Oct. 19, 1948. F. MASSA 2,451,967

VIBRATIONAL ENERGY TRANSMITTER OR RECEIVER

Original Filed June 2, 1944

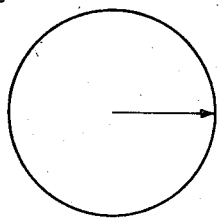


FIG. 1

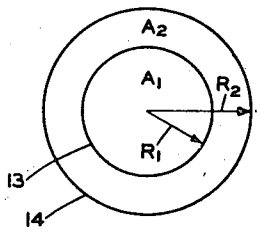


FIG. 2

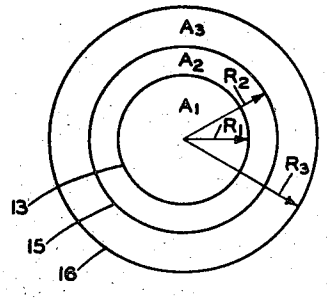


FIG. 4

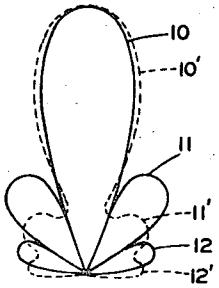


FIG. 3

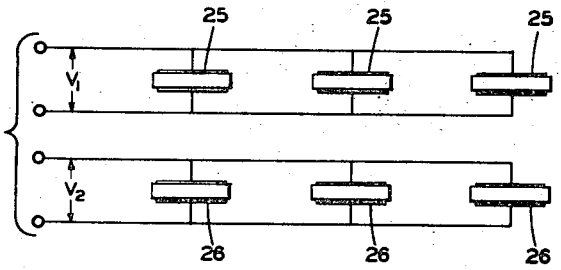


FIG. 5

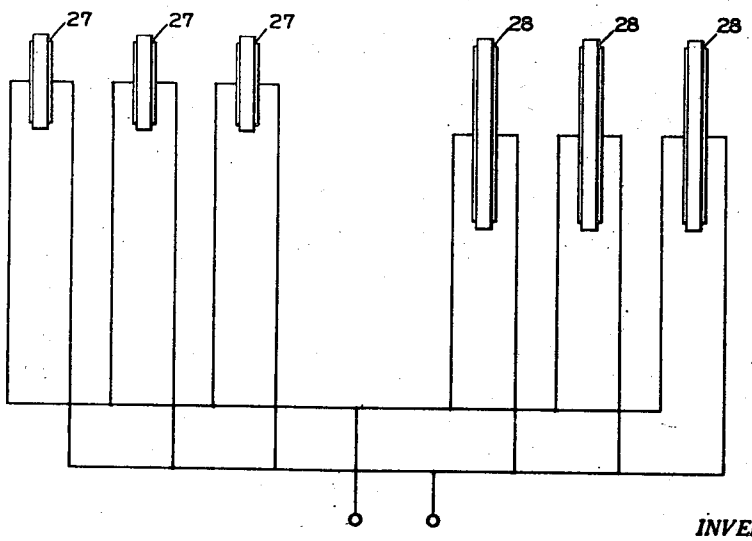


FIG. 6

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VIBRATIONAL ENERGY TRANSMITTER OR RECEIVER

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Original application June 2, 1944, Serial No. 538,469, now Patent No. 2,427,062, dated September 9, 1947. Divided and this application July 28, 1947, Serial No. 764,099

1 Claim. (Cl. 177—386)

1

This invention pertains to transducers for radiating and/or receiving vibrational energy and more particularly to transducers having a composite piston surface vibrating with a plurality of emplitudes whereby the ratio of the vibrational energy in the main lobe of its directional pattern to the vibrational energy in the minor lobes of the pattern is a maximum.

This application is a division of my application Serial No. 538,469, filed June 2, 1944, now Patent No. 2,427,062, granted September 9, 1947, for Vibrational energy transmitter or receiver.

An object of the invention is to provide a transducer for radiating and/or receiving vibrational energy which has a directional pattern comprised of a main and minor lobes in which the ratio of the vibrational energy in the main lobe to the vibrational energy in the minor lobes is maximum.

Another object of the invention is to provide new and novel piezoelectric transducers.

It is also an object of this invention to provide a new method of manufacturing piezoelectric transducers.

It is also an object of the invention to provide a transducer whose directional pattern may be easily changed.

A further object of the invention is to provide a transducer of simple, practical construction yet which closely approximates certain optimum conditions which are obtainable only with more complicated and expensive construction.

Other objects and a fuller understanding of the invention may be had by referring to the specification, claims and to the single sheet of drawing.

In accordance with this invention there is provided, in a transducer, a substantially circular piston surrounded by a first and by a second annular piston section. The circular piston is adapted to vibrate wtih an amplitude A_1, the first annular piston vibrates in phase with the circular piston but with an amplitude A_2, and the second annular piston vibrates in phase with the circular piston but with an amplitude A_3. The ratio of thet radii R_1, R_2 and R_3 of the circular, first annular and second annular pistons, respectively, is as follows: R_1 to R_2=6.76, R_1 to R_3=.476; and the ratio of A_1 to A_2 is 1.9, while the ratio of A_1 to A_3 is 5.8. This causes the ratio of the main lobe energy radiated normal to the plane of the pistons to the secondary lobe energy to be a maximum.

In the single sheet of drawing, Fig. 1 diagrammatically represents a circular vibrating piston;

2

Fig. 2 diagrammatically represents a composite piston comprised of a circular piston surrounded by an annular piston; Fig. 3 represents by a solid line the directional pattern of the vibrating piston of Fig. 1, and by a dotted line the directional pattern of the vibrating composite piston of Fig. 2; Fig. 4 diagrammatically represents a vibrating piston comprised of a circular piston and two concentric annular pistons surrounding the circular piston; Fig. 5 is a circuit diagram showing one form of my invention, and Fig. 6 is a circuit diagram showing another form of my invention.

In the past it has been general practice to design transducers for receiving and/or transmitting vibrational energy in the form of a circular piston which vibrates with substantially the same amplitude and phase throughout its area. Such a piston is diagrammatically illustrated by Fig. 1 and it has a directional response pattern which is illustrated by the solid lines in Fig. 3 and comprised of a main lobe 10, a secondary lobe 11 and a tertiary lobe 12. Other minor lobes may be present but for the purpose of illustrating my invention showing them in the figures might only lead to confusion.

In order to obtain a better response pattern than is obtainable from a single vibrating piston (Fig. 1), the effect of a composite piston comprised of a central circular piston with an annular piston surrounding it should be obtained, and certain relationships should exist between the radii and amplitudes of vibration of the several parts of the composite piston. This effect may be obtained by utilizing separate piston surfaces, or a single piston surface may be driven with a plurality of amplitudes.

When a certain ratio of amplitudes of motion of the circular and annular pistons exists and when a certain ratio of radii of the circular and annular pistons exists, it is possible to obtain a maximum in the ratio of vibrational energy in the main lobe compared to the vibrational energy in the minor lobes.

In Fig. 2 there is shown a circular vibrating piston 13 of radius R_1 and an annular vibrating piston 14 having an inner radius R_1 and an outer radius R_2. If the annular piston 14 vibrates through an amplitude A_2 which is less than the amplitude A_1 of vibration of the circular piston 13 and the main lobe of the polar distribution pattern will be somewhat broadened as is shown by the dotted line 10' in Fig. 3, and at the same time the secondary lobes as illustrated by the reference characters 11' and 12' will be materially reduced in sensitivity. The optimum de-

sign for a transducer having a composite vibrating surface comprised of the circular piston 13 and one annular piston 16 is as follows: The ratio of the amplitude of movement A_1 of the circular piston 13 to the amplitude of movement A_2 of the annular piston 16 should be about 2.4. The ratio of the radius R_1 of the circular piston to the radius R_2 of the annular piston 16 should be about .607. When these two ratios exist the vibrational energy in the main lobe 10' of the directional pattern of the transducer compared to the vibrational energy in the minor lobes 11', 12' of the directional pattern is a maximum. For example, if the directional pattern 10, 11, 12 has an 18 db. reduction between its main lobe 10 and its secondary lobe 11, the directional pattern 10', 11', 12' obtained from a transducer having the optimum design ratios will have approximately 32 db. reduction between the peak of its main lobe 10' and the peak of its secondary lobe 11'.

The three-section piston surface diagrammatically illustrated by Fig. 4 should have the following ratios of radii and amplitude of movement in order to obtain the best directional pattern. The ratio between the amplitude A_1 of movement of the circular piston 13 and the amplitude A_2 of movement of the first annular piston 15 should be about 1.9, and the ratio of the amplitude A_1 of movement of the circular piston 13 to the amplitude A_3 of movement of the second annular piston 18 should be about 5.8. The ratio of the radius R_1 of the circular piston to the radius R_2 of the first annular piston should be about .676, and the ratio of the radius R_1 to the radius R_3 of the second annular piston 16 should be about .476. When these ratios exist there will be approximately 38 db. reduction in signal intensity between the peak of the main lobe and the peak of the secondary lobes.

It is also possible to design transducers having more than two annular piston portions and a slightly better directional pattern will be obtained. However, the improvement over the three-section composite piston surface is not such as to warrant the added manufacturing cost of such a unit unless special results are desired.

The improvement arises from the main lobes of the response patterns of the circular and annular pistons reinforcing each other while the secondary lobe of the response pattern of the circular piston and the tertiary lobe of the response pattern of the annular piston tend to cancel each other as they are out of phase. Thus, in order to obtain the maximum improvement the magnitudes of the secondary lobe of the response pattern of the circular piston should be the same as the magnitude of the tertiary lobe of the response pattern of the annular piston. The secondary lobe of the response pattern of the annular piston is reduced in magnitude to a point below the peak of the secondary lobe of the response pattern of the composite piston as the main lobe of the response pattern of the circular piston is out of phase with the secondary lobe of the response pattern of the annular piston and partially cancels it.

The optimum ratios for a two and a three-section composite piston are given and there is illustrated by mathematics the method of designing a two-section composite piston. A person skilled in the art will then be able to design a composite piston having more than two sections.

The amplitude of a sound wave at a point P distant from a sound source making an angle θ with the normal to the plane of the circular piston may be expressed by the following well-known equation:

$$\text{Amplitude at } P = A_1 r_1^2 \left[\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right]$$

and the amplitude of a sound wave at the point P distant from the sound source making the angle θ with the normal to the plane of the annular piston may be expressed by the following well-known equation:

$$\text{Amplitude at } P = A_2\left[r_2^2 \frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta} - r_1^2 \frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right]$$

Where

A_1 = the amplitude of movement of the circular piston
r_1 = the radius of the circular piston
A_2 = the amplitude of movement of the annular piston
r_2 = the radius of the annular piston
J_1 = Bessel function

$$k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c}$$

where

f = frequency
c = velocity of sound in the medium

The amplitude of the sound wave at point P due to the composite piston therefore is:

Eq. (1)

$$\text{Amplitude at } P = A_1 r_1^2\left[\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right] + A_2\left[r_2^2 \frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta} - r_1^2 \frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right]$$

Eq. (2) Amplitude at $P =$

$$(A_1 - A_2) r_1^2 \frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta} + A_2 r_2^2 \frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta}$$

From Bessel function tables

$$J_1\frac{(Z)}{Z}$$

has maxima for $Z = 0;\ 1.638\pi;\ 2.666\pi;\ 3.694\pi;$ - - -

The first term in Eq. (2) will have its secondary maxima at

$$kr_1 \sin\theta = 1.638\pi \text{ or } \sin\theta = \frac{1.638\pi}{kr_1}$$

The second term in Eq. (2) will have its tertiary maximum at

$$kr_2 \sin\theta = 2.666\pi \text{ or } \sin\theta = \frac{2.666\pi}{kr_2}$$

To reduce the secondary maximum of the response pattern of the composite piston source as much as possible the secondary maximum of the response pattern of the circular piston is made to coincide in space with the tertiary maximum of the outer annulus which is out of phase with the secondary maximum. This means that the angles are made to coincide or, expressed mathematically:

$$\frac{1.638\pi}{kr_1} = \frac{2.666\pi}{kr_2}$$

Eq. (3) $$\frac{r_2}{r_1} = \frac{2.666}{1.638} = 1.629 \text{ or } \frac{r_1}{r_2} = .61$$

Another condition which must be satisfied is that the ratio of the combined amplitudes of the Bessel functions at angle zero to the combined amplitudes at the angle at which the secondary and tertiary maxima coincide shall be a maximum.

From Bessel tables we find:

$$J_1(1.638\pi) = -.3401$$
$$J_1(2.666\pi) = +.2702$$

Substituting in Eq. (2)

$$\left[(A_1=A_2)r_1^2\frac{-.3401}{1.638\pi}+A_2(1.629r_1^2)\frac{.2702}{2.666\pi}\right]=0$$

Eq. (4) which gives

$$\frac{A_2}{A^1}=.42 \text{ or } \frac{A_1}{A_2}=2.38$$

The invention contemplates utilizing any means for vibrating the several sections of a composite piston, but one of the best is to utilize piezoelectric crystal elements.

Expander crystals are highly successful, and there are several ways of obtaining the desired different amplitudes of motion of the several sections of the piston.

One method, shown in Fig. 5 for the transducer schematically shown in Fig. 2, is to connect all of the crystal elements **25** comprising the circular piston portion of the transducer in parallel to a voltage source V_1, and to connect all of the crystal elements **26** comprising an annular piston to a voltage source V_2. The crystal elements **25** are equivalent to the crystal elements **26** in size and thickness, but V_1 is greater than V_2 in accordance with the desired amplitude ratio A_1 to A_2; i. e. for a two-section piston $V_1=2.4V_2$, and for a three-section piston having three banks of crystals $V_1=1.9V_2=5.8V_3$.

Fig. 6 illustrates another method for obtaining different amplitudes of vibration. The expander crystal elements **28** comprising the center portion of the diaphragm are longer than the expander crystal elements **27** comprising an annular portion of the diaphragm by an amount determined by the desired amplitude ratio, and all are connected in parallel to a single source of voltage. Thus, the longer crystals **28** will vibrate with greater amplitude than the shorter crystals **29**, in accordance with the ratio of their lengths.

Other methods such as varying the thickness of the crystals and various combinations of the several methods, all apparent to those skilled in the art, may also be utilized.

Details of the construction of several transducer devices utilizing the invention may be found in the aforementioned parent application

which specifically claims the two-section composite transducer.

While the invention has been described with a certain degree of particularity, it is to be understood that the illustrated means are by way of example, and that changes may be made in the construction and arrangement of parts without departing from the spirit and scope of the invention.

I claim as my invention:

In a transducer for radiating and/or receiving vibrational energy and having main and secondary directional lobes, a substantially circular piston of radius R_1, a first substantially annular piston of inner radius R_1 and outer radius R_2 surrounding and lying in the same plane as said circular piston, a second substantially annular piston of inner radius R_2 and outer radius R_3 surrounding and also lying in the same plane as said circular piston, said circular piston being adapted to vibrate at a given frequency with an amplitude A_1, said first annular piston being adapted to vibrate in phase with said circular piston with an amplitude A_2, and said second annular piston being adapted to vibrate in phase with said circular piston with an amplitude A_3, the ratio of R_1 to R_2 being substantially .676, the ratio of R_1 to R_3 being substantially .476, the ratio of A_1 to A_2 being substantially 1.9, and the ratio of A_1 to A_3 being substantially 5.8, whereby the ratio of the main lobe energy radiated substantially normal to the plane of the said pistons to the secondary lobe energy is maximum.

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The following references are of record in the file of this patent:

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