Jan. 3, 1928. W. HAHNEMANN ET AL. 1,655,267

SOUND APPARATUS FOR PRODUCING AND RECEIVING SOUND WAVES

Filed Aug. 7, 1925

Fig. 1

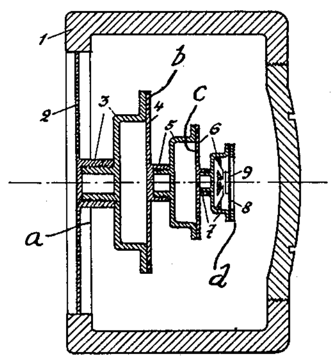


Fig. 1a

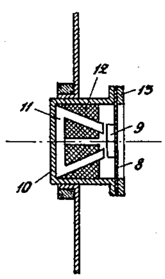


Fig. 1c

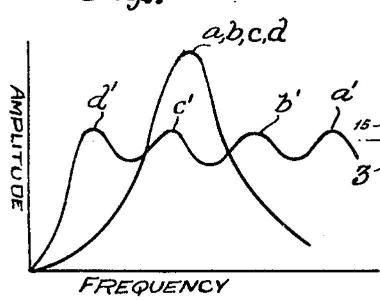
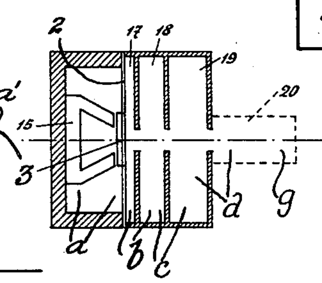


Fig. 2



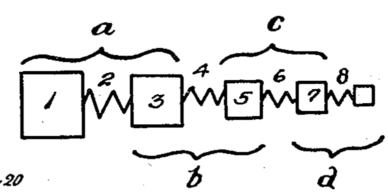
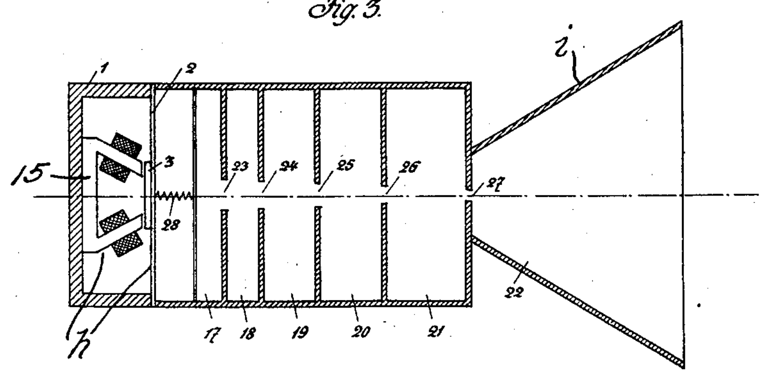


Fig. 1b

Fig. 3.



Inventors
Walter Hahnemann
Heinrich Hecht
per
Ezekiel Wolf
Attorney

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UNITED STATES PATENT OFFICE.

WALTER HAHNEMANN, OF KITZEBERG, NEAR KIEL, AND HEINRICH HECHT, OF KIEL, GERMANY, ASSIGNORS TO SIGNAL GESELLSCHAFT MIT BESCHRANKTER HAFTUNG, OF KIEL, GERMANY, A FIRM.

SOUND APPARATUS FOR PRODUCING AND RECEIVING SOUND WAVES.

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The invention refers to apparatus for the production and reception of sound waves and more generally for the purpose to transfer vibratory mechanical energy from or to the sound propagating medium and to transform mechanical vibratory energy into electrical vibratory energy and vice versa.

It is the problem of the invention to produce devices of the kind above specified which are adapted to produce and to reproduce sounds of a very broad range of frequencies with, as far as possible, equal efficiency at all frequencies and with a high degree of efficiency, and particularly to avoid distortion.

A further object of the invention is to transfer energy with good efficiency between different vibratory structures forming a part of the device, for instance between a diaphragm and a detector (microphone or the like). It is also the object of the invention to produce a device for the reception and reproduction of noises, for instance noises in water originating from the rotation of ships' propellers, and also a device for the reception and reproduction of music and speech.

These several objects are accomplished by coupling a plurality of equally tuned mechanical vibratory structures, forming elements of the apparatus described, in such a manner that the resonance crests in the resonance curve of the coupled structures of the apparatus are substantially evenly distributed over the desired range of frequencies and that the ordinates of this curve between the resonance crests do not sink below an undesired level, for instance below 30% of the ordinate of the neighboring resonance crests. Another feature of the invention consists in providing at least three vibratory structures coupled in the manner above described. A further feature of the invention consists in inserting a series of such coupled structures between the sound emitting and receiving element (diaphragm) and the energy converting means (detector, microphone) of the apparatus. Another feature of the invention is that the intermediate structures are coupled with one another in series; that is, that each structure is coupled with the ones adjacent to it and with no others.

These particular features of the invention and others may be seen more clearly from the embodiment described below in connection with the drawing in which:

Figure 1 shows a sectional view of a sound producing and receiving device comprising a series of mechanical vibratory structures each consisting of masses and connecting elastic members.

Figure 1^a shows a modification of the structure shown in Figure 1.

Figure 1^b shows diagrammatically the structure of Figure 1.

Figure 1^c shows a resonance curve such as might be expected from a structure such as shown in Figure 1.

Figure 2 shows a further modification of the invention with a series of coupled resonators, and

Figure 3 shows a modification having a combined system composed of coupled resonators and diaphragms.

In the art of communication or the like, in many cases it is desirable to operate over a very broad range of frequencies with one and the same apparatus, either for the production and reception of sound waves, or for other purposes wherever mechanical or electrical vibrations have to be transferred or transformed. Special examples of this kind are the following:

In submarine signaling it is often necessary to have submarine sound transmitters which are particularly adapted to receive water noises. While transmitters for signals covering a very small range of frequencies with high efficiency are known, real satisfactory solutions of the problem of transmission of noises do not exist, i. e. there are transmitters today which are capable of picking up and transferring sound over a small range of frequencies, as for instance over a range of 10% to 20% of the vibrations in the vicinity of the natural frequency of the transmitter, but transmitters have not been designed to operate successfully over a greater range of frequencies as for instance one octave or more or from 500 to 1000 cycles.

It is also advantageous to provide a telephone for the reception of such noises efficiently and without distortion. Telephones possessing good receptive properties for single tones and frequencies are known, but the working range over varying frequencies with good efficiency is limited to 20%–30%

of their resonance frequency (i. e. for instance from 900 to 1200 cycles). Naturally these telephones are not satisfactory for the reception and transformation of electrical fluctuations produced by water noises transmitted from submarine sound receivers where a high efficiency over a broad range of frequencies is desired. This invention is applicable therefore for the development of telephones capable of operating over a broad range of frequencies, for example over a range of one octave. Besides it is very desirable to produce telephones of a high efficiency for a broader range of frequencies, especially for the purpose of transforming speech vibrations, in which case it is desirable for avoiding distortion to have a uniform efficiency over a number of octaves, if possible even more than five octaves.

What has been said above applies to loud speakers also. Apparatus of this kind has been developed recently which has a good efficiency for a definite range of frequencies, but even in this case this range of frequencies was limited from about 30% to 50% of the middle frequency for which the devices were designed. It has been proposed to employ a number of devices of this kind operating together, each of them being tuned to a different range of frequencies so that the whole range of frequencies to be transmitted is covered with equally efficient devices. However, as the human speech contains frequencies ranging over many octaves (at least five to six) a very great number of such individual devices would have to be applied for covering this whole range with a satisfactory degree of efficiency. As it is desirable to dispense with a greater number of devices and to use as few as possible, preferably only one, this invention is particularly useful in this respect.

The invention is based upon coupling a plurality of vibratory structures (three or more) with one another. The invention consists in adjusting in such devices with relation to one another the damping and the degree of coupling so that the resonance crests in the resonance curve of the coupled system are evenly distributed over the range of frequencies to be transmitted and that the emitted or received energy at all frequencies of this range is a substantial per cent of the maximum energy at the points of the resonance crests themselves. The even distribution of the resonance crests is obtained according to the invention by tuning to the same natural frequency all the coupled vibratory structures of the apparatus. The structures are mechanically connected so that each structure of the ordinal number n is coupled at one side with a structure $n-l$ and at the other side with a structure $n+l$ without being coupled with any other structure of the whole system.

The following discussion may elucidate more clearly the invention:

If in a plurality of vibratory structures coupled with one another a good transfer of energy from one structure to the next one is desired the damping and the degree of coupling particularly have to be considered. If energy travels through a series of coupled systems a resonance diagram results with a plurality of resonance points. If the efficiency of the transfer is to be made satisfactory the individual structures should be tuned to the same natural frequency. The resonance crests mentioned above in the coupling curve are under such conditions positioned a distance from one another depending upon the degree of coupling between the individual structures. Broad resonance curves are obtained by coupling the structures closely, each structure forming one crest. Where many structures are coupled together the resonance curve has a number of peaks equal to the number of structures, which peaks become broader the greater the number of structures coupled together. As the theory shows for a given natural frequency of the structures the resonance crests cannot move farther towards the higher frequency than to one and a half times the natural frequency, while towards the lower frequencies crests can exist until to the lowest frequencies. One of the main features of the invention is that in all cases the number of the structures coupled with one another and the degree of coupling between them is so adjusted that the desired range of frequencies is satisfactorily covered. Where the structures have slight damping the peaks of the resonant curves are sharp and the amplitudes on both sides of the peaks fall off very rapidly for changing frequencies. To maintain therefore great amplitudes between peaks of the resonance curve it is necessary to have the peaks close to each other. Thus a great number of resonant structures are necessary to provide a good efficiency at all points. The damping itself may be caused by radiation of energy or by wasting of energy. In the most cases besides the desired broad resonance curve an initial vibratory structure is already provided, for instance in the case of a submarine sound receiver the diaphragm taking up the energy from the water and also the final vibratory structure, the particular detector (microphone, electromagnet or the like). For these elements generally defined vibratory dimensions are given, especially the value of the masses and the elasticity of the elastic members carrying the masses, with regard to the desired properties of the apparatus. For a submarine sound receiver with relatively large damping, generally a relatively large area of the diaphragm is necessary, and consequently a relatively large mass and high elastic force of the carrying member, while for detectors, especially for the normal microphone with carbon granules, the mass apparently may be very much smaller than the mass of a large receiving diaphragm. It may easily be understood that it is extremely difficult to couple two such structures tightly together where there are entirely different masses, especially if the usual and most convenient manner of coupling, namely coupling the structures by combining parts of their masses, is employed, as is necessary for obtaining the desired broad responsiveness. The invention shows a way by which, in spite of the disparity of the initial structure and the final structure, with regard to their mass and elasticity, a tight coupling between these structures may be obtained. This way consists in inserting between the initial structure and the final structure a sufficient number of intermediate vibratory structures which increase in number inversely as the masses decrease. If, for instance, the ratio of the masses of the initial structure and the final structure is 1:100, a case in which for coupling by masses the greatest possible degree of coupling is 10%, by inserting only two additional intermediate structures the individual ratio of masses between neighboring structures may be lowered to 1:5, the coupling being enhanced in this way from 10% in the before mentioned case to 45%, and the resonance diagram being broadened accordingly. A further broadening of this diagram arises from the fact that, instead of two crests with 10% distance, now four crests with about 40% distance from one another exist. In this way by the means of the invention i. e. by the interconnection of a plurality of conveniently coupled structures in this case not only a broad resonance diagram but also the best transfer of energy between the initial structure (diaphragm with great radiation damping) and the final structure (microphone of high sensitiveness i. e. with small mass) is obtained.

To explain this feature a little more fully, suppose that the initial structure receiving the sound weighs 100 and the final structure used to transform the sound to electric oscillation weighs 1, both being measured in the same units. These two structures may be coupled through a mass structure weighing 10. The result would be a coupling of a rather loose nature. Suppose, however, there were inserted structures stepping down from the 100 weight to the 1 in the ratio of 5 or approximately that, then the coupling would be closer and in addition there would also be a broadening and flattening of the resonance curve tending to produce a system capable of responding over a considerable range of frequency.

In the drawing in which some practical examples of the invention are shown, Figure 1 represents a submarine sound transmitter and receiver, the initial structure of which is a diaphragm *a* and the final structure of which is a detector *d*, in this case an electromagnetic detector. Diaphragm and detector are coupled with one another by two additional vibratory structures *b* and *c*. Each two neighboring structures comprise a common mass so that the masses and elastic members are distributed to the structures as follows:

Structure *a*: masses 1 and 3, elastic member 2.

Structure *b*: masses 3 and 5, elastic member 4.

Structure *c*: masses 5 and 7, elastic member 6.

Structure *d*: masses 7 and 9, elastic member 8.

These structures above are shown analytically in Figure 1^b. The mass 1 is coupled to the mass 5 by means of the coupling mass 3, while 5 is coupled to 9 by means of the mass 7. As is shown there are really four oscillatory structures, since all but the outer masses serve as mass elements of two vibratory structures.

As has been stated above each of these oscillatory structures are tuned to the same frequency, each is similar to the other. In Figure 1^c it will be noted that the resonance curve of each individual structure *a*, *b*, *c*. *d*, is illustrated as being the same.

These oscillatory structures are combined together closely coupled so that a considerable amount of energy may be transferred from one to the other. They are combined together by so arranging them in order that the masses are arranged in steps according to their effective magnitude. In this way the coupling becomes very close and a broad resonance results. The peaks which formerly came together are now separated even though the individual structures have the same natural frequency.

The result is that a structure is produced which is substantially equally responsive over a large range of frequencies. As will be noted the peaks of the structures of smaller weights go towards the higher end of the range while the heavier structures descend below their natural frequency.

The curve of Figure 1^c having the four peaks is the resonance curve of the coupled structure. A loud speaker or the like having a resonance curve of this nature will respond equally well to the low vibrations as to the high ones. In this case it is not really a question of interposing intermediate structures for the transfer of energy from the initial to the final structure but the evolution of a coupled tuned resonant structure which is capable of responding to sounds of all frequencies.

In the actual combination all the structures cooperate together, some responding and taking up the burden of operation when their particular structure is most affected by the vibrations, and others responding for sounds of other frequencies. The idea is to have the sum total of responses of all structures about the same at all frequencies. By closely coupling these oscillatory structures together the oscillatory energy is easily transferred from one vibratory structure to the other so that the one which should respond most has the energy and is capable of doing its part in the whole operation.

Mass 1 is the outer casing of the apparatus, masses 3, 5 and 7 are metal casings carrying the elastic members 4, 6 and 8 respectively. All elastic members in the example of Figure 1 are diaphragms. They may be replaced by other elastic bodies, as rods, strips or the like. The final structure is more clearly indicated by Figure 1[a]. It consists of a casing 10 containing the core 11 of an electromagnet having a coil wound about each arm. The armature 9, corresponding to mass 9 in Figure 1, is held by the diaphragm 8 which at its rim is held upon the casing 10 by a flange 13.

Figure 2 shows a telephone built up according to the invention and adapted to reproduce noises of the kind received by apparatus designed according to Figure 1. The problem in this case is to have the diaphragm cooperate with the telephone and the ear canal efficiently over a broad range of frequencies. According to this modification a number of coupled resonators *b*, *c*, *d*, are interconnected between the initial structure *a* and the final structure *g*. The initial structure *a* consists of two masses, the telephone casing 14 together with the field magnet 15 and the armature 16, which are connected with one another by an elastic diaphragm 17. Similarly, as in Figure 1 the resonators have common masses so that:

Resonator *b* embraces chamber 17 and partly 18.

Resonator *c* chamber 18 and partly 19.

Resonator *d* chamber 19 and partly 20.

A similar device shows Figure 3 in which the mechanical system *h* of a loud speaker is coupled with radiating funnel *i* by means of interconnected resonance chambers 17, 18; 18, 19; 19, 20; 20, 21; 21, 22; these chambers and the openings 23—27 in the walls between the chambers being so adjusted or dimensioned that a gradual increasing ratio of the masses of neighboring structures exists and a degree of coupling of such tightness that a good transfer of energy between *h* and *i* is obtained. In this case a very tight coupling must be used on account of the very broad range of frequencies (speech and music) desired to be reproduced and therefore the masses have to decrease very slowly from structure to structure. Therefore it is difficult to obtain a sufficient tight coupling between the first structure (diaphragm 2 with armature 3) and the cooperating chamber without intermediate structures. According to the invention in this case one or more coupled mechanical structures with gradual decreasing masses must be inserted between the initial structure and the first resonance chamber, as it is shown at 28 in Figure 3.

In all three examples described above (Figure 1–3), all structures, the mechanical ones and the resonator chambers preferably must be tuned substantially to the same frequency.

It may be understood that the invention is not limited to the examples shown in the figures. The invention may be applied generally in all cases in which two definite vibratory structures, an initial structure and a final structure are to operate with one another over a broad range of frequencies. If this range is excessively broad as for instance for the human voice and music which include vibrations from the highest to the lowest frequencies according to the invention a large number of vibratory structures has to be interconnected between the two end-structures. The closer the coupling between them the better the condition of a broad resonance diagram can be fulfilled with as few interconnected vibratory structures as possible.

We claim:—

1. Acoustical vibratory apparatus consisting of a plurality (at least three) vibratory structures built up of separate masses and connecting elastic members coupled with one another in series with the aid of their masses and each elastic member being held at its rim by one of the said masses and carrying in its middle zone the following mass.

2. Acoustical vibratory apparatus consisting of a plurality (at least three) of equally tuned vibratory structures coupled in series with one another, the said apparatus comprising an initial vibratory structure and a final vibratory structure of vibratory magnitudes (mass and elastic force) of different value; the value of the vibratory magnitudes of the intermediate structures decreasing gradually in equal steps towards the structure with the smallest vibratory magnitudes.

3. Acoustic vibratory apparatus comprising two end masses and a plurality of intermediate masses, a plurality of elastic members, each mass being coupled to the adjacent mass by one of said elastic members, said masses being so adjusted with regard to magnitude that the resonance crests of the apparatus are evenly distributed over the range of frequencies for which the apparatus is to be used.

4. Acoustic vibratory apparatus comprising two end masses and a plurality of intermediate masses, a plurality of elastic mem-

bers, each mass being coupled to the adjacent mass by one of said elastic members, forming a series of vibratory structures of masses coupled by elastic members, each of the intermediate masses serving as a coupling mass, said masses being so proportional with regard to weights and said structures being so damped that the resonance crests of the apparatus are evenly distributed over the range of frequencies for which the apparatus is to be used and the peaks are not more than twice the lowest point of the resonance curve.

5. Acoustic vibratory apparatus comprising a casing, a diaphragm supported by said casing, a mass having a circular flange attached to said diaphragm, a second diaphragm mounted on said circular flange, and a plurality of similar structures, each having a mass and an elastic member mounted serially on said first elastic member.

6. Acoustic vibratory apparatus comprising a casing, a diaphragm supported by said casing, a mass having a circular flange attached to said diaphragm, a second diaphragm mounted on said circular flange, and a plurality of similar structures, each having a mass and an elastic member mounted serially on said first elastic member, said masses being proportioned to one another in only gradually diminishing steps.

7. Acoustic vibratory apparatus comprising two end masses and a plurality of intermediate masses, said masses being proportioned to one another successively in gradually diminishing steps, and a plurality of elastic members, each mass being coupled to the adjacent mass by one of said elastic members.

In testimony whereof we affix our signatures.

WALTER HAHNEMANN.
HEINRICH HECHT.