Sept. 19, 1950 E. G. COOK 2,522,567

AMPLIFIER FEEDBACK SYSTEM FOR MAGNETIC MOTORS

Filed June 21, 1946 2 Sheets-Sheet 1

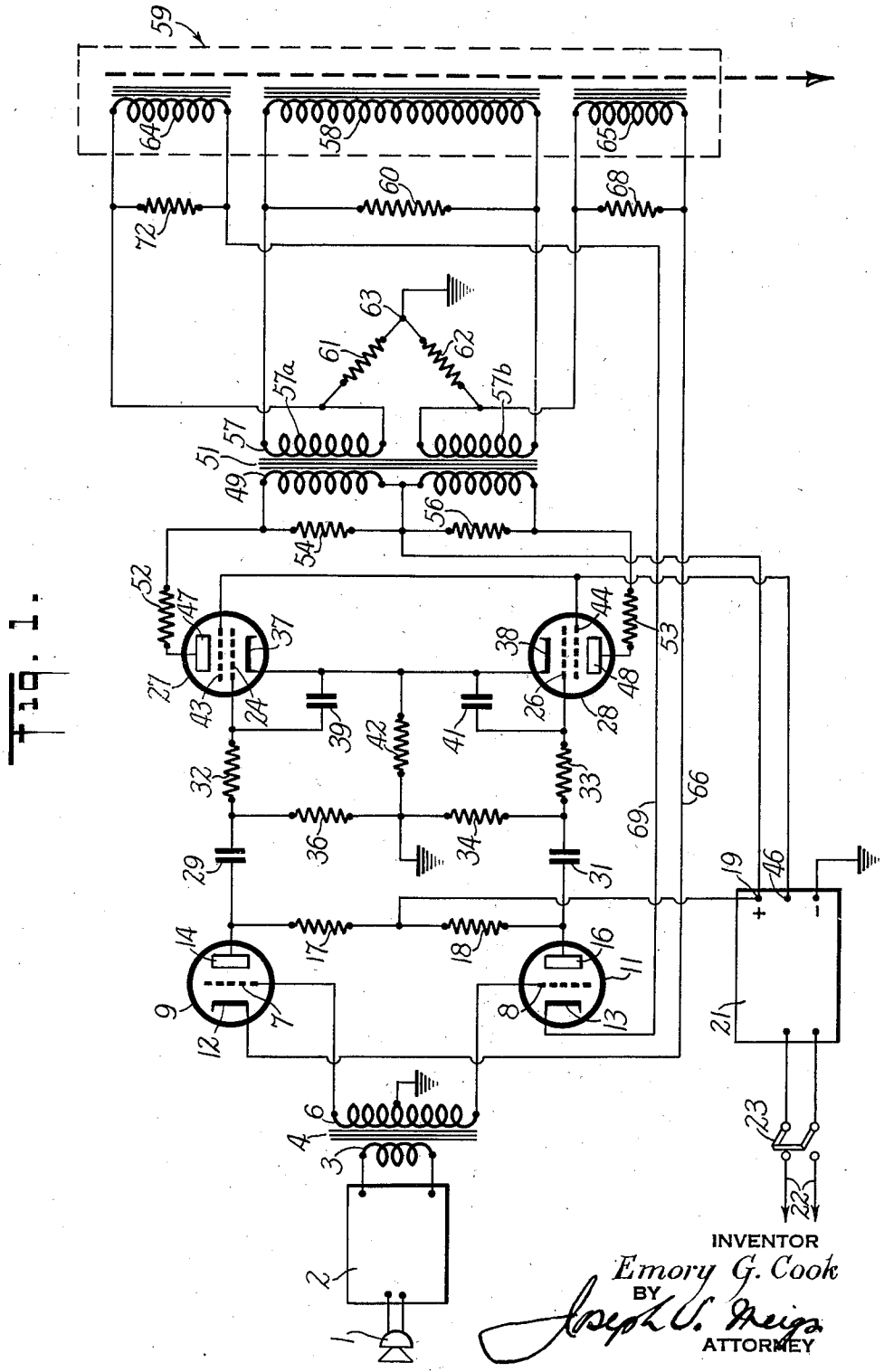


Fig. 1.

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Fig. 2.

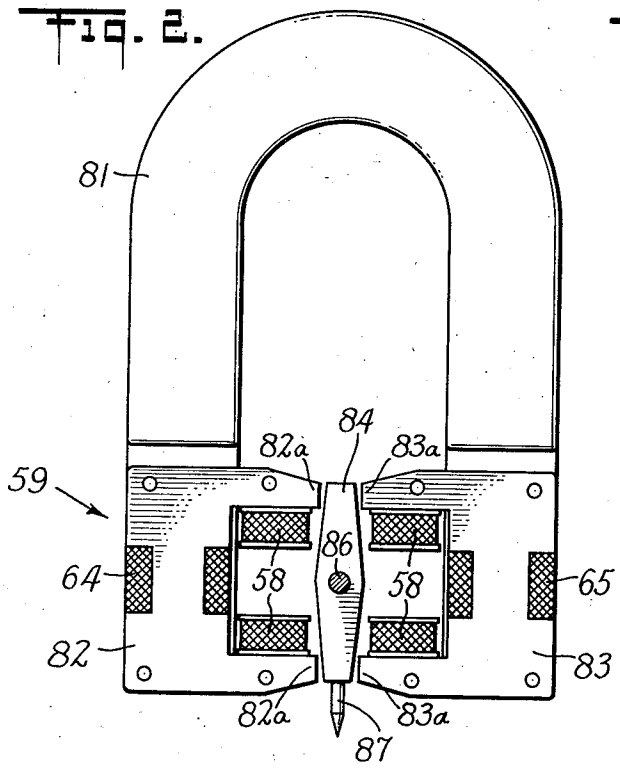


Fig. 3.

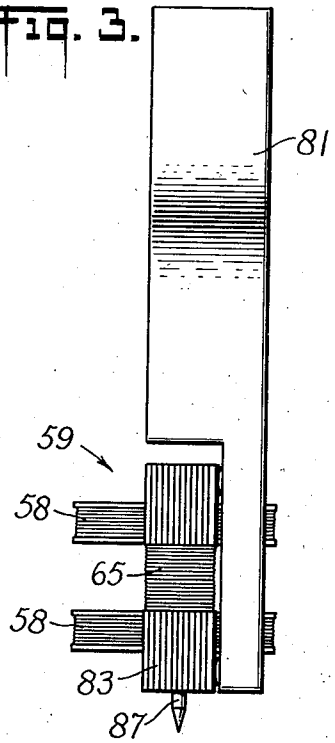
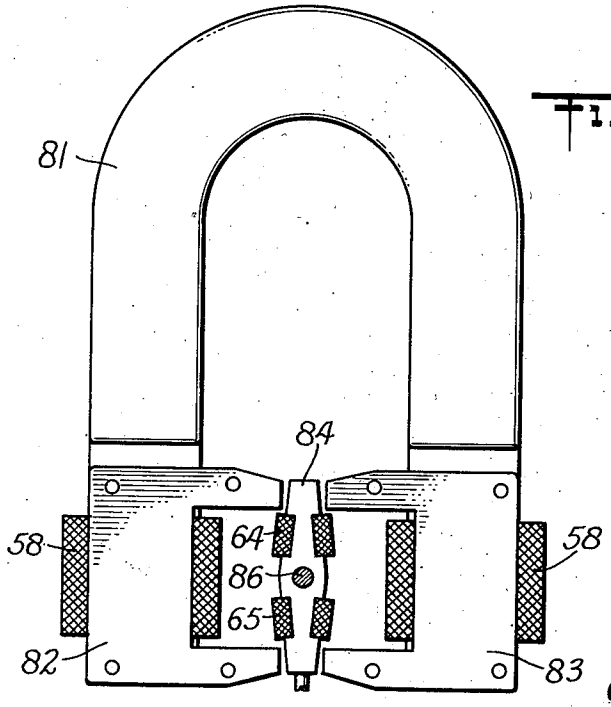


Fig. 4.



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AMPLIFIER FEED-BACK SYSTEM FOR MAGNETIC MOTORS

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Application June 21, 1946, Serial No. 678,241

12 Claims. (Cl. 179—100.4)

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This invention relates to methods and apparatus for improving the operation of electromagnetic motors, and more particularly to feed-back arrangements for use with such devices wherein the feed-back signal is so derived as to be a function of the mechanical forces or movements in the driven device.

The term, an electromagnetic motor, as used herein, is intended to refer generally to magnetically operated devices for the interconversion of electrical signals and mechanical motions; and more particularly to such of these devices that include a driving coil for establishing a magnetic field and a movable armature operated by that field, and in which the reactance of the driving coil is sufficiently high at the frequencies of operation that the current therethrough is appreciably out of phase with the voltage existing across the terminals of the coil.

In most devices of this type it is desirable that the torque applied to the movable element be proportional to the driving current or voltage in order that the movable element may respond accurately to the variations of the applied signal.

In many instances electronic amplifiers are associated with such magnetic devices, and it is desirable under these circumstances that the movement of the armature follow faithfully the variations in the signal applied to the input terminals of the amplifier.

It has been an accepted practice in electronic amplifiers to couple a small portion of the output signal of the amplifier back to the input circuit in such manner that distortion inherent in the electronic amplifier is neutralized. Systems in which the phase of the signal fed back to the input of the amplifier is such as to decrease the effective amplitude of the external signal applied to the amplifier input are usually termed negative or inverse feed-back systems. The use of negative feedback decreases the gain of the amplifier, but provides compensating advantages including an increase in amplifier stability, the reduction of amplitude, phase, and frequency distortion, and the reduction of variations in amplification with changes in power supply voltages.

If such an amplifier is used in conjunction with an electromagnetic motor, the operation of the overall system is adversely affected by distortion occurring within the motor unit itself. Although the feed-back circuits referred to above compensate for distortion within the amplifier proper, they do not correct for the distortion occurring within the driven unit i. e. the

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electromagnetic motor. The desirability of an overall feed-back system encompassing both the amplifier and the electromagnetic motor unit may be readily appreciated. Several such systems have been proposed but have failed to solve the problem satisfactorily. For example, many such devices include a member mounted on the driven element to produce a feed-back signal dependent on the movement of the driven element in the motor unit, but the additional load thereby placed on that element precludes its use for many purposes. Such systems usually are unstable and do not operate over wide ranges of frequencies and amplitudes without giving rise to self-sustained oscillations or erratic operation. For these and other reasons, the proposed systems have failed to provide a satisfactory remedy for such distortion.

In accordance with the present invention a thoroughly practicable, highly stable, and efficient feed-back system is provided whereby compensation is achieved automatically for distortion produced both by the amplifier and the magnetic motor unit being driven thereby. One feed-back signal is provided that varies in accordance with the rate of change of magnetic flux existing within the ferromagnetic core of the motor unit and which is substantially unaffected by changes of the magnetic flux in the air surrounding the core. An additional feed-back signal, which varies in accordance with the instantaneous signal current in the output circuit of the amplifier, is provided for stabilizing purposes.

The novel methods and apparatus of the present invention are described herein as embodied in an electromagnetic sound recorder system. Because of design limitations, the magnetic circuit of such a sound recording unit usually is operated at high flux densities with consequently increased distortion. In an ideal unit, the resultant movement of the armature would be at all times proportional to the signal current through the driving coil of the recorder unit. Because of the magnetic characteristics of available materials, such an ideal unit does not exist. The present invention provides apparatus and methods for so modifying the applied signal that distortion inherent in the magnetic system is compensated for automatically and the torque applied to the movable armature is substantially proportional to the external signal applied to the input of the amplifier.

Accordingly, it is an object of this invention to provide methods and structures for improving the operation of electromagnetic motor devices.

A further object of the invention is to provide a system for operating an electromagnetic motor in which a feed-back signal is derived from changes in flux density within the ferromagnetic core of the driven device to permit compensation for the distortion inherent in the magnetic motor unit.

Still another object is to provide means for neutralizing inherent distortion in a system including an electronic amplifier and an electromagnetic motor by means of negative feed-back arrangements in which the amplitudes and phase relationships are so controlled as to provide highly stable operation.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts, and methods of operations, as will be exemplified in the structures and sequences and series of steps to be hereinafter indicated, and the scope of the application of which will be set forth in the appended claims.

Figure 1 is the circuit diagram of a sound recording system, including an electronic amplifier, embodying the present invention,

Figure 2 represents, diagrammatically, an electromagnetic sound recorder unit suitable for use in the sound recording system of Figure 1,

Figure 3 is a side view of the recorder unit shown in Figure 2, and

Figure 4 illustrates a modification of the record cutter shown in Figure 2.

This specification and the accompanying drawings show and describe a preferred embodiment of the invention and various modifications thereof as incorporated in a sound recording system; but it is to be understood that these are not intended to be exhaustive nor limiting of the invention, but on the contrary are given for the purposes of illustration in order that others conversant with the art may fully understand the invention and the principles thereof and the manner of applying it in practical use so that they may modify and adapt it in various forms each as may be best suited to the conditions of a particular use.

The sound recording system shown in Figure 1 includes a microphone 1 connected to the input terminals of the pre-amplifier 2, which may be of conventional design and may advantageously incorporate any desired control and filter circuits. The signal delivered by pre-amplifier 2 to primary winding 3 of an audio frequency transformer 4. The midpoint of the secondary winding 6 of transformer 4 is connected to ground and the outer ends of this winding are connected, respectively, to control grids 7 and 8 of two triode tubes 9 and 11. The cathodes 12 and 13 of these tubes are returned to ground through a feed-back arrangement to be described below. The anodes 14 and 16 of these tubes are connected through resistances 17 and 18 to a high voltage terminal 19 of a conventional power supply unit 21 which derives its power from commercial supply mains 22 through a switch 23.

The audio signal voltages appearing at anodes 14 and 16 of triodes 9 and 11 are transferred, respectively, to control grids 24 and 26 of two tetrode tubes 27 and 28 through coupling condensers 29 and 31 and series resistances 32 and 33. The grid return circuits to ground are completed through resistances 34 and 36. Control grids 24 and 26 of these tubes are coupled to their respective cathodes 37 and 38 through stabilizing condensers 39 and 41, and these cathodes are connected to ground through a common bias resistance 42. Operating voltages for anodes 47 and 48 are supplied from the terminal 19 of power supply 21 through a center-tapped primary winding 49 of a transformer 51 and suppressor resistances 52 and 53. Two resistances 54 and 56 are connected in parallel with the separate halves of winding 49.

The secondary winding 57 of transformer 51 is divided into two substantially equal sections 57*a* and 57*b*. The outer terminals of these sections are connected to the driving coil 58 of an electromagnetic recorder unit, generally indicated at 59. A damping resistance 60 is connected in parallel with the driving coil 58. The other ends of sections 57*a* and 57*b* are connected in series through resistances 61 and 62 and the connection between these resistances is grounded at 63. Two feed-back windings 64 and 65 are closely coupled to the ferromagnetic core of recorder unit 59 and produce feed-back voltages across resistances 68 and 72, respectively, in accordance with the rate of change of flux within this ferromagnetic core. The voltages produced by windings 64 and 65 are added, respectively, to those which exist across resistances 61 and 62 and the resultant voltages are fed back to the amplifier input circuit. The circuit which feeds back to cathode 12 of input triode 9 may be traced from this cathode through lead 66, the parallel connection of feed-back winding 65 and resistance 68, and through resistance 62 to ground; the cathode circuit of input tube 11 may be traced from cathode 13 through lead 69, the parallel connection of feed-back winding 64 and resistance 72, and through resistance 61 to ground.

The electromagnetic recorder unit 59 is shown in greater detail in Figures 2 and 3. It includes a permanent horseshoe magnet 81 which is rigidly attached to two laminated C-shaped pole pieces 82 and 83. These ferromagnetic pole pieces 82 and 83 are mounted in the same plane with their pole tips 82*a* and 83*a* suitably spaced apart and facing each other. The feed-back windings 64 and 65, each comprising several thousand turns of small wire, surround, respectively, recessed portions of pole pieces 82 and 83. These windings are thus coupled very closely to the ferromagnetic core formed by the pole-pieces and the voltage induced therein is substantially unaffected by changes in the flux in the air adjacent to the core. A vibratable armature 84 is positioned vertically between the pole tips 82*a* and 83*a* to oscillate, about a pivotal axis 86, on some suitable mounting arrangement (not shown). This mounting arrangement advantageously includes a spring type construction which biases the armature toward a position midway between pole pieces 82 and 83, The armature 84 does not completely occupy the space between pole tips 82*a* and 83*a* thus forming four air gaps in the magnetic circuit. A cutting stylus 87 is suitably secured to the lower end of armature 84 and is adapted to move laterally as the armature pivots about axis 86.

The driving coil 58, surrounding armature 84, consists of several thousand turns of small wire and is divided into two sections mounted between pole pieces 82 and 83. The output signal current from the amplifier shown in Figure 1 passes through this winding and produces a magnetic field which varies in response to changes in this output current causing the stylus-carrying armature 84 to vibrate about the pivotal axis 86. Flux linkages created by current variations in coil 58 pass through windings 64 and 65 provided the

flux is confined to the ferromagnetic path formed by pole pieces **82** and **83**, but flux linkages existing in the air surrounding the ferromagnetic circuit do not couple to the windings. The mechanical moment of armature **84** about the axis **86**, caused by the signal current flowing through driving coil **58**, is substantially proportional to the instantaneous flux density existing in the four air gaps between armature **84** and the pole tips **82***a* and **83***a*, and the mechanical moment, acting on armature **84**, therefore is proportional to the total flux within the ferromagnetic core produced by the driving coil. However, in the record cutter head shown, as is usual in conventional type lateral cutters, driving coil **58** is necessarily loosely coupled to armature **84**. Therefore, a large number of the flux linkages surrounding coil **58** will pass entirely through air or through a portion of the magnetic core which does not include the air gaps between the armature **84** and pole tips **82***a* and **83***a*. Thus the total flux within the magnetic core does not bear a linear relationship to the total flux created by coil **58**. The feed-back circuit of the present invention modifies the current through driving coil **58** in such manner that the flux within the magnetic core is maintained at all times proportional to and in phase with the signal voltage applied to the input circuit of the amplifier. Windings **64** and **65** are very closely coupled to the ferromagnetic core and a voltage is induced in each coil proportional to the rate of change of flux with respect to time within the magnetic core surrounded by windings **64** and **65** and is substantially independent of changes in flux linkages occurring in air adjacent thereto. As shown in Figure 1, winding **65** is connected in series with cathode **12** of input tube **9** to provide a feed-back voltage. The phase relationship of this voltage is such that its effect is degenerative. Similarly the instantaneous polarity of the voltage induced in winding **64** is equal to and of opposite polarity from that induced in winding **67**, and it is applied to the cathode circuit of the other input tube **11**. The effect of these feed-back signals is to so modify the characteristics of the amplifier that the output signal current will maintain that portion of the total flux within the magnetic core of the record cutter proportional to the input signal voltage applied to the amplifier.

Feed-back systems that encompass a driven unit as well as an amplifier, tend to become unstable and oscillation or "singing" troubles are encountered. Such troubles are occasioned by progressive series of phase-shifts throughout the amplifier and driven unit. Consequently in accordance with this invention an additional or secondary feed-back circuit is provided to increase the stability of the system.

This secondary feed-back effect is achieved by means of the resistances **61** and **62** which are in series with the secondary winding of output transformer **51** and, in addition, with the cathode circuits of input tubes **11** and **9**, respectively. Thus, a voltage proportional to and in phase with the output signal current of the amplifier is added to the feed-back voltage from the electromagnetic unit **59** and the resultant voltage is impressed as a degenerative feed-back voltage on the input of the amplifier.

The motion of armature **84** is in phase with the flux, produced by coil **58**, in the air gaps between the armature and the pole tips **82***a* and **83***a*. In turn, this flux, although not directly proportional to the field produced by driving coil **58**, is in phase with this field in point of time, and the field is in phase with the signal current through the driving coil. Thus, by means of the secondary feed-back loop, which provides a feed-back signal in phase with the current through driving coil **58**, the initial flux produced in the ferromagnetic core structure of the cutter **59** is so corrected in phase that it follows closely in point of time the original signal voltage applied to the input of the amplifier.

The secondary feed-back loop is designed to provide a feed-back signal in phase with the output current because the load on the output of the amplifier is inductive, causing the voltage to lead the current. If the secondary feed-back loop voltage were in phase with the output voltage rather than the output current, the flux variations, and hence the motion of armature **84**, would lag behind the signal voltage applied to the amplifier input. With such a system, the superimposing of an overall feed-back loop would result in unstable operation.

The feed-back system of the present invention also provides a desirable damping action. If an external force, as for example, one caused by an imperfection in the record blank, is applied in such manner as to displace the armature **84** from its midposition between the pole pieces **82** and **83**, the flux in the magnetic core of the cutter varies as the armature starts to move. This variation in flux induces a voltage in feed-back coils **64** and **65** in such a direction that the feed-back signal, which is returned to the input of the amplifier and hence to coil **58**, will apply a force to the armature **86** substantially proportional to the velocity of the original displacement and in such direction as to return the armature to its symmetrical position between the pole pieces.

The resistances **54** and **56** are provided to decrease resonant peaks accurring near the frequency at which winding **49**, together with associated circuit capacities, forms a parallel resonant circuit, and resistances **52** and **53** are provided to suppress similar series resonance. These resistances reduce the rate of change of phase with change in signal frequency and together with resistances **32**, **33**, **60**, **68**, and **72** and condensers **39** and **41** provide increased stability for the amplifier throughout the entire frequency range. Resistance **60** also provides electrical damping for the cutter when low frequency signals are being recorded.

The amplifier of Figure 1 may advantageously use a single dual triode tube, for example a 6SL7GT, for the input tubes **9** and **11** and two 6L6 beam power tubes for output tubes **27** and **28**. Typical values for certain of the resistances are listed below:

Resistance: Value, ohms

60	1,000
61	25
62	25
68	5,000
72	5,000

The positions of the driving coil and feed-back windings may be rearranged as shown in the embodiment illustrated in Figure 4. In this modification of the invention the feed-back coils **64** and **65** are closely coupled to and supported by the armature **86**, and the two sections of the driving coil **58** surround the outside portions of the pole pieces **82** and **83**. The axes of coil **58**

and windings 64 and 65 are substantially parallel as in the previous example. This arrangement provides several advantages such as the better form factor of coil 58, which is more closely coupled to the magnetic circuit, and advantageously may be wound with larger diameter wire thus lowering the D. C. resistance of this winding. This arrangement also makes available greater space between the pole pieces and the armature for positioning auxiliary mechanical or electrical components such as the armature mounting structure.

This magnetic cutter unit may be utilized with the feed-back system described above wherein its operation is substantially the same as for the cutter shown in Figure 2. This embodiment of the invention provides the same advantageous and highly stable distortion correction.

Sound recording systems embodying the present invention are well adapted to be economically manufactured, because the separate features are well suited to common production methods, and they are capable of a variety of modifications as may be desirable in adapting the invention to different applications.

As many possible embodiments may be made of the above invention and as many changes might be made in the embodiments above set forth, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limited sense.

I claim:

1. In a system for the interconversion of electrical signals and mechanical motion, a distortion-correcting arrangement comprising, in combination, an electronic amplifier, a magnetic motor having a ferromagnetic core, a ferromagnetic armature movable in response to changes in flux in said ferromagnetic core and a winding connected to an output circuit of said amplifier and having appreciable inductive reactance at the frequency of operation, an overall negative feed-back loop carrying a feed-back signal responsive to changes in flux within said core and connected from said magnetic motor to an input circuit of said amplifier for neutralizing distortion in said amplifier and magnetic motor, means for generating a supplementary negative feed-back signal in phase with the driving current through said winding, and means coupling said supplementary feed-back signal connected from the output circuit of said amplifier to an input circuit of said amplifier to enhance the stability of operation of said amplifier and motor.

2. In a system for the conversion of electrical signals into mechanical motion, a feed-back circuit for eliminating inherent distortion, comprising, in combination, an amplifier, a magnetically operated motor including a movable ferromagnetic armature and a winding having appreciable inductive reactance at the frequency of operation coupled to the output of said amplifier, a primary negative feed-back signal generator cooperating with said motor and responsive to the rate of change of flux therein, a connection for applying said primary feed-back signal to an input of said amplifier to neutralize distortion in said system, a coupling circuit cooperating with said amplifier and producing a secondary negative feed-back signal in phase with the driving current through said winding and proportional to the magnitude thereof, and a circuit for coupling said secondary feed-back signal to an input of said amplifier, to increase the stability of operation of said system.

3. A system for the conversion of electrical signals into mechanical movements, comprising, in combination, an electronic amplifier, an electromagnetically operated motor including a driving coil having appreciable inductive reactance at the frequency of operation, and a movable ferromagnetic armature responsive to the changing of current through said driving coil, a connection coupling the output circuit of said amplifier to said driving coil for producing a signal current therein, a network producing a first degenerative electrical feed-back voltage instantaneously proportional to and in phase with the current through said driving coil, a second degenerative feed-back voltage in accordance with the rate of change of flux within said ferromagnetic armature, and a connection coupling said first and second feed-back voltages to an input of said amplifier, whereby the distortion of the overall system is reduced and stable operation achieved.

4. In a system for the conversion of electrical signals into mechanical motion, a feed-back arrangement comprising, in combination, an amplifier, a magnetically operated motor including a movable ferromagnetic armature and a winding having appreciable inductive reactance at the frequency of operation and coupled to the output of said amplifier, a generator coupled with said motor to produce a first negative feed-back signal, a connection applying said first feed-back signal to an input of said amplifier, resistive means in series with said winding for producing a second negative feed-back signal proportional to the magnitude of and in phase with the driving current through said winding, and a connection coupling said second feed-back signal to an input of said amplifier, thereby correcting for distortion inherent in said amplifier and said motor means and providing stable operation.

5. A system for recording sound signals comprising, in combination, an electronic amplifier, an electromagnetic recording head including inductive driving means coupled to the output circuit of said amplifier and a movable ferromagnetic armature responsive to the changing of current through said driving means, feed-back signal generating means responsive to changes in flux in said electromagnetic recording head producing a first negative feed-back signal, means coupling said first feed-back signal to an input of said amplifier to compensate for distortion inherent in said motor, resistance means in series with said driving means for producing a second negative feed-back signal in phase with the signal current through said winding, and means coupling said second feed-back signal to an input of said amplifier to increase the stability of operation.

6. A system for recording sound signals comprising, in combination an electronic amplifier, an electromagnetic recording head including a driving coil having appreciable inductive reactance at the frequency of operation coupled to the output circuit of said amplifier, a ferromagnetic core, and a movable ferromagnetic armature responsive to the changing of current through said driving coil, feed-back signal generating means for producing a first feed-back signal responsive only to the rate of change of flux within said ferromagnetic core, means coupling said first feed-back signal to an input circuit of said ampli-

fier, to compensate for distortion inherent in the overall system, means for producing a second negative feed-back signal substantially in phase with the output signal current through said driving coil, and means coupling said second feed-back signal to an input of said amplifier, for stabilizing the operation.

7. In a system for recording sound signals, a feed-back system for eliminating inherent distortion, comprising, in combination, an amplifier, an electromagnetic recording head including a movable ferromagnetic armature and an inductive driving coil coupled to the output of said amplifier, means for producing a primary feed-back signal in accordance with the instantaneous force acting on said armature, means for applying said primary feed-back signal to an input of said amplifier, means for producing a secondary negative feed-back signal quantitatively related to and in phase with the signal current through said driving coil, and means for coupling said secondary feed-back signal to an input of said amplifier, thereby stabilizing the system and compensating for inherent distortion.

8. A system for the conversion of electrical signals into mechanical motion, comprising, in combination, an amplifier, a magnetically operated motor means including a movable ferromagnetic armature and a winding having appreciable reactance at the frequency of operation coupled to the output of said amplifier, means for producing a primary negative feed-back signal in accordance with the instantaneous mechanical moment acting on said armature, means for applying said primary feed-back signal to an input of said amplifier, means for producing a secondary negative feed-back signal quantitatively related to and in phase with the signal current through said winding, and means for coupling said secondary feed-back signal to an input of said amplifier, thereby compensating for inherent distortion and increasing the stability of operation.

9. A system for recording sound signals comprising, in combination, an amplifier, an electromagnetic recording head including a ferromagnetic core and a driving winding having appreciable reactance at the frequency of operation, a movable ferromagnetic armature and coupled to the output of said amplifier, a primary negative feed-back signal generator responsive only to flux changes within said ferromagnetic core and substantially independent of flux changes outside said core, a circuit applying said primary feed-back signal to an input of said amplifier, thereby compensating for inherent distortion, a coupling circuit producing a secondary negative feed-back signal responsive to the signal current through said winding, and a circuit coupling said secondary feed-back signal to an input of said amplifier to stabilize the operation.

10. In a system for the interconversion of electrical signals and mechanical motion, an arrangement for modifying the response characteristics of the system, comprising, in combination, an electronic amplifier, a magnetic motor driven by said amplifier and including a ferromagnetic core and a ferromagnetic armature movable in response to changes in flux in said ferromagnetic core, a generator producing a first negative feed-back signal the instantaneous value of which is a function of the rate of change of flux within said armature, a circuit coupling said first feed-back signal to an input circuit of said amplifier, a coupling circuit cooperating with an output circuit of said amplifier for producing a second negative feed-back signal, and a circuit coupling said second feed-back signal in series with said first feed-back signal to an input circuit of said amplifier, whereby the two feed-back signals cooperate to modify the response characteristics and enhance the stability.

11. In a system for the interconversion of electrical signals and mechanical motion, the method of compensating for overall distortion of said system and enhancing the stability of operation, comprising the steps of, amplifying an electrical input signal to produce an output signal current, passing said current through an inductive reactance to produce magnetic flux, driving a movable ferromagnetic armature in accordance with said flux, producing a first negative feed-back voltage in accordance with the rate of change of said magnetic flux producing a second negative feed-back voltage proportional to and in phase with said output signal current, combining said second feed-back signal with said first feed-back signal, and subsequently combining said feed-back signals with said electrical input signal.

12. A system for amplifying and recording electrical signals, comprising, in combination, an electronic amplifier having an input and an output circuit, a resistance connected in series with said output circuit, means coupling the voltage produced across said resistance to said input circuit to stabilize the operation of said amplifier; a recorder unit driven by said amplifier and having a ferromagnetic circuit formed of a first C-shaped pole piece, a second C-shaped pole piece spaced apart from said first pole piece with the open sides of these pole pieces facing each other, and a magnetically permeable armature mounted between said first and second pole pieces and pivotally supported to vibrate about a transverse axis in response to flux variations in said ferromagnetic circuit; a permanent magnet joining said pole pieces, a recording stylus affixed to one end of said armature, a driving coil coupled to said ferromagnetic circuit and to the output circuit of said amplifier to cause signal currents to flow through said driving coil to produce a varying flux in said ferromagnetic circuit and actuate said armature, and a feed-back winding closely coupled to said ferromagnetic circuit and coupled to the input circuit of said amplifier, whereby a voltage is applied to said amplifier input circuit in accordance with the rate of change of flux within said ferromagnetic circuit and substantially independent of flux changes outside said circuit to compensate automatically for distortion inherent in the system.

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