Oct. 2, 1928. **1,685,913**

L. ESPENSCHIED

RECORDING AND REPRODUCING OF SOUND WAVES

Original Filed Dec. 17, 1919 2 Sheets-Sheet 1

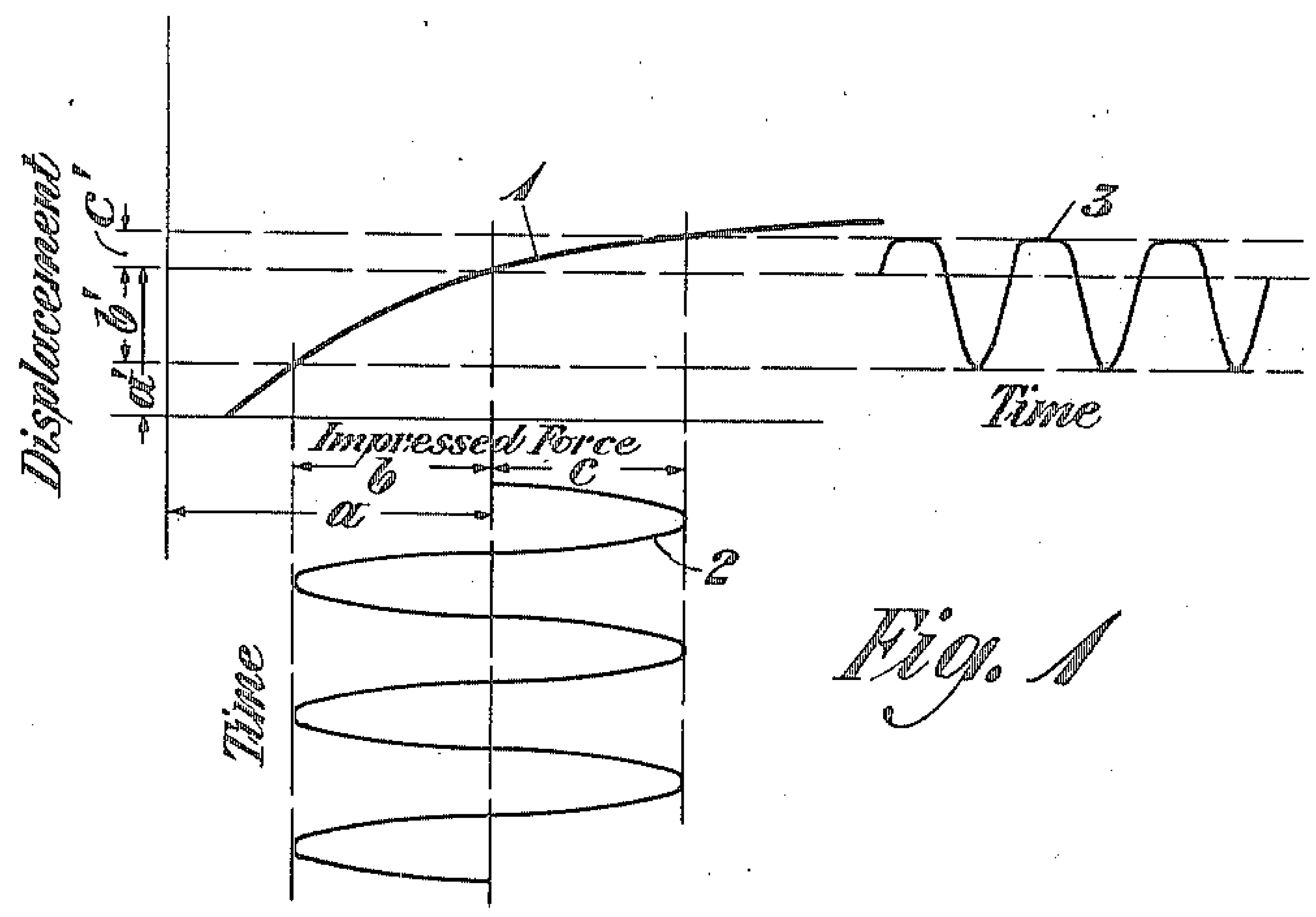

Fig. 1

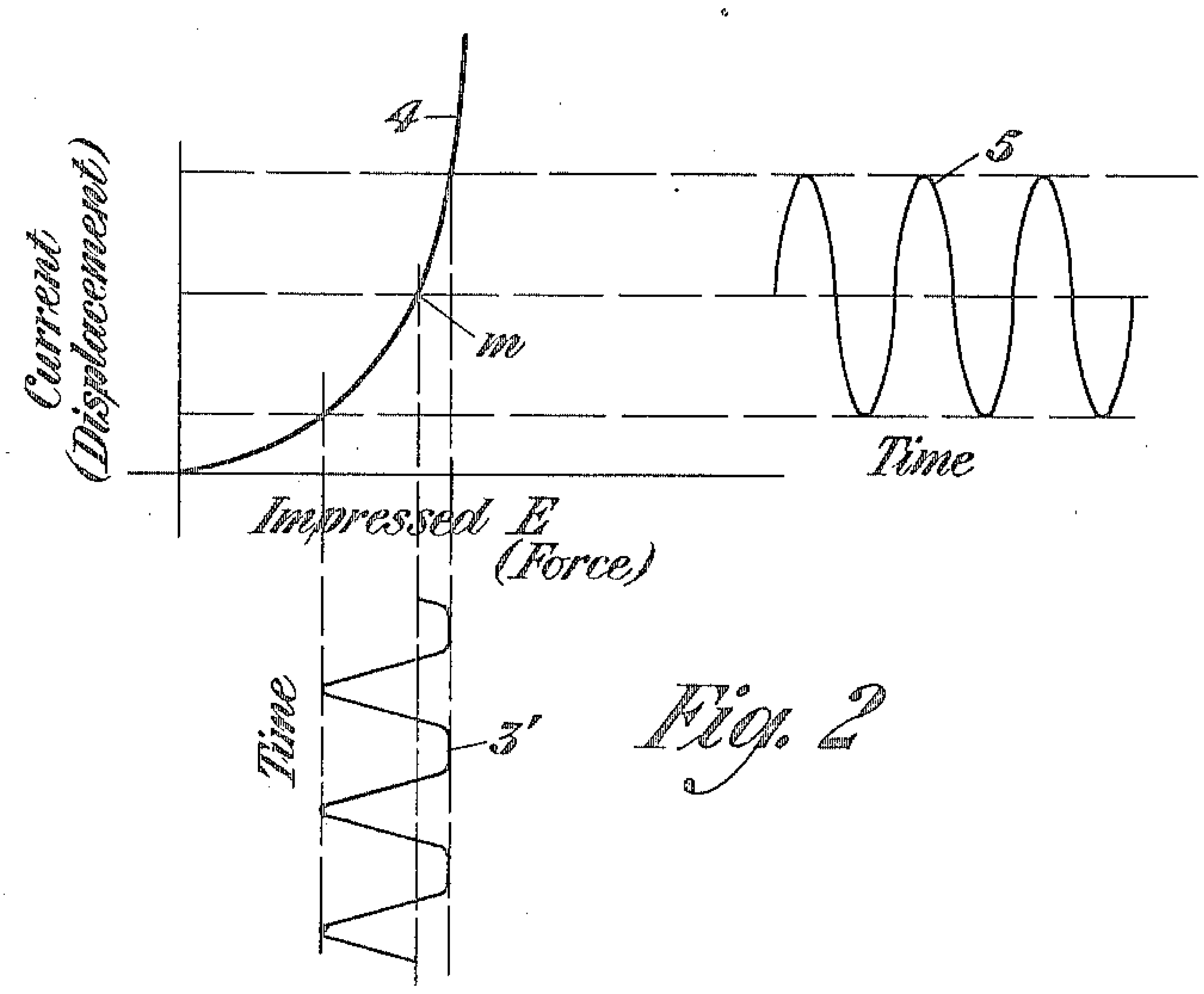

Fig. 2

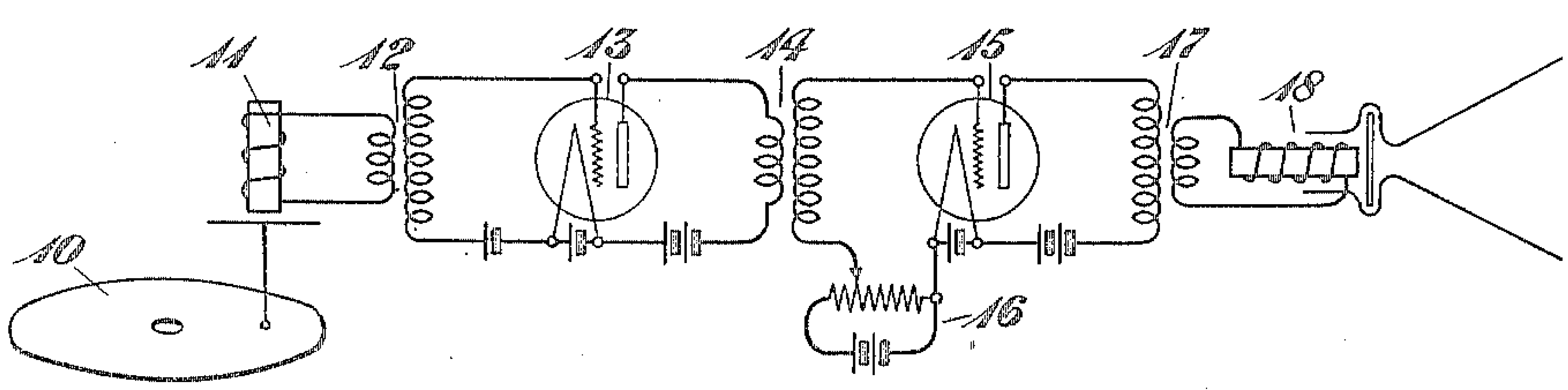

Fig. 3

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RECORDING AND REPRODUCING OF SOUND WAVES

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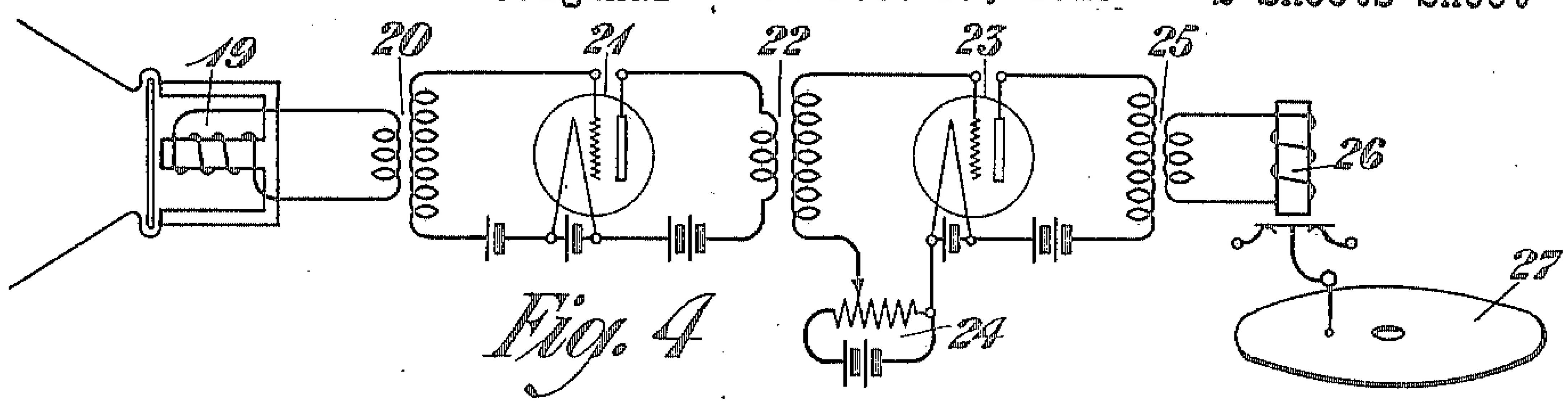

Fig. 4

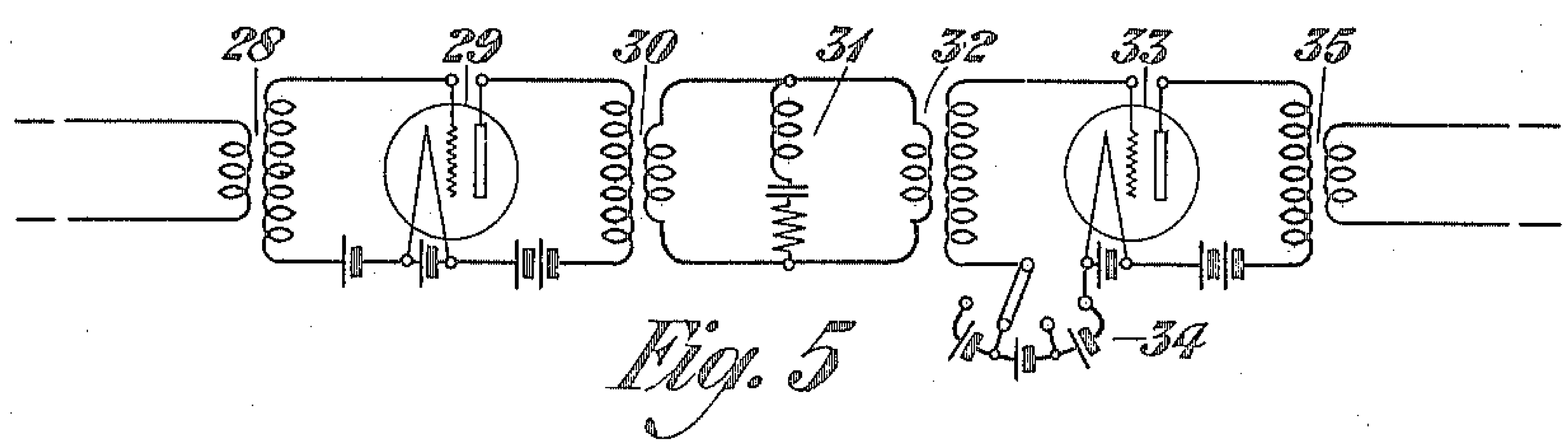

Fig. 5

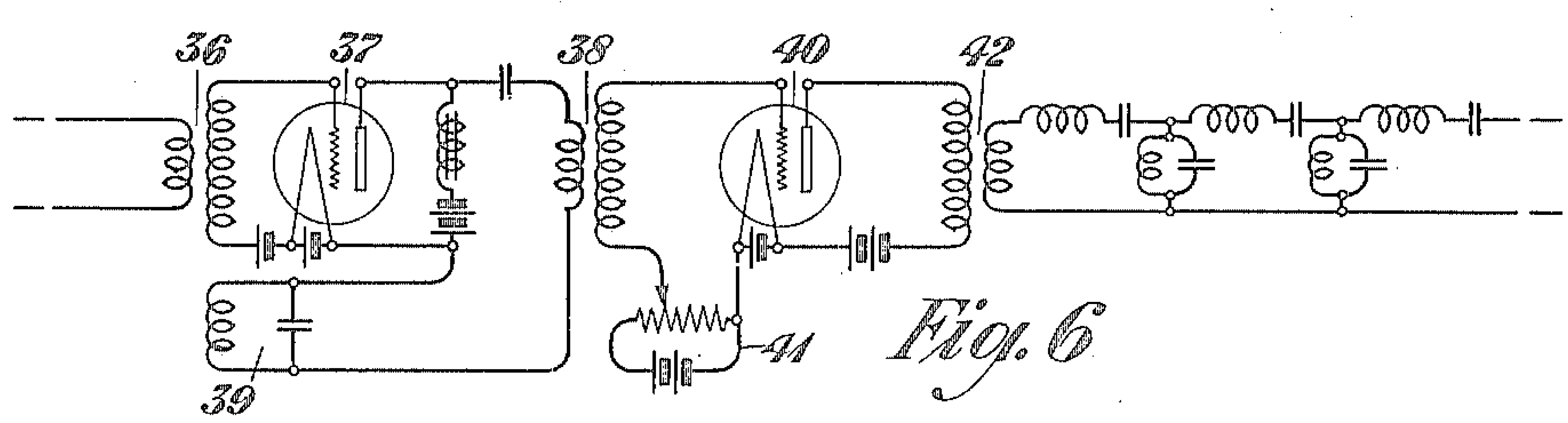

Fig. 6

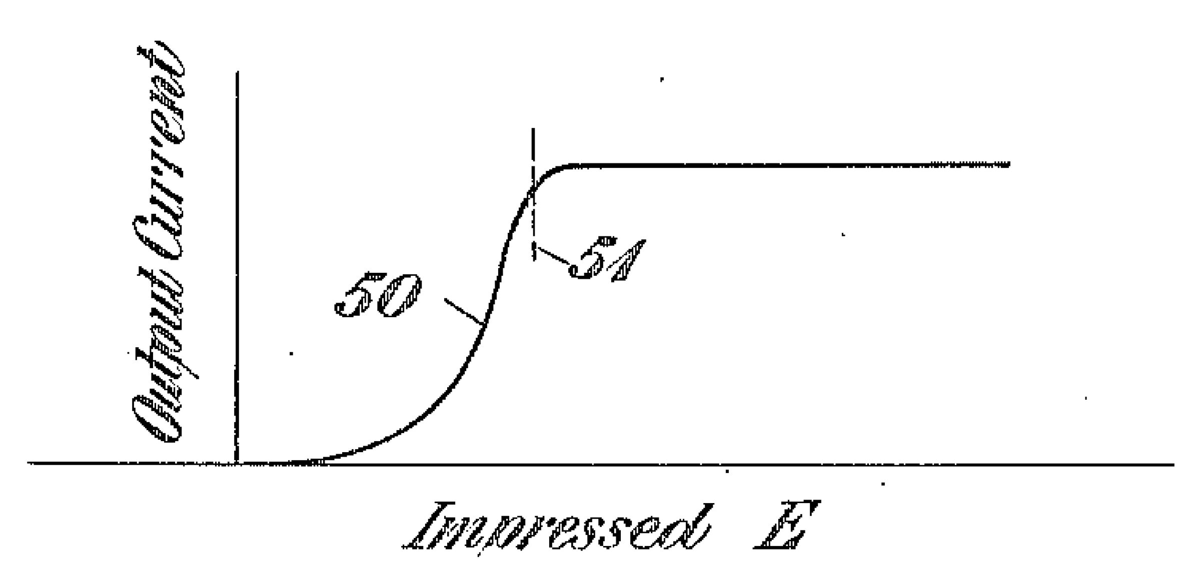

Fig. 7

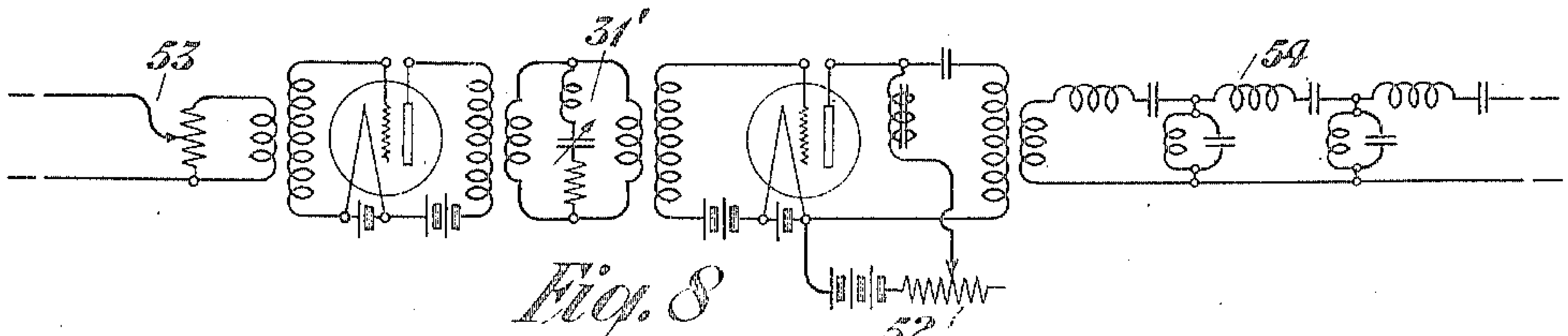

Fig. 8

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Patented Oct. 2, 1928. **1,685,913**

UNITED STATES PATENT OFFICE.

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RECORDING AND REPRODUCING OF SOUND WAVES.

Application filed December 17, 1919, Serial No. 345,591. Renewed April 23, 1927.

The invention relates to a method of and means for improving the quality and volume of reproduction of sound waves.

The object of the invention is to provide means for improving the clarity, naturalness and fidelity of sounds as reproduced from phonographic devices. Another object is the improvement of the timbre or tone quality of musical reproduction and a further object is to enable the timbre and volume of the reproduced music to be controlled at the will of the player or operator.

The tone quality deficiency of phonographic devices is caused by distortion of the sound waves from their true forms, this distortion occurring during both the recording and reproducing processes. One important type of distortion is what may be termed amplitude or volume distortion, arising from the fact that the instantaneous values of amplitude which a wave successively assumes are not recorded or reproduced in strict proportionality.

This amplitude non-proportionality type of distortion arises wherever the reaction of the medium in which the translation takes place, such as the material of a record, is other than a straight-line function of the impressed force. The desired condition for which no distortion of this type occurs is that the amplitude of displacement, for example, of the record imprint be directly proportional to the magnitude of the impressed force. This condition is analogous to that obtaining in an electric circuit of constant impedance wherein the current is directly proportional to the electromotive force. If the impedance varies with change in current, that is if the current is not a straight line function of voltage, then the current wave shape is distorted as compared with the voltage wave shape. Similarly in a phonograph, if for instance the resistance of the record to the impressed scribing force increases with increased displacement of the scribing needle into the record, then the shape of the recorded wave will differ from and be distorted as compared with that of the impressed force or original sound wave. Distortion of this type is more fully explained below in conjunction with the means provided in accordance with the present invention for correcting the same.

Another type of distortion is that due to non-uniformity of reproduction in respect to frequencies, waves or wave components of different frequencies being reproduced in disproportionate amplitudes. This may be called resonant distortion since it is caused largely by the natural periods of the diaphragm devices, air chambers, horns, etc., of the recording and reproducing instruments. The distortion, or change in wave shape of the reproducer as compared with the original wave, is caused in this case by the disproportionally large volume with which frequencies corresponding with the natural periods of the phonograph system are reproduced in comparison with off-resonant frequencies.

These effects, usually present in combination, are the causes of the imperfect reproduction so readily discernible in all ordinary phonographs. For example, the non-linearity type of distortion first mentioned is particularly responsible for the disagreeable effect so often observed in orchestral pieces where the instruments do not sound individually clear but are rather inter-mixed or blurred into a conglomerate. The resonant or second type of distortion is discernible as a loss of timbre richness, and by an over emphasizing of certain tones, which, together with the other distortion, produces a monotonous artificial character to the selections. In general, distortion of the first type tends to make the wave form more complex by adding artificially derived frequencies while distortion of the second type tends to smooth out the waves and to suppress the component frequencies of waves originally complex. Unfortunately these phenomena are not mutually correcting and each has to be treated individually.

The present application is directed at overcoming primarily the first type of distortion and secondarily the second type in combination therewith. The means employed are electrical. The methods involved, however, are not limited to these means and other means for applying them will become evident to those skilled in the art.

In the figures:—

Figure 1 delineates in curve form the manner in which the amplitude type of distortion occurs.

Figure 2 shows in similar form the action involved in correcting such distortion by a counter distortion.

Figure 3 illustrates apparatus means for carrying out this method of distortion correction during the reproduction of a record in a phonograph.

Figure 4 illustrates the application of the correcting process during the taking of an original record.

Means for correcting simultaneously for both types of distortion noted above are disclosed in Figure 5.

Figure 6 illustrates an alternative arrangement for such combined correction.

Figure 7 indicates the use for distortion correction of another portion of the characteristic curve of the thermionic amplifier.

Figure 8 represents diagrammatically means whereby the timbre or tone quality as well as the volume of music may be controlled for purposes of giving personal expression during the rendering of a selection.

In Figure 1, curve 1 delineates the variation in the displacement or amplitude of say the imprint, (plotted as ordinates), with variation in the impressed force (plotted as abscissa). The curve shows that the displacement does not increase directly proportional to but falls off for each added increment of the impressed force. This is what usually occurs in the making of a phonograph record of the mechanical type. The scribing needle as it cuts or pushes into the record encounters increasingly more resistance so that its displacement becomes rapidly disproportional to the impressed force. That is, the wave as recorded is disproportional to and therefore distorted in comparison with the original sound wave. This same effect is usually present also in the carbon granule microphone type of translating device which sometimes is employed in translating between the air waves of sound and the waves of mechanical motion involved in the recording or reproducing action.

The effect of this non-linear characteristic of the phonograph in distorting and changing the timbre of a musical note is illustrated in Fig. 1. Here curve 2 represents a pure tone of sinusoidal wave form impressed upon the phonograph system having the force-displacement characteristic of curve 1. The action of characteristic 1 in translating between what may be termed the input wave 2 and the output wave 3 will be apparent upon considering Fig. 1. Assume, as a concrete case, that the characteristic curve 1 applies to the effect obtained in a phonographic recorder, and in particular to what goes on in the forming of the record itself. In the taking of a record the phonograph needle is pressed against the record surface by a force of amount (a) which causes the needle to be normally displaced into the record material by the amount (a'). A sound wave incident upon the recorded diaphragm superimposes upon the initial biasing pressure (a) a varying impressed force as indicated by curve 2. This incident pressure wave of intensity (b) plus (c) causes excursions of the needle in the record material, the magnitude of which excursions are indicated on the ordinate as (b') plus (c'). It will be noted that the two equal halves (b) and (c) of the incident wave do not produce displacements of equal magnitude (b') and (c') on the record, the half which represents precession into the record being much less than that representing recession. This inequality in the effect produced by the two halves of the incident wave is manifest in the wave imprinted upon the record as a distorted wave, as illustrated by curve 3. It will be seen that each point on curve 3 is reproduced from a corresponding point on curve 2 thru the translation of characteristic 1. Curve 3 may be considered to represent in inverted form the wave traced on a record as seen enlarged in cross section. It illustrates the observed condition that the troughs of the waves, corresponding to the upper halves of curve 3, are flattened out.

Upon reproduction, this distortion is apparent to the ear as a note of the same frequency as the original but differing in timbre or quality. The change in wave shape is evident to the ear as a change in timbre because of the addition of harmonics brought about by the non-linear characteristic 1. Were the original wave 2 of complex wave form, as is the usual musical note which itself has harmonics, then the distortion imposed by curve 1 may so materially modify or modulate the wave by the addition of further harmonics as to materially depreciate the musical value of the reproduction.

In accordance with the present invention, distortion of this kind is corrected by introducing a counter-distortion having an opposite effect upon the wave shape. The sum of the two distortions is thus made substantially zero. This correcting distortion is obtained by introducing somewhere into the phonograph system, either in the recording, in the copying of records, or in the reproducing of the sound waves, an element having a force-displacement characteristic the opposite of that normally obtaining.

Such a characteristic is illustrated in curve 4 of Fig. 2. The curve is plotted in electrical terms analogous to the mechanical terms employed above, because the specific means employed in the present invention for obtaining it are electrical. The impressed force is represented, in the abscissa, as impressed E. M. F. and the displacement, in the ordinate, as current. It will be noted that the curve 4 is concave, the current varying more rapidly than the first power of the E. M. F. and is the opposite type of characteristic to curve 1 of Fig. 1 which is convex because the displacement varies at a rate less than the first power of the force. For perfect correction the two characteristics should be as nearly as possible conjugate functions. If for instance in curve 1 the displacement varies as the square root of the impressed force, then the correcting characteristic, curve 4, preferably should be such that the displacement current varies as the square of the impressed force.

Figure 2 demonstrates the correction of distortion of the type arising in Figure 1 because the distorted output wave 3 of Figure 1 is shown to be the wave 3′ fed into the device having characteristic 4, and the resultant output wave 5 is seen to be of substantially sinusoidal shape similar to the original wave 2 of Fig. 1. The derivation of curve 5 from curve 3′ through characteristic 4 is similar to the corresponding derivation of Figure 1 and need not be explained in detail. It will be understood that whereas Figure 1 has been described in terms of the distortion caused in the taking of the original record itself, it is meant to apply in its full significance to the overall distortion of the phonograph system including all diaphragm or other translating devices and all record effects. Likewise the correcting characteristic of Figure 2 is intended to represent overall correction irrespective of where it is introduced into the phonograph system, whether previous or subsequent to the point in the process at which the major distortion occurs. Furthermore, this correction may be lumped in a single stage of the phonograph process, as in recording, or may be distributed among several stages or devices, as illustrated and explained below.

A specific means for carrying out the distortion correcting action described above is shown in Fig. 3 wherein said means is employed in the reproducing of sounds from a record, i. e., in a phonograph device proper. The undulations of the record 10 actuate the electromagnetic device 11 which is similar to an ordinary polarized telephone receiver. (This device may be of any of several well known types such as a carbon microphone transmitter with polarizing battery or an electrostatic transmitter.) Electric currents, carrying the record distortion, are thereby generated and are transmitted through input transformer 12 to the well known audion or thermionic amplifier tube 13. The currents are thus amplified and then passed to a second audion tube 15 through a suitable input transformer 14. This tube is adjusted by means of a negative C battery and potentiometer 16, to operate at a point around the lower knee of the characteristic curve. The lower knee of the audion characteristic is of the shape of curve 4 in Fig. 2, i. e., in general opposite in effect to the characteristic in the phonograph which it is desired to overcome. It is by this adjustment to an appropriate position on the tube characteristic such as point *m* of curve 4, that the correction of the magnitude type of distortion is obtained. Tube 15 is therefore operated as a distorter or modulator as distinguished from the purely amplifying tube 13. The redistorted or corrected current wave then passes through output transformer 17 to translating device 18 which may be a loud speaking telephone receiver.

The same distortion correcting means is shown in Fig. 4 as applied in the making of an original record. The sound waves to be recorded enter and operate the electromagnetic translating device 19 illustrated as a telephone receiver. The current waves thus generated in the receiver windings flow through the input transformer 20 and are impressed upon amplifier 21 and in turn upon the distorting tube 23. The operation of this tube is similar to that of the corresponding tube 15 of Fig. 3. The currents emerge from the output transformer 25 predistorted and are impressed upon the translating device 26 and the undulations are thereby impressed upon the record 27. The distortion imparted to the sound waves while in electric form by 23 may be made sufficient to compensate for all the distortion of this type which will be experienced in the subsequent copying upon original record 27 and reproduction in a phonograph. That is, the master record may be not only corrected but also predistorted to compensate for any amplitude distortion which may occur in the following steps of the phonograph process. This is what I regard as one of the important embodiments of the invention. By thus over-distorting, as it were, during the recording process by an amount corresponding closely to the distortion which, it having been determined in advance by wave analysis, will obtain in the reproducing machine, the record predistortion will automatically neutralize the distortion of the phonograph machine. In this way by a single use in recording of the amplifying and distorting means, volume and quality improvement is made effective, through the records, to all phonographs without modification of them. The economic advantage of this method of correcting distortion in advance in the records as compared with that of doing it in each reproducing machine individually, is obvious. To obtain the best results it is necessary that all phonograph reproducers be held, during manufacture, to close limits as to their distortion characteristic.

A further improvement in the quality of reproduction may be obtained by combining means for correcting magnitude non-linearity distortion with means for correcting distortion of the natural period type. This combination is illustrated in Fig. 5 where the means for correcting the latter type of distortion are indicated as 31. This consists of a shunt across the circuit comprising a seriesconnected inductance capacity and resistance The circuit of Fig. 5 is generally similar to those of Figs. 3 and 4 and need not be described in detail. The theory of the action of such a selective shunt as 31, in correcting for inequality in the efficiency with which different frequencies of the sound wave spectrum are transmitted, is elucidated in my copending application previously referred to. Such a selective shunt acts to impart to the circuit a frequency-transmission characteristic the opposite of that normally obtaining. It reduces the efficiency of the system in a range of frequencies at which the efficiency is disproportionally high because of resonance effects in diaphragms etc. Fig. 5 therefore illustrates a distortion correcting means operative for correcting both types of distortion which are due to non-proportionality of reproduction in respect to (*a*) amplitude variation and (*b*) frequency variation.

Fig. 6 illustrates another arrangement for accomplishing the same result. The means for correcting type (*b*) distortion is changed from that of a selective shunt 31 of Fig. 5 to a selective circuit 39 forming a part of a feed back circuit of say the first vacuum tube stage. The feed back circuit is formed by connecting the output circuit back upon the input circuit, the coupling being between the input coil 36 and the coil of the output selective circuit 39. The selective circuit 39 is tuned to the frequency of the natural period which it is desired to compensate. Contrary to the usual feed-back circuit employed for increasing the effective amplification, the coil of circuit 39 is poled in a mutually opposing manner with respect to input coil 36. The feed-back currents oppose the currents incident upon the input circuit from the originating source and since the feed-back action is a maximum for frequencies corresponding to the natural period in question, a selective reduction in the effective amplification of tube 37 is effected at said natural period. The tuning may be done in either the output circuit as illustrated or in the input circuit. Furthermore either or both of said circuits may be tuned to a plurality of frequencies corresponding to a plurality of natural periods of the phonograph system.

The invention is not intended to be limited to the correction of distortion arising from force-displacement characteristics of the type of curve 1 of Fig. 1.

Considering for the moment this curve to represent the overall performance of the system including both recording and reproducing, then it may be assumed to represent the composite or resultant of two curves of different shapes summed together, one having a greater and the other a lesser slope than curve 1. One of these component curves may represent the distortion of the recording and the other of the reproducing process. If in this case the distortion is corrected entirely at the recording end, then a single device having a characteristic of Fig. 2, may be employed. If, however, the distortion of the two stages be corrected individually then the recorder distortion correcting device is designed to have the characteristic necessary for counteracting its distortion, and similarly with the reproducer.

The characteristic which actually obtains in a practical case may differ materially in shape from curve 1, may be irregular in shape or may even obey an entirely different law. As an extreme and not representative case, for example, a phonograph device may exhibit the type of characteristic shown in curve 4 of Fig. 2. In this case an equalizing characteristic of the type of curve 1, Fig. 1 would be employed. This latter general type of curve may be also obtained from a thermionic tube by using the upper or saturation knee of the familiar potential current characteristic curve, as illustrated by curve 50 of Fig 7. In Fig. 7 the lower portion of curve 50 corresponds to curve 4 of Fig. 2 and is intended to follow substantially a second power law. The upper knee corresponds in a general way with the characteristic of curve 1, Fig. 1. Considering now the manner in which characteristic 50 is employed in compensating for the distorting effect of curve 4,—the audion tube is adjusted by means of its C or biasing battery to a point on the upper knee such as 51 of Fig. 7. The tube then operates to distort or modulate the currents in a manner the opposite of the phonograh device having characteristic 4.

Fig. 8 illustrates vacuum tube means for controlling the shape of the saturation knee of the characteristic 50 of Fig. 7, to the end that the distortion when employing this portion of the characteristic may be readily controlled. The general circuit of Fig. 8 is similar to the preceding ones and need not be described in detail. The first tube is intended as a straight amplifier while the second one is the distorter for which curve 50 obtains. The curvature of the saturation knee is controlled by a variable resistance 52 in the battery supply circuit. By increasing this resistance from some nominal value up to a value comparable to the internal plate resistance of the tube, the upper knee may be greatly sharpened. This effect of sharpening the saturation knee by the use of a relatively high value of resistance in the plate circuit is not novel with the present invention, it being already known in vacuum tube engineering. It is caused by the battery supply circuit resistance taking up a controlling proportion of the plate circuit voltage as the internal plate-filament resistance drops with increase of impressed potential.

A further feature of the present invention resides in the use of these vacuum tube distorters in changing and controlling at will the timbre of music rendered from a phonograph, irrespective of the distortion correcting uses previously described. That is, distortion may be intentionally introduced in this way into the music as the phonograph is being played, for the purpose of enabling personal expression to be imparted to the rendering thereof. The characteristic employed for this purpose is preferably one giving distortion rich in harmonics. The saturation knee of curve 50, sharpened by such means as are illustrated in Fig. 8, is employed in communication engineering for the production of harmonics and is well adapted for this purpose in music. In producing such timbre or tone effects the harmonic-producing tube may be intentionally so overloaded that it operates over its entire characteristic curve including both lower and upper knees. This obviously may be done also in the correcting of distortion where the characteristics to be equalized are complex.

Another feature illustrated in Figs. 7 and 8 is the use of a band filter 54 in the output circuit for the purpose of eliminating undesired frequency components. This filter has the property of transmitting a band of frequencies lying within certain limiting frequencies and of cutting off all frequencies outside of said band. The band filter illustrated is but one of several possible forms all of the general type of filter circuit disclosed in U. S. Patent Nos. 1,227,113 and 1,227,114 to George A. Campbell. Such filters may be used to suppress all harmonics above a certain frequency or may be employed in reducing or eliminating fundamentals below a certain frequency or for suppressing frequencies both above and below certain limits.

In Fig. 8 means are provided in the potentiometer 53 for controlling the amplitude or volume of reproduction, and in the variable capacity of selective shunt 31′ for controlling the frequency equalizing action, and in the variable resistance 52 for controlling the timbre, all in accordance with the will of the player or operator. It will be understood therefore that in accordance with Fig. 8, the present invention provides means for controlling and manipulating the amplitude or volume and the frequency composition or tone quality of a phonograph during either the making of the records or their reproduction in a phonograph instrument.

From the above description it will be apparent that one of the important features of the invention is that of amplifying the sound wave energy. By so doing it is possible not only to offset the losses incurred in the translating actions, but to over-compensate the same so that the energy of the reproduced sound is greatly enhanced. It is particularly advantageous to employ this amplifying feature of the invention in the original recording of the sound waves for the purpose of diminishing the scratching sound so common to the every day phonograph. For this purpose the increased energy made available in the recording electromotor device such as 26 of Fig. 4 is used to increase the ratio of the sound wave undulations of the record to the irregular undulations causing the scratch. This may be done by allowing the increased energy to impress undulations in the record of amplitude larger than heretofore. By then operating the reproducing instrument at reduced sensitivity, as by increasing the damping of its diaphragm, the extraneous scratch will be lost out in comparison with the desired sound. Another way of similarly employing the increased energy is to increase the diaphragm damping of the recording device. The impressing or cutting needle is thereby more rigidly controlled and transcribes a cleaner or smoother record and one which is correspondingly more free from irregularities. This manner of utilizing the increased energy of amplification is indicated in Fig. 4 by the damping springs bearing upon the diaphragm of the translating motor 26. Furthermore the increased energy may be availed of to work master records of material less soft than is the usual wax record. Such harder records may be employed for the purpose of obtaining sharper records which improve the reproduction of the higher frequency components, or with the object of obtaining greater homogeneity of texture and therefore less irregularity and resulting scratch, or for purposes of facilitating the reproduction and manufacture of records.

Obviously many variations are possible in the means employed for producing the desired results without departing from the intent and spirit of the invention as defined in the claims below. For example, the non-linear characteristics illustrated as being obtained by the use of a vacuum tube may be derived from any of a number of devices. They may for instance be realized by the use of iron core coils, the permeability of which cores vary with current strength, or by the use of mineral contacts commonly employed as detectors in radio telegraphy, etc.

Nor is the invention to be interpreted as being limited to the use of non-linear characteristics obtained electrically and applied through an interposed electric system since other means, such as mechanical, may be employed. For example, distortion correction may be obtained by transferring the record wave, such as 3 of Fig. 1, onto a second record, applying the wave in reverse manner. In the hill and dale type of record this would mean that the valley halves of the waves of the first record become the hill halves of the waves of the second record. Furthermore, it is obvious that the invention is not limited to the mechanical type of phonograph illustrated but may be applied as well to a sound reproducing system of any type, as to magnetic phonographs similar to the telegraphone where amplitude distortion tends to occur because of the non-linear nature of the characteristic B—H curve of the iron, etc.

Although I have herein described only certain specific manners of practicing the invention and illustrated and described only certain specific forms of embodiment thereof, it will be readily understood that many changes and modifications may be made therein without departing from the spirit and scope of the invention, it being my invention to claim the same broadly in whatever form its principles may be embodied.

I claim:

1. In a sound recording and reproducing system, the method of correcting amplitude distortion which consists in introducing into said system an amplitude distortion having distorting effect the opposite of said original distortion.

2. The method of modifying the tone quality of a phonograph system, which consists in imposing on the waves passing through the system and amplitude correction of a character predetermined with reference to the distortion in the record.

3. The method of modifying the tone quality of a phonograph system which consists in imposing on the waves passing through the system an amplitude correction of a character predetermined with reference to the distortion in the record by causing changes disproportionately to each other in the successive instantaneous amplitudes of the waves.

4. The method according to claim 3, in which the vibrations representing the sound are converted into electrical undulations, and in which the said disproportional changes in amplitude are imposed on said electric undulations by passing the wave through an element of the electrical system having a non-linear current voltage characteristic.

5. The method of correcting for the combined amplitude and resonance distortion suffered by waves passed through a phonograph system, which consists in imposing on the waves an amplitude distortion substantially equal and opposite to the amplitude distortion suffered by the waves because of said system, and imposing on the waves a resonance distortion substantially equal and opposite to the resonance distortion suffered by the waves because of said system.

6. The method of imparting a desired timbre to a musical note obtained from a sound producing system, which consists in imposing on the waves representing the note an amplitude distortion of such predetermined character as to give rise to harmonics of said note.

7. The combination with a phonographic system wherein the sound waves suffer amplitude distortion, of means subjecting the waves to substantially equal and opposite amplitude distortion.

8. The combination with a phonographic system wherein the sound waves suffer amplitude distortion, of means subjecting the waves to substantially equal and opposite amplitude distortion, comprising means for converting the waves representing sound into electrical undulations, and means having a non-linear voltage current characteristic interposed into the path of said undulations.

9. The combination according to claim 8, in which the said non-linear means comprises an electron tube, and means for causing the same to operate on a curved portion of its voltage current characteristic.

10. The combination according to claim 8, in which the said non-linear means comprises an electron tube, a polarizing source of electro-motive force, and means for operatively associating the same with the tube.

11. The combination according to claim 8, in which the said non-linear means comprises an electron tube of the three-element type and a polarizing source of electro-motive force in which the negative pole of the source is connected to the grid element of the tube so as to cause said tube to operate at about the lower knee of its voltage current characteristic curve.

12. The method of obtaining a record substantially free from amplitude distortion in the waves recorded thereon, which consists in imposing on the waves before being engraved on the record an amplitude distortion substantially equal and opposite to the distortion suffered by the waves when being engraved in the record material.

13. In a musical instrument or system, the combination with means for producing musical notes, of means for changing the timbre of the notes by impressing on the waves representing the notes a non-linear distortion of predetermined character to give rise to harmonics of the notes.

14. In a musical instrument or system, the combination with means for producing musical notes, of means for converting the sound waves into electrical undulations, and means for modifying the electrical undulations to change the timbre of the notes as they are finally emitted by the instrument, comprising a non-linear translating device for impressing on the undulations a non-linear distortion of predetermined character to give rise to harmonics of the notes.

15. In a musical instrument or system, the combination with means for producing musical notes, of means for changing the timbre of the notes, comprising a device for impressing a non-linear distortion of predetermined character on the waves representing

the notes to give rise to harmonics of the notes, and means for filtering out undesired frequencies.

16. In a musical instrument or system, the combination with means for producing musical notes, of means for impressing a non-linear distortion on the waves representing the notes, together with means for compensating for resonant distortion by the system.

17. In a system of sound recordation in which by virtue of record limitations or for other reasons the waves of greater amplitude have been reduced in comparison with waves of lesser amplitude, the method of expanding the amplitude range of the reproduced sound, which consists in converting the reproduced waves into electric current waves, so modulating said current waves as to enhance the amplitude of the waves of greater amplitude in comparison with those of lesser amplitude, and finally reproducing as sound the currents so modified.

18. The method of recording and reproducing sound, which consists in (1) forming a record which is distorted by virtue of the maximum undulations being limited in value to a substantially greater extent than the weaker undulations, and then (2) reproducing said record with an amplitude distortion the opposite of that carried by the record.

19. The sound producing machine, comprising means for generating electric waves, means for developing harmonics of said waves, means for reproducing said waves as sound waves, and filtering means for restricting the reproduced waves to predetermined frequencies.

20. In a musical instrument, the combination of a source of current corresponding to sound vibrations, vacuum tube means for controlling at will the generation of desired harmonics and in turn the timbre of the reproduced sound, means for controlling the volume thereof, and means for translating the current into sound waves.

21. The method of imparting a desired timbre to a musical note obtained from a sound producing system, which consists in imposing on the waves representing the note an amplitude distortion of such predetermined character as to give rise to harmonics of said note, and then filtering the desired from the undesired components.

22. In an electrical sound producing instrument, means to produce alternating currents of the acoustic range of frequencies, and electric circuit means for reproducing such currents as sound waves, comprising means in said circuit for controlling the volume of the sound waves and for independently giving them a desired timbre.

23. In a phonographic system, the method of transferring sound waves or their equivalent, which consists in amplifying them, generating harmonics of said waves by subjecting them to the action of a non-linear translating device, and finally selecting by electric filter circuits the frequency range to be reproduced.

24. In a phonograph system, means for converting sound waves into electrical waves, means for distorting said electrical waves to offset or neutralize resonant distortion of the system, means for effecting a non-linear distortion of the waves to give rise to harmonics, means for re-converting the electrical waves into sound waves and reproducing them as sound, and means for controlling the volume of the reproduced sound.

In testimony whereof, I have signed my name to this specification this 16th day of December, 1919.

LLOYD ESPENSCHIED.