

Nov. 20, 1934.

A. C. KELLER

1,981,793

SOUND REPRODUCER

Filed Oct. 24, 1929

FIG. 1.

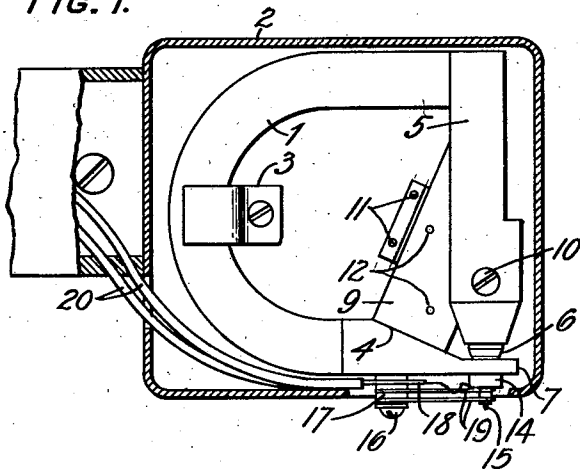


FIG. 2.

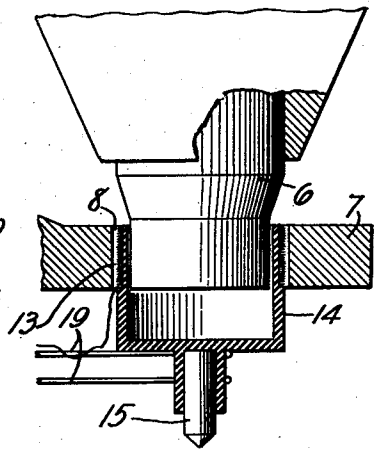


FIG. 3.

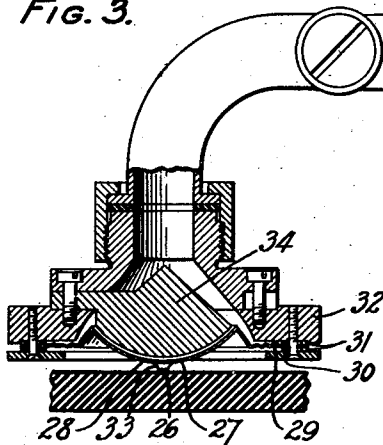


FIG. 4.

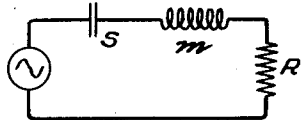


FIG. 5.

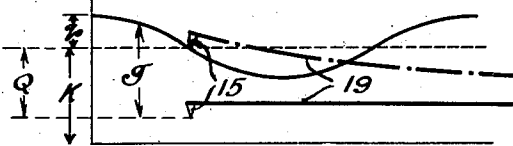
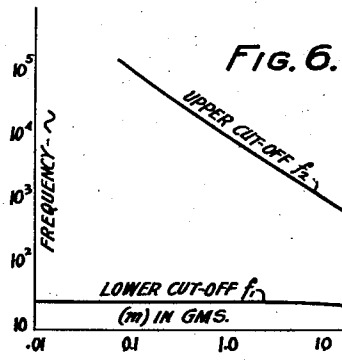
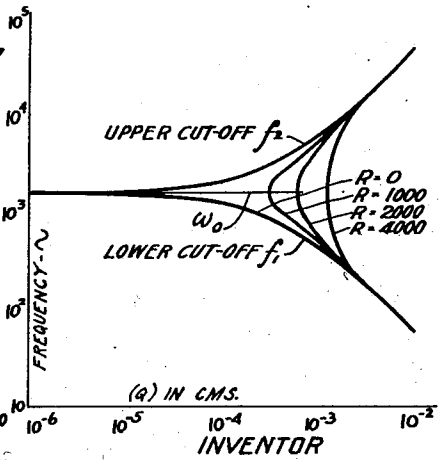


FIG. 7.



INVENTOR
A. C. KELLER
BY
J. M. Campbell
ATTORNEY

UNITED STATES PATENT OFFICE

1,981,793

SOUND REPRODUCER

Arthur C. Keller, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application October 24, 1929, Serial No. 402,128

9 Claims. (Cl. 179—100.41)

This invention relates to sound reproducing devices and is principally concerned with the general features of phonograph reproducer design which are applicable to both electric and acoustic types adapted for use with hill and dale records.

The object of the invention is to provide a reproducer structure which may be proportioned for efficient and substantially uniform response over the full frequency range of speech and music or for an even greater range if desired.

Heretofore in the art, the tendency of reproducers of the hill and dale type to leave the surface of the record has limited the maximum groove amplitude to a very low value and prevented the satisfactory reproduction of frequencies in both the high and low portions of speech and music.

In accordance with the present invention, however, it is recognized that for faithful reproduction from hill and dale records the fundamental requirement in the design of the reproducer is that its mechanical constants shall be such that the total force tending to hold the reproducer on the record shall never become less than the product of the needle point velocity and the needle point impedance over the frequency range of interest. When this condition is fulfilled the device is at all times positively driven according to the recorded wave regardless of its own natural period or periods, so that by proper choice of constants it can be made to respond to a range very much in excess of that obtained heretofore. Since it is not free to resonate this reproducer differs radically from both lateral and hill and dale reproducers previously proposed in that the uniform frequency response is obtained without damping the action of the moving system.

A feature of the invention is an elastic mounting for the moving system which deflects when the reproducer is set on a record, thereby setting up a restoring force of the proper magnitude which supplements the action of gravity so that the stylus can be made to follow the grooves accurately with a moving system of any desired mass.

A further feature of the invention is the reduction of record wear by proportioning the mass and stiffness of the reproducer to obtain the minimum pressure on the record which will keep the stylus on the groove for the frequency range to be covered.

This invention will be more clearly understood from a consideration of the following detailed description in connection with the accompanying drawing in which Fig. 1 is a general view of an electrical reproducer designed in accordance with this invention;

Fig. 2 is a sectional view of a portion of the

reproducer of Fig. 1 showing particularly the arrangement of the moving system and an elastic mounting therefor;

Fig. 3 is a general view of an acoustic reproducer in accordance with the general features of this invention;

Fig. 4 is a schematic showing the mechanical elements of a reproducer according to this invention considered as analogs of the elements of a corresponding electrical system;

Fig. 5 is a schematic of a portion of a record groove of the hill and dale type;

Fig. 6 is a graph showing the effect on the cut-off frequencies of varying the mass of the vibrating system; and

Fig. 7 is a similar graph showing the effect of varying the initial displacement of the mounting of the moving system.

Referring to Fig. 1, a U-shaped magnet 1 having legs of unequal length is held in position against one wall of the casing 2 by a bracket 3. The pole pieces 4 and 5 are so shaped and positioned that the central piece 6 of the pole piece 5 projects into an opening in the reduced end portion 7 of the pole piece 4 to form an air gap 8. While it is preferable that this be an annular air gap, obviously it may be made elliptical or any other desired shape. For convenience the pole piece 5 is made hollow so in assembling a mandrel may be used for accurately aligning pole piece 5 with respect to pole piece 4. The brass bracket member 9 is then soldered in place to maintain the alignment so that when the center piece 6 is inserted and secured by screw 10 the gap will be of uniform width throughout. Screws 11—11 secure this assembly to the casing 2 and threaded holes 12—12 permit the cover of the casing, not shown, to be fastened by similar screws.

Arranged within the air gap 8 is a coil 13 which may consist of about 40 turns of fine ribbon wire, preferably aluminum, wound on a hard rubber form 14 which is fitted with a suitable stylus 15 as shown more clearly in Fig. 2. The elastic mounting for this moving system is provided by two pieces of spring steel wire 19—19 of about 9 mils diameter bent around the stylus holding portion of the form 14 and clamped by screw 16 in a block of hard rubber 17 which is secured to the pole piece 4. The ends of the coil 13 are left long enough to be slightly looped and connected to terminals 18—18 as shown, from which wires 20, 20 may be connected to the amplifiers of the sound reproducing system.

An acoustic reproducer also designed in accordance with the general features of the invention as set forth more in detail below, is shown in Fig. 3. The above mentioned requirement for distortionless reproduction is met by fastening the stylus 26 to the acoustic diaphragm 27 and properly proportioning the masses and dia-

phragm stiffness as already described for the electrical reproducer. A structure which can readily be adapted to the requirements of such an acoustic reproducer and is at the same time capable of transmitting the diaphragm vibrations to the tone arm with minimum loss is disclosed in Patent 1,705,545 to E. C. Wentz, April 2, 1929. As in the Wentz patent and as described more in detail in Patent 1,734,624 to H. C. Harrison, Nov. 5, 1929, the diaphragm 27 comprises a stiff dish-shaped piston portion 28, a flexible corrugated portion 29 and a flat portion 30 which is clamped between rings 31, 31 on the housing structure 32. The stylus 26 may be fitted directly into a pressed out portion of the diaphragm, or may be attached to it as shown by means of a piece of amber or other suitable lightweight substance 33. The initial deflection of the diaphragm when the reproducer is set on the record will, as in the previous case, provide the required restoring force for supplementing the mass in keeping the stylus on the record groove. The metallic plug 34 serves the same purpose as in the Wentz patent, namely to improve the transmission of high frequency diaphragm vibrations, but inasmuch as this and the other features required to make up a complete reproducer form no part of the present invention, it is believed that no further description of them need be given. It will be understood, of course, that this reproducer as well as the one previously described, should be mounted on a properly balanced tone arm so that the stylus will exert only sufficient pressure on the record to produce the necessary deflection in the elastic mounting member. When this adjustment has been made, the operation of the reproducer is similar in principle to those well-known in the art, that is to say, the stylus being in contact with the rotating record having grooves of the hill and dale type, the diaphragm will be vibrated in accordance with the grooves and these vibrations will be transmitted through the structure shown to a suitable horn in the well-known manner.

The considerations involved in the above fundamental requirement and the manner in which the design may be varied to suit the requirements and conditions of any particular case, will be better understood from the following description of the analytical method used in the study of the problem of hill and dale recording which resulted in the present invention.

It is obvious that for distortionless reproduction the stylus must faithfully follow the variations of depth in the record grooves, one of which has been schematically represented in Fig. 5, where q_0 represents the maximum variation in the surface of the groove from the average depth and also the maximum variation in the position of the moving system of the reproducer when the stylus is tracking the groove. Q is the initial vertical displacement of the moving system with respect to the magnet structure due to the reproducer resting in a groove of average depth. The equation of the stylus movements when tracking such a groove, in terms of time, may be written

$$q = Q + q_0 \cos \omega t \quad (1)$$

where q is the instantaneous displacement (the algebraic sum of Q and q_0) at any time t . It is generally recognized in the art that mechanical vibrating systems may be studied conveniently by considering the mechanical elements as analogs of the elements of a corresponding electrical system. In the present case, the structure of

either of the reproducers described may be represented by the diagram of Fig. 4 in which m is the total effective mass in grams of the moving system, S is the stiffness in dynes per centimeter of the elastic mounting, and R is the damping effect in mechanical ohms exerted upon the moving system, all of which are referred to the stylus point.

The terms mass and stiffness as applied to mechanical vibrating systems such as the moving system of the reproducer under discussion are commonly understood in the art to mean, not the static values obtained for example by weighing the mass and deflecting a spring element to determine the force required to produce a unit deflection, but rather the dynamic values effective at the driving point (the stylus in this case) when the system is vibrated. These effective values which are often quite different from the static values are conveniently measured by means of mechanical impedance bridges of the types disclosed in Patent 1,880,425 and in a copending application of P. B. Flanders Serial No. 664,308 filed April 4, 1933.

Since the mass of this system must always be in contact with the record, the sum of the forces tending to maintain the contact must never become less than zero. Expressing this analytically

$$\Sigma F = Sq + R \frac{dq}{dt} + m \frac{d^2q}{dt^2} \geq 0 \quad (2)$$

the solution of which is:

$$\Sigma F = SQ - q_0[(S - m\omega^2) \cos \omega t - R\omega \sin \omega t] \geq 0 \quad (3)$$

Since this latter expression has a minimum value the requirements of the design will be met if the stylus remains in contact with the groove for this extreme case. Hence differentiating this expression and equating it to zero we obtain:

$$\frac{\partial(\Sigma F)}{\partial t} = -(S - m\omega^2) \sin \omega t - R\omega \cos \omega t = 0 \quad (3a)$$

from which it follows that:

$$\tan \omega t = \frac{R}{m\omega - \frac{S}{\omega}} \quad (4)$$

substituting Equation (4) in Equation 3 we have:

$$SQ \geq q_0 \omega \bar{Z} \quad (4a)$$

where

$$\bar{Z}^2 = R^2 + \left(m\omega - \frac{S}{\omega}\right)^2$$

From Equation (4a) since $q_0 \omega = V$, the maximum vibrational velocity at a given frequency, and is a positive quantity:

$$\bar{Z} \leq \frac{SQ}{V} \text{ i. e. } SQ = F \geq VZ \quad (5)$$

which is the analytical expression for the fundamental requirement for keeping the stylus in contact with the groove.

Assuming both members of Equation (4a) positive quantities leads directly to the following equation in ω :

$$Vm\omega^2 \mp \omega \sqrt{S^2 Q^2 - V^2 R^2} - VS \leq 0 \quad (6)$$

There are four roots to this equation when set equal to zero two of which are positive solutions and hence are those of interest. Setting Eq. (6) equal to some quantity less than zero as indicated results in solutions of ω falling between the two limiting positive solutions obtained by setting the left-hand member of this equation

equal to zero. The lower limiting value for undistorted reproduction, ω_1 , and the upper limiting value ω_2 , are given below. For values of ω falling between these two values the conditions necessary for the stylus to faithfully follow the groove are satisfied. Expressed in the more usual manner the undistorted band lies between ω_1 and ω_2 :

$$2\pi f_1 = \omega_1 = -\sqrt{\frac{S^2 Q^2 - V^2 R^2}{4V^2 m^2}} \left[1 - \sqrt{1 + \frac{4SmV^2}{(S^2 Q^2 - V^2 R^2)}} \right] \quad (7)$$

and

$$2\pi f_2 = \omega_2 = +\sqrt{\frac{S^2 Q^2 - V^2 R^2}{4V^2 m^2}} \left[1 + \sqrt{1 + \frac{4SmV^2}{(S^2 Q^2 - V^2 R^2)}} \right] \quad (8)$$

Consider the case of a typical system of the type assumed for this analysis and assume constants of the order of those commonly used in commercial lateral type reproducers for tracking records embracing a frequency range of less than 5,000 cycles such as $S=10 \times 10^6$ dynes per cm., $m=.1$ gm and $R=.020$ cms. and $V=3.0$ cms. per sec. The solution of Equations (7) and (8) yield values of f_1 and f_2 of 34 and 100,000 cycles respectively, which means that insofar as ability to follow the record groove is concerned a reproducer according to this invention having these constants will reproduce all frequencies between these values.

Figs. 6 and 7 indicate how the cut-off frequencies, that is to say, the undistorted frequency band covered by the reproducer varies when the values of the mass and the initial displacement are varied. Having developed general formulae of Equations 5, 7 and 8, it will be obvious that it is a simple matter to so proportion the constants of the proposed reproducer that it will respond to any desired range of frequencies. The curves of Fig. 6 which have been based on the values of S , Q and V already given show clearly how decreasing the mass of the moving system increases the undistorted band by raising the upper cut-off frequency. Fig. 7 has been given primarily to show that for a given stiffness, such as 10^7 dynes per centimeter, the undistorted band becomes wider as the initial displacement is increased so that the range of the reproducer may be readily extended in this way without otherwise altering the design. As already pointed out damping is not required in a properly designed reproducer of this kind. It is possible however that in commercial production it may be desirable to use some damping to prevent transient effects rather than to rely on the manufacturer to attain the otherwise necessary precision. For instance if the elastic mounting is not sufficiently resistant to torsional motion the friction of the stylus on the groove may set up transient vibrations or stuttering effects due to a slight rocking of the coil in the gap. This could readily be eliminated without materially reducing the proper motion in various ways such as by the use of oil in the gap which would exercise the required damping by being displaced vertically by the rocking movement of the coil. From the curves of reproducers having various amounts of damping as indicated it is obvious that the damping has practically no effect upon the frequency range of such a reproducer when designed for high quality work.

It has been found that by proper choice of constants a structure may be obtained which in addition to satisfying Equation (5) is so low in mechanical impedance that wear on hard records is materially reduced and such a reproducer may be employed for playing back soft wax records re-

peatedly without impairing their value as master records from which commercial pressing may be made. In other words it will be apparent from the example just cited that the values of mass and stiffness commonly used are very much higher than are required if the moving system is proportioned in accordance with applicant's fundamental Equation (5). Due to the high value of the mass and stiffness of prior reproducers, their mechanical impedance is so high that satisfactory tracking, even for limited frequency ranges, can be obtained only by operating them with record pressures

$$\left(\frac{SQ}{980} \right)$$

of from 100 to 200 grams. This high pressure soon wears out hard records and causes such a device to destroy an original recording entirely in a single playing. As previously pointed out, applicant has discovered that such pressures are entirely unnecessary and that a structure can be designed in accordance with his formulae to track a groove embracing the entire audible range of frequencies with a pressure of the order of 10 grams or less.

From the foregoing explanation of the design it will now be clear that the resonant frequency of the structure of the moving system can have no effect on the response of the device so that uniform response is obtained throughout the range for which it is designed. It should be noted however that the resonant frequency does have a bearing upon the amount of record wear. To cover a given range with the least possible pressure on the record with a moving system of given mass, the stiffness should be such that the resonant frequency f_0 is the geometric mean of the limiting frequencies of the range to be covered as shown in Fig. 7. When this is so the steady A. C. force on the record represented by SQ may be such that is just counteracted by the sum of the reactions of Equation (2) at both the limiting frequencies of the band. If the resonant frequency occurs at any other frequency the A. C. force-frequency curve will not be symmetrical with respect to the band so that the A. C. force will be greater at one than at the other and the steady force will of necessity be large enough to balance the greater force and therefore will cause greater wear than in the previous case.

Since the upper limiting frequency of a reproducer of this type may be made a great deal higher than that obtainable with any structures of the prior art, it now becomes possible for the first time to reproduce the entire audible range and even higher frequencies.

The invention has been described with reference to specific structures for illustrative purposes but it is intended to be limited only by the following claims.

What is claimed is:

1. A reproducer for sound records embracing all frequencies within the audible range comprising a magnetic circuit having an air-gap and other elements including a member in the air-gap, an elastic support for the member and a stylus needle connected to and adapted to vibrate the member, the elements being so proportioned that the mechanical impedance of the reproducer for audible frequencies does not exceed

$$\frac{SQ}{V}$$

where S is the effective stiffness of the elastic

support, Q is the displacement of the stylus from its normal position when the reproducer is resting in a groove of average depth and V is the maximum velocity imparted to the stylus by the groove of the record and so that the pressure

$$\frac{SQ}{980}$$

required to keep the reproducer in contact with the grooves of records is of the order of 10 grams.

2. A reproducer for hill and dale records comprising a magnetic circuit, a generating element within the circuit, a stylus associated with the generating element and elastic mounting means for the element, the mechanical constants of the reproducer being so proportioned that its mechanical impedance over any desired frequency range does not exceed

$$\frac{SQ}{V}$$

where S is the stiffness of the elastic mounting, Q is the average displacement of the stylus from its normal position and V is the maximum velocity imparted to the stylus by the grooves of the records.

3. A phonograph reproducer in accordance with claim 2 having values of effective mounting stiffness S and effective mass M such that the resonant frequency of the reproducer

$$f = \frac{1}{2\pi} \sqrt{\frac{S}{M}}$$

occurs in the neighborhood of the geometric mean of the limiting frequencies of the frequency range of the reproducer.

4. A moving system for reproducers of the hill and dale type comprising a movable element, a stylus for driving the element and means for mounting the element, the mechanical constants of the system being so proportioned that its mechanical impedance over any desired frequency range does not exceed

$$\frac{SQ}{V}$$

where S is the stiffness of the mounting, Q is the average displacement of the stylus from its free position and V is the maximum velocity imparted to the stylus by the grooves of the records.

5. An acoustic phonograph reproducer for hill and dale records comprising a casing and a moving system for vibrating the air within the casing comprising a diaphragm and a stylus for driving the diaphragm, the mechanical constants of the system being so proportioned that its mechanical impedance over any desired frequency range does not exceed

$$\frac{SQ}{V}$$

where S is the stiffness of the mounting, Q is the average displacement of the stylus from its free position and V is the maximum velocity imparted to the stylus by the grooves of the records.

6. In a reproducer for phonograph records a moving system comprising a movable element, a stylus for driving the element and means for mounting the element the system being so proportioned that its mechanical impedance over any desired frequency range does not exceed

$$\frac{SQ}{V}$$

where S is the stiffness of the elastic mounting, Q is the average displacement of the stylus from its normal position and V is the maximum velocity imparted to the stylus by the grooves of the record and so that the pressure

$$\frac{SQ}{980}$$

required to keep the reproducer in contact with the grooves of the records is of the order of 10 grams.

7. A reproducer having a moving system including a stylus, a mass element and a resilient supporting member for the element, the mechanical constants of the system being so proportioned that its mechanical impedance over any desired frequency range does not exceed

$$\frac{SQ}{V}$$

where S is the stiffness of the mounting, Q is the average displacement of the stylus from its free position and V is the maximum velocity imparted to the stylus by the grooves of the record.

8. A phonograph reproducer for high quality hill and dale records comprising a magnetic circuit including an air gap and a moving system comprising a coil in the air gap, an elastic support therefor, and a stylus for driving the coil, the mechanical impedance of the system at the stylus point over the frequency range of the reproducer being not in excess of

$$\frac{SQ}{V}$$

where S is the effective stiffness of the elastic support, Q is the displacement of the stylus from its normal position when the reproducer is resting in a groove of average depth and V is the maximum velocity imparted to the stylus by the groove of the record, and the pressure

$$\left(\frac{SQ}{980}\right)$$

required to keep the stylus in contact with the grooves of the record being substantially less than 100 grams.

9. A reproducer for phonograph records comprising a magnetic circuit having an air gap and other elements including a member in the air gap, an elastic support for the member, and a stylus needle connected to and adapted to vibrate the member, the elements being so proportioned that the mechanical impedance of the reproducer for a range of frequencies in excess of 5000 cycles does not exceed

$$\frac{SQ}{V}$$

where S is the effective stiffness of the elastic support, Q is the displacement of the stylus from its normal position when the reproducer is resting in a groove of average depth and V is the maximum velocity imparted to the stylus by the groove of the record and so that the pressure

$$\left(\frac{SQ}{980}\right)$$

required to keep the stylus in contact with the record does not exceed 30 grams.

ARTHUR C. KELLER.