June 25, 1957 P. K. HEERWAGEN 2,796,636

ACOUSTIC TILE

Filed Dec. 16, 1952 2 Sheets-Sheet 1

Fig. 1.

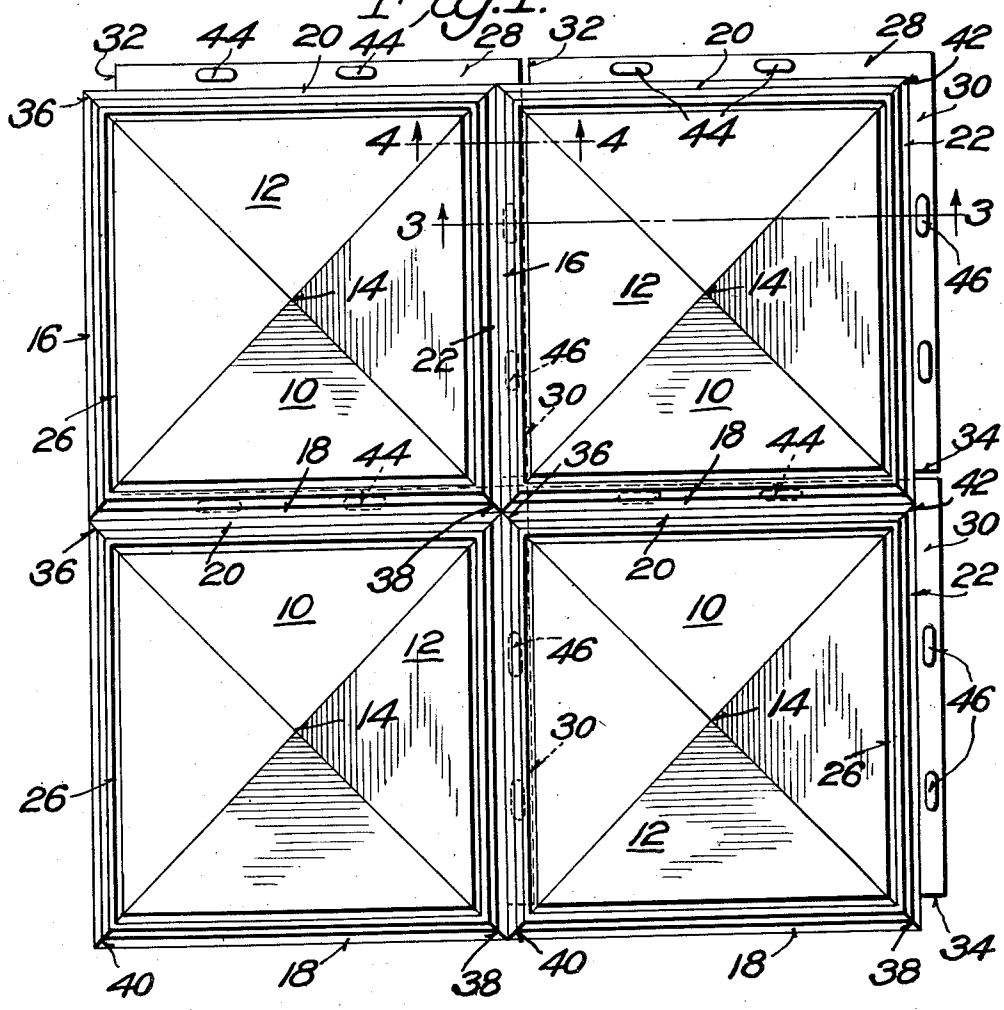
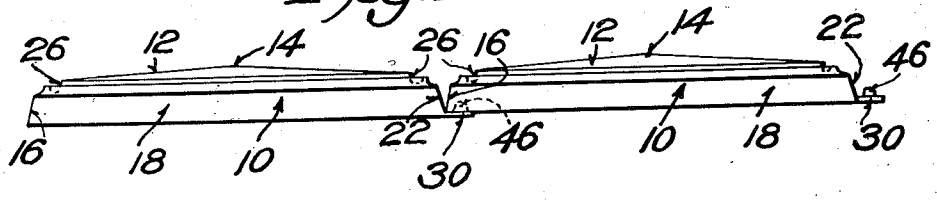


Fig. 2.



INVENTOR

PAUL K. HEERWAGEN,

BY Philip H. Sheridan

ATTORNEY

June 25, 1957 P. K. HEERWAGEN 2,796,636

ACOUSTIC TILE

Filed Dec. 16, 1952 2 Sheets-Sheet 2

Fig. 3

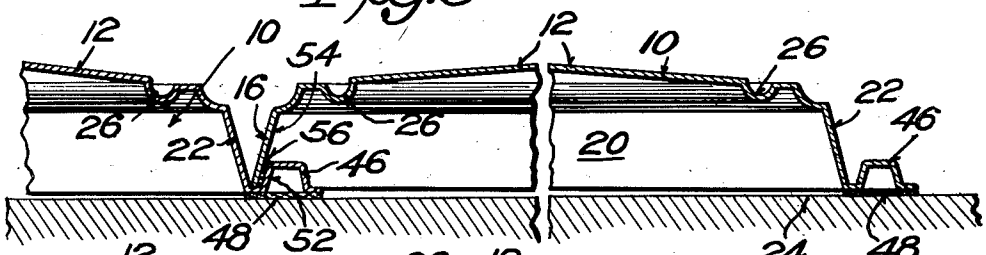


Fig. 4.

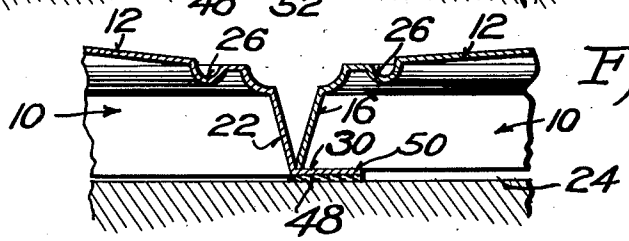


Fig. 5.

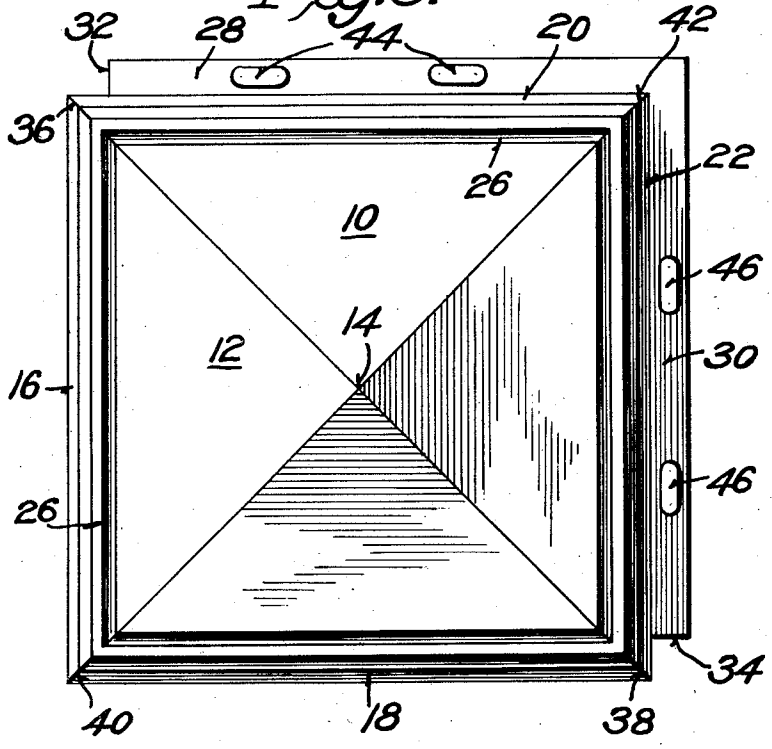
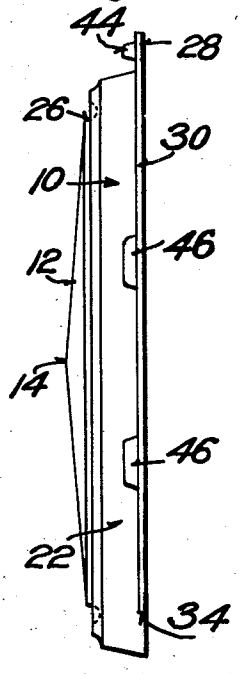


Fig. 6.



INVENTOR

PAUL K. HEERWAGEN,

BY Philip H. Sheridan

ATTORNEY

United States Patent Office

2,796,636

Patented June 25, 1957

2,796,636

ACOUSTIC TILE

Paul K. Heerwagen, Fayetteville, Ark.

Application December 16, 1952, Serial No. 326,236

5 Claims. (Cl. 20—4)

This invention relates to a sound correction means consisting of a plurality of acoustic tiles for attachment to a surface, such as a wall, ceiling, or partition.

The present invention is an improvement of the structures shown in Patents Nos. 2,090,043, granted August 17, 1937, and 2,161,708, granted June 6, 1939, to P. K. Heerwagen.

One of the principal objects of the invention is to provide an acoustic unit or tile having means for connecting the same to adjacent tiles and to a supporting surface which is provided with a plurality of free corners, whereby said corners may vibrate without interference from its supporting surface or from the surfaces of adjacent tiles.

An additional object of the invention is to provide an acoustic tile which is so constructed that sound waves which strike the surface of the tile diaphragm are variably dispersed, due to the non-symmetrical diaphragmatic action, due to the fact that certain of the sides of the tile are fixed to a supporting surface, while other sides are not fixed to said surface.

An additional object of the invention is to provide in connection with the structure set forth in the next penultimate paragraph, means whereby sound waves which strike the diaphragm are absorbed by the trapped or dampened air space, which absorption of said sound waves is augmented by the free portions of certain of the sides and ends of each tile. Said free portions act both as a reed and as a bellows, in that they accelerate both the diaphragmatic action of the tile and the air which is trapped in the space formed by the diaphragm and the walls of the tile. The reed function of the free tile sides is the same as a reed which vibrates through certain sound frequencies, and the bellows function of the tile allows a slow escape of the trapped air, and a diffusion of sound waves takes place of those waves which strike the surface of the diaphragm portion. These are minutely diffused or broken up, due to the non-symmetrical movement of the diaphragm and the periodic oscillation action of the free portions of the inclined tile sides.

Yet another object of the invention is the provision of an acoustic tile which is so constructed that sound waves are clarified of all harshness and of unwanted noise, such as reverberations and echoes, resulting in purified tones of sound and pitch.

A further object of the invention is to provide an acoustic tile which is characterized by a high proportion of absorption of sound of low frequencies.

Other objects will be apparent from the following description taken in connection with the accompanying drawings, in which:

Figure 1 is plan view of a plurality of tiles of the present invention which are connected to each other;

Figure 2 is a side elevational view of the structure shown in Figure 1;

Figure 3 is a sectional view taken on the line 3—3 of Figure 1;

Figure 4 is a sectional view taken on the line 4—4 of Figure 1;

Figure 5 is a plan view of one of the tiles shown in Figure 1; and

Figure 6 is a side elevational view of the structure shown in Figure 5.

Theory

There are three well known wasy whereby sound intensity is absorbed upon impinging on a wall and may be described by the terms viscous, resilient, and membranous (or diaphragmatic). The materials that absorb by viscous damping are usually most effective in the high frequencies. Resilient materials, such as carpets, are generally effective in the middle range while membranous materials are particularly effective in the lower frequencies. Since higher frequencies are absorbed in part by the air, and since there are no materials as effective as the diaphragmatic type for the lower frequency ranges, the importance of this type material for stopping unwanted reflected sounds is easily seen.

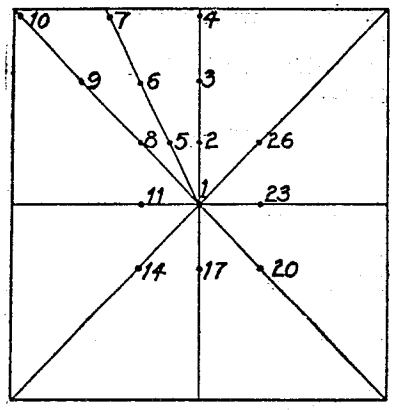
The theory that explains the absorbing characteristics of the acoustic tile of this invention is associated with the mechanical hysteresis found in all actual vibrating bodies. A perfectly elastic body follows Hooke's law when subjected to a distorting force, and a graph of the stress as ordinates plotted against strain as abscissae will be a straight line. Since there is always some internal resistance, the actual force necessary to cause a given distortion is greater than that which is called for according to Hooke's law for increasing stresses and less than that which is called for according to Hooke's law for decreasing forces. This internal resistance will produce a loop in the stress-strain graph, the area of which is a measure of the internal resistance; i. e., mechanical hysteresis. As a sound absorber, the energy dissipated is measured by the internal resistance (r) or resistances, multiplied by the square of the velocity (v) of motion of the vibrating mass, or masses. The study of the energy dissipation for the vibrating system may be approached in a manner analogous to the electrical resonant circuit by the following method: Let the mass reactance be mw, and the elastic reactance be s/w, where m, w, and s represent the effective vibrating mass, the angular velocity ($2\pi f$), and the force per unit displacement, respectively. The reactive energy factor, Q, defined here as the mass reactance to the mechanical resistance, yields the equation, $Q=mw/r$. When defined as above, Q may be evaluated also, at the resonant frequency, f_0, by the equation, $Q=f_0/f_2-f_1$), where f_1 and f_2 are frequencies whose amplitudes are $1/\sqrt{2}$ that of the resonant frequency (f_0). Moreover, a zero reactance at the resonant frequency gives $mw=s/w$ so that $r=s/wQ$. Since s, the force per unit displacement may be measured experimentally, a method is indicated here for calculating the mechanical resistance, r. The rate of dissipation of acoustical energy at the resonant frequency will be $(\frac{1}{2})rv_m^2$ where v_m is the maximum velocity of the vibrating mass.

Application of the above simplified theory in the various experiments has been of great value in checking the explanations for the absorption characteristics noted.

Vibration characteristics

The vibration characteristics have been studied by attaching a tiny electrodynamic-type microphone probe to positions on top of the diaphragmatic section. The microphone is connected to an amplifier with proper controls. The figure below shows a top view of a standard sized tile with four positions lettered only. A description of what happens here when sound impinges on the surface is typical of the vibratory patterns for other

sections. Sound is generated at constant voltage and the vibratory characteristics are plotted.



Four numbered positions

Resonant peaks in one E–I tile were found at position 1 for approximate frequencies 380 (very pronounced), 950, and 2100; at position 2 for approximate frequencies 260 (fairly pronounced), 725, 1000, and 3000; at position 3 for approximate frequencies 260 (very pronounced), 1000, and 2050; at position 4 for approximate frequencies 700 (large), 2050, and 4000.

It is important to note that there are several non-harmonic frequencies at which the material vibrates and that the material does not vibrate in a single frequency pattern but has several superimposed non-harmonic vibrations. This should be expected in view of what is known about the non-harmonic vibration characteristics of rectangular plates and of disks.

The experiments were conducted with and without a closed back for trapping the air. The experiments showed that the resonant velocity amplitude peaks were much greater when the air was sealed under the tile. This is important in installation of the tile.

Role of trapped air

A resonant frequency for the vibrating tile may be calculated as soon as the impedance of the material can be determined. Since complete impedance calculations are difficult, a simple approach to a resonant frequency calculation is to assume the simplest possible physical conditions. There are three important reactive terms: (1) the mass reactance, (2) the mechanical stiffness, (3) the air reactance; i. e., trapped air. A much better approximate cause of the absorption could be calculated by use of (3) combined with (1) rather than (2) combined with (1). Calculation of one prominent resonant frequency by combination of (1) and (3) gives

$$f=(c/2\pi)(SP_0/1m)^{1/2}=390 \text{ cycles/sec.}$$

for one approximate resonant frequency. This means that the stiffness of the material is less important than the trapped air to fix the maximum absorption frequency patterns. In the above formula, c is the velocity of sound, S is the cross-sectional area, P_0 is the density of air, 1 is the depth of the tile, and m is the mass of the vibrating tile.

One should carefully note that peak absorptions are found at each frequency region where a resonant vibration is found.

Acoustically alive room without reverberation

An acoustically alive room must be corrected for reverberation time so that the whole room is properly treated rather than the room on the average being properly treated. A room corrected by materials that leave the room with dead sections, often described as "spotty," are unsatisfactory and appear to be lifeless. The room departs from the simple sabine geometrical sound pattern

assumed to be desirable for good room acoustics. Since dispersive centers for the sound is a valuable corrective feature for diffusing the sound pattern, the acoustic tile of the present invention offers this valuable dispersive characteristic as one of its acoustical advantages.

The more desirable acoustic naturalness of voice or music is obtained, therefore, with the acoustic-diaphragmatic tile of this invention, as well as the needed absorption, since this absorbing material supplies its own dispersion centers because of its non-symmetrical absorbing characteristics. Acoustic naturalness in rooms treated with this material have been noted by many people.

The acoustical liveliness found in the tile of the present invention is further enhanced by the very nature of the sound frequency patterns. Both musical and spoken sounds are made up of widely variable frequencies. Hence the multiple diffusing and absorbing centers are changing continuously. The sound is more diffused for liveliness and is absorbed at the same time.

Referring to the drawings, in which the numerals designate like parts in each of the several views, **10** designates a unit, panel, or tile made from any suitable resonant or sound wave vibratory material which has diaphragmatic qualities, such, for example, as sheets composed of treated organic fibers, or inorganic substances. Specifically, pulp board may be used, but preferably sheets of unwoven cotton fabric impregnated with plastics and other impregnants have been found to produce satisfactory results.

The size of the individual units or tiles is not critical, but satisfactory results have been obtained by the covering of a wall or ceiling with square units whose dimensions are about 12" x 12". While units of this size are typical, other installations may permit the use of smaller or even much larger tile where a single unit will suffice to cover an entire wall, ceiling, or other area.

It will further be understood that the configuration or design may be varied, and may be of a different shape than the square shape which has been shown for purposes of illustration. The units can be made at the site of construction of the structure in which they are to be used, but preferably are prefabricated at the factory.

Each tile has a diaphragm portion **12** in the general shape of a pyramid provided with an apex **14**, and sides or lips **16**, **18**, **20**, and **22** that incline to the surface **24**; i. e., the plane of the wall or ceiling to which the units are attached. Actually, the amount of incline is slight. Each tile has a square depression **26** forming the marginal edges of the diaphragm, although a round, oblong, or a depression of a different design may be used in place of the depression shown.

As shown in the several figures, each tile has a pair of securing flanges **28** and **30**, one preferably being integrally joined to the other, while the other two sides **16** and **18** do not have flanges. Flanges **28** and **30** terminate at the edges **32** and **34** respectively, which edges are located inwardly of the diametrically opposite corners **36** and **38** respectively. The other diametrically opposite corners are indicated at **40** and **42**, as shown in Figure 5. As stated hereinafter, this construction provides three "free" or vibrating corners **36**, **38**, and **40** and one fixed corner **42**.

Each flange **28** and **30** has a pair of buttons or humps **44** and **46** respectively; although it is possible to provide a single hump, or three or more humps on each flange, according to conditions to be met in actual constructions, or the materials used in the tiles. These buttons or humps are pressed-up portions of the material of the flanges **28** and **30** and are formed, as are the apex **14**, depression **26**, sides **16**, **18**, **20**, and **22**, and the flanges themselves, during the shaping of the units as part of the manufacturing operation. Said buttons assist in interlocking the sides of adjacent tiles without disturbing the vibratory movements thereof during the absorption of sound waves thereby.

The tiles are affixed to a supporting surface such as the wall or ceiling 24 by adhesive 48 which is applied to the undersurface portions 50 of flanges 28 and 30. In this manner only portions of two of the sides of each tile are held to a supporting surface; and two of the sides, i. e. sides 16 and 18, as well as corners 36, 38, and 40, together with diaphragm portion 12, are free to vibrate in accordance with sound waves which strike the diaphragm.

As seen in Figure 3, wherever the inner side 52 of a button 44 or 46 of one unit is in juxtaposed position to the inner portion 54 of side walls 16 and 18 of another unit, an adhesive 56 is applied. In other words, the humps on the two flanges of one unit are for the purpose of securing the free edge or side of an adjoining tile. In place of, or supplemental to, such adhesive, a tack or staple (not shown) may be used. Also in place of, or supplemental to, the adhesive 48, tacks, nails, or other mechanical fastenings could be used to attach flanges 28 and 30 to the surface 24.

Figure 3 only shows adhesive at 56, but, if necessary, adhesive may be applied in the space between hump 46 and side 22 covering the exterior face of 16 at the hump area. If this were done and it is preferable in many instances, two units 10 would be assembled by applying adhesive on the underside of both flanges of the two units. Thereafter, one unit is placed on the surface 24 and adhesive is applied to that unit in the space between side 22 and the humps 46. Then a side 16 of the second tile is received, as shown in Figure 3, just prior to its application to the surface 24. It is clear that the space between the hump and side 22 is preferably the only area where the free edge 16 would be secured.

It will be understood that the acoustical unit herein described may not only be used in surfacing walls and ceilings in residences, apartments, auditoriums, schools, churches, and theaters, but also in aircraft and other vehicles of various kinds, such as ships, trains, and automobiles. The invention has further application in the electronics field, such as in cabinets for radio and television sets.

The above description and drawings disclose several embodiments of the invention, as specific language has been employed in describing the several figures. It will, nevertheless, be understood that no limitations of the scope of the invention are thereby contemplated, and that various alterations and modifications may be made such as would occur to one skilled in the art to which the invention relates.

Having thus described the invention, what is claimed as new and what is desired to be secured for Letters Patent is:

1. An acoustic tile construction comprising a hollow box-like unit formed from a substantially rectangular diaphragm portion and integral sides extending at a slight outward slope from the edges of said portion for spacing the portion from the surface to which it is to be secured, said sides and portion forming four corners, the terminating edges of a pair of juxtaposed sides having an out-turned securing flange integrally connected therewith and engageable with the surface for mounting the unit thereon, each flange having one end thereof terminating substantially at the corner common to said pair of sides and its other end terminating short of the other corner of which each of said pair of sides forms a part, means for securing the flanges to the surface whereby three of said corners, a pair of sides and said diaphragm may vibrate in accordance with sound waves which strike said diaphragm, and means for securing a pair of flangeless sides of similar tile construction to said unit without substantially interfering with the said vibratory movement, said last named means including at least one projection upstanding from each of said flanges, each projection being spaced from the ends of its respective flange, each flange being substantially flat for a distance from its ends at least several times as long as the width of the flange.

2. An acoustic tile construction as defined in claim 1 wherein the flanges are joined at the common corner to fix said common corner on the surface when the unit is secured thereto.

3. An acoustic tile construction as defined in claim 1 wherein each projection is also spaced from the side from which a flange extends whereby a portion of a side of the similar tile construction may be positioned therebetween and secured in such position by adhesive.

4. An acoustic tile construction as defined in claim 3 wherein there are only two projections on each flange, both of which are relatively small compared to the size of said flanges and are spaced substantially from the other ends thereof and from each other, said projections being raised portions forming humps in said flanges.

5. An acoustic tile construction as defined in claim 4 wherein the diaphragm portion is of a configuration similar to a pyramid and is provided adjacent its marginal edges with a continuous depression, said sides sloping outwardly from the edges of said diaphragm portion to form therewith angles slightly greater than right angles.

References Cited in the file of this patent

UNITED STATES PATENTS

330,916	Northrop	Nov. 24, 1885
855,816	Sagendorph	June 4, 1907
857,718	Calkins	June 25, 1907
1,913,249	Sersen	June 6, 1933
2,090,043	Heerwagen	Aug. 17, 1937
2,156,277	Corbin	May 2, 1939
2,323,417	Pauli	July 6, 1943
2,494,157	Beck	Jan. 10, 1950
2,497,912	Rees	Feb. 21, 1950

FOREIGN PATENTS

721,802	Germany	July 22, 1942