Oct. 28, 1952 P. G. A. H. VOIGT 2,615,995

MOVING COIL LOUD-SPEAKER

Filed Oct. 26, 1949 2 SHEETS—SHEET 1

FIG. 1.

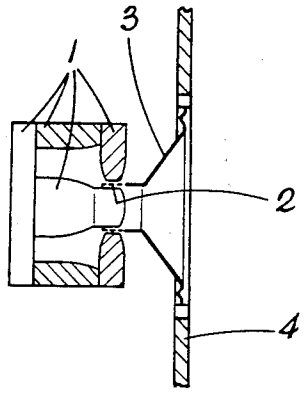


FIG. 2.

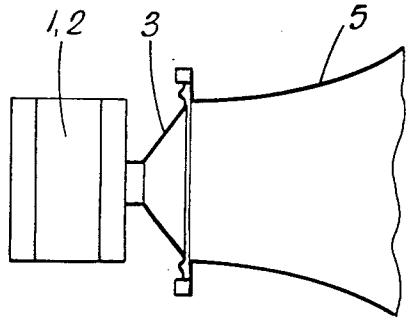


FIG. 3.

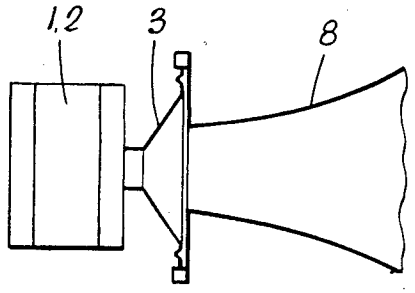
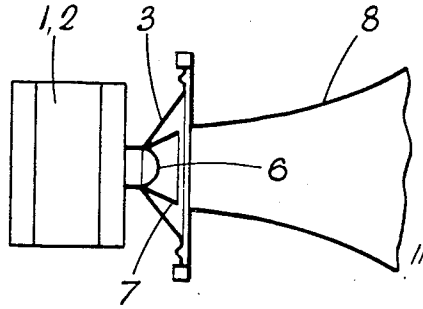


FIG. 4.



INVENTOR

P. G. A. H. Voigt.

BY Emory L. Groff

ATTORNEY.

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MOVING COIL LOUD-SPEAKER

Filed Oct. 26, 1949 2 SHEETS—SHEET 2

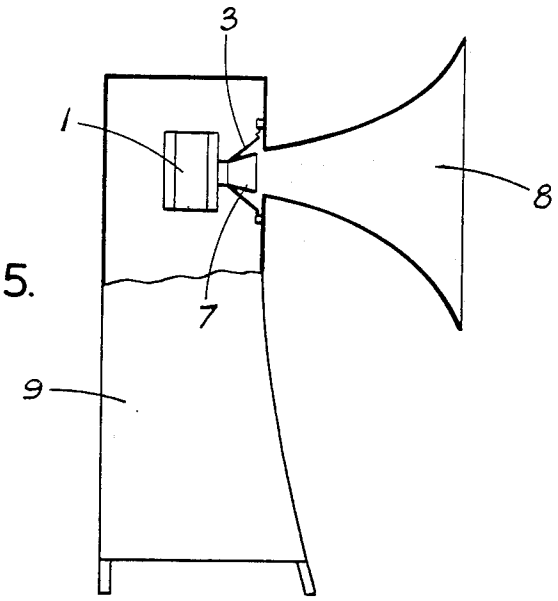


FIG. 5.

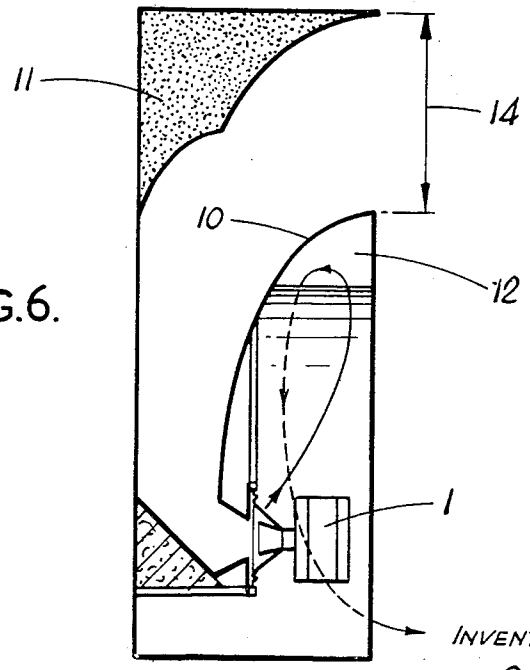


FIG. 6.

INVENTOR
P. G. A. H. Voigt.

BY Emory L. Groff

ATTORNEY.

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UNITED STATES PATENT OFFICE

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MOVING COIL LOUD-SPEAKER

Paul Gustavus Adolphus Helmuth Voigt,
Upper Norwood, London, England

Application October 26, 1949, Serial No. 123,574
In Great Britain October 29, 1948

9 Claims. (Cl. 179—115.5)

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This invention relates to moving-coil loud-speakers particularly those intended for high quality reproduction and having magnets which produce high flux densities, of say 15,000 gauss or over, in the magnetic gap.

Moving-coil loud-speakers can be divided broadly into two types. The enclosed high pressure and the open low pressure types. There is also an intermediate type various forms of which cover the whole region between the two main types.

This invention relates particularly to the open low pressure type and those intermediate variations which depart not too far from the open low pressure type.

The object of my invention is to improve the accuracy of reproduction of the sound, as set forth in the accompanying drawings in which:

Figure 1 is a diagrammatic view illustrating the application of the invention to an arrangement including a flat baffle.

Figures 2 to 6, inclusive, are diagrammatic views illustrating the invention in an arrangement including a horn.

Similar reference characters designate corresponding parts throughout the several figures of the drawing.

Among loud-speaker designers there exists a deep seated idea that for "perfect" reproduction of sound there is required for the high frequencies, a very light diaphragm with a correspondingly light coil, and for the low frequencies, a large relatively heavier diaphragm with a correspondingly heavier coil.

Such an idea is directly compatible with the natural order of things in which almost invariably, the sources of high frequency sound are small and light, while sources of low frequency sound are large, bulky and relatively massive. In fact low frequency sources are often simply high frequency sources scaled up.

Further, when the design of loud-speakers was still in its infancy, the question of weight relationship as between diaphragm and speech coil was investigated mathematically and it was deduced that for maximum efficiency, the weights of diaphragm and speech coil should be equal. It seemed therefore that there should be a constant relation between the parts irrespective of size.

Since this deduction fitted exactly into ordinary experience, its findings have been generally accepted, and are still mentioned in up to date text books: Ref: H. F. Olson, "Elements of Acoustical Engineering"; publishers, D. Van Nostrord Co. Inc., of New York, 2d edition, 1947, page 127; though it is mentioned that to make the coil as heavy as the diaphragm is often not practical.

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To comply with this requirement for coils of different weights with the different diaphragms in a wide range loud-speaker, a great deal of ingenuity has been expended.

The method most generally employed is simply to use entirely separate loud-speakers with coils and diaphragms of different weights situated close together, or by adopting special designs made so that they can be located concentrically one within the other.

From there it is a simple step to arrangements with a common magnet with separate diaphragms driven by separate speech coils operating in separate gaps, or even in a common gap. Then there is the further development of a wide range diaphragm structure driven by a complex coil structure of such kind that at high frequencies, a part only of the coil structure drives the diaphragm while at low frequencies the whole of the coil is working, the control being effected by external circuit ararngements, or it may be inherently automatic, for example by induction which is frequency selective.

My invention, which deals with loud-speakers suitable for wide range reproduction, does not propose yet another arrangement for obtaining the effect of a light coil at high frequencies and a heavy one at low ones. Instead, it depends upon my opinion that the heavy coil for the low frequencies is quite unnecessary, I therefore dispense with it, and make the light high frequency coil do the whole of the work.

By this, I do not imply that there was any error in the early mathematical investigations, or in the deduction therefrom, namely that for maximum efficiency (under the conditions assumed) the coil and diaphragm should be of equal weights. The error, as I now see it, was generally made by designers when they absorbed the natural idea that a relatively heavy speech coil was desirable at low frequencies without first making sure that the conditions assumed for the mathematical investigation applied in their case, and without realising that maximum efficiency in the low frequencies was only desirable in a wide range loud-speaker if the higher frequencies had an equal efficiency.

If the matter is examined, it will be found that a considerable difference between diaphragm and coil weights may exist before the loss in efficiency becomes serious. Secondly, if there is a choice of magnets with different flux densities

in the gap, it can be shown that for a specific efficiency, the coil weight required varies inversely as the square of the flux density. Thus, a diaphragm/coil system with a certain efficiency in a gap density of 10,000 gauss can be replaced when a 20,000 gauss magnet is available by one in which the coil has only one quarter the previous weight.

Thirdly, if a copper coil is replaced by one of aluminium there is, roughly while retaining equal conductivity per turn, a further halving of the coil weight.

Taking all these factors together I find that at high flux densities the permissible discrepancy between coil weight and diaphragm weight becomes so great that diaphragm weight ceases to be a factor of first importance when determining coil details in loud-speaker design, and that available flux density, coil material, and the operating conditions of the coil are the primary factors. Since the operating conditions are affected by the area of the diaphragm, and by the manner in which the diaphragm is worked, e. g. whether it is on an open baffle or horn loaded, and since a large area diaphragm is normally heavier than a small one, there remains an indirect influence connecting diaphragm weight with coil design, it is however very remote and quite accidental.

In order to prove that the theory upon which my claims are based is correct, I have experimented with diaphragm/coil assemblies in which the weight of the coil conductor was less than 1% of the weight of the diaphragm. As expected, the efficiency was not as high as that obtainable with a heavier coil, but as the loss in efficiency was general over the whole scale, the resulting sound had the lowest and highest frequencies reasonably in balance, moreover there was not the slightest difficulty in producing the lowest frequencies.

An inherent property of a coil of unusually low weight is that the actual volume of the metallic conductor is also much less than usual. This is of very direct importance when designing the appropriate magnet since it permits the use of a very narrow gap, in which it is much easier to produce the intense flux density required for these extremely light coils to operate at a reasonable efficiency. The reduction in coil weight which becomes permissible (for constant efficiency) as the flux density is increased thus helps to make possible without increased cost the increased flux density which it calls for.

From the point of view of the reproduction of high frequencies, the use of a very high flux density is specially advantageous for several reasons, of which probably the most important is that the current required to produce the necessary acceleration forces is reduced in direct proportion as the flux density is increased.

The use of such exceptionally light coils further reduces the magnitude of the said acceleration forces, thereby helping the highest frequencies further.

Alternatively, if the matter is considered mechanically, these very light coils do not act as a massive barrier in the sequence preceding the diaphragm, and it is only necessary to use a diaphragm structure capable of transforming the high frequency impulses as well as those of lower frequency efficiently into sound waves in order to have a loud-speaker unit suitable for covering the whole audible scale.

The need for separate high frequency and low

frequency arrangements and cross over networks is thereby avoided.

According to this invention I depart completely from the theory that the weight of the speech coil should equal or approach the weight of the diaphragm and I determine the weight of the speech coil by considering four factors which I regard as primary and then varying from the weight so ascertained as convenient or desirable according to secondary requirements.

I will give later in the specification a formula for determining what I regard as the maximum desirable weight in relation to the main factors.

All the secondary requirements except efficiency call for further diminution of mass.

The primary factors concerned are:

(1) The mean flux density in which the conductor is situated, a matter which depends on the design of the magnet system.

(2) The material of the conductor, and here I prefer aluminium to copper.

(3) The desired "motor" efficiency, and

(4) The load on the diaphragm.

This fourth factor often varies with frequency, especially when resonances occur, or when the diaphragm drives, as in the normal flat baffle case, into air free to escape sideways. The load on the diaphragm then decreases rapidly as the frequency is reduced and the corresponding sound wavelength increases beyond a dimension comparable with the diaphragm diameter.

Such variation causes the speech coil weight computation to give different results at different sound wavelengths. For a given frequency range however, limits would be found below which the coil weight should lie, the heaviest weight corresponding to the frequency at which the diaphragm is satisfactorily loaded.

Consideration of the above factors leads me to the conclusion that the speech coils should be far lighter than customary, especially when high intensity magnetic fields are used.

As normally constructed, the low pressure open type of loud-speaker, has a magnet with an annular gap, a speech coil situated in the gap and coupled mechanically to a conical diaphragm usually of paper of maximum diameter of 4" to 8" which is driven to and fro by the coil. Smaller so called midget sizes and larger sizes up to about 16" diameter are also made, but the 4" to 8" group of sizes is the most usual.

These loud-speakers are generally mounted on flat baffles, or in box-like containers which serve to prevent the air displacement on one side of the diaphragm from flowing round the edge and neutralising the displacement on the other side.

In order to increase the frequency range over which the diaphragm is satisfactorily loaded, I prefer to operate the diaphragm into a directional baffle or wide throat horn. The loss in loading due to sideways escape of the air at lower frequencies is then prevented down to the cut off frequency of the horn, and uniformity of diaphragm loading above that frequency is much improved. A coil of appropriate weight can then perform under satisfactory conditions over a wide frequency range.

The diaphragm may be a simple truncated cone of the usual type or such a cone provided with a forward pointing central cone or dome, such as is ordinarily used as a dust seal.

In an arrangement which I favour the main cone is supplemented by a smaller sharper cone with a free edge. This supplementary cone acting as a good radiator for frequencies so high as

to be above the region where the main cone is efficient.

When the speech coil weight is considered in connection with such a multiple cone, the different cones considered individually may call for different maximum coil weights. Under those conditions judgement must be applied, but the coil weight should not exceed the heaviest resulting from any of the computations concerned.

The best way of showing how the coil weight is assessed according to this invention is by working out a numerical example. For this I select the preferred case of a diaphragm working into a large throat horn.

Considering a plane wave front in free air, if the velocity of the air particles is 1 cm./sec., then the associated pressure is just over 42 dynes/sq. cm. An ideal wide throat horn preserves this velocity/pressure ratio at its throat over a frequency range from near the horn cut off upwards. If therefore we take the specific case in which the horn throat and diaphragm projected area are equal, then the load on the working face of the diaphragm at 1 cm./sec. velocity is approx. 42 dynes for each sq. cm. of projected area.

Assuming a normal 6'' diameter diaphragm (=15.24 cms.)

$$\text{the projected area} = 15.24 \times \frac{\pi}{4} = 182\tfrac{1}{2} \text{ sq. cms. approx.}$$

and the work pressure (horn side only) at 1 cm./sec. velocity is about $42 \times 182\tfrac{1}{2}$ = say 7,670 dynes. This is a measure of factor 4, i. e. the load. Factor 1 is the mean flux density; let this be 15,000 gauss in our case.

In considering the mass of the speech coil conductor, it is irrelevant whether this is divided into many turns of fine wire or fewer turns of thicker wire. For the numerical example, I am assuming the use of such size wire as might be employed to obtain a working impedance about equal to that common in normal loud-speakers.

Let the conductor be 200 cms. long, then at 1 cm./sec. vibration velocity,

$$\text{the back E. M. F. generated} = \frac{1 \times 200 \times 15{,}000}{10^8} = .03 \text{ volt}$$

To provide the work pressure, the current flowing in the coil must be

$$\frac{7{,}670}{200 \times 15{,}000} =$$

.00256 absolute E. M. units of current = .0256 amperes

(Stiffness, inertia and accidental air load on the back of the diaphragm are ignored at this stage.)

.03 volt at .0256 amp. gives an impedance due to motion of 1.17 ohms, corresponding to the useful work done.

Now the moving-coil/magnet system of a loudspeaker can be regarded as the "motor" part of the instrument. Basically, the efficiency (factor 3) of this motor, as in the general electrical case is

$$\frac{\text{useful output}}{\text{total input}}$$

Ignoring inertia, inductance and other losses as secondary, the main loss is the heat loss due to the resistance of the coil. Now for a given length of conductor, the loss due to the resistance depends upon the material, and varies inversely with the sectional area or weight. A doubling in conductor section (which doubles the weight) halves the resistance in consequent heat loss. The coil weight is thus directly involved according to the motor efficiency desired.

100% efficiency requires the complete elimination of resistance loss, it therefore demands a conductor of infinitely large sectional area and corresponding weight. This is not only impracticable but coil inertia—hitherto regarded as secondary—would take charge and suppress motion. The overall electrical-mechanical efficiency would therefore be nil. A lower "motor" efficiency, say 25%, which would give results only 6 db down on the impracticable maximum 100% motor efficiency eliminates all the impracticable features.

When obtaining 25% motor efficiency, the useful output is ¼ of the input, the remaining ¾ of the input being lost, mainly as heat in the conductor resistance. With the 200 cm. conductor assumed therefore, if the useful work impedance of 1.17 Ω is to be ¼ of the total, that total will be 4.68 ohms, and the D. C. resistance will be 3.51 ohms.

For 50% efficiency conditions, the resistance loss is half the total, i. e., 1.17 ohms out of a total of 2.34 ohms. The conductance, conductor section, coil weight and bulk are all therefore three times their value for 25% efficiency.

Working out the weight of a copper coil corresponding to 1.17 ohms, we get in the 50% case .51 grams, while for 25% efficiency, the weight of the finer wire corresponding to 3.51 ohms is only .171 gram. Aluminum for the same conductivity weighs about half these amounts, i. e. only .086 gram for the 25% efficiency case.

As the associated diaphragm made of present day materials would almost certainly weigh 2 grams or more, we have here a speech coil weighing less than $\frac{1}{20}$ as much as the diaphragm, while even with the heavier copper wire and the larger section to get 50% motor efficiency, the weight is only about a quarter of the diaphragm weight.

These coils, especially the aluminium ones, particularly if maximum efficiency is relinquished, are so light that coil inertia and coil inductance both tend to become negligible at all but the very highest frequencies.

To reduce inertia losses still further, I prefer to make the coils in the form of a two layer winding, with a layer of paper in between, this paper forming the speech coil tube and eliminating the usual heavy former. Advantage can be taken of the small bulk of these very light coils to reduce the magnetic gap, thereby driving up the flux density possible with a given magnetic drive and thus, by altering factor 1, making a still lighter coil desirable. Pole tips of special alloys to drive up the flux density are helpful in this connection.

For example, in a field of 20,000 gauss, the back E. M. F. would be

$$\frac{20{,}000}{15{,}000} = 1\tfrac{1}{3}$$

of that in the 15,000 gauss field assumed for the numerical example. The work current for the same output would however be only

$$\frac{15{,}000}{20{,}000} = \tfrac{3}{4}$$

The work impedance would thus be

$$1\tfrac{1}{3} \times \frac{1}{\frac{3}{4}} = 1.78$$

times higher for the same conductor length. If the resistance was left as before, the efficiency

would now be higher. To restore the previous slightly lower efficiency, the conductor can be reduced in section, making the corresponding coil weights

$$\frac{1}{1.78}$$

or 56% of their previous amounts.

Not only does that reduction in coil mass permit a reduction in the magnetic gap, thus simplifying the problem of obtaining the higher flux, but inertia and inductance losses are both driven further up the scale.

A coil of .56 of the previous weight of .086 gm. would weigh only 48 milligrams, while still lighter coils would correspond to yet higher flux densities.

From the above it will be seen that a relatively simple formula can be used for determining coil weight for a variety of conditions.

Such a simple formula for the case in which the diaphragm is feeding a wide throat horn in which the horn throat area bears a 1:1 ratio to the diaphragm area, and the desired "motor" efficiency is 50%, (resistance losses only considered) is:

$$m=K=\frac{A\times D}{\text{Flux density}^2}$$

where

m=mass in grams
A=projected area of diaphragm in sq. cms.
D=density/conductivity ratio, taking aluminium as equal to 1.

and

K=a constant depending upon the desired "motor" efficiency and being approx. 3.6×10^5 for 50% "motor" efficiency.

The table below has been calculated on this basis and is applicable to a 6" diaphragm (182½ sq. cms.) with an aluminium coil situated in various flux densities.

Mean Flux Density Over Coil	Coil Weight (Aluminium)
	Milligms.
15,000	287
16,000	250
17,000	220
18,000	195
20,000	158
22,000	127
24,000	110
25,000	102

I am expecting that practical experience will prove optimum conditions to be obtained with coils having weights of the order indicated (speech energy, input at relatively low impedance, being assumed); however, while I expect that such coils will be about optimum, wide variations are possible since the optimum is only a compromise.

I therefore limit my claims to a maximum weight of double that shown in the above table in the case of 6" diaphragms of the open type or with a wide throat horn 1:1 ratio.

The use of still lighter coils reduces both damping and efficiency but coils of one quarter the weight and even less give a surprising performance.

For smaller diaphragms the coil weight for equivalent conditions goes down proportionately with the diaphragm area. If the wide throat horn is removed and a normal flat baffle employed sound whose wavelength is large compared with diaphragm diameter is driven not only forwards and backwards but escapes sideways. The load on the diaphragm therefore diminishes at those lower frequencies. This permits a diminution in coil weight below the amount calculated from the formula above.

It will be seen therefore that there are factors which permit the use of coils much lighter even than the very light coils indicated in the table above. Other factors will be mentioned later.

I am not therefore claiming any minimum to the weight of my coils.

The distinguishing feature of the high pressure type of loud-speaker is that the diaphragm is enclosed on one side, the enclosure leading to a horn, the throat area of which is much smaller than the diaphragm area.

Air displaced by the movement of the diaphragm is therefore forced into the much smaller throat area. By "much smaller" I mean $\frac{1}{10}$ or even less. This large ratio in areas causes the velocity in the horn throat to be very much greater than the diaphragm velocity. The high pressure associated with the high throat velocity is however also spread over the whole surface of the diaphragm and thus gives rise to the type description.

This method of operation permits the use of quite small diaphragms, rarely more than 3" in diameter and sometimes less than 2" in diameter. They are generally made of very thin light metal formed to shapes which give rigidity.

In such loud-speakers, because of the strong shape and the small distances between the speech coil and the remoter parts of the diaphragm, it is generally assumed that over the whole diaphragm surface the vibrations are identical and that the diaphragm and coil move as one. On account of their small size and the lightness of the material used, the weight of the diaphragm may come between ¼ and one gm. The standard theory that coil weight should equal diaphragm weight thus indicates weights of this order for the coil as suitable in the high pressure case.

With open type low pressure diaphragms it is generally assumed, owing to the larger distances involved, that at high frequencies, only those parts of the diaphragm immediately adjacent to the speech coil vibrate with it, and that the parts remote from the speech coil are no longer rigidly controlled, so that large phase differences occur and resonances in the higher frequencies are expected. Much work has been done to make any such resonances as harmless as possible.

One way of doing this is by bringing up the general efficiency. Below resonance, this can be done by diminishing the losses due to sideways flow near the diaphragm. This being effected by making the diaphragm feed into a "directional baffle" or wide throat horn as already mentioned. Such a wide throat horn may have a throat area corresponding to the projected area of the diaphragm, or the throat area may be less so as to build up pressure slightly, a ratio of 4:3 or 4:2 is suitable, but if it exceeds 4 or 5:1, the horn is likely to obstruct somewhat the direct radiation from that part of the diaphragm adjacent to the speech coil, and thus what I hold to be an important advantage of the open type of radiator will be lost.

The efficiency above resonance can be raised and the resonance itself can be damped if the magnetic flux density is increased, the increased

cost of a better magnet however is usually the limiting factor.

By abandoning the usual theory, and designing my coil on the basis of the several factors enumerated earlier, I arrive at coil weights far lower than normal. Such coils have reduced bulk and can therefore operate in narrower gaps. This makes possible a higher magnetic flux density without additional cost.

For constant "motor efficiency" an increase in flux density permits a reduction in coil weight equal to the square of the increase in flux density. The increase in flux density made possible because of the first reduction in coil bulk calls for a further reduction in the coil mass and bulk, this makes possible a further increase in flux density and so on. Ultimately, factors such as magnetic saturation and essential working clearances will determine the final optimum design conditions for a given cost of magnet.

My invention thus leads not only to the use with low pressure open type diaphragms of coils of low weight, such as have hitherto been used only with the much smaller diaphragms intended for high pressure units, but it leads to the use of coils far lighter, especially in very high density magnet gaps.

In practice, with a 6'' diaphragm, and a flux density of about 16,000 gauss, the optimum speech coil weight probably lies between $\frac{1}{10}$ and $\frac{2}{3}$ grammes, aluminium wire being used, and the diaphragm load being kept reasonably constant by using a 1:1 area ratio wide throat horn. Calculation shows that a weight of about $\frac{1}{4}$ gramme would, if there were no losses other than electrical resistance losses, give an efficiency of 50%. A weight above this increases the efficiency, and in particuluar provides a margin for other losses, while a reduction helps to diminish coil inertia losses at extremely high frequencies, therefore giving a better relative response at very high frequencies than with the heavier coil of greater general efficiency lower down the scale.

As already mentioned, when the throat area is smaller than the diaphragm area, the velocity in the throat goes up but the back pressure associated with the increased velocity, is spread over the whole diaphragm area.

For a given diaphragm velocity therefore with, for example, a 4:1 ratio between diaphragm and horn throat area, the velocity and pressure in the throat goes up four times, this increased pressure being spread over the whole diaphragm involves four times the drive current (and four times the input power) without change of back E. M. F.

The work impedance drops to one quarter and if the previous efficiency is to be retained the conductor D. C. resistance must be reduced proportionately. This calls for a proportionate increase in the conductor's section and consequently of coil weight.

When a diaphragm is used in conjunction with a horn such as to obtain an increased air velocity in the horn throat, the weight as obtained by the formula above must be multiplied by a factor T similar to a transformer ratio proportional to the area ratio.

$$\frac{\text{Diaphragm area}}{\text{Horn throat area}}$$

A 4 or 5:1 increase in coil mass I regard as approximately the limit that is desired.

I therefore limit the correction to the formula i. e., the multiplier T when a horn is used to a maximum of 5.

In other words, for the purpose of this invention, T is the air transformation ratio as above but to be taken as 5 if the ratio exceeds that amount.

One other reason for avoiding the heavier coils is that they constitute the "lumped mass." Such a lumped mass can be regarded as a barrier or obstacle at the point where the electric energy is converted into sound, the coil cannot itself set the diaphragm into motion at high frequencies until it has itself been accelerated.

A light coil with reduced mass requires less acceleration force in the first place and, because the coil is less bulky, it can operate in a shorter magnetic gap. This makes possible a higher flux density without additional cost.

By using special high saturation alloys, the flux density can be driven up yet higher and still lighter coils then become appropriate. Reducing the load on the diaphragm by operating on a nat baffle also calls for reduced weight.

Apart from the reduced inertia, such coils have less inductance, with corresponding increase in current at very high frequencies. A further advantage is that with the elimination of the "lumped mass," represented by the normal relatively heavy speech coil, the resonant characteristics of the diaphragm are favourably affected, resonances being less marked.

At first sight it might seem that with such light coils, magnetic damping would be greatly reduced. In practice however the damping on each milligram of coil conductor increases with the square of the flux density. Since these ultra light coils permit a smaller gap and correspondingly increased flux density, the damping on the material of the coil itself can be made greater. This can compensate in part for the fact that the diaphragm is coupled to a smaller mass of coil. Another factor is involved however, namely that any energy returning from the diaphragm is not reflected back by the inertia of the normal heavy coil, but sets the light coil in motion effectively with consequent conversion of this unwanted mechanical energy into electrical energy which is absorbed.

To give the coil the best chance to damp a diaphragm, even with these light coils, it is desirable to avoid lumping its mass by using a small diameter pole. When such a pole has to be used on account of other considerations, then a coil weight below the usual optimum for that size diaphragm may be preferable in order to diminish lumped mass effects. Similarly with large diaphragms, which represent a bigger load owing to their increased area and would require a larger coil for equal "motor" efficiency, it may be desirable not to let the coil weight go up according to the diaphragm area, unless the pole diameter is altered.

At medium and low frequencies at which even the normal weight coils do not reflect vibrational energy coming in from the diaphragm, the use of these ultra light coils is likely to result in some reduction in magnetic damping, I am of opinion however that, especially with high intensity magnetic fields it is possible to overdo the damping.

Summarising therefore, according to this invention, I abandon for low pressure open type diaphragms and the intermediate types in which diaphragm to horn throat area does not exceed 10:1 when used with high intensity fields, the theory that the speech coil weight should be related to the diaphragm weight and instead make my coils extremely light. For example, about

.6 or ½ gm. max. and preferably about ¼ gm. or even less with a 6" open diaphragm 1:1 horn and a 1½" centre pole when the flux density is 15,000. A reduction should accompany a reduced pole diameter, also a reduction proportional to the square of any increase in flux density or if a reduction in diaphragm diameter should take place.

With larger diaphragms coil weight may be increased especially if the coil diameter is increased but 1 gm. should be regarded as maximum even with a large diaphragm if good high frequency response is required.

It is difficult to illustrate this invention by drawings since the thickness of the coil would be so slight that it would have to be exaggerated by the draftsman in order to show at all on the drawing.

I propose therefore merely to describe and illustrate applications in a few selected cases, which must be considered as being by way of example only.

Fig. 1 shows diagrammatically the simplest practical case in which 1 is a high flux density magnet, 2 represents the very, very light speech coil, 3 the orthodox conical diaphragm, and 4, flat baffle to prevent the pressure generated on one side of the diaphragm from flowing round the edge and being neutralized at the other side of the diaphragm.

Fig. 2 shows diagrammatically a similar magnet, coil and diaphragm the same numerals applying, but this time the baffle is replaced by a wide throat horn 5 of throat area substantially the same as the diaphragm area. Such a wide throat horn prevents the sideways motion of the air in the immediate neighbourhood of the diaphragm and throws back on to the diaphragm an air load which is relatively uniform above the cut off of the horn.

Fig. 3 shows a similar arrangement but in which the wide throat horn 8 has an area about one third that of the diaphragm, thereby throwing an increased load on the diaphragm, which would make a somewhat heavier coil appropriate for driving that diaphragm. As discussed earlier, however, the decision as to whether the coil weight should in fact be raised is one which would depend on other factors, since it may not be desirable to raise the efficiency in a lower part of the scale under certain conditions.

Fig. 4 shows a similar arrangement, but employing a multiple diaphragm in which, in addition to the main outer cone, there is provided a dust sealing dome 6 and an intermediate free edge cone 7.

Fig. 5 shows a further development, in which the loud-speaker is enclosed in a closed tapering tube 9 so that the air in this tube is set in motion much as the air in a horn is set into motion, but in this case the work is done by the back of the diaphragm, the front of the diaphragm driving into a horn as before, the tapering tube being so dimensioned that it loads the diaphragm in the region below the horn cut off. The open mouth of the tube may conveniently be situated near the floor in the corner of a room so that the sound emerging therefrom radiates into ⅛ of a sphere only.

Fig. 6 shows a further development, in which the horn 10 is arranged to point upwards on to a distributing curved reflector 11, such a reflector, by distributing sound, can eliminate undesirable directional properties of a horn. The tapering tube 12 in this case is folded over so as to fit into the space below the opening 14 by which the high and medium frequency sound reflected from the reflector 11 radiates into the room, the very lowest frequencies from the folded tapering tube coming out near floor level.

I am aware of the existence of complex speech coil structures in which for example, a copper coil situated in the gap drives the diaphragm at low frequencies through an elastic coupling, and at high frequencies is used to induce currents in a closed single turn circuit also situated in the gap, said closed circuit acting as the driving conductor at high frequencies.

Such a closed turn may conceivably have a low weight, and I do not claim any such or similar arrangements. The physical presence of the copper coil, by increasing the gap thickness makes a more powerful magnet necessary for a given flux density. In my case the voltage is applied to the active conductor directly by suitable connecting means, and inducing coils dispensed with.

I claim:

1. A moving-coil loud-speaker comprising a magnet having a narrow air gap, a moving coil mounted in said air gap, and a diaphragm mechanically coupled to said coil, wherein the flux density in said air gap is of the order of at least 15,000 gauss and wherein the mass of said moving coil, being less than one gramme is less than twice the value of the expression:

$$3.6\times10^{5}\frac{ADT}{B^{2}}\text{ grammes}$$

where

A is the projected area of said diaphragm in square centimetres,
D is the specific ratio of the density to the conductivity of the coil conductor, taking the ratio of the density to the conductivity of aluminium as unity,
T is the air transformation ratio of the loud-speaker, that is, the ratio of the diaphragm area to the horn throat area, and
B is the flux density in the air gap in gausses.

2. A moving-coil loud-speaker comprising a magnet having a narrow air gap, a moving coil mounted in said air gap, an open diaphragm mechanically coupled to said coil and a baffle operatively associated with said diaphragm, wherein the flux density in said air gap is of the order of at least 15,000 gauss and wherein the mass of said moving-coil, being less than 1 gramme, is less than twice the valve of the expression:

$$3.6\times10^{5}\frac{AD}{B^{2}}\text{ grammes}$$

where,

A is the projected area of said diaphragm in square centimetres,
D is the specific ratio of the density to the conductivity of the coil conductor, taking the corresponding ratio for aluminium as unity, and
B is the flux density in the air gap in gausses.

3. A moving-coil loud-speaker comprising a magnet having a narrow air gap, a moving coil mounted in said air gap, a diaphragm mechanically coupled to said coil, a horn operatively associated with said diaphragm, said horn having a throat, wherein the cross-sectional area of said throat is approximately equal to the projected area of said diaphragm, and wherein the flux density in said air gap is of the order of at least 15,000 gauss and the mass of said moving coil,

being less than 1 gramme is less than twice the value of the expression:

$$3.6\times10^{5}\frac{AD}{B^{2}}\text{ grammes}$$

where,

A is the projected area of said diaphragm in square centimetres,

D is the specific ratio of the density to the conductivity of the coil conductor, taking the corresponding ratio for aluminium as unity, and

B is the flux density in the air gap in gausses.

4. A moving-coil loud-speaker comprising a magnet having a narrow air gap, a moving coil mounted in said air gap, a diaphragm mechanically coupled to said coil, and a horn operatively associated with said diaphragm, said horn having a throat, wherein the cross-sectional area of said throat is between the projected area of said diaphragm and one fifth thereof, and wherein the flux density in said air gap is of the order of at least 15,000, gauss and the mass of said moving coil, being less than 1 gramme, is less than twice the value of the expression:

$$3.6\times10^{5}\frac{ADT}{B^{2}}\text{ grammes}$$

where,

A is the projected area of said diaphragm in square centimetres,

D is the specific ratio of the density to the conductivity of the coil conductor, taking the corresponding ratio for aluminium as unity,

T is the ratio of the projected area of the diaphragm to the cross-sectional area of said

throat, the value taken per T not to exceed 5, and

B is the flux density in the air gap in gausses.

5. A moving-coil loud-speaker as claimed in claim 1, including a plurality of diaphragms mechanically coupled to said coil.

6. A moving-coil loud-speaker as claimed in claim 1, including a horn and a reflector operatively associated with said diaphragm.

7. A moving-coil loud-speaker as claimed in claim 1, including a bass loading chamber operatively associated with said diaphragm.

8. A moving-coil loud-speaker as claimed in claim 1, including a bass loading chamber on one side of said diaphragm and relatively higher frequency loading means on the opposite side of said diaphragm.

9. A moving-coil loud-speaker as claimed in claim 1, including a plurality of diaphragms mechanically coupled to said moving coil.

PAUL GUSTAVUS ADOLPHUS
HELMUTH VOIGT.

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