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SOUND ABSORPTIVE STRUCTURAL BLOCK

Filed Oct. 25, 1968

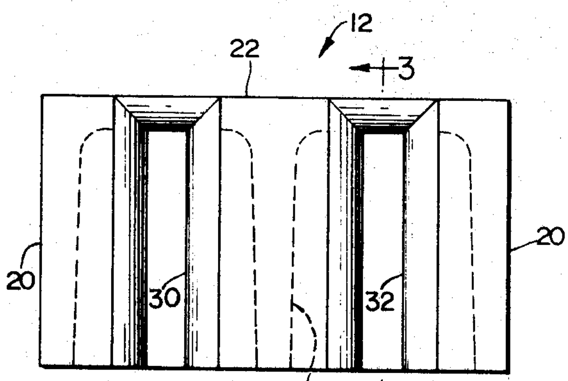

FIG. 1

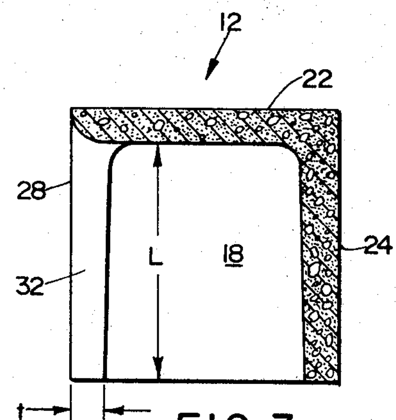

FIG. 3

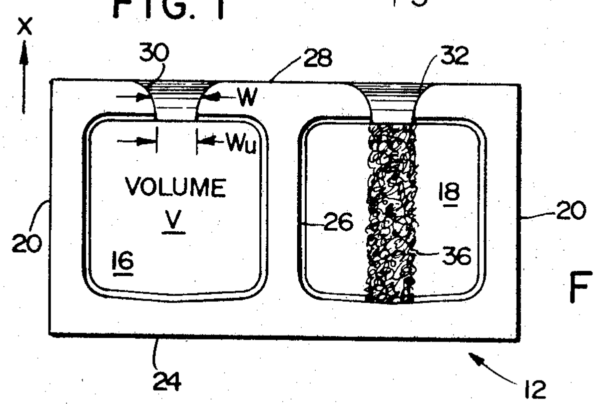

FIG. 2

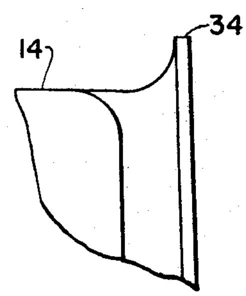

FIG. 5

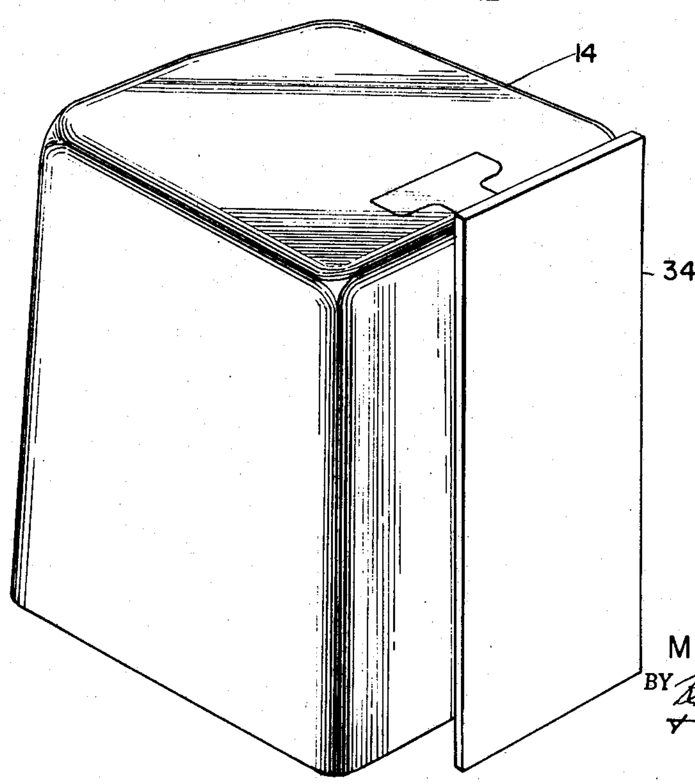

FIG. 4

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SOUND ABSORPTIVE STRUCTURAL BLOCK

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U.S. Cl. 181—33 3 Claims

ABSTRACT OF THE DISCLOSURE

A sound absorptive block of molded structural material has a cavity or cavities in communication with the sound source through an elongated slot or slots flared in width from the cavity toward the outer surface of the block. Within a certain frequency range, the air in the cavity reacts resonantly to impinging sound waves to cause significant air movements within the slot and consequent dissipation of sound energy through turbulence and friction losses. The flare in the slot increases the aperture area exposed to the sound. It also provides an impedance matching effect that increases the transmission of impinging sound energy into the cavity and its dissipation therein at frequencies above the resonant frequency.

BACKGROUND OF THE INVENTION

The U.S. Patent to O. Zaldastani and the present applicant No. 2,933,146 discloses a sound absorbing block of molded structural material such as concrete. This block has one or more cavities communicating with a source of impinging noise through one or more slots, whereby sound energy is dissipated by a combination of several effects. These include a so-called Helmholtz resonance effect resulting in the dissipation of sound energy within the walls of the slot and a "black body" effect resulting in the dissipation of sound energy by multiple reflections within the cavity.

The usefulness of this block as a sound absorber is a function of the aperture area of the slot exposed to impinging sound and of the acoustic impedance of the cavity as viewed from the source of impinging sound. The acoustic impedance of the cavity at low frequencies is spring-like and large, at frequencies near the Helmholtz resonance it is resistive and small, and at frequencies above the Helmholtz resonance it is mass-like and large. In practice the conditions are such that the Helmholtz resonance occurs between 10 and 300 Hz., approximately, and it is relatively unimportant to dissipate sound energy at frequencies below this range but of substantial practical importance to dissipate sound energy at frequencies above this range.

The block described in said patent provides effective sound dissipation at frequencies near the Helmholtz resonance. Here, the impedance of the cavity is well matched to that which characterizes the incident sound waves, namely a relatively small, purely resistive impedance that is effectively independent of frequency. As noted above, the impedance mismatch that occurs at lower frequencies is not disadvantageous. However, a limitation on the sound absorbing performance of the block exists at middle and higher frequencies above the Helmholtz resonance where an impedance mismatch limits the transmission of sound energy through the slot into the cavity.

It is a principal object of this invention to provide an improved block capable of greater sound absorption at frequencies above the Helmholtz resonance.

Additional objects are to achieve the desired sound absorption by economical and reliable means and without sacrifice of the various advantages attributable to the block described in said patent, and to achieve an aesthetically pleasing appearance in applications where partitions formed of the blocks are significant factors in architectural design.

SUMMARY OF THE INVENTION

This invention consists in a masonry structure having a slot or slots of improved configuration that enhances the sound transmission to an enclosed cavity or cavities, whereby a greater dissipation of sound energy is achieved. The configuration, referred to generally as "flared," is one of variable width increasing from the extremity of the slot adjacent the cavity toward the opposite or outer extremity. This enables the slot aperture to comprise a larger fraction of the surface of the structure exposed to sound, as compared with slots of uniform width equal to that adjacent the cavity. It also results in an improved absorption cross section of the cavity whereby a higher transmission ratio is achieved, thus leading to greater sound absorption by the slotted structure. This higher transmission ratio is achieved by matching the acoustic impedance of the cavity to the impedance which characterizes the incident sound waves.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a front elevation of a masonry block embodying the invention.

FIG. 2 is a bottom view of the block shown in FIG. 1.

FIG. 3 is an elevation in section taken on line 3—3 of FIG. 1.

FIG. 4 is an isometric view of a mold plug used in casting the block of FIGS. 1 to 3.

FIG. 5 is a fragmentary side elevation of the mold plug.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A masonry block **12** according to this invention is shown in FIGS. 1 to 3. It is manufactured in the usual manner by means of a block mold adapted to pack the hardenable aggregate around a pair of tapered plugs **14**, the latter having means to form the slots. The masonry material may be any hardenable type such as concrete or the like.

After compacting the material, the hold is stripped, the block is cured, and when hardened is a load-bearing structural element having cavities **16** and **18**. The block has a pair of closed end walls **20**, a third or top closed wall **22** contiguous with the walls **20**, a fourth or back closed wall **24** contiguous with the walls **20** and **22**, a closed partition wall **26** (or plural partition walls if there are more than two cavities), and a fifth or front wall **28** opposite the fourth wall and intended to face the source of sound to be suppressed.

The wall **28** has apertures in the form of flared slots **30** and **32** by which the cavities **16** and **18** are in communication with air propagating the sound to be suppressed. The width of these slots increases uniformly from their extremities adjacent the cavities to the opposite or outer extremities as hereinafter further explained. This shape of the slots is preferably produced in the fold by means of inserts **34** received in slots in the plugs **14**, the inserts being shaped in the desired manner. Alternatively, the plugs may have integral fins shaped like the inserts **34**.

Various flared shapes may be used according to this invention. A straight line or V-shaped taper, that is, one in which the width of the slots varies linearly between its extremities, is one form. The preferred form is an exponential taper, that is, one in which the slot width varies approximately as a constant raised to a power which is a linear function of the position between the slot extremities. This results in smooth slot walls that are free of sharp exposed outer corners or edges and of pleasing appearance, as viewed in FIG. 1. It also results in better impedance matching, as more fully explained below.

The blocks **12** are laid up in successive courses with mortar to form partition walls or ceilings. Thus one course closes the cavities **16** and **18** of an adjacent course except for the slots, whether or not the joints between the side walls **20** are offset between successive courses.

As thus laid up in a masonry structure, the blocks are effective to absorb and dissipate the sound impinging on the wall **28**. Dissipation results in part from multiple reflections within the cavities **16** and **18**, which is the so-called "black body" effect. Dissipation also results from losses within the slots **30** and **32** that are enhanced at frequencies for which there is acoustical resonance, with sound waves of maximum amplitude oscillating within the slots. This phenomenon is associated with the Helmholtz resonance effect.

It is evident that the flaring of the slots increases the fraction of incident acoustic energy that is transmitted into the cavity where it is absorbed. In physics terminology, the absorption cross section of the cavity is increased.

Also, the flared slots match the impedance of surrounding air to that of the cavities in the manner of an ear trumpet used by the hard of hearing. The result is a more effective sound absorptive structure. This will be evident from a consideration of the theory of acoustical horns, as presented for example in H. F. Olson, Elements of Acoustical Engineering, 2nd ed., D. Van Nostrand Co. (New York, 1947), pp. 94–112. Although textbooks generally deal with horns as devices coupling a high-impedance source to the atmosphere, whereby acoustic energy flows from the throat to the mouth of the horn, these analyses are, by virtue of the reciprocity principle, equally applicable to energy flow in the reverse direction, whereby energy flows from the mouth to the throat. The effect of the flared shape is such that in the medium frequency range above the Helmholtz resonance, the transformation ratio is small and a phase shift is effected from a reactive impedance at the throat to a resistive impedance at the mouth, that is, an improved impedance match as compared with the blocks described in said patent. At low frequencies, i.e., near and below the Helmholtz resonance, the transformation ratio is unity and the sound absorption is comparable to that achieved by the blocks described in said patent. A mismatch of impedances occurs at frequencies below the Helmholtz resonance, but this is of no practical disadvantage.

As previously noted, the preferred shape of slots is exponential. This produces a larger ratio of resistance to reactance, that is, better impedance matching than a straight sided taper, although the latter as well as other flared shapes can be used in many applications.

Comparing a cavity having a slot of uniform width w_u with one having a flared slot with a minimum width equal to w_u adjacent the cavity, it is found that the latter has a higher natural or resonant frequency. This may be seen by considering the general formula for the natural or resonant frequency f of a Helmholtz resonator.

(1)
$$f=\frac{1}{2\pi}\left(\frac{k}{m}\right)^{1/2}$$

in which k is the mechanical stiffness of the cavity and constant in this comparison, and m is proportional to the kinetic energy of the mass of air in the slot, augmented by the accession to inertia or entrained mass of air. For a slotted masonry block in which the thickness t of the wall **28** is significantly larger than the width of the slot, the accession to inertia is small compared to the mass of air actually located in the slot, and may be ignored. From this expression, it is seen that the ratio of the natural frequency f_h for the flared slot to the natural frequency f_u for the uniform slot is given by

(2)
$$\frac{f_h}{f_u}=\left(\frac{m_u}{m_h}\right)^{1/2}=\left(\frac{T_u}{T_h}\right)^{1/2}$$

in which T_u and T_h are the corresponding kinetic energies for equal air velocities v_u at the throat. The kinetic energy of the air in the slot depends on its shape. For an exponentially flared slot, the slot width w at any position x measured from the cavity toward the outer extremity is given by

(3)
$$w=w_u e^{ax}$$

in which a is the flare constant. The air velocity v at the position x is given by

(4)
$$vw=v_u w_u, \text{ or } v=v_u e^{-ax}$$

This expression gives recognition to the fact that the air is substantially incompressible within the range of frequencies of interest, and therefore the mass flow rate is a constant at every cross section of the slot.

The kinetic energy T_u for the uniform slot may be expressed by using the formula for kinetic energy which applies when the velocity is the same at all the cross sections.

(5)
$$T_u=\tfrac{1}{2}\rho L w_u t v_u^2$$

in which "ρ" is the density of air, and L the vertical slot length. By similar means and using Equations 3 and 4, the expression T_h for the flared slot is obtained.

(6)
$$T_h=1/2\rho L w_u v_u^2\int_0^t e^{-ax}dx=T_u\left(\frac{1-e^{-at}}{at}\right)$$

Using Equation 6, Equation 2 may be rewritten.

(7)
$$\frac{f_h}{f_u}=\left(\frac{at}{1-e^{-at}}\right)^{1/2}$$

The expression for f_u is derived from Equation 1, in which

(8)
$$k=\frac{L^2 w_u^2 B}{V}$$

B is the bulk modulus of air, and V is the volume of the cavity. Thus,

(9)
$$f_u=\frac{B^{1/2}}{2\pi\rho^{1/2}}\left(\frac{Lw_u}{Vt}\right)^{1/2}=2160\left(\frac{Lw_u}{Vt}\right)^{1/2}$$

with f_u expressed in Hertz and length in inches. By Equations 7 and 9,

(10)
$$f_h=2160\left[\frac{Lw_u a}{V(1-e^{-at})}\right]^{1/2}$$

The ratio (7) is always larger than one; hence the natural frequency for the flared slot always exceeds that for a uniform slot. If the above analysis is refined to account for the accession to inertia, the ratio in Equation 7 is increased.

From the foregoing description it will be evident that each block may have one or more cavities. Also, although the drawing shows the slots **30** and **32** as extending the full height to the wall **22**, one or both of these slots may be shorter in length, if desired. Further, although the plug **14** of FIGS. 4 and 5 is adapted to produce a slot with its end surface tapered, it may be modified to produce a slot with a flat end surface, either at right angles or at an acute angle to the front wall **28**. As a still further modification, sound absorptive material such as a body **36** of fibrous material may be inserted in the blocks in such a position as to extend across the inner end of the slot. This material prevents some kinds of foreign matter from being inserted in the blocks and assists in damping the sound and dissipating its energy. Other variations in the structure will occur to a person skilled in this art, and will also fall within the spirit and scope of this invention.

I claim:

1. A sound absorptive block of molded structural material having a cavity, a pair of opposite closed end walls, third and fourth contiguous closed outer walls each contiguous with each of the end walls, a side having an opening opposite the third wall and extending to the cavity, and a fifth outer wall opposite the fourth wall, having an

exposed surface facing the direction of noise to be absorbed and having a slot therein leading to the cavity, said slot being elongated, having one end terminating at said opening, extending in length from the opening toward the third wall, and being of variable width increasing from its extremity adjacent the cavity to said exposed surface.

2. A block according to claim **1**, in which the walls of the slot are smoothly flared toward the exposed surface of the fifth outer wall.

3. A block according to claim **2**, in which the walls of the slot are flared substantially exponentially toward the exposed surface of the fifth outer wall.

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ROBERT S. WARD, Jr., Primary Examiner

U.S. Cl. X.R.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,506,089 Dated April 14, 1970

Inventor(s) Miguel C. Junger

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 49, cancel "10" and insert -- 100 --.

Column 2, line 44, cancel "hold" and insert -- mold --;

Column 2 ,line 60, cancel "fold" and insert -- mold --.

SIGNED AND
SEALED
AUG 4 - 1970

(SEAL)
Attest:

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Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents