Dec. 17, 1940. W. P. MASON 2,225,312

ACOUSTIC DEVICE

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FIG. 1

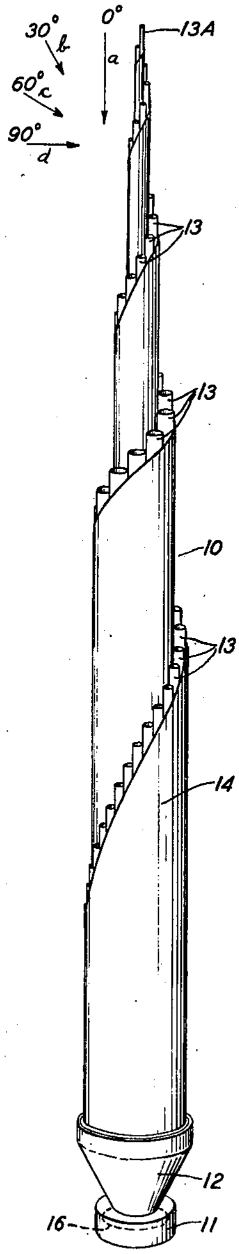


FIG. 2

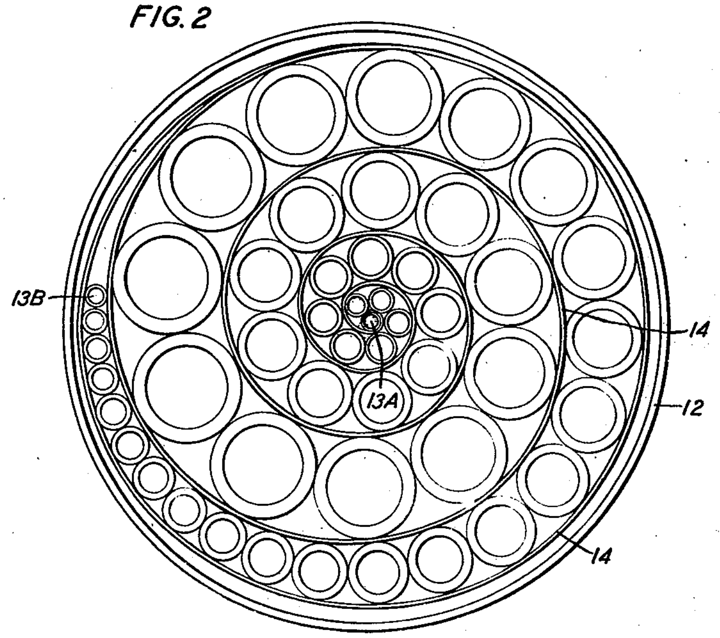


FIG. 4

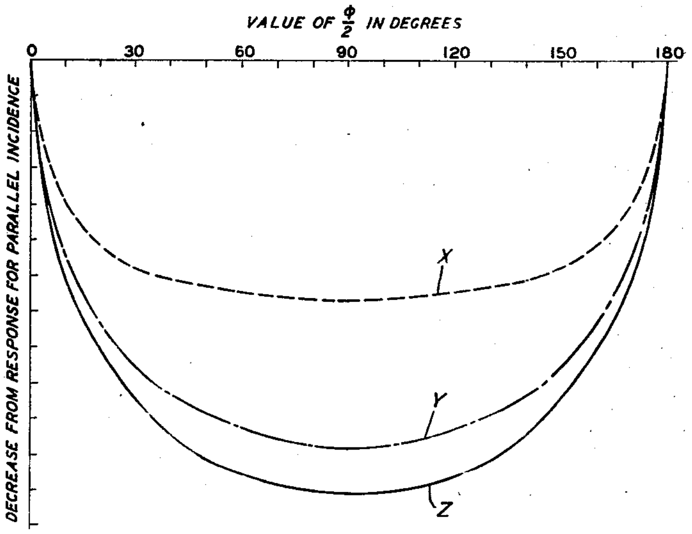
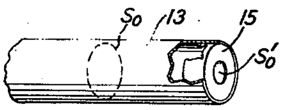


FIG. 3



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2,225,312

ACOUSTIC DEVICE

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9 Claims. (Cl. 181—0.5)

This invention relates to acoustic devices and more particularly to sound translating devices capable of converting sound waves into electrical variations and including an acoustic impedance element of the general constructions disclosed in my Patent 1,795,874, granted March 10, 1931, and Patent 2,085,130, granted June 29, 1937, to Andrew E. Swickard.

One object of this invention is to increase the directional selectivity characteristic of sound translating devices. More specifically, one object of this invention is to increase the discrimination, by a sound translating device, between sound waves emanating from a source located at a particular direction with respect to the translating device and sound waves emanating from points at other directions with respect to the device.

In one illustrative embodiment of this invention, a sound translating device comprises a transmitter element, an impedance element including a cluster of open-ended tubes of progressively increasing length and a compression or coupler element acoustically connecting one end of each of the tubes to the vibratile element, for example the diaphragm, of the transmitter.

In accordance with one feature of this invention, the tube or the inlet orifices thereof are made of areas progressively varying in a predetermined relation whereby a high degree of discrimination is obtained between sound waves traveling parallel to the longitudinal axis of the impedance element and incident upon the inlet ends of the tubes and sound waves traveling in other directions.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a perspective view of a sound translating device comprising an impedance element illustrative of one embodiment of this invention;

Fig. 2 is an end view of the impedance element illustrated in Fig. 1 showing the configuration, relative areas and disposition of the tubes;

Fig. 3 is a detail perspective view with parts broken away illustrating a modification of the tubes of the impedance element shown in Figs. 1 and 2; and

Fig. 4 is a graph illustrating the directional discrimination for sound translating devices including an impedance element constructed in accordance with this invention.

Referring now to the drawing, the directional sound translating device shown in Figs. 1 and 2 comprises an acoustic impedance element **10**, a transmitter **11**, which may be of the electrostatic, electrodynamic or other type, having a diaphragm or other vibratile member **16**, and a compression or coupler member **12** connecting the impedance element **10** to the transmitter **11**.

The acoustic impedance element **10** comprises a plurality of parallel cylindrical tubes **13** open at opposite ends and arranged in substantially spiral formation as shown in Fig. 2. The tubes **13** are of progressively varying length, may be held together in a compact assembly by a spiral band **14**, and have their ends nearest the transmitter **11** coplanar and equally spaced from the diaphragm **16** or other vibratile element of the transmitter. There may be, for example, forty-nine tubes **13** increasing in length according to an arithmetical progression along the spiral. The length of the longest tube **13A** preferably is substantially equal to the wave-length of the lowest frequency to be translated by the device and the shortest tube **13B** may have a length substantially one-forty-ninth the length of the longest tube. Preferably each tube is of a length slightly longer than that which would result from the arithmetical progression indicated in order to introduce a small attenuation which tends to make the response characteristic more uniform.

In the operation of the device shown in Figs. 1 and 2, sound waves enter the ends of the tubes **13** remote from the transmitter **11**, pass through the tubes and into the coupler member **12** where they produce pressures reacting upon the diaphragm **16** or other vibratile element of the transmitter whereby the sound waves are translated into electrical impulses. If the sound wave arrives at the impedance element **10** traveling in the direction indicated by the arrow *a* in Fig. 1, parallel to the longitudinal axis of the impedance element **10**, all of the components of the wave passing through the tubes **13** arrive at the transmitter **11** in phase and at the same time, despite the different lengths of the tubes, inasmuch as in a tube of appreciable size the velocity of sound is substantially the same as the velocity in open air. Hence, the waves passing through the individual tubes combine in the coupler member **12** and create a pressure, which is the arithmetical sum of the pressures attributable to the various waves.

When, however, the sound waves incident upon the impedance element **10** are traveling in other directions, such as indicated by the arrows *b*, *c* and *d* in Fig. 1, the waves traversing the individual tubes will arrive in the compression or coupler member at different times inasmuch as the time of travel of a wave through a tube, under these circumstances, is dependent upon the length of the particular tube traversed. Consequently, an out-of-phase relationship will obtain at the entrance to the coupler member for waves traversing different length tubes and cancelation of the pressures attributable thereto will occur with the result that but a relatively small electrical output of the transmitter will obtain. Hence, the device discriminates between incident sound waves traveling parallel to the longitudinal axis of the impedance element and incident waves traveling at angles to the axis of the impedance element. This discriminating effect is dependent upon, among other factors, the relative length and number of the tubes and the angle of incidence of the sound waves. If the tubes are of equal cross-sectional areas, the ratio of the sum total of the pressures or volume velocities created in the coupler member for sound waves incident at an angle to the longitudinal axis of the impedance element to the sum total when the waves travel parallel to this axis may be expressed as

$$\frac{V_\theta}{V_N}=\frac{1}{n}\left[\frac{\sin\frac{n\phi}{2}}{\sin\frac{\phi}{2}}\right] \quad (1)$$

where V_θ is the sum total of the pressures or volume velocities for sound waves incident at an angle θ to the longitudinal axis of the impedance element, V_N is the sum total for sound waves incident parallel to the longitudinal axis of the impedance element, n is the number of tubes, and φ is

$$\frac{\omega l}{c}(1-\cos\theta)$$

ω being 2π times the frequency, l the difference in length between successive tubes and c the velocity of sound.

A plot of this equation for a forty-nine tube impedance element, the tubes being of equal areas, is shown by the curve X in Fig. 4, wherein the decrease in response is plotted as ordinates against abscissae of the angle of sound incidence.

The magnitude of the volume velocity of a wave traversing any of the tubes is dependent upon the received volume velocity of the wave which is dependent upon the effective cross-sectional area of the tube or the area of the inlet end thereof. That is to say, inasmuch as the pressure and particle velocity at the inlet ends of the tubes are constant, the volume velocity will be proportional to the effective cross-sectional area of the tube. Thus, different volume velocities may be obtained by making the tubes of different cross-sectional areas, as illustrated in Fig. 2, or by having the tubes of the same cross-sectional area but with inlet orifices of different areas. In one form, shown in Fig. 3, the inlet end of each tube 13 of area S_0 may have fitted therein a cap 15 having a central orifice of area

$$S_0'$$

The particle velocity through the orifice will be a constant and the volume velocity will be reduced in the ratio

$$\frac{S_0'}{S_0}$$

If the cross-section areas (or inlet orifices) of the tubes are varied progressively in the relation given by the series

$$1,\ 2\ .\ .\ .\ \frac{n-1}{2},\ \frac{n+1}{2},\ \frac{n-1}{2}\ .\ .\ .\ 2,\ 1 \quad (2)$$

that is, if the longest and shortest tubes have the same cross-sectional area, the next longest and next shortest tubes have equal areas twice as large as the areas of the shortest and longest tubes, and so on, it can be shown that the absolute value of the ratio for the summation of the volume velocities of the tubes of the impedance element is given by the relation

$$\frac{V_\theta}{V_N}=\left[\frac{2}{n}\,\frac{\sin\frac{n\phi}{4}}{\sin\frac{\phi}{2}}\right]^2 \quad (3)$$

The total volume velocity for such an impedance element is given by the relation

$$V_\theta=V_0e^{-\frac{j\omega L}{c}}\left[1+e^{j\omega l(1-\cos\theta)}+e^{-\frac{jn\omega l}{2c}(1-\cos\theta)}\right]^2 \quad (4)$$

where L is the length of the longest tube, e is the Naperian base, V_0 is the total volume velocity for $\theta=0$ and the remaining characters are as defined hereinabove.

From a comparison of Equations 1 and 3 it will be seen that the latter is the square of the characteristic of half the number of tubes all having equal areas. The directional discrimination of a sound translating device including an impedance element of forty-nine tubes the areas of which vary progressively in the relation noted above is indicated by the curve Y in Fig. 4 from which it will be apparent, by comparison with curve X, that thus progressively varying the areas of the tubes (or the inlet orifices thereof) increases discrimination of the device against sound waves incident at an angle to the longitudinal axis of the impedance element.

The degree of discrimination may be increased by using area relationships which correspond to fewer terms and a higher power in the right-hand side of Equation 4. This, it will be noted, requires a greater variation between the largest and smallest area tubes.

A particularly suitable construction is obtained if the area of the tubes (or the inlet orifice thereof) is made proportional to the sine of successively increasing angles as indicated by the relation

$$S_1=A\sin\alpha;\ S_2=A\sin 2\alpha;\ .\ .\ .\ S_N=A\sin N\alpha \quad (5)$$

where S_1 is the area of the shortest tube, A is a constant and S_2 . . . S_N are the areas of succeeding tubes according to length.

It can be shown that the greatest discrimination obtains when $(n+1)\alpha=\pi$, n being the number of tubes. For this case, the absolute value of the ratio of the response for waves incident at an angle to the longitudinal axis of the impedance element to the response for waves incident parallel to this axis is given by the relation

$$\frac{V_\theta}{V_N}=\frac{\pi}{4(n+1)}\left[\frac{\cos\left(\frac{n-1}{2}\right)\alpha\cos\left(\frac{n+1}{2}\right)\varphi}{\sin^2\frac{\alpha}{2}-\sin^2\frac{\varphi}{2}}\right] \quad (6)$$

where the characters are as defined heretofore.

The discrimination obtained with an impedance element having tubes the areas of which vary progressively in accordance with the relation 5 is illustrated by curve Z in Fig. 4 from which it will be apparent that the discrimination is greater than for a device wherein the tube areas vary progressively as given by relation 2. It may be noted, furthermore, that for a forty-nine tube impedance element the sine series variation in areas requires a variation in area of only 16 to 1 from the tube of greatest area to the tube of smallest area whereas the power series requires a variation of 25 to 1 in areas.

It will be understood, of course, that the specific embodiments of this invention shown and described are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An acoustic sound wave receiving device comprising a cluster of closely adjacent parallel open-ended tubes varying in both length and effective cross-sectional area in predetermined progressive relations such that the sensitivity of the device is a maximum for sound waves incident thereon parallel to said tubes.

2. An acoustic device in accordance with claim 1 wherein said tubes increase progressively in length and the effective cross-sectional area of successive tubes according to length increases from both the longest and shortest tubes to an intermediate tube.

3. An acoustic device in accordance with claim 1 wherein said tubes are of the same cross-sectional area and have inlet orifices varying in predetermined progressive relation.

4. An acoustic device in accordance with claim 1 wherein the shortest and longest tubes have the smallest and substantially the same effective cross-sectional area and corresponding successive longer and shorter tubes have substantially the same effective cross-sectional area.

5. An acoustic impedance element comprising a cluster of parallel open-ended tubes of progressively increasing lengths, the effective cross-sectional area of any tube being proportional to $A \sin N\alpha$, where A is a constant, N is the number of the tube determined by its position according to length,

$$\alpha=\frac{\pi}{n+1}$$

and n is the number of tubes.

6. An acoustic impedance element comprising a cluster of open-ended tubes of progressively increasing lengths, the effective cross-sectional area of said tubes varying in accordance with the relation

$$1, 2 \ldots \frac{n-1}{2}, \frac{n+1}{2}, \frac{n-1}{2} \ldots 2, 1$$

where n is the number of tubes.

7. A sound translating device comprising a multiplicity of closely adjacent parallel tubes arranged in spiral relation and each having an inlet end and an outlet end, the outlet ends of said tubes being in a common plane, said tubes being of progressively increasing lengths and varying in effective cross-sectional area in succession according to length such that the total volume velocity of sound waves traversing said tubes is a maximum for waves incident upon the inlet ends of said tubes parallel to the longitudinal axes of said tubes.

8. A sound translating device in accordance with claim 7 wherein the shortest and longest tubes have the smallest and substantially the same effective cross-sectional area and corresponding successively longer and shorter tubes have substantially equal effective cross-sectional areas.

9. A sound translating device comprising a multiplicity of closely adjacent tubes arranged in spiral relation and of progressively increasing lengths, said tubes having one end in a common plane, and said tubes varying in effective cross-sectional area in succession according to length, the effective cross-sectional area of each tube being proportional to $A \sin N\alpha$, where A is a constant, N is the number of the tube determined by its position according to length,

$$\alpha=\frac{\pi}{n+1}$$

and n is the number of tubes.

WARREN P. MASON.