April 30, 1963 G. KURTZE 3,087,567

HIGH ACOUSTIC-ENERGY TRANSMISSION-LOSS PANEL AND THE LIKE

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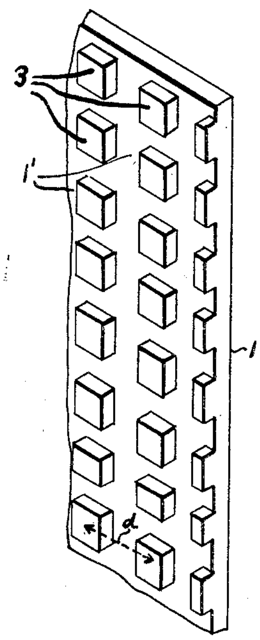

FIG. 1

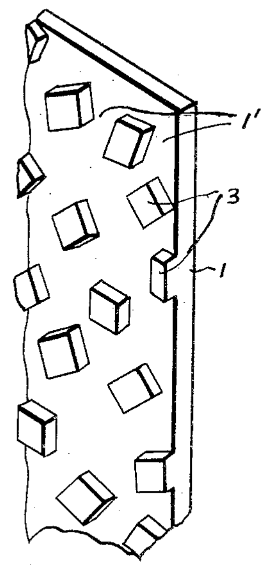

FIG. 2

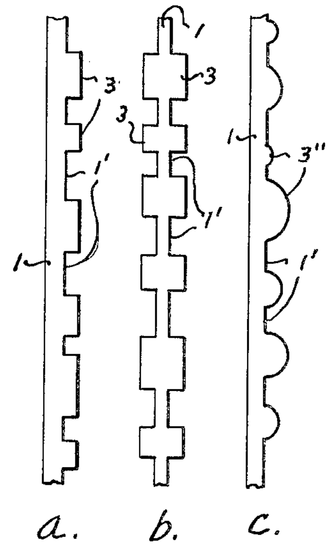

FIG. 3

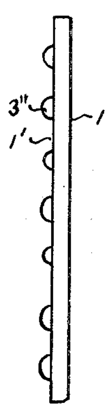

FIG. 4

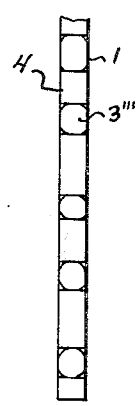

FIG. 5

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HIGH ACOUSTIC-ENERGY TRANSMISSION-LOSS PANEL AND THE LIKE

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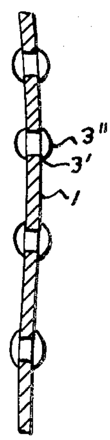

FIG. 6

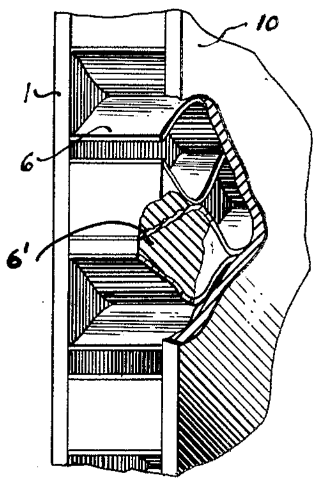

FIG. 7

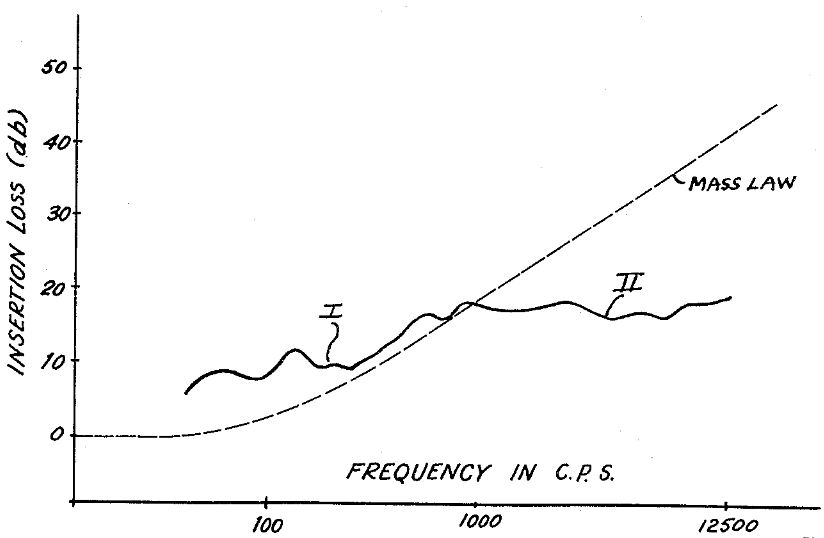

FIG. 8

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HIGH ACOUSTIC-ENERGY TRANSMISSION-LOSS PANEL AND THE LIKE

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The present invention relates to wall structures, partitions, surfaces, compartments and the like, all hereinafter referred to by the generic phrase "panel and the like," and, more particularly, to such structures designed to provide high acoustic-energy transmission loss.

It has heretofore been appreciated that the upper limit of the acoustic-energy transmission loss of a single panel and the like is determined by mass law; that is, by the transmission loss which results when there is no vibrational coupling between adjacent mass elements of the panel and the like. This implies that the effect of the coupling between adjacent mass elements, as determined by the panel stiffness, always tends to reduce the transmission loss. Though this is generally proved experimentally for isotropic panels and the like, it has been found not to be necessarily true for all types of panels and the like.

An object of the present invention, indeed, is to provide a novel construction for a panel and the like that will provide for an acoustic-energy transmission loss over a broad band of the lower and intermediate acoustic frequencies that is greater than that attainable by mass law considerations.

A further object is to provide a new and improved panel structure of more general utility.

Other and further objects will be explained hereinafter and will be more particularly pointed out in connection with the appended claims.

The invention will now be described in connection with the accompanying drawing.

FIG. 1 of which is a fragmentary perspective view illustrating a panel and the like constructed in accordance with the present invention;

FIG. 2 is a similar view of a preferred embodiment;

FIGS. 3*a*, 3*b* and 3*c* are side elevations of further modifications;

FIGS. 4, 5 and 6 are similar views of additional modified panel constructions, with FIG. 6 partially sectionalized;

FIG. 7 is a fragmentary perspective of still a further modified construction, drawn upon an enlarged scale, and partly sectionalized to illustrate details of construction; and

FIG. 8 is a graph comparing the performance of an embodiment of the present invention with the optimum theoretical transmission loss to be expected from mass law considerations.

In accordance with the present invention, panel structures are provided the mass of which is not uniformly distributed over all of the panel area, but, rather, is concentrated at points, spaced from one another in a well-defined way, and separated by relatively light, but non-porous, sheet or panel material therebetween. As an example, a thin panel of sheet material, such as metal foil and the like, is shown at **1** in FIG. 1, loaded with regularly distributed elemental mass portions **3**, such as lead weights or the like, with the thin panel elemental portions **1'** therebetween. If a panel **1** of this kind is exposed to an incident acoustic wave in the air or other medium surrounding the panel and the like, the wavelength of which wave is large compared with the distance *d* between the successive elemental mass portions **3**, the response of the different elemental surface portions **1'**, **3** will be different. Below a certain limiting frequency, the unloaded intermediate elemental portions **1'** of the panel **1** act as springs or stiffness-type impedance elements (corresponding in electrical analog to capacity), while the elemental portions **3** act as mass-type impedance elements (corresponding to electrical inductance). If there is no dissipation, the motions of the mass and spring elemental portions are directed opposite to one other. As the resonant frequency determined by the magnitudes of the elemental portions **1'**, **3**, as well as by their surface areas, the amplitudes of motion of both types of elemental portions **1'** and **3** will be such that the integral motion is zero; i.e. at this frequency, the acoustic transmission loss of the assumed non-dissipative panel **1** will be infinite.

The performance of the structure of FIG. 1 may perhaps be more readily understood by considering the electrical analogs. The stiffness of a normal isotropic panel will be represented by capacity connected in series with inductance. This yields zero impedance at resonance, corresponding to zero acoustic transmission loss at coincidence. At low frequencies f, plotted along the abscissa in FIG. 8, the transmission loss, indicated along the ordinate, approaches the mass-law dash-line curve, but never can exceed it, the capacity being proportional to $1/f^2$ in this case. In the panel of FIG. 1, however, the coupling between elemental portions is such that the capacity **1'** is connected in parallel with the inductance **3**, so that infinite impedance is attained at the resonance frequency and hence infinite transmission loss. At the lower audio frequencies, as indicated by the left-hand portion I of the solid-line curve of FIG. 8, the transmission loss approaches mass law, but is always higher than that, being above the lower portion of the dashline curve. Above resonance, however, the transmission loss drops below mass law, as indicated at II. This is not a serious disadvantage, however, since mass law involves an increase of the transmission loss by six decibels per octave with increasing frequency, so that usually a wall has far too high a transmission loss at high frequencies when it is matched to the demands at low frequencies.

The resonant frequency at which infinite transmission loss is obtained will be the lower, the larger the point masses **3** and their spacing *d*, and the smaller the stiffness of the supporting plate portions **1'**. In physically simple cases, this resonant frequency can be calculated, but in general it will be easier to determine the parameters of the panel experimentally in order to obtain the desired resonant frequency.

The panel structure of FIG. 1, of course, has a regular or uniform distribution of the masses **3**, and hence, a well-defined resonant frequency. The panel **1** will be restricted in application, thus, to cases where high transmission loss is wanted at a single frequency; that is, so as to provide shielding against a pure tone of high intensity, as an illustration. The panel **1** may also be used as an acoustic filter.

In general, however, a broad band increase of transmission loss is desired. This requirement cannot be fulfilled by damping the effective "resonance circuit," since damping will reduce the gain below mass law at any point of the transmission loss curve. It can be done, however, when a somewhat statistical or random distribution of the masses **3** is chosen in place of the regular distribution of FIG. 1, such that the resonant frequencies are distributed over a frequency range of about one to two or even three octaves. The same effect is obviously achieved when the weight, instead of or in addition to the spacing of the masses **3**, is statistically distributed. Thus, in FIG. 2 a statistical distribution of mass elemental portions is provided with the mean or average distance *d* therebetween being less than the acoustic wavelengths in the medium surrounding the panel. In FIGS. 3*a*, 3*b* and 3*c*, however, a somewhat statistical weight and/or weight and spacing distribution is provided; FIGS. 3*a* and 3*c* employing respective masses 3 and 3'' on one side of the panel, and FIG. 3*b*, masses 3 on both sides.

The actual response I, II of FIG. 8, before mentioned, was experimentally obtained for a 3-mil aluminum foil panel 1, as shown in FIG. 2, loaded with masses of 0.25 gram spaced a mean or average distance apart of 1.2 centimeters. The resonant frequencies lie within the desired frequency range I for which high transmission loss is sought. The mass law dash-line curve of FIG. 8 was plotted for a panel of mass 0.224 gram per square centimeter.

In the above examples, the stiffness of the panel portions **1'** will be essentially determined by its bending stiffness. This, of course, is not the only possibility, since the elemental portions **1'** of the panel in between the masses **3** can as well act as membranes and still provide the desired performance of a stiffness-controlled elemental portion of the panel surface. There is, thus, a large number of possible variations in the design of panels in accordance with the invention, ranging from a curtain-type partition comprising a plastic layer or the like loaded with masses such as glass spheres or beads, as later discussed, to a mass-loaded solid sheet of gypsum or even concrete or the like. In FIG. 4, as a further example, elements **3''** of high density, such as substantially hemispherical beads, are distributed over a panel surface **1** of relatively low density, as of thin plastic material and the like. The high density elements **3''** are covered and thus concealed in the panel of FIG. 5, however, by a further sheet **4**. In the panel of FIG. 6, on the other hand, the mass elements **3''** are interposed within apertures **3'** in a flexible plastic or other sheet **1**.

The mass regions **3**, moreover, may either be integrally or otherwise formed of the same material as the panel **1**, as by providing thicker elemental portions on **3''**, FIGS. 3*a*, *b* and *c*, or they may be of different material, as before discussed in connection with, for example, FIGS. 1 and 2, attached to and protruding from the panel surface. In FIGS. 7, indeed, a honeycomb spacer structure **6** is shown supporting inner and outer homogeneous panel surfaces or skins **1** and **10** in sandwich construction, with the mass elemental portions provided by filling predetermined cells with high-density metal or other material, as at **6'**. In all cases, the common characteristic of the panels of the present invention resides in the non-uniform distribution of the mass and/or stiffness of the elemental portions thereof, whereby the average or mean distance between the successive alternate mass-controlled elemental portions **3** and between the successive stiffness-controlled intermediate elemental portions **1'** is small compared with the wavelengths of the acoustic energy in the air or other surrounding medium within the frequency range in which high transmission loss is desired. In the design of such panels, the magnitudes of the masses and stiffness, moreover, are matched to each other so that the resulting resonant frequency is within the desired frequency range.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims. In the claims, the term "sheet-metal-like" is intended to embrace materials which are like sheet metal in the function performed by the designated element in the acoustic panel; for example, material such as aluminum foil or thin plastic sheet are "sheet-metal-like" when they serve as the panel member of the invention. Similarly, such materials are "metal-like" when they serve as the masses of the invention.

What is claimed is:

1. An acoustic panel for providing over a broad band of low acoustic frequencies, an acoustic-wave transmission loss greater than that obtainable by mass-law considerations, comprising a thin panel member of sheet-metal-like resilient material supporting a plurality of metal-like masses spaced along the length and width of the panel member and coupled mechanically to each other directly through freely vibratory resilient sheet-metal-like material portions of the panel member disposed between successive masses, the distance between the said masses being less than the wave lengths corresponding to the said frequencies and the weight of the said masses being substantially greater than that of the said resilient material portions, the weight of the masses and the degree of resilience of the said resilient portions being correlated to produce a mechanical resonance at an acoustic frequency within the said band.

2. An acoustic panel as claimed in claim 1, and in which the said masses are randomly distributed over the panel member and the mean distance between the masses is less than said wave lengths.

3. An acoustic panel as claimed in claim 1, and in which the panel member is formed of foil.

4. An acoustic panel as claimed in claim 1, and in which the masses protrude from a surface of the panel member.

5. An acoustic panel as claimed in claim 1, and in which the masses protrude from opposite surfaces of the panel member.

6. An acoustic panel as claimed in claim 1, and in which the masses are of the same material as the panel member material but are thicker.

7. An acoustic panel as claimed in claim 1, and in which the masses are disposed at least in part within the panel member.

8. An acoustic panel as claimed in claim 1, and in which the panel member comprises a pair of spaced outer layers bounding the masses therebetween.

9. An acoustic panel as claimed in claim 8, and in which the layers are spaced apart by a honeycomb and the masses comprise high density cells of the honeycomb.

10. An acoustic panel as claimed in claim 1, and in which the masses are formed of material having higher density than the panel member.

11. An acoustic panel as claimed in claim 1, and in which the resilient material is a thin plastic sheet and the said masses are imbedded therein.

12. An acoustic panel as claimed in claim 1, and in which the panel member comprises a pair of spaced homogeneous outer layers and the masses comprise spacer elements of different density sandwiched between the layers.

13. An acoustic panel as claimed in claim 1, and in which the weight of said masses differs randomly over the panel member.

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