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S. KELLY

3,308,904

LOUDSPEAKERS

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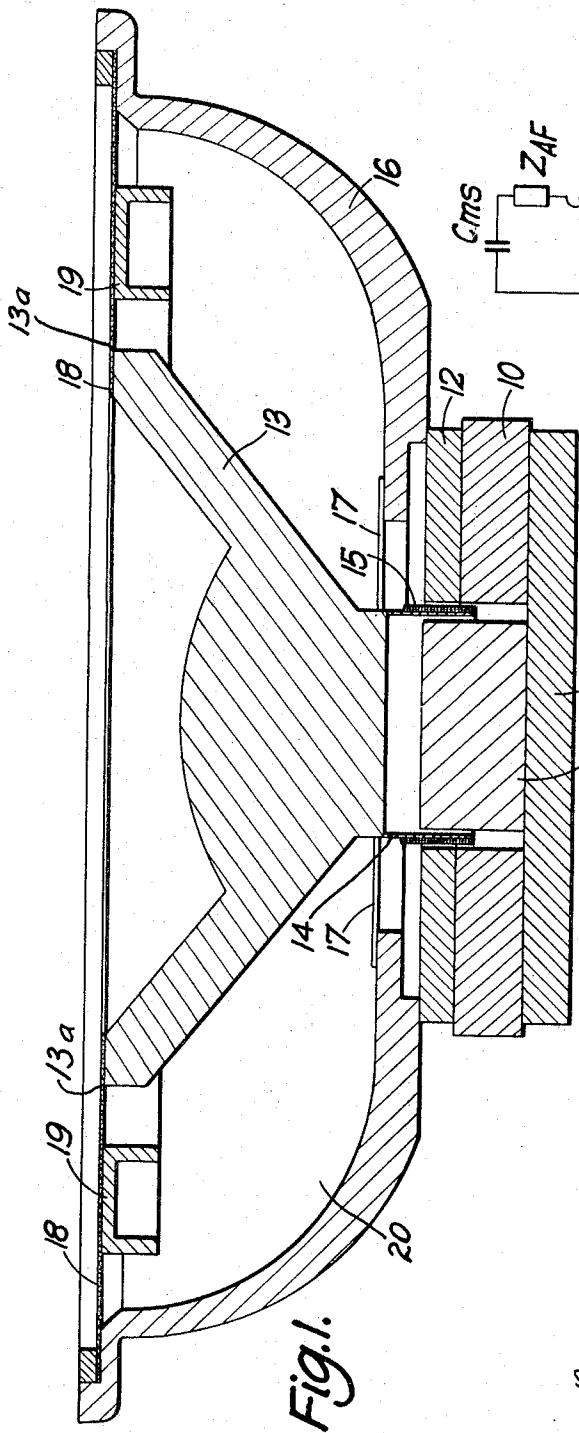


Fig. 1.

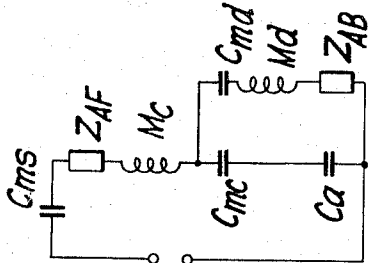


Fig. 2.

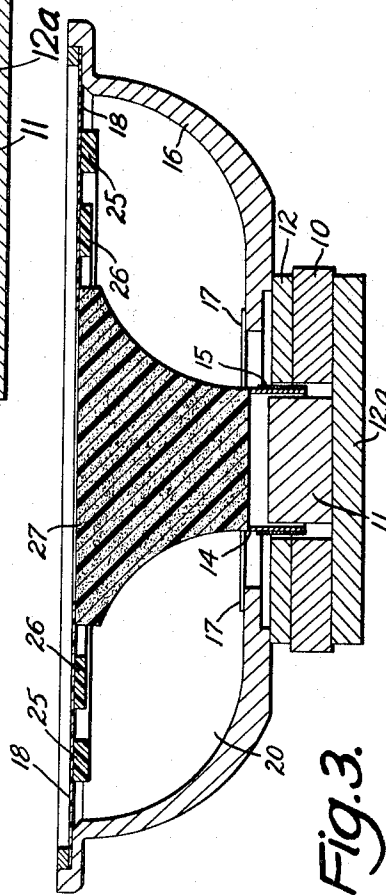


Fig. 3.

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LOUDSPEAKERS

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4 Claims. (Cl. 181—32)

This invention relates to loudspeakers.

The lower frequency response of a loudspeaker system depends on the resonant frequency determined by the acoustic stiffness of the enclosure (referred to the mechanical driving point of the loudspeaker unit), the compliance of the loudspeaker restoring force and the mass of the loudspeaker diaphragm together with the air loading. It is well known that the low frequency response of a loudspeaker system can be extended by providing what is commonly called a "vented enclosure" on one side of the diaphragm; such an enclosure has a port or tube through one wall of the enclosure so tuning the system in the form of a Helmholtz resonator. The port may be replaced by a lightly suspended diaphragm, the mass of this diaphragm being adjusted to that of the optimum reflected mass of the air vent; this improves the efficiency of the system in that the overall effective volume of the enclosure is increased because of the absence of the port or tube.

The present invention is directed towards further improving the efficiency of a loudspeaker system.

According to this invention, a loudspeaker comprises a piston driven by an electro-mechanical transducer whereby the piston is moved with respect to a fixed part of the assembly in accordance with applied electrical signals, and an annulus surrounding the piston and compliantly coupled to the piston and to said support, the annulus and compliant coupling together forming an air seal between the piston and support and the annulus being formed of a rigid element or a number of separate rigid elements having a mass and effective area to give multiple resonances at or near the nominal low frequency resonance of the piston when measured in free air. By effective area is meant the area normal to the direction of movement of the piston. It will be understood that the piston need not be circular and it may for example be elliptical; the annulus would be suitably shaped. The piston may be a cone or it may be flat or of dish-shape.

The aforesaid support conveniently comprises a rigid frame constituting part of the loudspeaker housing assembly.

The compliant coupling may comprise a flexible material, e.g. a fabric, such as a doped linen sheet or an artificial fibre sheet, or a plastic foil such as a polyvinyl chloride sheet, or a metal foil such as an aluminium foil. Conveniently this flexible material extends over the whole region between the piston and the support, the aforesaid annulus being fixed to the flexible material to provide the required mass and rigidity.

For optimum performance, the effective area and mass of the annulus are made equal respectively to the effective area and mass of the piston; and the compliances of the piston to the support (C_{ms}), the piston to the annulus (C_{md}), and the annulus to the support (C_{mc}) are so proportioned that together with the reflected compliance of the enclosure formed by the piston, annulus and support, the two resonant frequencies of the system are displaced from the nominal resonant frequency by

$$\pm \frac{1}{\sqrt{2}}$$

of the nominal resonant frequency of the piston (less the annulus mass M_a and the annulus to support compliance

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C_{mc}) when measured in free air. It will be seen that this system is analogous to a "vented enclosure" loudspeaker system but, in place of the port mass and air load, there is provided the piston to annulus compliance C_{md} , the annulus mass M_a and the air load. The introduction of the compliance C_{md} , which has no counterpart in a vented enclosure system, increases the loading on the piston at frequencies below resonance thereby preventing excessive excursion of the piston and consequential damage to the system.

Preferably the piston for the above described loudspeaker system is made of an expanded thermo-setting resin having hard skinned surfaces and of a density between 1 and 3 lb. per cu.-ft. as described in the specification of copending application Ser. No. 481,622, filed August 23, 1965. Preferably also the piston and enclosure are arranged so that the piston area is related to the volume of the enclosure in the manner set forth in the specification of copending application Ser. No. 481,581, filed August 23, 1965.

In the accompanying drawings:

FIGURE 1 is a diagrammatic illustration of one construction of loudspeaker;

FIGURE 2 is an electrical analogue of the mechanical acoustic system of the loudspeaker; and

FIGURE 3 illustrates a modification of FIGURE 1.

Referring to FIGURE 1, the loudspeaker has an electro-magnetic transducer system including a permanent magnet 10 and a central pole member 11 located between outer magnetic members 12 and 12a. A cone-shaped piston 13 with a domed center is attached to a member 14 carrying a moving coil 15. In order that the piston 13 can vibrate as a rigid member, it is considerably thicker than the paper cones in common use and is preferably made of an expanded thermo-setting resin, e.g. foamed polyurethane, with a hard skin on its surface and having a density between 1 and 3 lb. per cu.-ft. The effective area of the piston 13 is the area normal to the direction of movement of the piston, that is the area of a flat plane, the boundary of which is defined by the peripheral edge 13a of the piston 13. The piston 13 is carried within a rigid outer support 16 by a resilient mount 17 having a compliance C_{ms} . A sheet of flexible material 18 extends across the region between the periphery of the piston 13 and the outer support 16 and attached to this material 18 is a rigid annular element 19 having an area equal to the effective area of the piston 13 and having a mass M_a equal to the mass M_c of the piston 13. The element 19 is conveniently a metal ring of channel section to give the required rigidity; it is not essential however that it should extend continuously around the annular region between the piston 13 and the support 16 provided it has the required area and mass and provided there is an air-tight seal across this region; this seal is constituted by the flexible material 18 which provides a compliance C_{md} between the piston 13 and annular element 19 and a compliance C_{mc} between the element 19 and support 16. The flexible material 18 has to form an air-tight seal and may for example be linen which is doped to make it non-porous, or a sheet of nylon fabric or polyvinyl chloride foil or aluminium foil. There is thus an airtight enclosure 20 within the outer support 16, the piston 13, the flexible material 18 and the annular element 19.

In order to obtain optimum values of the compliances C_{ms} and C_{md} , two separate annular members, possibly of different thickness may be employed. These may be corrugated to give more precise control of these compliances. Such an arrangement is illustrated in FIGURE 3 which shows a modification of the arrangement of FIGURE 1, two rigid annular members 25, 26 being secured to the flexible material 18. FIGURE 3 also shows a flat piston 27 in place of the cone-shaped piston with a dished center

illustrated in FIGURE 1. Apart from these distinctions, the arrangement of FIGURE 3 is similar to that of FIGURE 1.

FIGURE 2 illustrates in conventional form the electrical analogue of the mechanical-acoustic system, Z_{AF} and Z_{AB} represent the load impedance of the air to the piston 13 and element 19 respectively. It will be noted that there are two series resonances; one is formed by M_c and C_{mc} and C_a (where C_a is the reflected compliance provided by the air in the enclosure 20) and the other is formed by M_c and M_d with C_{md} . There is also an anti-resonance formed by M_d with C_{md} , C_{mc} and C_a . The various compliances are so proportioned that the two resonant frequencies are 1.414 and 0.707 times the nominal resonant frequency in free air of the piston 13 (discounting the mass M_d of the element 19 and the compliance C_{mc}). It will be noted that the compliance C_{md} loads the piston 13 at low frequencies so preventing excessive displacement of the piston at low frequencies. The resonant frequency of the piston is one of the main factors determining the low frequency response of the loudspeaker system and, by having these further resonances near the nominal low frequency resonance of the piston in free air, the low frequency response is improved.

In the construction illustrated in FIGURE 1 and in FIGURE 3, the piston conveniently is circular in plan form and its diameter is related to the volume of the air in the enclosure 20, for the reasons set forth in the specification of the aforementioned application Ser. No. 481,581, the preferred diameter D in inches being equal to $0.86 \sqrt[4]{V}$ where V is the enclosure volume 20 in cubic inches.

The low frequency radiation (that is where the radiating members are small compared with wavelength of sound at the frequency in question) is a function of radiator area and its velocity. Because the radiation resistance is very small, "Q" factors of the order of 5 to 20 can easily be realised at frequencies below 200 c./s. If therefore a number of substantially rigid radiators are mechanically connected together through compliant members, a series of resonant structures will be obtained in which the resonant frequency of each radiator is a function of its mass, the coupling compliance and the reflected reactance of the other radiators at the frequency in question. By this means it is possible to make a small central driving diaphragm to which the voice coil is connected and have a multiplicity of concentric rigid rings each being driven by a compliance from the preceding ring. This will result in a series of coupled resonances and by suitably proportioning the ratio of mass and compliance these resonances can extend over a range of at least two octaves, with considerably enhanced low frequency performance.

Referring to FIGURE 2, the analogue equivalent of a second annular member may be considered as the provision of a further series circuit comprising a compliance (capacitance), a mass (inductance) and a load (resistance) in shunt across M_d and Z_{AB} . A third annular member would be represented by a similar series circuit, containing compliance, mass and load, in shunt across the mass and load of the second annular member. In this way further resonances can be introduced.

I claim:

1. A loudspeaker comprising a fixed support, an electro-mechanical transducer mounted in said support, a rigid circular piston driven by said transducer whereby the piston is moved with respect to the support in accordance with applied electrical signals, a rigid annulus surrounding the piston and concentric therewith, and a sheet of flexible material secured to the piston and to said fixed support, which sheet extends outwardly in a radial plane from the piston, said annulus being secured on said sheet of flexible material whereby the flexible material forms a compliant coupling between the piston and the annulus and between the annulus and the support, the flexible material and annulus together forming an air seal between the piston and the support, the annulus having a mass and effective area equal respectively to the mass and effective area of the piston, and the spacing between the piston and annulus and between the annulus and support being so proportioned that the compliance between the piston and annulus is equal to the compliance between the annulus and the support.

2. A loudspeaker comprising a fixed support, an electro-mechanical transducer mounted in said support, a rigid circular piston driven by said transducer whereby the piston is moved with respect to the support in accordance with applied electrical signals, at least two rigid concentric annular members surrounding said piston, and a sheet of flexible material secured to the piston and to said fixed support, which sheet extends outwardly in a radial plane from the piston, said annular members being secured on said sheet of flexible material whereby the flexible material forms a compliant coupling between the piston and innermost annular member, between adjacent annular members and between the outermost annular member and the support, the flexible material and annular members together forming an air seal between the piston and the support, the annular members having a mass equal to the mass of the piston and an effective area equal to the area of the piston, and the compliances between the annular members and between the outermost annular member and the support being equal to the compliance between the piston and the innermost annular member.

3. A loudspeaker as claimed in claim 1, wherein said piston is flat.

4. A loudspeaker as claimed in claim 1 wherein said flexible material extends over the whole region between the piston and the support, the annulus being fixed to the flexible material to provide the required mass and rigidity.

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