

Jan. 22, 1963

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3,074,504

LOUD-SPEAKER

Filed May 25, 1961

4 Sheets-Sheet 1

Fig. 1

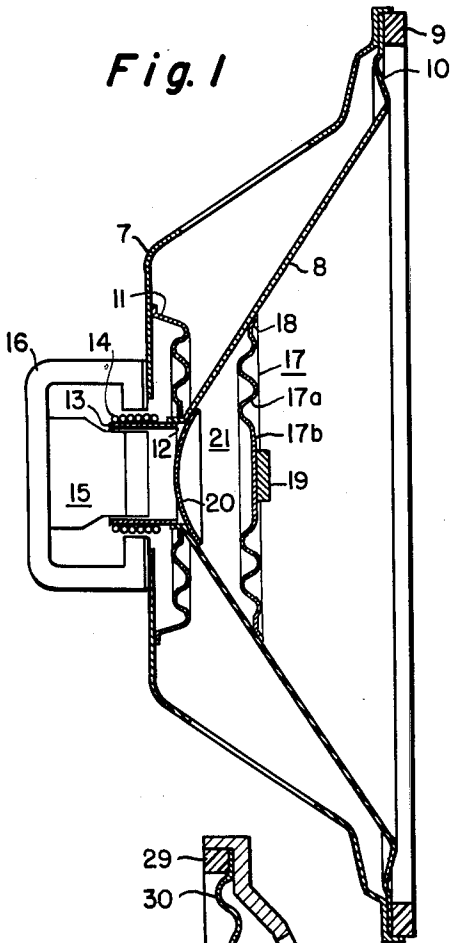


Fig. 2

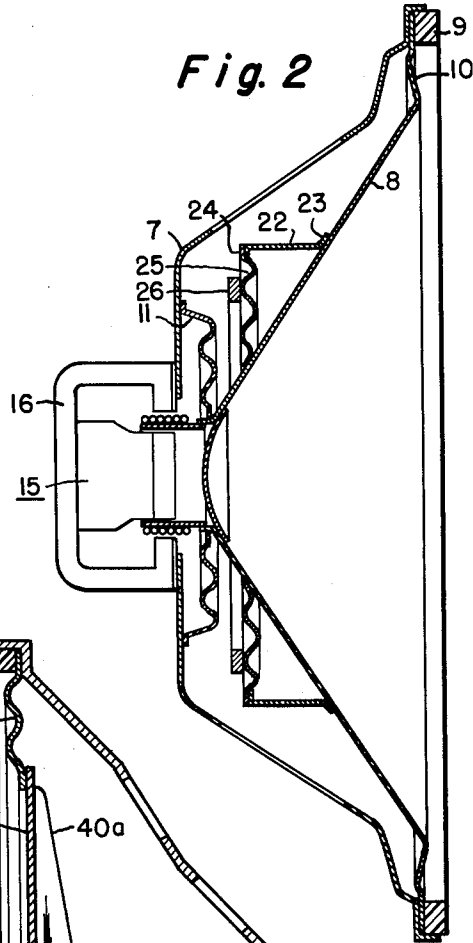


Fig. 6

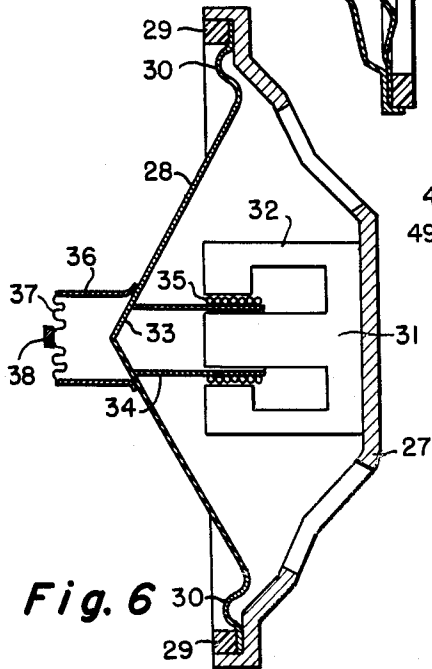
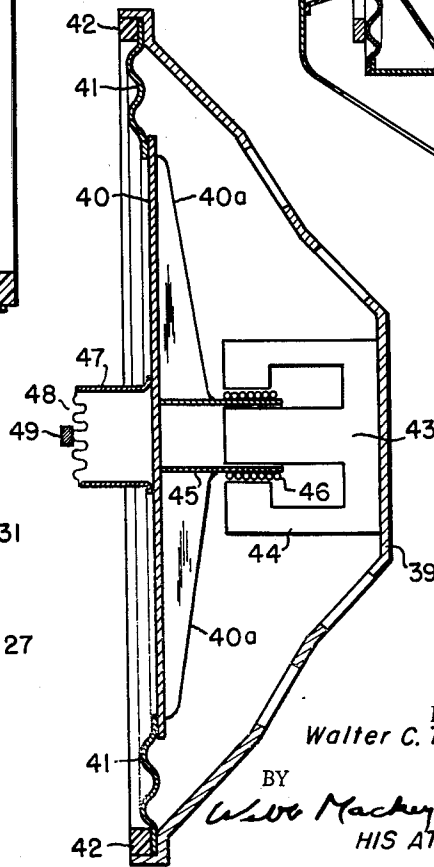


Fig. 7



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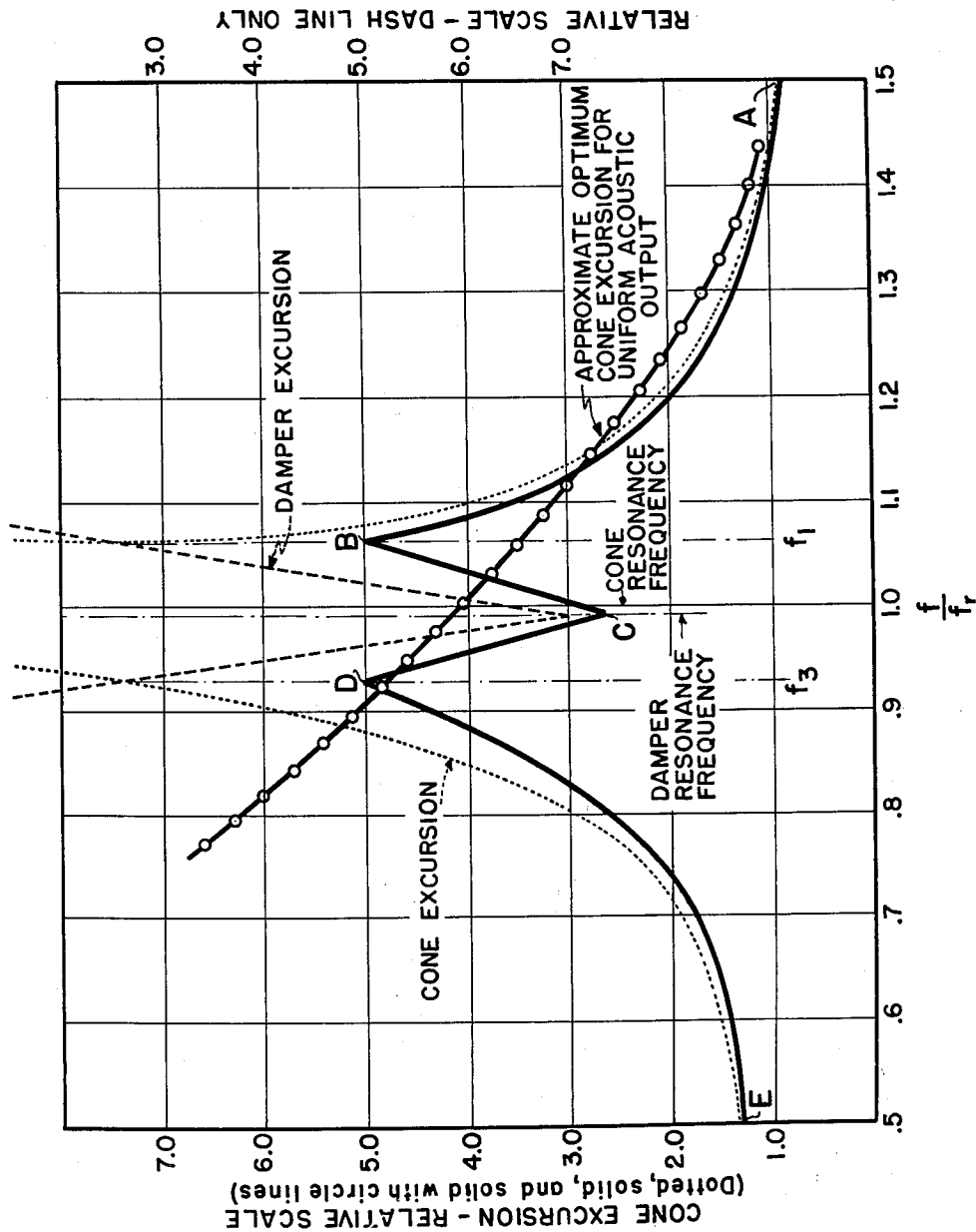


Fig. 3

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4 Sheets-Sheet 3

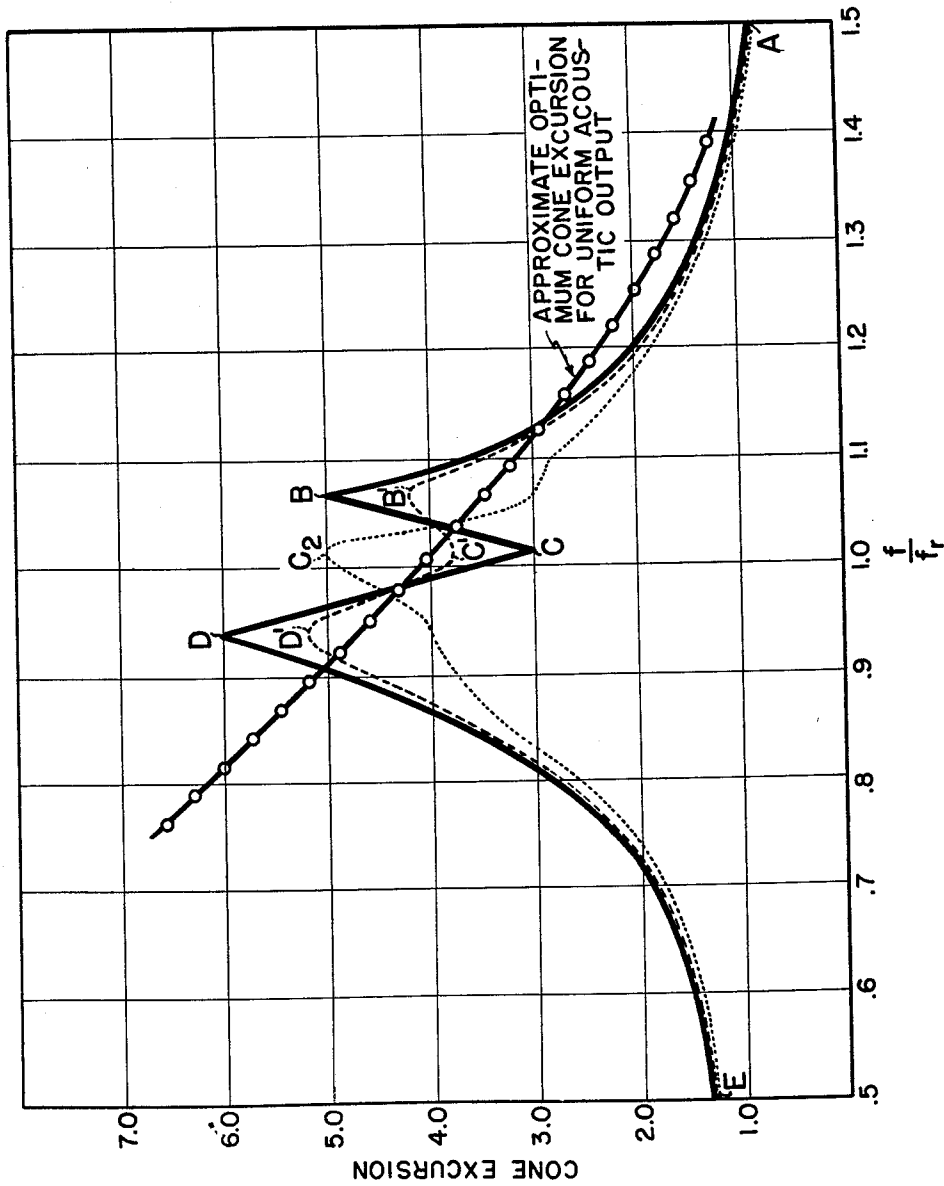


Fig. 4

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4 Sheets-Sheet 4

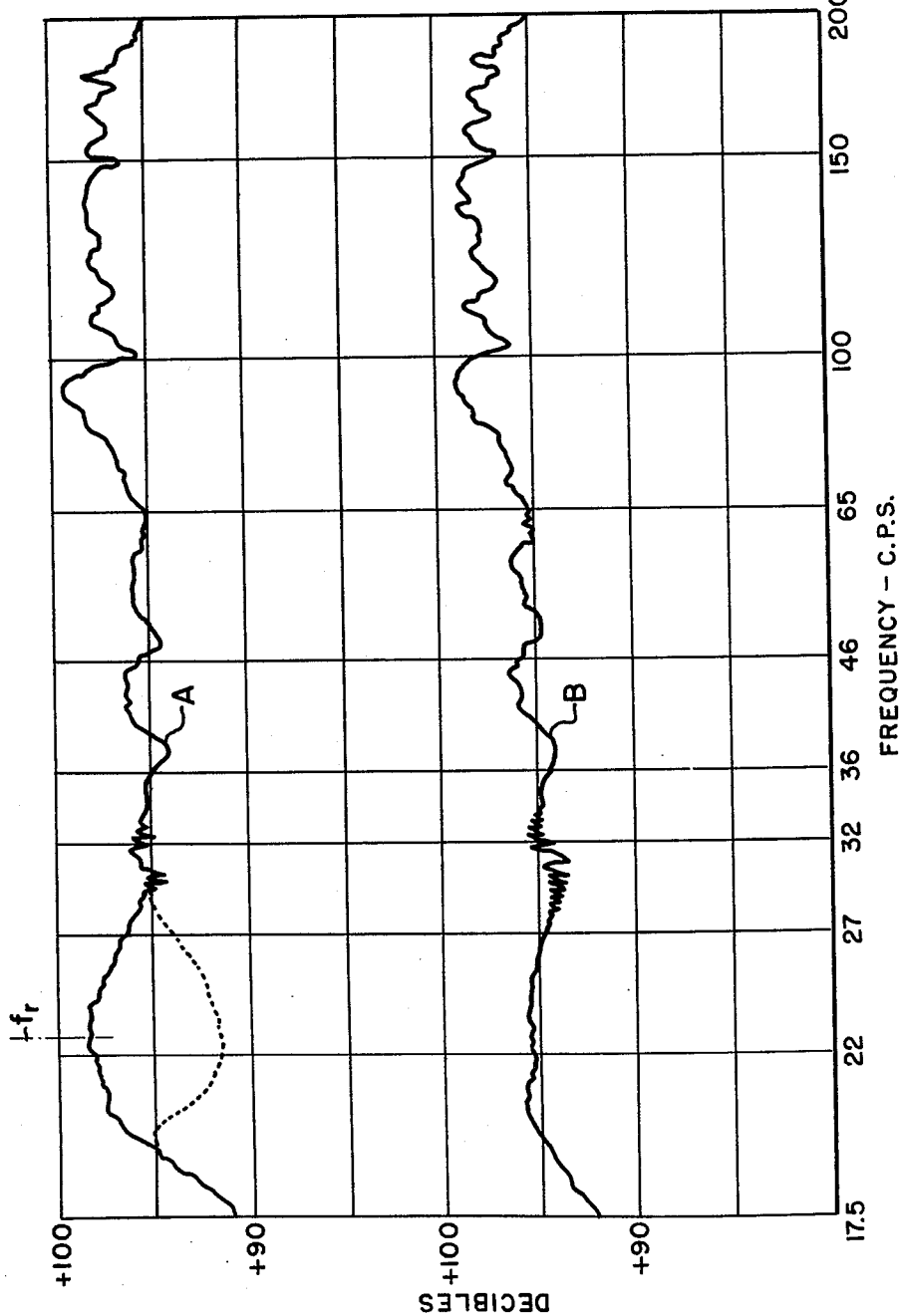


Fig. 5

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LOUD-SPEAKER

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6 Claims. (Cl. 181—32)

This application relates to a loud-speaker. More specifically, it relates to the damping of vibratory diaphragms of loud-speakers of the electrodynamic, direct radiator type. The diaphragm may be of any shape—cone, inverted cone, spherical, paraboloid, or flat.

In loud-speakers of this type, the speaker diaphragm is resiliently suspended and is vibrated by a voice coil secured to the speaker diaphragm adjacent its center in response to signals received by the voice coil from an amplifier. The speaker diaphragm assembly, including a suspension at the outer edge of the cone, a spider to support the diaphragm at its inner end, and a voice coil, has a natural frequency of oscillation and, as is well known, an outstanding defect of such speakers is that, when the diaphragm is driven by the voice coil at its natural frequency, excessive diaphragm motion and excessive acoustic output develop because of resonance. In addition to the excessive acoustic output, there is the further defect that the diaphragm assembly tends to go out of the control of the voice coil at resonance frequency and vibrates in accordance with its own frequency rather than the frequency of the current in the voice coil. This produces distortion because the oscillation of the diaphragm at its natural frequency tends to be harmonic, whereas the control current which is passed to the voice coil generally has a quite different wave form.

Many attempts have been made to overcome this defect in direct radiator or piston type speakers. One course has been the use of a variety of cabinets or enclosures for the speaker. These cabinets are bulky and expensive. Electrical feedback within the amplifier has also been attempted but such an arrangement is not effective unless the efficiency of the speaker is at least 50% and the amplifier source has a zero impedance. Such speakers are theoretically attainable but, as a practical matter, they are not. The efficiency of the average loud-speaker varies from 3 to 5%, and the most expensive loud-speakers have efficiencies only up to 15%.

I have developed a loud-speaker having a control for the acoustic output of the speaker at the resonance frequency of the speaker diaphragm which is built into the loud-speaker itself and which is controlled by the loud-speaker and which, therefore, is not dependent upon the use of a special enclosure or of an electrical damping circuit.

In the accompanying drawings, I have illustrated certain presently preferred embodiments of my invention, in which:

FIGURE 1 is a sectional view of a loud-speaker embodying my invention;

FIGURE 2 is a sectional view showing a speaker embodying a modified form of my invention;

FIGURES 3 and 4 are graphs showing speaker diaphragm excursions at frequencies above and below the resonance frequency of the diaphragm;

FIGURE 5 is a graph showing two curves in which is plotted acoustic output against frequency for a speaker embodying my invention and for the same speaker without my invention;

FIGURE 6 is a sectional view of a loud-speaker having a different type of speaker diaphragm to which my invention has been applied; and

FIGURE 7 is a sectional view of a loud-speaker having

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a third type of speaker diaphragm to which my invention has been applied.

Referring to FIGURE 1, there is shown a loud-speaker having a basket 7, a speaker diaphragm 8 of the cone type which is secured at its large end to the basket by means of a mounting gasket 9, and a cone suspension 10 integral with the cone. A spider 11 is secured to the basket 7 and to the inner end 12 of the cone. The inner end of the cone is also secured to a cylinder 13 around which is wrapped a voice coil 14. A permanent magnet 15 having a return path yoke 16 extends within the cylinder 13 to a point within the voice coil 14.

The loud-speaker so far described is conventional. To such a speaker, I add a circular damper diaphragm 17 which, as shown in FIGURE 1, is secured to the cone at its outer edges 18 at a point in proximity to the inner end of the cone. The diaphragm 17 is flexible and porous and has convolutions 17a which permit a flat central portion 17b of the diaphragm to move laterally. A weight 19 is attached to the center of the diaphragm.

An impervious dust cap 20 closes the inner end of the cone. The diaphragm 17 and the dust cap 20 thus enclose within the cone an air cavity 21. The size of this air cavity is not critical. It is desirable, however, to mount the diaphragm and the weight in proximity to the inner end of the cone.

The diaphragm 17 and weight 19 act as a damping means to control the excursion of the cone 8 at resonance frequency. As stated above, the diaphragm 17 is flexible and the weight and the diaphragm are so designed that they have a natural frequency of vibration very near to and slightly higher than the cone resonance frequency. The determination of the natural frequency will be later described. When the cone vibrates at its resonance frequency, the weight and diaphragm oscillate at their natural frequency. However, the motion of the weight and diaphragm is not in phase with the motion of the cone but is actually 180° out of phase with the cone motion. The weight thus moves outwardly when the cone moves inwardly and inwardly when the cone moves outwardly because the weight is elastically coupled to the cone through the flexible diaphragm. The motion of the weight thus produces a counter-force which can be used to subdue the excess cone motion at the resonance frequency of the cone.

FIGURE 2 shows a loud-speaker to which a modified form of my invention has been applied. The only difference between the speaker shown in FIGURE 2 and that in FIGURE 1 is that, in FIGURE 2, the weight and the diaphragm have been mounted on the rear side of the cone rather than the front side as shown in FIGURE 1. Referring to FIGURE 2, a cylinder 22 is secured to the backside of the cone 8 by flanges 23 which are bent outwardly from one end of the cylinder and secured to the backside of the cone 8. The other end 24 of the cylinder 22 carries a flexible porous diaphragm 25 which is circular and which has a circular central opening. The edges of the diaphragm about the circular opening are glued to the backside of the cone 8. An annular weight 26 having a diameter intermediate the inner and outer diameters of the diaphragm 25 is secured to one side of the diaphragm 25 as shown in FIGURE 2.

The operation of the diaphragm and weight in the speaker shown in FIGURE 2 is the same as the operation of the diaphragm and weight in the speaker of FIGURE 1.

The manner of using the damping force of the weight is illustrated in FIGURES 3 and 4. In FIGURE 3, frequencies above and below the resonance frequency are plotted against cone excursion motion. In the graph, the frequencies are the ordinates and are stated in terms of ratios of the frequencies to the resonance frequency

of the cone, the resonance frequency being indicated as "1.0."

In FIGURE 3, the dotted line represents the relative excursion of a cone without any damping means at frequencies above and below its resonance frequency. The dashed line represents the motion of the weight when it and the damper diaphragm are attached to the cone.

To obtain a minimum amplitude of the cone at its resonance frequency, the resonance frequency of the damper must be less than the resonance frequency of the cone. This is due to the nonsymmetrical shape of the "universal resonance curve" of any vibrating mass near the lower portion of the curve. See FIGURE 3 where the "universal resonance curve" for the cone is shown by the dotted line. The difference between the frequency of the damper and of the cone is expressed by the formula:

$$f = \frac{1}{1 + \frac{\text{damper mass}}{\text{cone mass}}}$$

where

$$f = \frac{\text{damper resonance frequency}}{\text{cone resonance frequency}}$$

Referring to FIGURE 3, the motion of the cone when the damper diaphragm and weight are attached to the cone is shown by the solid line curve A, B, C, D, E when the above equation is satisfied and minimum cone amplitude at resonance frequency is obtained. The solid line with circles shows the approximate optimum cone excursion relative to frequency for uniform acoustic output. The sharp increase in amplitude with decreasing frequency is due to the fact that the output of a cone loud-speaker drops at a high rate below resonance frequency.

Comparing the solid curve A, B, C, D, E with the solid line with circles it will be seen that the curve resulting from adding the damper diaphragm and weight to the cone does not conform to the curve for uniform acoustic output. At the frequency f_1 (corresponding to the point B on the curve), the attenuation of the cone motion is not sufficient. At the cone resonance frequency, the attenuation is too great.

The defects in the cone motion mentioned above can be partially corrected by slightly increasing the natural frequency of the weight and diaphragm. The resulting motion of the cone is shown by the curve A, B, C, D, E in FIGURE 4 in which resonance frequency is plotted against cone excursion in the same manner as in FIGURE 3. Comparing curve A, B, C, D, E of FIGURE 3 with curve A, B, C, D, E of FIGURE 4, it can be seen that, by slightly increasing the natural frequency of the weight and diaphragm, the amplitude at C has been increased.

However, the cone motion shown by the curve A, B, C, D, E in FIGURE 4 is still not satisfactory because the amplitude at B is too great and the motion at C has still been attenuated too much. This is due to the fact that the mechanical "Q" of the weight and diaphragm is too high. The mechanical "Q" of any oscillating system can be reduced by applying damping or resistance to movement to the system. In the present case, resistance is added to the weight and diaphragm by decreasing the porosity of the diaphragm so that the resistance to the passage of air through the diaphragm is increased as the cone forces air in and out of the air cavity 21 through the diaphragm. The porosity of the diaphragm can be decreased in a variety of ways. One way which I have found to be suitable is to make the diaphragm from cloth which is both resilient and porous, such as the material conventionally used for the spider supports of cone loud-speakers, and to spray concentric rings of rubber cement on the diaphragm starting from the outer periphery of the diaphragm and working inwardly as far as required.

FIGURE 4 also shows the effect of adding resistance

to the weight and diaphragm assembly, the resultant cone motion being shown by the dash line A, B', C', D', E. It will be seen that the point B of the former cone motion (without resistance in the diaphragm) has been reduced to B', the point C of the former motion has been raised to C', and the point D has been lowered to the point D' on the new curve. By varying the resistance applied to the diaphragm and weight system, the amplitude of the cone at resonance frequency (the point C) can be adjusted to any desired value. For example, by adding resistance, the point C could be raised to the point C₂ on the dotted line in FIGURE 4.

The application of the foregoing principles to the construction of a damper for any particular speaker will now be described. The ideal speaker is one which produces a constant acoustic output over the entire frequency range of the speaker. In the operation of such a speaker, the amplitude and frequency of the cone at constant power input should have a relationship which can be expressed mathematically (using the symbols in FIGURE 3) as follows:

$$\frac{\text{amp. at } D}{\text{amp. at } B} = \left(\frac{f_1}{f_2}\right)^2$$

The selection of a diaphragm and weight for a particular loud-speaker should be such as to bring about that relationship as closely as possible. This is done by first determining the resonance frequency of the cone and cone suspension of the speaker and then attaching to the cone a diaphragm and weight having a natural frequency of oscillation which will produce minimum cone excursion at cone resonance frequency as explained in the discussion of FIGURE 3. A constant power input is applied to vibrate the cone with the damper diaphragm and weight attached and the cone amplitude at the points B and D on the curve in FIGURE 3 is then measured. The frequency of the diaphragm and weight system is then raised in increments (by decreasing the weight) until succeeding amplitude measurements show that the above mathematical relationship is satisfied and the cone excursion varies with frequency in a manner similar to that shown in the curve A, B, C, D, E in FIGURE 4.

To determine the amount of resistance to be added to the weight and diaphragm (and thereby determine the amount of attenuation of the cone motion at resonance frequency), the acoustic output of the speaker over the frequency range of the speaker is measured and recorded in terms of sound pressure in decibels against frequency. Since the weight and diaphragm have very little resistance, the resulting response curve will show a pronounced dip in output at resonance frequency (i.e., the point C in FIGURE 4). Resistance is then added by closing some of the pores of the mesh of the diaphragm starting in annular bands at the periphery of the diaphragm and working inwardly until the desired response curve is obtained.

In order to reproduce on a production basis diaphragms having the porosity which has been determined experimentally as above described, the diaphragm and weight are removed from the cone and the resistance of this assembly to air flow is determined by any standard method. Diaphragms having this resistance to air flow can then be manufactured out of any material having the flexibility and porosity of the diaphragm which was selected experimentally. For example, the diaphragm could be made of solid plastic sheets which are corrugated for flexibility and perforated for porosity. Likewise, the diaphragms could be made of wire or plastic mesh. The essential requirements of the diaphragm are resilience and controllable porosity.

In FIGURE 5, I have reproduced frequency response curves which show the effects of my invention on an actual speaker. In FIGURE 5, curve A shows the response curve of the speaker without the diaphragm and weight on the cone. It can be seen that, at a frequency of approx-

imately 23 cycles per second, the resonance frequency of the cone assembly has a peak of three decibels, as shown at the point f_r on the curve. An increase of three decibels is the equivalent of doubling the acoustic output. The dotted line in curve A shows the effect of mounting on the cone a diaphragm and weight system without resistance. It will be seen that the curve shows a pronounced dip in output at the resonance frequency of the cone.

Resistance was added in increments to the system by decreasing the porosity of the diaphragm until acoustic output measurements produced the frequency response curve which is reproduced as curve B in FIGURE 5. It can be seen in curve B that the speaker produced a substantially flat response at frequencies just above and below the resonance frequency of the speaker.

Comparing curves A and B in FIGURE 5, it will be seen that the weight and diaphragm produce no discernible loss in output at frequencies removed from the resonance frequency of the speaker. This is due to the fact that at such frequencies the weight is substantially motionless since all energy to move it is transmitted through the diaphragm which is so flexible that it cannot effectively overcome the inertia of the weight.

FIGURE 6 shows my invention applied to a loud-speaker, the speaker diaphragm of which is of the inverted cone type. The speaker includes a basket 27 and a diaphragm 28 of the inverted cone type which is secured at its outer periphery by means of a mounting gasket 29 and a diaphragm suspension 30. The basket 27 supports a permanent magnet 31 having a return path yoke 32. The apex portion 33 of the diaphragm carries a lightweight cylinder 34 which extends inwardly and around the magnet 31 and carries on its end between the magnet and the return yoke 32 a voice coil 35.

A lightweight cylinder 36 is secured to the outer surface of the diaphragm 28 and surrounds the apex of the diaphragm. A porous damper diaphragm 37 is fastened across the open outer end of the cylinder 36 and a weight 38 is secured to the center of the diaphragm 37.

The operation of the diaphragm and weight in the speaker shown in FIGURE 6 is the same as the operation of the diaphragm and weight in the speaker of FIGURE 1.

FIGURE 7 shows my invention applied to a loud-speaker, the speaker diaphragm of which is of the flat piston type. The speaker includes a basket 39 and a flat piston type diaphragm 40 which is mounted in the basket by means of a separate suspension 41 which is glued to the outer edge of the diaphragm and which is held to the basket by a mounting gasket 42. The basket supports a permanent magnet 43 having a return path yoke 44. A lightweight cylinder 45 extends inwardly from the central portion of the diaphragm 40 and carries a voice coil 46. Stiffening ribs 40a for the diaphragm extend from the diaphragm to the cylinder 45.

A lightweight cylinder 47 is centrally positioned on the outer side of the diaphragm 40 and, at its outer end, carries a damper diaphragm 48. A weight 49 is secured to the center of the damper diaphragm 48.

The operation of the diaphragm and weight in the speaker shown in FIGURE 7 is the same as the operation of the diaphragm and weight in the speaker of FIGURE 1.

From the foregoing, it can be seen that I have invented a simple and effective solution to the problem of distortion of speakers at the resonance frequency of the cone assembly. The damper is part of the speaker itself and it is not necessary to place the speaker in an elaborate enclosure or to use an electrical feedback system. The dampening mechanism is mounted on the cone in relatively close proximity to the voice coil so that potentially excessive cone excursions are attenuated before they reach the cone suspension and create difficulties.

While I have described certain presently preferred embodiments of my invention, it is to be understood that it

may be otherwise variously embodied within the scope of the appended claims.

I claim:

1. A loudspeaker comprising,
 - A. a speaker diaphragm,
 - B. a mount for said diaphragm,
 - C. means for resiliently securing said diaphragm to said mount,
 - D. means for vibrating the speaker diaphragm,
 - E. a flexible porous damper diaphragm mounted on said speaker diaphragm,
 - F. a weight mounted on said damper diaphragm, and
 - G. a closed air cavity formed between the diaphragms by spacing the major portions at least of the diaphragms away from each other,
 - H. said porous damper diaphragm providing resistance to the movement of air in and out of said cavity.

2. A loud-speaker as described in claim 1 in which the damper diaphragm and weight have a natural frequency of vibration greater than the resonance frequency of the speaker diaphragm assembly.

3. A loud-speaker as described in claim 2 in which the resistance of the porous damper diaphragm to the passage of air therethrough is such that the motion of the damper diaphragm and weight thereon due to vibration of the speaker diaphragm approximately counterbalances any increase in amplitude of the speaker diaphragm due to resonance.

4. A loud-speaker as described in claim 1 in which, when the means for vibrating the speaker diaphragm drives it with constant power input, the amplitude at the point of highest speaker diaphragm excursion at frequencies greater than the resonance frequency of the speaker diaphragm bears to the amplitude at the point of highest speaker diaphragm excursion at frequencies less than resonance frequency of the speaker diaphragm the following relationship:

$$\frac{D}{B} = \left(\frac{f_1}{f_2} \right)^2$$

where D is the amplitude at the point of highest speaker diaphragm excursion at frequencies above the resonance frequency of the speaker diaphragm, B is the amplitude at the highest point at frequencies below the speaker diaphragm resonance frequency, f_1 is the frequency at which amplitude B occurs, and f_2 is the frequency at which amplitude D occurs.

5. A loud-speaker as described in claim 4 in which the resistance of the porous damper diaphragm to the passage of air therethrough is such that the motion of that diaphragm and weight thereon upon vibration of the speaker diaphragm approximately counterbalances any increase in amplitude of the speaker diaphragm due to resonance.

6. A loud-speaker comprising,
 - A. a loud-speaker cone having an open small end,
 - B. a mount for said cone,
 - C. means for resiliently securing said cone at its large end to said mount,
 - D. means secured to the open small end of the cone for vibrating said cone,
 - E. a dust cap closing the open small end,
 - F. a flexible porous damper diaphragm mounted across the inner side of the cone and spaced from said dust cap, and
 - G. a weight on said damper diaphragm,
 - H. said dust cap and said damper diaphragm forming a closed air cavity between them and said damper diaphragm providing resistance to the movement of air in and out of said cavity.

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