Sept. 20, 1932. E. B. LYFORD 1,878,409

APPARATUS AND METHOD FOR THE ABSORPTION OF SOUND

Original Filed March 6, 1929

Fig. 1.

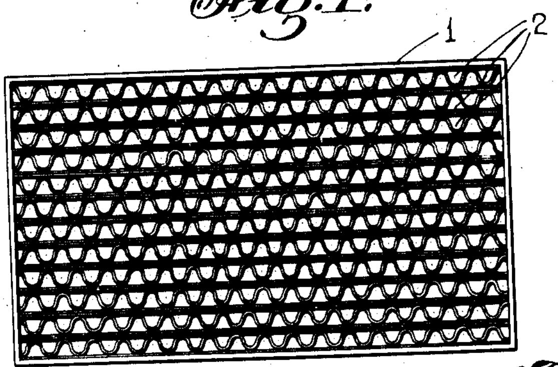


Fig. 2.

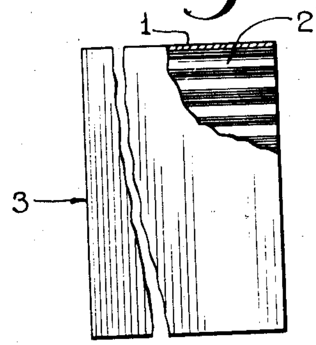


Fig. 3.

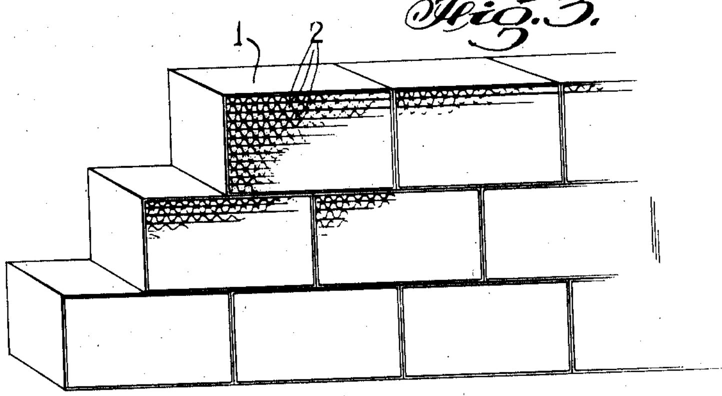


Fig. 4

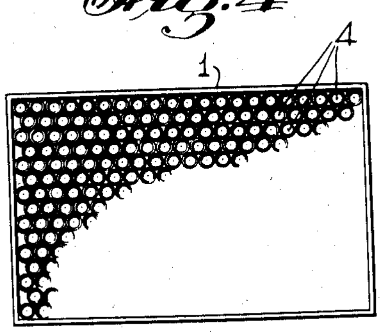
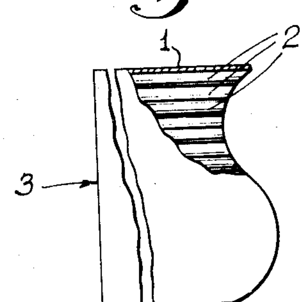


Fig. 5.



INVENTOR.

BY

ATTORNEYS.

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1,878,409

UNITED STATES PATENT OFFICE

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APPARATUS AND METHOD FOR THE ABSORPTION OF SOUND

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The object of my invention is to provide a sound-absorbing structure, whereby undesired sounds and noises can be absorbed and even suppressed rather than reflected as they are from smooth solid walls (including floors and ceilings within the term "walls"), or passed on as they are by open spaces and ordinary screens.

In brief, my invention comprehends and is illustrated by an assembly of a considerable number of closely-packed or relatively thin-walled, elongated or pipe-like cells (resembling one side of an unfilled honey comb in this respect) made of or otherwise formed in a material resembling in its action the moderately heavy paper used in the manufacture of corrugated card-board for boxes and cartons, the cells being open at one end at least, of relatively small diameter, that is to say, of the order of one-sixth of an inch in diameter, and each being of such length that the column of air contained within it tends to resonate at substantially the frequency of the sound it is intended particularly to suppress, or where the sound or sounds to be suppressed include a number of different frequencies, of such length that it tends to resonate at substantially the lowest of those frequencies. I have learned that such a cell absorbs a considerable part of the energy reaching it in the form of sound waves of the frequency at which it tends to resonate, and also a considerable part of the sound energy of higher frequencies throughout a considerable range. By "tends to resonate," I mean that the length of each cell, if closed at one end, is equal to substantially one-fourth the wave length corresponding to the particular frequency being considered; if open at both ends, the cell length is substantially one-half that wave length.

The shape of the pipes or cells in cross-section seems to be relatively immaterial; that is to say, it seems to be immaterial whether each pipe is round or of some other regular shape in cross-section, or whether it has an irregular shape in cross-section, except as the shape of the pipes or cells may restrict the flexing or other working of the pipe walls or surface material, or unduly reduce the friction to which air flow within the pipes is subjected, where, as I hereafter explain I think is the case in most instances, the absorption of the sound is due to these factors. The assembly of pipes can be built up of a number of plane partitions as it were; or by assembling corrugated or otherwise bent sheets of suitable material which, as placed together and with or without interposed plane sheets, form a mass of pipe-like cells as does an assembly of corrugated card-boards; or the cellular structure may be made by assembling individually separate tubes; or by casting or piercing a unitary structure; or in any other way that an assembly or structure of pipes or elongated cells can be formed of or in a suitable material.

For constructional reasons I prefer to produce the pipe assemblies in the form of blocks or tiles of convenient size, from which a wall can be built up or which can be laid like tiles against an existing wall. In use against or in a wall, the pipes will be closed at one end; they can be closed by resting the ends of the pipes against a surface of the wall or in some other manner.

The cellular structure is so disposed as to receive the disturbing sound or sounds into the open ends of the pipes. And while at least one end of each pipe is intended to be open in effect to receive the compressions and rarefactions which constitute sound waves in air, the "open" ends may be closed to the eye, that is to say, covered by decorative or other coverings so long as the coverings be of a nature which permits the energy of the sound waves to reach and enter the pipes sufficiently freely.

While the air within the cells may resonate, or tend to resonate, as does the air within organ pipes and resonating pipes in general (for which reason I refer to the individual cells as "pipes"), the action is contrary to the action of resonators, so-called; by my invention sound is absorbed at the resonating frequency and harmonics thereof, rather than seemingly strengthened and amplified. This I believe is due to the nature of the structure, or to the nature of the material of the structure, or both, in or of which the pipes are formed, as indicated by the examples of structure and materials I have given above; I believe that the structure or the material of which the structure is made (or both), needs to be such that it is capable of taking in and retaining (that is to say, taking in without returning to the air columns again) a considerable portion of the energy conveyed into the pipes by the sound waves and therein appearing in the form of wave motion within the contained air, which wave motion, in the narrow tube, is restricted by the viscosity of the air.

The proper lengths for the pipes, with respect to a sound of any given frequency, are determined by known acoustic laws for resonating pipes as before indicated. A simple formula is l (length of a pipe in inches) is equal to 3350 divided by n (frequency of the sound, or the lowest frequency of a complex sound or a number of sounds, particularly intended to be absorbed, expressed in cycles per second); this formula is readily derived from the known acoustic laws, and the factor 3350 is based on the pressure of the air and the velocity of sound at sea level, and may be modified for greater altitudes as will be understood. By way of example: For pipes closed at one end, the length of each pipe may be substantially or quite equal to one-fourth the wave-length of the sound it is intended to particularly absorb or suppress, or longer; thus a closed pipe to absorb or suppress a sound pitched two octaves above middle C, may be about three and one-quarter inches long, or longer than three and one-quarter inches. Closed pipes longer than one-quarter a wave length will absorb energy like electrical transmission lines with plenty of attenuation.

My invention is illustrated in the accompanying drawing wherein Fig. 1 is a face view of a block or tile of my invention containing pipes built up of and by assembling double-faced corrugated cardboards; Fig. 2 is an end view of the same partly broken away to show some of the corrugated cardboard in edge view; Fig. 3 illustrates how such blocks or tiles can be laid up brick-like to form or against a wall; Fig. 4 illustrates a block or tile in which the pipes are formed by assembling a number of separate tubes; Fig. 5 is an end view of a block or tile of my invention in which the pipes are of various lengths.

The blocks of Figs. 1, 2 and 5 are composed of an outer container or holder 1 in which layers or sheets 2 of double-faced corrugated cardboard are fitted, placed one against another. The container is open at one side as shown to expose one corrugated edge of each of the cardboards, and thereby expose one end of each of the pipes formed by the corrugations and the plane faces of the boards. The opposite wall 3 of the container can be assumed to be glued or cemented to the opposite edges of the cardboards so as to assure the pipes being closed at that end. It can be assumed that the corrugated cardboard here shown is such as is used commonly for making boxes and cartons, or an equivalent substance. In laying these blocks up at any place where, for example, reflection of sound is to be prevented and sound absorbed or suppressed, the open sides of the containers, and hence the open ends of the pipes, are exposed to the oncoming sound or sounds, that is to say, form the face of the wall exposed to the sounds (Fig. 3), so that the sound waves, or at least the energy of the sound waves can enter the air contained within the pipes. The containers 1 may furnish the structural support. In the form of Fig. 4, in which a number of separate tubes 4 (with fuzzy or rough inner and outer surfaces) form the pipes, it will be observed that not only does the interior of each tube form a pipe, but also pipes are provided by the spaces between the tubes. If desired, or necessary, pipes of different lengths (of such lengths that they tend to resonate at different fundamental frequencies, and usually at fundamental frequencies which are not harmonics of each other) can be incorporated in the same container and/or in the same structure or against the same wall, as indicated in Fig. 5; by this means it is possible to suppress tones of the higher frequencies to a greater degree than the tones of the lower frequencies.

As a result of a laboratory study made of my invention, I have learned that my sound absorber functions to absorb a large part of the sound energy reaching it when the pipes are long with respect to the wave length and in diameter are small in comparison with one-fourth the wave length. That is to say, pipes of the kind I have indicated, of such length as to tend to resonate for sounds of a given frequency, absorb efficiently over, a considerable band of higher audible frequencies also, but at frequencies less than the resonating frequency, the percent of sound absorbed is relatively minor. The resonating frequency therefore, is a dividing line, as it were, although not a sharp dividing line, between the frequencies at which a given pipe will absorb a considerable part of the sound energy, reaching it and the frequency at which the pipe absorbs relatively little energy. Maximum absorption occurs however at a frequency or frequencies somewhat above the resonating frequency. I believe that the absorption is due in considerable part at least to the fuzziness or roughness of the inner surfaces of the pipes, whereby movement of the air within the pipes, while permitted, is made against considerable friction; by restraining movement of the air along the pipe walls, the viscosity of the air within the pipes is made to absorb the sound energy. Whence it is apparent that pipes of various lengths may be used for the proper attenuation of the various frequencies to be absorbed, and of suitably small diameter; or pipes of equal lengths and diameters may be used, each being long enough to resonate at the lowest frequency to be absorbed and of sufficiently small diameter to act efficiently on the highest frequencies to be absorbed, all the pipes then acting alike; or these two forms of my invention may be employed conjointly; or long pipes of one length may be used jointly with long pipes of other lengths. Furthermore:

First, the term "pipe" is not intended to limit the aperture or cell to a "pipe" in which the longitudinal walls are parallel; apparently any form will suffice where the wall material is not smooth, and/or imposes frictional restraint on air flow, although a parallel-sided form now seems to be most convenient and adaptable. Second, for energy absorption purpose there may be used any form of structure or any kind of material that is capable of absorbing considerable amounts of energy from air waves of the frequencies and amplitude encountered without returning to the air again a considerable part of the energy originally taken in; and this structure and/or material can bear to the air columns any relation in which it or they will take energy from the air waves within the columns by imposing restraint on (but without preventing) movement of the air within the pipes. However, I believe it preferable to obtain this restraint by using for the pipe walls a material of such fuzziness or roughness as will afford considerable restraint to air movement along its walls. Such I believe to be the action with the corrugated cardboard forms of the invention previously described. Third, whatever the form and nature of the energy absorbing structure or material, it should be, preferably, aperiodic in its action, or if it have a natural period of its own, its natural period should be far removed from the natural period of the air columns which serves it. Fourth, since the sound energy is absorbed into the mass of the structure in which the pipes or air columns are formed, as great a mass should be employed as possible in a given space. However it is not sufficient, for example, to pierce a large mass of energy-absorbing material with a few pipes of resonating length and small diameter located remote from each other, for this leaves a large part of the mass beyond the reach of and unaffected by the air within the pipes; furthermore this provides a considerable area of face from which the sound waves, finding no pipe, can be reflected more or less. The pipes must be located so close together that so far as possible every part of the mass feels the effects of the air waves within the pipes, responds thereto, and accordingly absorbs energy and preferably absorbs energy to as great a degree as possible. Hence the pipes must be numerous, closely-packed or placed close together, with relatively thin walls between the air columns. And at least when the energy-absorber is the material constituting or placed on the pipe walls, they must be of relatively small diameters in order that the absorption due to the viscosity of the air may be pronounced. In diameter they should be, apparently, of the order of one-seventh of one-quarter of the shortest wave length they are particularly intended to absorb, or smaller than this; that is to say, for closed pipes, the diameter should be of the order of one-seventh of the length of the pipe or less. For pipes intended to absorb sounds of both high and low pitches, it is obvious that the actual diameters will be a great deal less than one-seventh (or one-fourteenth) their lengths. And then the pipes should be spaced apart a distance (as measured from the edge of one pipe to the edge of the next) less than the diameter of a pipe, and preferably considerably less than one-half the pipe diameter.

It will be understood that the references herein to the "diameter" of the pipes is not intended to limit my invention to round pipes; the term is used in a broad manner to indicate the cross-areas of the pipes. In general my invention is not limited to the details described except as hereafter appears in the claims.

I claim:

1. A sound absorber comprising an assembly of a multiplicity of closely-packed relatively thin-walled, elongated pipe-like cells open at one end at east, formed in a material resembling in its action the moderately heavy paper used in the manufacture of corrugated cardboard for boxes and cartons, the cells being of the order of one-sixth of an inch in diameter, and each being of such length that the column of air contained within it tends to resonate at substantially the lowest frequency of the sound it is intended particularly to suppress.

2. A sound absorber comprising an assembly of a multiplicity of pipes open at one end at least, formed in a structure capable of taking in and retaining a considerable portion of the energy conveyed into the pipes by sound waves, each pipe being of such length that the column of air contained within it tends to resonate at substantially the frequency of an audible sound intended particularly to be suppressed by that pipe and having a diameter of the order of one-seventh of one-quarter of the wave length of that sound or less, and the distance between the pipes, as measured from edge to edge of the air columns, being less than the internal diameters of the adjacent pipes.

3. The subject matter of claim 2, characterized by the fact that the diameters of the pipes are of the order of one-seventh of one-

quarter of the wave length of a harmonic of the frequency of the sound on which the lengths of the pipes are based.

4. The subject matter of claim 2, characterized by the fact that the surface of the walls of the pipes is rough to the flow of air thereover.

5. The subject matter of claim 2, characterized by the fact that surfaces of the walls of the pipes impede any change in the air conditions existing within the pipes and absorb in internal friction a considerable portion of the energy that enters.

6. A sound absorber comprising an assembly of a multiplicity of closely-packed pipes closed at one end and open at the other, formed in a structure capable of taking in and retaining a considerable portion of the energy conveyed into the pipes by sound waves, and each pipe being of such length that the column of air contained within it tends to resonate at substantially the frequency of an audible sound intended particularly to be suppressed by that pipe structure.

7. A sound absorber comprising an assembly of a multiplicity of closely-packed pipes open at one end at least, of relatively small diameter, formed in a material capable of being deformed by the air compressions of the sound waves to take in and retain a considerable portion of the energy conveyed into the pipes by sound waves, and each pipe being of such length that the column of air contained within it tends to resonate at substantially the frequency of an audible sound intended particularly to be suppressed by that pipe.

8. The subject matter of claim 6, characterized by the fact that the walls of the structure between the pipes are relatively thin and are flexed by the sound waves, the energy being absorbed by the flexing of said walls.

9. The subject matter of claim 2, characterized by the fact that the assembly of pipes includes pipes of different lengths.

10. A sound absorber comprising an assembly of a multiplicity of pipes closed at one end and open at the other, formed in a structure capable of taking in and retaining a considerable portion of the energy conveyed into the pipes by sound waves, the distance between pipes, as measured from edge to edge of the air columns, being less than the internal diameters of the adjacent pipes.

11. A sound absorber comprising an assembly of a plurality of pipes open at one end at least and arranged internally to restrain free movement of the air within them, each pipe being of such length that the column of air contained therein tends to resonate at substantially the lowest frequency intended particularly to be suppressed by that pipe and having a diameter not greater than one-seventh of one-quarter of the wave length of the highest pitched of the sounds it is intended particularly to absorb.

12. A sound absorber comprising a plurality of pipes open at least at one end, formed in a material restraining free movement of the air along their walls, the length of each pipe being at least seven times its diameter, and the distance between pipes, as measured from edge to edge of the air columns, being less than the internal diameters of the adjacent pipes.

13. A sound absorber comprising a plurality of pipes open at least at one end, formed in a material restraining free movement of the air along their walls, the length of each pipe being at least seven times its diameter, and the distance between pipes, as measured from edge to edge of the air columns, being less than one-half the internal diameters of the adjacent pipes.

14. A sound absorber comprising a plurality of pipes open at least at one end, formed in a material restraining free movement of the air along their walls, the length of each pipe being at least seven times its diameter, and the distance between pipes, as measured from edge to edge of the air columns, being less than the internal diameters of the adjacent pipes, the said plurality of pipes being of different lengths.

15. The combination with a wall, of a sound absorber applied thereto comprising a plurality of corrugated sheets of a rough material placed substantially parallel to each other and with their corrugations placed at an angle to the wall, at one face of the absorber the ends of the pipes produced by the use of the corrugated material being open, the opposite ends being closed.

In testimony whereof, I have signed this specification.

ELMORE B. LYFORD.