even modes with even numbers.

Such division of modes into odd and even tends to
20 produce two groups of substantially orthogonal modes. The transducer location can then be optimised for one or other of the groups.

Alternatively, the odd modes may be the antisymmetric
symmetry modes with respect to a predetermined axis,
25 typically one of the symmetry axes of the resonant panel.

For example, where the panel is rectangular, the odd modes may be the antisymmetric modes with respect to the axis parallel to the short side of the rectangle. The

even modes are then the symmetric modes with respect to the same axis. For an elliptical panel, the antisymmetric and symmetric modes can refer to the symmetry about the minor axis of the ellipse.

5 It is important to distinguish between modes antisymmetric about an axis and modes along that axis. Some resonant bending wave modes have a mode shape in which the distance of the panel to the median plane of the panel varies significantly along one axis but not along an
10 orthogonal axis. Such modes are essentially one-dimensional and can be said to be modes along the said one axis. Fig. 1 will be discussed in more detail below but it will briefly be remarked here that the $n=2$ mode shown is such a mode along the x axis, i.e. with variation along
15 that axis whereas the $n=3$ mode shown is a mode along the y axis. Modes along an axis are symmetric about that axis, but may be either symmetric or antisymmetric about the orthogonal axis.

 In cases where there are two symmetry axes, the modes
20 may be said to be antisymmetric or symmetric with respect to each of the symmetry axes. The resonant bending wave modes can thus be divided into four groups of modes: antisymmetric/antisymmetric, if they are antisymmetric about each symmetry axis, antisymmetric/symmetric if they
25 are antisymmetric about the long axis and symmetric around the short axis, symmetric/antisymmetric if symmetric around the long axis and antisymmetric around the short axis, or symmetric/symmetric if symmetric about both axes.

In embodiments, the transducer can be arranged to preferentially couple to some or all of these modes. In particular, symmetric/symmetric modes may couple much more strongly to the surroundings such as walls or enclosures than antisymmetric/antisymmetric, antisymmetric/symmetric or symmetric/antisymmetric modes. There may then be an advantage in providing one or more transducers to couple preferentially to the antisymmetric/antisymmetric, antisymmetric/symmetric and/or symmetric/antisymmetric modes, but to avoid as far as possible coupling to the symmetric/symmetric modes. A loudspeaker made in such a way may have reduced interaction with its surroundings compared to a loudspeaker in which all modes are equally coupled.

A further transducer or transducers may be provided to preferentially couple to other groups of modes. Each of the groups of modes may be coupled to one or other of the transducers. In embodiments, the odd modes are coupled to one transducer and the even modes to another transducer. The location of each of the transducers may be separately optimised for the corresponding group of modes; this may give better results than attempting to optimise each transducer for all modes.

The acoustic device may be a loudspeaker, the transducer or transducers then being an exciter to excite the modes of the panel to cause an acoustic output from the panel.

In a second aspect, the invention provides a panel in

which a transducer is mounted in one of the regions marked with an "X" in Figure 3 or 4. Preferably, one transducer is located in a region marked with an "X" in Figure 3 and one in a region marked with an "X" in Figure 4.

5 The invention also provides a method of manufacture of an acoustic device, including the steps of

providing a panel having a plurality of bending wave modes, the bending wave modes being divided into a plurality of groups of modes, and

10 attaching a transducer to the panel at a location where it preferentially couples with the modes of one of the groups.

For a better understanding of the invention a specific embodiment will now be described, purely by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a lowest modes of a resonant panel,

Figure 2 shows the nodal lines of the modes of the panel of Fig. 1

20 Figure 3 shows the nodal lines of the antisymmetric modes of the panel of Fig. 1

Figure 4 shows the nodal lines of the even modes of the panel of Fig. 1.

Figure 5 shows a loudspeaker in accordance with the invention.

25 In Fig 1, a rectangular panel 1 is shown, together with x and y axes. Considering the two-dimensional bending wave equation, a number of resonant modes exist.

The mode number in frequency order will be labelled with the integer n . The zeroth order mode ($n = 0$) corresponds to the whole body motion of the panel 1 and is not shown. The first mode ($n = 1$), of lowest frequency has a pair of nodal lines (the locus of locations with no movement) as shown along axes; such mode is truly a twisting and not a bending mode. The second mode ($n = 2$) is in effect the bending wave mode of lowest frequency and has two nodal lines extending roughly parallel to the short axis and spaced apart along the long axis. The third mode ($n = 3$) has two nodal lines extending roughly parallel to the long axis and spaced apart along the short axis. These three modes are illustrated in Figure 1. The "+" and "-" signs on the Figure indicate whether the bending has positive or negative sign, i.e. whether at a given time whether the displacement of the panel from the median plane of the panel is above or below that median plane. The modes are classified into two groups, odd or even, depending on the value of n .

The bending waves shown result from theory, and represent the solution of a fourth order differential equation. The modes calculated from solving the equation are not simple sine waves as they would be for second order equations, but are in fact combinations of trigonometric and hyperbolic trigonometric functions, as is known from classical theory. Of course, the real modes of an actual panel may depend for example on the mounting of the panel, any clamping provided or on any boxes or

baffles located close to the member. However, the same approach may still be used.

The nodal lines for the lower modes are shown in Figure 2. These can be split into the nodal lines for the odd modes which are shown in Figure 3 and the nodal lines for the even modes shown in Figure 4.

The transducer locations suggested by the aforementioned patent application W097/09842 are those in which all of the lower modes are as far as practicable coupled to the transducer. To cause good coupling to the modes, transducers should be located spaced away from the nodal lines. Various suitable regions are marked with an "X" in Figure 2; some of these correspond to the locations taught to be beneficial in W097/09842.

The "X"s are not intended to mark single points, but regions. Indeed, the transducers are of finite size and good mounting positions for transducers are available over a reasonable range of positions away from the nodal lines.

Suitable regions for preferentially coupling to the odd modes are shown with an "X" in Figure 3. The regions are located away from the nodal lines of the odd modes. In a similar way, suitable regions for preferentially coupling to the even modes are shown with an "X" in Figure 4.

A first transducer is attached to a location preferentially coupling to the odd modes and a second transducer to a location preferentially coupling to the even modes. Better performance for the whole panel may be

achievable in this way by using two exciters each placed at a location suitable for exciting all of the modes.

Figure 5 shows a schematic diagram of a loudspeaker using this technology. Unlike Figures 2 to 4, it is not drawn to scale. A panel 1 has a first exciter 3 coupled to it at a location that preferentially excites odd modes and a second exciter 5 coupled to it at a location that preferentially excites even modes.

There are a number of reasons why the use of positions in which odd or even modes are preferentially coupled might be advantageous. In particular, preferential excitation allows another degree of freedom to a loudspeaker designer which can be used to tune the response output to meet desired aural characteristics.

In embodiments the nodes can be divided into antisymmetric/antisymmetric, symmetric/antisymmetric, antisymmetric/symmetric and symmetric/symmetric modes then one or more transducers may be provided to excite some or all of these groups. If it is desired to avoid symmetric/symmetric modes, for example to reduce boundary effects, then one, two or three transducers may be provided to preferentially excite the antisymmetric/antisymmetric, symmetric/antisymmetric and antisymmetric/symmetric modes.

Another issue is that typical inertial exciters couple to and energise a large range of modes. In the future, exciters may become available that selectively excite certain classes of mode; one example is the

torsional exciter as described in International patent publication number WO00/13464 to New Transducers Limited which has the capability to selectively excite certain modes, or at least to ignore the whole body mode. As an example, such torsional excitation may be achieved by placing opposed inertial exciters on each side of a nodal line. If the exciter is placed to surround several nodal lines of the antisymmetric group, or of the symmetric group, this approach allows torsional excitation of the modes of that group. It may be difficult to find suitable locations to excite both the antisymmetric and symmetric modes equally, since no locations may be available through which pass large numbers of nodal lines of both antisymmetric and symmetric modes. Therefore, an approach exciting antisymmetric and symmetric modes separately may be particularly suitable to torsionally excite modes using inertial exciters.

Although the embodiment described relates to a loudspeaker, the coupling of transducers preferentially to odd and even modes may also be applied to other applications of a distributed mode panel, for example as a microphone or other acoustic device. In such cases however the transducers will of course need to be appropriate to the application.

CLAIMS



1. An acoustic device comprising
a panel (1) supporting a plurality of resonant bending wave modes each mode having a resonant frequency,
5 the resonant bending wave modes being divided into a plurality of groups of modes of overlapping resonant frequencies, and
at least one transducer (3) located so as to couple preferentially with one of the said groups of modes.
- 10 2. An acoustic device according to claim 1 wherein the modes of each group are substantially orthogonal to the modes not in that group.
3. An acoustic device according to claim 2 wherein the modes are divided into groups consisting of odd modes and
15 even modes.
4. An acoustic device according to claim 3 wherein the modes are divided into odd modes and even modes by labelling the modes by numbering the modes in order of increasing frequency such that the odd modes are those
20 labelled with odd numbers and the even modes those labelled with even numbers.
5. An acoustic device according to claim 3 wherein the odd modes are be the antisymmetric symmetry modes with respect to a predetermined axis.
- 25 6. An acoustic device according to claim 5 wherein the predetermined axis is a symmetry axis of the resonant panel (1).
7. An acoustic device according to claim 6 wherein

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the panel (1) has a long symmetry axis and a short symmetry axis and

the resonant bending wave modes are divided into four groups of modes: antisymmetric/antisymmetric, if
5 antisymmetric about each symmetry axis, antisymmetric/symmetric if antisymmetric about the long axis and symmetric around the short axis, symmetric/antisymmetric if symmetric around the long axis and antisymmetric around the short axis, and
10 symmetric/symmetric if symmetric about both axes.

8. An acoustic device according to claim 7 wherein the or each transducer is positioned and arranged to couple preferentially to the antisymmetric/antisymmetric, antisymmetric/symmetric and/or symmetric/antisymmetric
15 modes, but to avoid coupling to the symmetric/symmetric modes.

9. An acoustic device according to any preceding claim further comprising a further transducer or transducers to preferentially couple to a group of modes other than said
20 one group to which said at least one transducer preferentially couples.

10. An acoustic device according to any preceding claim wherein the at least one transducer is an exciter for exciting the resonant bending wave modes of the panel to
25 cause an acoustic output from the panel.

11. A method of manufacture of an acoustic device, including the steps of

providing a panel having a plurality of bending wave





modes, the bending wave modes being divided into a plurality of groups of modes of overlapping frequencies, and

attaching a transducer to the panel at a location
5 where it preferentially couples with the modes of one of the groups.

12. An acoustic device comprising

a rectangular panel capable of supporting bending wave modes as shown in Figures 3 and 4,

10 a transducer coupled to the panel in a region marked with an "X" in Figure 3, and

a further transducer located in a region marked with an "X" in Figure 4.

13. An acoustic device comprising

15 a panel capable of supporting resonant bending wave modes, the modes being divided into a first group of symmetric modes and a second group of antisymmetric modes,

a first transducer coupled to the panel at a location such that the first transducer couples preferentially to
20 said first group of modes, and

a second transducer coupled to the panel at a location such that the second transducer couples preferentially to said second group of modes.

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