

# PATENT SPECIFICATION

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(21) Application No. 11452/77 (22) Filed 17 March 1977  
(31) Convention Application Nos.  
668 580 (32) Filed 19 March 1976  
677 827 16 April 1976 in  
(33) United States of America (US)  
(44) Complete Specification published 26 Nov. 1980  
(51) INT. CL.<sup>3</sup> G05D 19/02  
G11B 21/04  
(52) Index at acceptance  
G3R A382 A522 BS



## (54) SYSTEM FOR DAMPING VIBRATIONS IN A DEFLECTABLE TRANSDUCER

(71) We, AMPEX CORPORATION, a Corporation organized and existing under the laws of the State of California, United States of America, of 401 Broadway, Redwood City, State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to transducers and particularly to a transducer which forms part of a helically-scanning machine which 15 plays back video signals from tracks on a magnetic tape by means of a transducing head which is positionally deflectable relative to a rotary carrier in order that it may be caused to follow a track.

20 According to the invention there is provided a transducer in which an arm which supports a transducing head is capable of producing deflection of the head in response to an electrical control signal and in which 25 transducer vibratory deflection of the head is damped by degenerative feedback derived from the instantaneous displacement or velocity of displacement of the head.

Reference will now be made to the 30 accompanying drawings, in which:

FIG. 1 is a simplified perspective view of a portion of a helical videotape recorder;

FIG. 2 is a perspective view of a transducer assembly for use in the recorder 35 illustrated in FIG. 1;

FIG. 2a is an enlarged cross-section of a portion of the transducer assembly shown in FIG. 2 and illustrating the layered construction of the assembly;

40 FIG. 3 is a block diagram of a feedback control system embodying various aspects of this invention for controlling vibrations in a bimorph read transducer assembly;

FIGS. 4a and 4b graphically illustrate the 45 frequency and phase response of the

bimorph transducer assembly used in the control system of FIG. 3;

FIG. 5 is a schematic diagram of the control system illustrated in FIG. 3;

FIG. 6 shows prior art methods of deflecting a bimorph;

FIG. 7 illustrates an improved method of deflecting a bimorph;

FIG. 8a illustrates an improved method of varying the direction and magnitude of 55 deflection of a bimorph;

FIG. 8b graphically illustrates the net voltage which is applied to one element of the bimorph shown in FIG. 8a;

FIG. 9 shows an improved method of 60 driving a bimorph when the bimorph deflection signal does not include very low frequency or DC components;

FIG. 10 is a schematic diagram of a deflectable read transducer system embodying 65 the improved bimorph deflection method illustrated in FIG. 8a.

Broadly stated, this invention is directed 70 toward apparatus for damping vibrations in a deflectable videotape read transducer 70 without restricting the dynamic range of the transducer and without the adverse results experienced by dead-rubber pads in the high G environment of such a transducer.

The desired damping is achieved in this 75 invention by apparatus which includes a deflectable transducer support arm and a signal generator for generating a signal representative of instantaneous deflection velocity of the arm. A negative feedback loop 80 is coupled between the output of the signal generator and the support arm for converting the deflection velocity signal to a damping signal. The damping signal is applied to the transducer support arm to 85 damp its vibrations.

In a preferred embodiment of this invention, the generator which produces the transducer velocity signal includes a bimorph support arm having an in- 90

tegral sensor for developing a signal representative of the instantaneous deflected position of the transducer. A differentiator in the feedback loop converts the transducer 5 position signal to a transducer velocity signal. The feedback loop also includes phase compensation means for stabilizing the loop at frequencies near the resonant point of the bimorph. To compensate for differences in 10 responses of bimorphs at their antiresonant frequencies, means are included for artificially adjusting antiresonant frequency since loop stability relies on it being at a predictable frequency in order to maintain 15 stability.

Referring to the drawings, and particularly FIG. 1, a scanning drum 20 of a helical videotape recorder is shown and has a rotatable portion which carries a reproducing or "read" head which contacts and scans successive tracks on a magnetic videotape.

The scanning drum 20 has a pair of drum portions 22 and 24 around which a videotape 26 is wrapped. The tape 26 is caused to move by tape transport means (not shown) in the direction of the arrows A and wraps around the drum portions 22 and 24 in a helical path. The tape 26 is kept in tight 30 contact and alignment with the drums by guide rollers 28 and 30 and by tension exerted on the tape by the tape transport.

In a helical videotape recorder the information tracks run diagonally with respect 35 to the lengthwise dimension of the tape, and a portion of one such track 32 whose size is exaggerated for clarity is shown in FIG. 1. In order to sense the information recorded on track 32 a read transducing 40 head 34 is mounted on drum portion 22 which rotates in the direction of the arrow B. The movement of the tape 26 and the rotation of the transducer 34 causes transducer 34 to contact the tape along the track 45 32 and to generate an electrical signal representative of the information previously recorded on the track. This electrical signal is fed to signal processing circuitry for processing in a manner well known in the art. 50 It is apparent that the extent to which the transducer 34 can faithfully reproduce the information originally recorded on the track 32 depends on the transducer 34 accurately following or tracking the track 32. Difficulties occur when, for example, videotapes 55 or the tracks become distorted, as by temperature or humidity induced dimensional changes in the tape, or by faulty tensioning mechanisms in the tape transport, for 60 example.

To avoid such difficulties it is desirable to sense the instantaneous position of transducer 34 with respect to track 32. When the tracking by the read transducer is not perfect, a corrective signal may be applied to a

deflectable support arm such as a bimorph on which the read transducing head is mounted. The correction signal causes the support arm to deflect the transducer toward track center and thus reduces tracking errors. 70

Deflection of the read transducer is also desirable in helical videotape recorders if slow motion and other effects in a reproduced video scene are generated by causing, 75 among other events, the multiple reading of a track. For this purpose a transducer may be physically repositioned at the beginning of the track which is to be repeated by, for example, applying an electrical reset signal 80 to the deflectable support arm upon which the read transducer is mounted and thereby deflecting the support arm and the transducer so as to reset the transducer to the beginning of the desired track. The reset 85 signal is in the form of an electrical impulse which may tend to cause the support arm to vibrate or oscillate, and such vibrations must be damped to assure correct alignment between the transducer and the tape. 90

Vibrations in the deflectable transducer support arm are also induced when the transducer makes and loses contact with the tape. For example, in the scanning drum arrangement of FIG. 1, read transducer 34 95 experiences a dropout because it loses contact with tape 26 in the gap between guide rollers 28 and 30 during each rotation of the drum 20. Contact between the transducer 34 and the tape 26 is re-established as 100 transducer 34 passes roller 28 as it rotates in the direction of arrow B.

The vibrations set up in a deflectable transducer support arm are, of course, undesirable since they can produce a loss 105 of tracking. This loss of tracking due to vibrations can be minimized or eliminated by sensing the vibrations in the deflectable support arm and applying a damping signal to the support arm to counteract the vibrations. 110

Thus, in helical videotape recorders in which it is desirable to include a deflectable support arm for reducing tracking errors, it is also desirable to include means for damping electrically and mechanically induced vibrations in the deflectable support arm. Preferably, damping the vibrations can be done electronically, in which case some means for sensing the amplitude of the 120 vibrations and for generating an electrical signal indicative thereof, is required. 115

A deflectable read transducer assembly which includes means for sensing vibrations induced therein is shown in FIG. 2 and is 125 indicated generally by reference numeral 36.

At one end of assembly 36 is the read transducer 34 itself. Its output is coupled via wires 38 to a pair of transducer output 130

terminals 40 from which the transducer output is fed via line 82 to a conventional video processing circuit 84 (Figure 3).

A support arm, indicated generally at 5 42, for holding and deflecting transducer 34 is a piezoelectric bimorph which deflects or bends when a deflection potential is applied to it. The bimorph is formed from a number of layers bonded together to act 10 as a piezoelectric motor 43 and includes a top piezo-ceramic element or layer 44 and a bottom piezo-ceramic element or layer 46. The various layers of transducer assembly 15 36 are shown more clearly in FIG. 2a. Piezo-ceramic elements 44 and 46 are both bonded to a common, electrically conductive substrate 48. Substrate 48 limits the movement of the bimorph to a bending motion in response to an applied electrical 20 potential.

In order to impress an electrical potential to piezo-ceramic elements 44 and 46, conductive layers 50 and 52 cover the outer surfaces of elements 44 and 46. Terminals 25 54 and 56 (FIG. 2) are electrically connected to layers 50 and 52, respectively, for receiving an electrical deflection potential. Substrate 48 also has an input terminal 58 to serve as electrical common for the applied 30 deflection potential. The electrical potential for deflecting support arm 42 is applied across piezo-ceramic element 44 between terminals 54 and 58 and across piezo-ceramic element 46 between terminals 56 35 and 58.

In order to force support arm 42 to deflect at its free end 60 where transducer 34 is mounted, arm 42 is cantilevered between insulating spacers 64 which may be 40 held in place by a bolt (not shown) passing through hole 66.

In operation, appropriate deflection potentials are applied across piezo-ceramic elements 44 and 46 via input terminals 54, 45 56 and 58. Support arm 42 then bends at its free end 60 and deflects transducer 34 in a direction and to an extent which is dependent on the magnitude and polarity of the potentials applied to terminals 54, 56 50 and 58.

In some applications, a piezoelectric motor need include only one piezo-ceramic element bonded to a substrate. For example, a single piezo-ceramic element could 55 have a top surface covered by a conductive layer and a bottom surface bonded to a conductive substrate which forces the element to bend when an electric potential is applied between the substrate and conductive layer. However, where large amounts of deflection are required, such as 60 in videotape transducers, a motor element comprising two piezo-ceramic elements 44 and 46, as shown in FIG. 2, is preferable. 65 In addition to having a piezoelectric

motor 43 for deflecting transducer 34, the assembly 36 also includes a deflection or vibration sensor in the form of a piezoelectric generator 68. The generator 68 includes, in the illustrated embodiment, an 70 edge portion 70 of the piezo-ceramic element 44 whose bottom surface is bonded to substrate 48 as previously described. It should be appreciated, however, the generator 68 could be formed by a portion located in 75 the center of the element 44. The generator has a separate conductive layer 72 overlying the element portions 70. The conductive layer 72 is isolated from conductive layer 50 by a dielectric gap 74 to electrically 80 isolate the output of generator 68 from potential applied to the conductive layer 50.

The generator 68 is cantilevered at 76 and has an opposite, free deflectable end 78. Thus, whenever vibrations or deflections occur in the motor 43 due to electrical or mechanical impulses, a corresponding deflection or vibration of the free end 78 of generator element 68 occurs and produces, 85 between the common substrate 48 and the 90 conductive layer 72, an electrical signal indicative of the instantaneous degree of deflection of the motor 43 and of the transducer 34.

In the description of the piezoelectric 95 motor and generator above, generator 68 was said to include a piezo-ceramic element portion 70 of the element 44 and the motor 34 includes the bulk of the piezo-ceramic element 44. As shown in FIGS. 2 and 2a, 100 piezo-ceramic element portion 70 is preferably part of the unitary piezo-ceramic layer or element 44. However, it is not necessary that the portion 70 be part of a larger unitary piece. For example, gap 74 could 105 be extended downwardly to cut through layer 44 and form a separate element 70. It has been found, however, that even with large amplitude deflection signals applied to the elements 44 and 46, these deflection 110 signals are not substantially coupled to generator 68 when the element portion 70 is part of the larger unitary element 44. However, cutting the element down to the 115 ground plane results in an increased isolation of the motor-to-generator and increases the element's tolerance to surface contamination.

Any vibration sensor which develops an 120 electrical output indicative of vibrations in arm 42 should be responsive to vibrations over a frequency range extending from approximately 10 Hertz up to at least 400 Hertz at which the illustrated bimorph support arm has a resonant frequency. The generator 68 of Figure 2, by extending 125 lengthwise along the support arm 42, does exhibit a good frequency response over the range desired. This response appears much better, particularly at low frequencies, than 130

the frequency response of a generator which may extend transverse to the lengthwise dimension of the support arm 42.

The preferred dimensions for support arm 5 42 include a length L extending from free end 60 to the cantilevered point 76 of approximately 0.9 inch and a width W of approximately 0.5 inch. Each of the layers 44, 46 and 48 are preferably approximately 10 0.006 inch thick while conductive layers 50, 52, and 72 have thicknesses in the range of a few microns. The width of the conductive layer 72, as measured between the gap 74 and the nearest edge of the support 15 arm 36, is preferably about 50 mils. The substrate 48 is preferably made of brass and the conductive layers 50, 52 and 72 are nickel depositions. The piezo-ceramic layers 44 and 46 are bonded to substrate 20 48 by an epoxy adhesive or the like.

The read transducer assembly 36 may be enclosed in a housing (not shown) having top and bottom portions which hold assembly 36 between them. The entire 25 housed assembly may be held together by a bolt passing through appropriate holes in a top portion of the housing, through hole 66 (FIG. 2), and through another hole in a bottom portion of the housing. A more 30 detailed description of a housing which may be used for assembly 36 is given in our copending application, No. 10036/77 (Serial No. 1 579 852).

The piezoelectric motor-generator combination described above is a low cost, reliable device capable of being controllably deflected and for simultaneously generating an output signal representative of the controlled deflection or of vibration-induced 40 deflection. It is particularly useful as part of a read transducer assembly for a videotape recorder and is illustrated schematically in connection with the videotape recorder systems described below.

45 The piezoelectric motor-generator combination described above which simultaneously deflects a read transducer and senses vibrations therein is used in an electronic feedback control system for 50 damping vibrations in a videotape read transducer.

There have been transducer damping schemes which have used so-called dead rubber pads to absorb vibrations in a transducer but the pads also limit the effective deflection range of the transducer. If the pads are mounted on the read head adjacent the transducer in a rotatable scanning drive, they are subjected to high G forces 60 as the drum rotates. Under these conditions, it can be difficult to keep the pads properly situated on the drum. An improved damping system in which the above-described motor-generator combination can 65 be used is shown schematically in FIG. 3.

Before describing the improved damping system, however, a brief description of associated transducer circuitry will be given in order to clearly indicate how the damping system cooperates with the associated circuitry. 70

Referring now to FIG. 3, a read transducer 34 operates as described above to sense or read previously recorded information in videotape tracks. The transducer 34 75 is part of the read transducer assembly 36 such as that shown in FIGURE 2 and has a deflectable support arm 42 for deflecting transducer 34 in response to deflection signals to correct the alignment of transducer 80 34 with a track or to reset transducer 34 to the beginning of a track, as in the slow motion mode of operation described above. The support arm 42 is cantilevered at point 76 and its opposite end portion which 85 supports transducer 34 is free to deflect.

The electrical signal output of transducer 34 appears on conductor 82 which conducts this signal to conventional video processing circuitry 84 for generating, for example, a 90 composite television signal for RF transmission.

The output of transducer 34 is also fed to a transducer position control circuit 86, which generates a "dither" signal of fixed 95 frequency for application to the deflectable support arm 42 for deflecting or "dithering" transducer 34 back-and-forth across a track at a fixed rate. Since dithering causes the transducer 34 to move transversely relative to the track, the signal output of transducer 34 will be amplitude modulated at the dither frequency. The amplitude modulated signal envelope contains information concerning the alignment 100 between transducer 34 and the track being read and is detected to produce a correction signal for moving the transducer 34 toward the center of the track. This correction signal and the dither signal appear on conductor 88 and are ultimately applied to the 105 deflectable support arm 42.

A transducer reset signal generator 90 develops an electrical signal for application to the deflectable support arm 42 for 110 selectively resetting the transducer 34 to the beginning of a track when such is required.

The reset signal from signal generator 90 and the dither correction signal from circuit 86 are both fed to a frequency compensator 120 92 which comprises an amplifier whose frequency response complements the undesired residual response variations of support arm 42 when electronic feedback control damping is applied to it as shown schematically in FIG. 3. Frequency compensator 125 92 augments the action of the electronic damping circuit in order to provide the desired uniform frequency response for the overall system. The area of augmentation 130

is in the 300 to 400 Hz region where the electronic damping action does not completely remove the rise in frequency response of arm 42 at its first-order mechanical 5 resonant frequency.

The frequency compensated deflection signals from compensator 92 are fed via conductor 94 to a summing amplifier 96 which sums the deflection signals with a 10 transducer damping signal generated by the feedback loop described below. The output of the summing amplifier 96 is fed via conductor 98 to a drive amplifier 100 which amplifies its input and applies it to deflectable support arm 42 for controllably deflecting transducer 34 to the center of the track and maintaining proper transducer to track 15 alignment.

The various deflection signals which are 20 applied to the support arm 42, particularly signals generated by the reset generator 90, may set up unwanted vibrations in the arm 42. This is particularly true where the arm 42 is a bimorph since bimorphs 25 exhibit resonance characteristics which tend to drive the bimorph into damped oscillation.

To damp such oscillations, a negative 30 feedback loop is included in the system shown in FIG. 3 for developing an electrical damping signal and for applying the damping signal to support arm 42 to dampen its vibrations or oscillations. The required damping signal is derived, in general, from 35 a signal generator which generates a deflection velocity signal representative of the instantaneous deflection velocity of the read transducer 34. In the embodiment illustrated in FIG. 3, said signal generator includes a sensor 102 integral to the support 40 arm 42 for generating a signal representative of the instantaneous deflected position of the transducer 34 and a differentiator 104 for converting the transducer position signal 45 to a transducer velocity signal. The sensor 102 is preferably a piezoelectric generator of the type shown in Figure 2 which is integrally formed with the bimorph support arm.

50 The output of sensor 102 is fed to a high input impedance amplifier 106 which presents a very small load to the sensor 102. Since the sensor 102 is typically equivalent to a voltage source in series with a capacitor, any electrical load on sensor 102 55 must be small in order to effectively couple low frequency signals from the sensor 102.

The output of amplifier 106 is coupled through a summer 108, whose other input 60 will be described below, and to the differentiator 104 which differentiates the transducer position signal from the sensor 102 and converts it to a signal representative of instantaneous transducer velocity.

65 The differentiator 104 is illustrated as

having an amplitude versus frequency characteristic similar to that of a high pass filter and therefore introduces a phase lead to the signals it passes. The significance of the phase shift experienced by a signal 70 traversing the feedback loop is explained immediately below in order to better appreciate the function of the remaining un-described elements of the feedback loop.

Because the support arm 42 is preferably a piezoelectric bimorph, it exhibits the well known first order resonance and anti-resonance characteristics of piezoelectric crystals, as well as higher order resonance characteristics. FIG. 4a illustrates the combined frequency response of a bimorph motor-generator combination of the type shown in FIG. 2. This response is generated by applying a varying frequency, constant 80 amplitude sine wave to the piezoelectric motor and measuring the resultant output of the piezoelectric generator. The results of such a measurement are shown in FIG. 85 4a which indicates a resonance point near 400 Hertz and an anti-resonance point, 90 which has been found to vary from around 700 Hertz to about 1000 Hertz, depending on the particular bimorph being used. The maximum output of the motor-generator 95 combination occurs at resonance and the minimum output occurs at very low frequencies and at anti-resonance. High order resonance characteristics are not shown in FIG. 4a.

Since the output of the motor-generator 100 combination is maximum at resonance, vibrations or oscillations will tend to occur at its resonant frequency when the bimorph is excited by an electrical or mechanical impulse. Therefore, to eliminate the possibility of such oscillations, the feedback loop 105 is tailored to feed back to bimorph damping signals which are 180 degrees out of phase with respect to the signals which initially excited the bimorph into oscillation, 110 thereby counteracting the tendency of the bimorph to oscillate.

To insure that the damping signals are of the correct phase, the phase response of the bimorph motor-generator combination must 115 be taken into account. As indicated in FIG. 4b on the curve labelled "bimorph", signals near resonance (about 400 Hertz) experience a phase shift of about 90 degrees in passing through the motor-generator combination, and high frequency signals experience a phase shift of 180 degrees. In order to ensure that signals near resonance experience a net phase shift of 180 degrees around the feedback loop, and since all 120 signals in the loop will be phase shifted 180 degrees by an inverting feedback amplifier prior to being applied to support arm 42, the signals near resonance must be phase 125 compensated by 90 degrees so that their 130

net phase shift is zero at the input to the inverting feedback amplifier. This insures that the loop will not oscillate at the resonant frequency due to instability in the 5 feedback system. Since signals having a frequency far from resonance have a very low amplitude, the loop gain of the feedback loop will always be less than unity for them so that the phase shift which they 10 experience will not cause instability in the loop.

Returning to the feedback loop of FIG. 3, the transducer velocity signal developed by differentiator 104 is fed to a low pass 15 filter 110 whose upper cutoff frequency is chosen to substantially attenuate signals attributable to second order and higher order resonance characteristics of the bimorph. Such signals generally have a 20 frequency of over 2000 Hertz and are attenuated at least 20 decibels by the filter 110. The filter 110 contributes some phase lag to signals which it passes in addition to the initial phase lag of 90 degrees due to 25 the bimorph itself (as shown in FIG. 4b).

To compensate for the total phase lag experienced by signals near resonance, a phase lead network 112 follows filter 110 and shifts the phase of signals received from the 30 filter 110 so that those signals having a frequency near resonance have net phase shift of zero degrees upon leaving the lead network 112. The curve labeled "with lead network" of FIG. 4b illustrates the effect of 35 lead network 112. In practice, the differentiator 104 also adds some phase lead and thereby assists the lead network 112 in properly adjusting the phase of the signals near resonance.

40 The signals near resonance from lead network 112 have a phase of zero degrees with respect to the signals initially exciting the bimorph and are in condition to be applied to a negative feedback amplifier 114 which 45 inverts the signals received from the lead network 112. The output of negative feedback amplifier 114 is the damping signal which is combined in the summer 96 with the transducer deflection signals from the 50 conductor 94, amplified by the drive amplifier 100, and applied to the bimorph support arm 42 to damp vibrations therein. The feedback amplifier 114 has a variable amount of negative feedback for adjusting 55 the gain of the feedback loop to accommodate differences among bimorphs.

The feedback loop illustrated in FIG. 3 also includes means for compensating for the different anti-resonance responses among 60 bimorphs. A frequency response curve is shown by the solid line in FIG. 4a and a dashed line indicates the variable nature of the anti-resonance characteristic among various bimorphs. For example, at 700 65 Hertz the frequency response of one bi-

morph may be considerably less than that of another bimorph, as indicated by the difference between the solid line and the dashed line at the frequency of 700 Hertz. Referring to FIG. 4b, the phase response 70 of the feedback system with the lead network is such that signals near 700 Hertz undergo a 180 degree phase shift. If signals having a 180 degree phase shift are applied to inverting feedback amplifier 114, they 75 will ultimately be applied to a deflectable support arm 42 in phase with the original exciting deflection signals and may lead to oscillations at that frequency if their amplitude is large enough at frequencies corresponding 80 to positive feedback conditions for the feedback loop. Bimorphs having a frequency response illustrated by the solid curve of FIG. 4a have a very small output at 700 Hertz so that the overall loop gain of the 85 system for such signals will be low enough to avoid oscillations, irrespective of their phase response. However, bimorphs exhibiting greater gain at 700 Hertz, as illustrated by the dashed line, may induce instability 90 into the system if not otherwise compensated for. The feedback system illustrated in FIG. 3 compensates for such differences between bimorphs by adding a portion of the exciting deflection signals to the output 95 of the sensing device 102 so that signals normally experiencing a 180 degree phase shift between their application to bimorph 42 and their output at sensor 102 will be effectively nulled. Signals experiencing such 100 a 180 degree phase shift are shown by FIG. 4b to be in the vicinity of anti-resonance. Therefore, signals near anti-resonance can be effectively nulled by coupling across the transducer assembly 36 a portion of the 105 signal normally fed thereto.

Referring to FIG. 3, a means for feeding through a portion of the deflection signal and combining it with the position signal developed by the sensor 102 includes the 110 potentiometer 116 and the summer 108. Deflection signals appearing at the output of the summer 96 are fed to both the drive amplifier 100 and the potentiometer 116, whereupon a portion of the deflection signals 115 are fed via conductor 118 to summer 108. Summer 108 also receives, from amplifier 106, deflection position signals developed by sensor 102. Deflection signals which undergo a 180 degree phase shift in passing through the input to support arm 42 to the output of sensor 102 (i.e. frequencies near anti-resonance) are nulled in summer 108 so that the loop is stabilized for frequencies 120 near anti-resonance. This operation effectively creates an artificial null near 700 Hertz so that, regardless of the bimorph being used in transducer assembly 36, it will appear to have an effective null near 700 Hertz so that the loop again for signals near 130

700 Hertz will always be less than unity and the feedback loop will be stabilized for signals at those frequencies.

Circuitry for effecting the functions of the various blocks in FIG. 3 is illustrated in FIG. 5. Transducer deflection signals, including the dither signal and reset signals referred to above, are applied at terminal 120 to frequency compensator 92 which includes a pair of conventional amplifiers 122 and 124. The frequency response of compensator 92 is shaped conventionally by the RC coupling around amplifier 122 and between amplifiers 122 and 124 to have an overall amplification which decreases with frequency in the 300 to 400 Hz region in order to compensate for the residual frequency-dependent variations in deflection sensitivity of support arm 42 after electronic damping has been applied.

The output of amplifier 124 is fed via conductor 94 to summing amplifier 96 which also receives, at its non-inverting input, an input from the feedback control loop. The output of summing amplifier 96 is applied to drive amplifier 100 via conductor 98.

The negative feedback loop begins at terminal 126 at which the output from sensor 102 appears. The signal from sensor 102 is applied to amplifier 106 which is a conventional, frequency compensated, feedback amplifier 128. The output of amplifier 128 is fed to the inverting terminal of summing amplifier 108 which also receives, at the same input, a portion of the transducer deflection signals for creating the artificial null at anti-resonance as described above. Diodes 131 protect amplifier 128 from damaging high voltage transients due to accidental short circuits between sensor 102 and the input to support arm 42.

The output of summing amplifier 108 is then conducted to differentiator 104, comprising serially connected capacitor 129 and resistor 130.

The low pass filter 110 which receives the output of differentiator 104 is an active elliptical filter comprised of amplifiers 132 and 134, and indicated generally at 135. The lead network 112 receives the output of the filter 110 and comprises a capacitor 136 serially coupled to resistor 138. The output of the lead network 112 is applied to the inverting input of a conventional feedback amplifier 114 whose feedback and therefore forward gain is varied by adjusting the variable resistor 140. The output of amplifier 114 is coupled to the non-inverting input of summing amplifier 96 and then applied to the drive amplifier 100 which, in turn, drives the deflectable support arm 42 for deflecting the transducer 34 in the manner previously described.

The damping system described above provides improved damping for deflectable

videotape transducers without restricting their dynamic range. The feedback control loop, in combination with the motor-generator transducer assembly, provides a reliable and low cost vibration damper for videotape recorders and other applications where vibrations in a deflectable bimorph transducer assembly require damping.

From the foregoing, it should be understood how a videotape read transducer can be controllably deflected and damped to maintain alignment between itself and a tape track. An improved bimorph transducer system, including a method of applying deflection signals to a deflectable bimorph to achieve maximum deflection sensitivity will now be described. Such an improved system is useful in the tape recorder apparatus already described and will be illustrated in that environment. It is understood, however, that the improved method of driving a deflectable bimorph disclosed below is also useful in other applications where it is desirable to achieve a large amount of bimorph deflection.

A bimorph which is used for bi-directional deflection consists generally of two layers of piezo-ceramic material bonded to opposite sides of a conductive substrate. One end of the bimorph is cantilevered and the opposite end is left free to deflect in response to a voltage applied to the bimorph.

The direction in which a bimorph deflects depends on the polarity of the voltage applied to it and the poling direction of the pair of piezo-ceramic elements. The poling direction of a piezo-ceramic element is established by being initially subjected to a unidirectional electric field which polarizes the element according to the direction of the field. The polarized piezo-ceramic element is then said to have a "poling direction" and thereafter exhibits unique mechanical properties when subjected to subsequently applied voltages.

A known method of causing a bimorph to deflect or bend is illustrated in FIG. 6 wherein a bimorph 142 includes piezo-ceramic elements 144 and 146 bonded to opposite sides of conductive substrate 148. Bimorph 142 is cantilevered at 150 while its opposite end 152 is free to deflect.

Piezo-ceramic elements 144 and 146 are each shown with an arrow to indicate their respective poling directions. When they are aligned as shown in FIG. 6 with their arrows pointing in the same direction, they are referred to herein as having a common poling direction.

The poling directions shown are obtained by applying a voltage across a piezo-ceramic element such that the more positive potential is at the tail of the arrow and the

more negative potential is at the head of the arrow. For example, in FIG. 6, bimorph 142 is shown being deflected upwardly by a voltage source 154 connected between elements 144, 146 and substrate 148. The polarity of source 154 is such that it is applying a voltage to element 144 in the same direction as its original polarizing voltage, whereas source 154 is applying a voltage to element 146 of a polarity opposed to its original polarizing voltage. When the polarity of a deflection voltage applied to a piezo-ceramic element is identical to the polarity of that element's original polarizing voltage, the applied deflection voltage is referred to herein as being applied in the poling direction. Thus, source 154 is applied to element 144 in its poling direction and is applied to element 146 in a polarity opposed to its poling direction.

When pairs of piezo-ceramic elements are aligned and cantilevered as indicated in FIG. 6, the bimorph will bend in the direction of the element which is being driven in its poling direction. Thus, bimorph 142 bends upwardly toward element 144 when driven by source 154 with the indicated polarity. When no voltage is applied to the bimorph, there is no deflection. When a source 156 is connected between substrate 148 and elements 144 and 146 as shown in FIG. 6, element 146 is driven in its poling direction and bimorph 142 deflects downwardly as indicated.

For some applications, the method of driving a bimorph illustrated in FIG. 6, wherein a deflection voltage is applied in the poling direction of one piezo-ceramic element and opposite to the poling direction of a second piezo-ceramic element is satisfactory. However, where a large amount of deflection is required, large deflection voltages are also required. It has been found that applying large voltages in a direction opposed to the poling direction of a piezo-ceramic element tends to depolarize that element and reduce its ability to bend or deflect.

A method of driving a bimorph with large amplitude deflection voltages without depolarizing either piezo-ceramic element is illustrated in FIG. 7. In the improved method, a bimorph 158 has a pair of electrically poled piezo-ceramic elements 160 and 162 which are also aligned in a common poling direction and bonded to a common substrate 164 between them. The bimorph 158 is cantilevered at one end 166 and is free to deflect at opposed end 168. In this improved method of deflecting a bimorph, deflection voltages are applied to the piezo-ceramic elements such that the polarity of the applied voltage is always in the poling direction of the element to which

it is applied so that a large degree of deflection of the bimorph can be effected without depolarizing either of the piezo-ceramic elements.

As shown in FIG. 7, when bimorph 158 is to be deflected upwardly, a voltage source 170 is connected between the piezo-ceramic element 160 and the substrate 164 such that the polarity of the applied voltage is in the poling direction of element 160. No opposed polarity voltage is applied to the element 162 since most of the bending of a bimorph is effected by the element which is driven in its poling direction.

When the bimorph 158 is to be deflected downwardly, a voltage source 172 is connected between the element 162 and the substrate 164 such that the polarity of the applied voltage is in the poling direction of the element 162. No opposed polarity voltage is applied to the element 160.

When bimorph 158 is to remain undeflected, sources 170 and 172 of equal magnitudes are applied between the elements 160 and 162 and the substrate 164 so that both piezo-ceramic elements 160 and 162 are driven in their poling directions. The net result of driving both elements equally is that no deflection takes place.

Although the sources 170 and 172 are depicted as being constant amplitude voltage sources, they need not be. If the bimorph 158 is to be deflected upwardly and downwardly with variable amounts of deflection, sources 170 and 172 could be made variable to accomplish such movement. However, the polarity of the voltages applied to elements 160 and 162 should always be in the poling direction of the element to which the voltage is applied.

A method of varying the magnitude and frequency of the deflection of bimorph 158 is illustrated schematically in FIG. 8a. As shown therein, a DC voltage from a source 174 is applied to the element 160 in its poling direction. The element 162 receives a DC voltage from source 176 which is in its poling direction. Preferably, sources 174 and 176 generate positive and negative DC voltages respectively, of magnitudes equal to  $1/2 V_{max}$ , where  $V_{max}$  is the peak to peak amplitude of the largest deflection signal which will be applied to the elements 160 and 162. Elements 160 and 162 are thus oppositely "biased" to  $1/2 V_{max}$  and, in the absence of any other deflection voltages, no deflection of bimorph 158 will occur.

For effecting alternating deflection of bimorph 158, an AC deflection source 178 is coupled between elements 160, 162 and substrate 164 through a pair of amplifiers 180 and 182 and DC sources 174 and 176. The peak-to-peak magnitude of the AC

deflection signal applied in phase to elements 160 and 162 may now be as large as  $V_{max}$  without ever applying to either element a net voltage which is opposed to its 5 poling direction.

When the deflection signal from the source 178 varies generally sinusoidally, the net voltage which appears across element 160 is indicated in FIG. 8b. With 10 the elements 160 and 162 oppositely biased at  $1/2 V_{max}$  and the superimposed AC deflection signal applied in phase to the elements, the net voltage across each of the 15 elements 160 and 162 always has a polarity which is in the poling direction of elements. The curves labeled "deflection" in FIG. 8b indicate that bimorph 158 deflects in accordance with the two times the instantaneous amplitude of the AC deflection 20 voltage provided by source 178.

When the net voltage on element 160 becomes more (or less) positive about  $1/2 V_{max}$ , the net amplitude of the voltage on element 162 becomes less (or more) negative correspondingly. However, because of the bias provided by source 176, the net voltage on the element 162 will always be in its poling direction as long as the magnitude of the AC deflection voltage does 30 not exceed  $V_{max}$ .

The system shown in FIG. 8a for driving the bimorph 158 is completely DC coupled so that bimorph 158 can be driven at very low frequencies by the source 178. In 35 applications where low frequency bimorph deflection is not required, a system such as that shown in FIG. 9 may be used. In the system of FIG. 9, only one amplifier 184 is needed for amplifying the AC deflection voltage from source 186. The amplified deflection voltage is applied to elements 160 and 162 via coupling capacitors 186 and 188, respectively. Separate DC bias voltage sources 190 and 192, each 45 having an amplitude of  $1/2 V_{max}$ , bias the elements 160 and 162 so that the net voltage on either element will be in its poling direction.

Referring again to FIG. 8a, the DC 50 source 174 and amplifier 180 are enclosed in a dashed triangle to indicate that, in practice, they may be embodied together in one composite amplifier which amplifies the deflection signal and also provides the 55 proper bias. Similarly, sources 176 and 182 may also be combined in a single composite amplifier. An example of a pair of composite amplifiers for driving a bimorph is shown in FIG. 10. The bimorph 60 which is being driven in FIG. 10 is part of a read transducer assembly 194 for use with the videotape apparatus shown in FIG. 3. Transducer assembly 194 is shown schematically and in simplified form in 65 FIG. 10 but is preferably similar to trans-

ducer assembly 36 shown in FIG. 2. (The piezo-ceramic generator 68 is not shown as part of transducer assembly 194 only in order to simplify the drawing).

The transducer assembly 194 has a top 70 piezo-ceramic layer 196 and a bottom piezo-ceramic layer 198 bonded to a common substrate 200 which is grounded. Deflection signals are applied to the transducer assembly 194 at upper and lower 75 conductive layers 202 and 204. Piezo-ceramic elements 196 and 198 are poled in a common direction as indicated by the arrows.

A read transducer 199 is mounted on 80 assembly 194 and is to be deflected in accordance with the principles and apparatus hereinbefore described. The piezo-ceramic layer 196 is driven by composite amplifier 206 and piezo-ceramic layer 198 85 is driven by the composite amplifier 208. The amplifiers 206 and 208 receive low level AC deflection signals at input terminal 210, amplify the deflection signals, and apply them superimposed on a DC 90 bias voltage, to conductive layers 202 and 204. Generally, amplifier 206 includes a first stage of amplification provided by differential transistor pair 212 and 214 and a second stage of amplification provided by 95 differential transistor pair 216 and 218. The output of transistor 218 is taken across constant current source transistor 220. The amplified signal at the collector of transistor 218 is applied to the bases of emitter 100 followers 224 and 226 and through emitter resistors 228 and 230 to an output terminal 232. The signal at terminal 232 is fed back to the base of transistor 214 via a feedback resistor 234 so that amplifier 206 operates 105 as an ordinary operational amplifier with negative feedback.

The DC bias appearing at output terminal 232 is typically +100 volts and is determined by resistors 236, 238, the feedback resistor 234 and the +200 volt power supply. An AC deflection signal of 200 volts peak to peak can appear at the output terminal 232 without opposing the polarization polarity of piezo-ceramic layer 196. 110 The transistors 240 and 242 provide short circuit protection for emitter followers 224 and 226, respectively, in order to limit their output current in the event that terminal 232 becomes inadvertently grounded. 120 Amplifier 208 is similar to amplifier 206 and provides an amplified deflection signal at its output terminal 244 superimposed on a DC bias of -100 volts. Amplifiers 206 and 208 can be used together to provide 125 the amplification performed by drive amplifier 100 in FIG. 3.

The composite amplifiers 206 and 208 provide large amplitude AC deflection signals superimposed on a DC bias voltage for 130

driving the deflectable bimorph without depolarizing it and thereby ensure that the driven bimorph does not lose its deflection sensitivity. The transducer system shown 5 in FIG. 10 and the methods illustrated in FIGS. 8 and 9 and described herein provide improved performance for deflectable bimorphs.

From the foregoing, it should be appreciated that various improved bimorph devices and methods have been described which, while representing different inventions, have been disclosed together in the environment of an improved videotape read 10 system. The bimorph motor-generator combination, for example, provides a compact, reliable device for sensing the instantaneous deflected position of a deflectable piezo-ceramic support arm. The illustrated 15 embodiment of this device shows it as part of an improved videotape read assembly for generating an output signal indicative of the deflected position of a read transducer. This novel assembly overcomes 20 problems associated with deflectable read assemblies which vibrate when they receive an electrical or mechanical impulse by generating an output signal which can be converted to a damping signal for damping 25 the transducer vibrations.

The damping of transducer vibrations is achieved by the described feedback control system which generates a signal indicative of the velocity of a deflected or vibrating 30 transducer, converts the velocity signal to a damping signal, and applies the damping signal to the transducer support arm to dampen vibrations therein. The improved bimorph motor-generator combination is 35 preferably used in this damping system to generate a signal indicative of instantaneous transducer position, the transducer velocity signal being derived by differentiating the transducer position signal. Various means 40 are included in the damping system for stabilizing the feedback control system at frequencies near the resonant and anti-resonant points of the bimorph-motor-generator. This feedback control system, 45 in combination with the novel bimorph motor-generator transducer assembly, provides effective damping of a deflectable videotape read transducer without restricting 50 the dynamic deflection range of the transducer. Moreover, this electronic damping system is not adversely affected 55 by the high G accelerations normally encountered in videotape read systems.

The damping signals and transducer 60 deflection signals are preferably applied to the bimorph transducer support arm by the method and apparatus described herein which overcomes the depolarizing effects associated with prior methods by ensuring 65 that the applied deflection signals are al-

ways in the poling direction of the piezo-ceramic element to which they are applied. A composite amplifier embodying this improved method receives large amplitude transducer deflection signals and applies 70 them to the bimorph so as to achieve large bidirectional bimorph deflection without depolarizing the bimorph, thereby maintaining high bimorph deflection sensitivity.

The above-described improvements have 75 been combined in a new improved videotape read system for use with videotape recorders, and particularly for use with helical videotape recorders. However, the improvements may be used independently 80 of one another and in applications other than videotape read systems.

This specification includes matter which is common to our copending applications Nos. 10036/77, 10505/77, 10991/77 and 85 11478/77 (Serial Nos. 1579852, 1579854, 1572050 and 1579856).

#### WHAT WE CLAIM IS:—

1. A transducer in which an arm which supports a transducing head is capable of 90 producing deflection of the head in response to an electrical control signal and in which transducer vibratory deflection of the head is damped by degenerative feedback derived from the instantaneous displacement 95 or velocity of displacement of the head.

2. A transducer according to claim 1, in which the head is a magnetic transducing head disposed to record or play back signals along a track in a magnetic recording 100 medium and the arm is disposed to provide deflection of the transducer to and fro in a direction across the track.

3. A transducer according to claim 2, in which the head is disposed for scanning 105 oblique tracks on a magnetic tape and for this purpose is mounted by way of the arm on a rotary carrier in a video signal recording or playback machine.

4. A transducer according to any foregoing claim in which a feedback network is provided to combine a drive signal for controlling the deflection of the head with a feedback signal, which damps that deflection, the network being disposed to derive 115 the feedback signal from a positional signal produced by a sensor which is coupled to the arm to sense the position of the head.

5. A transducer according to any foregoing claim in which the arm comprises a 120 piezoelectric bimorph.

6. A transducer according to claim 5 in which the bimorph incorporates a piezoelectric generator which provides on flexure of the bimorph a signal representing the 125 instantaneous deflected position of the head.

7. A transducer according to claim 5 or claim 6 in which the bimorph is in the form of a cantilever which carries the head at 130

its free end.

8. A transducer according to claim 6 or claim 7 in which the piezoelectric generator extends for substantially the whole length 5 of the cantilever.

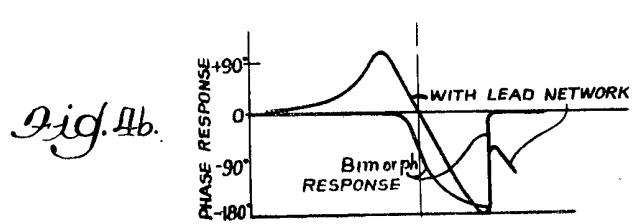
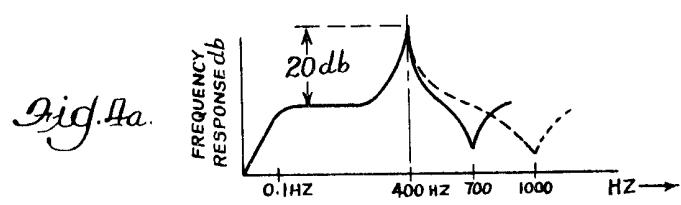
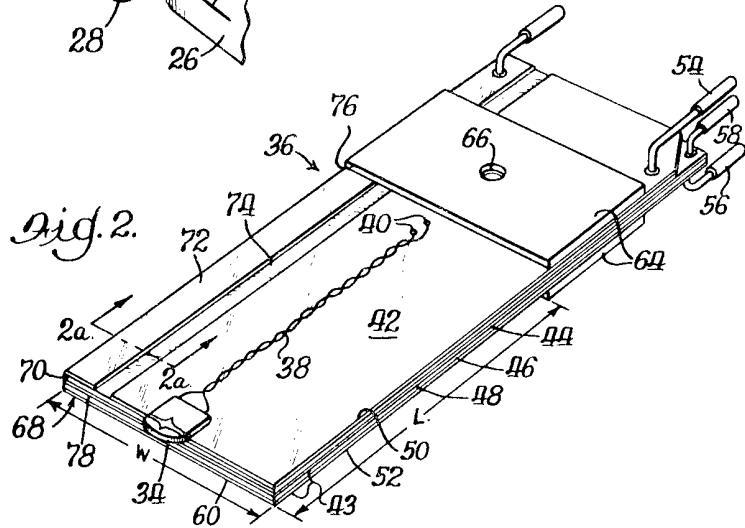
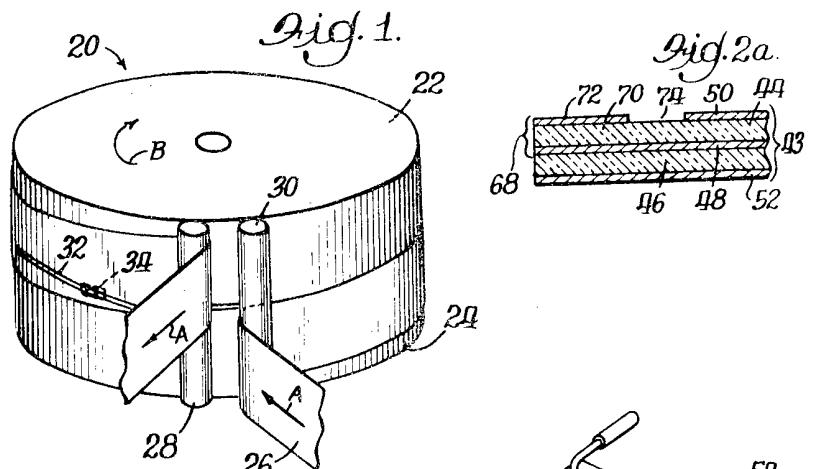
9. A transducer according to claim 4 and any of claims 5 to 8 in which the network includes a filter which excludes from the feedback signal those components of the 10 positional signal which are due to the existence of resonances, of higher order than the first, of the bimorph.

10. A transducer according to claim 4 and any of claims 5 to 9 in which the net- 15 work includes means for compensating phase shifts between the drive signal and

the feedback signal, in order to nullify oscillatory signals which are due to a first-order resonance of the bimorph.

11. A transducer according to claim 4 20 and any of claims 5 to 10 in which means are provided for augmenting the positional signal by part of the drive signal to reduce the gain of the said network in respect of signal frequencies in the region between 25 the first and next higher order of anti-resonance of the bimorph.

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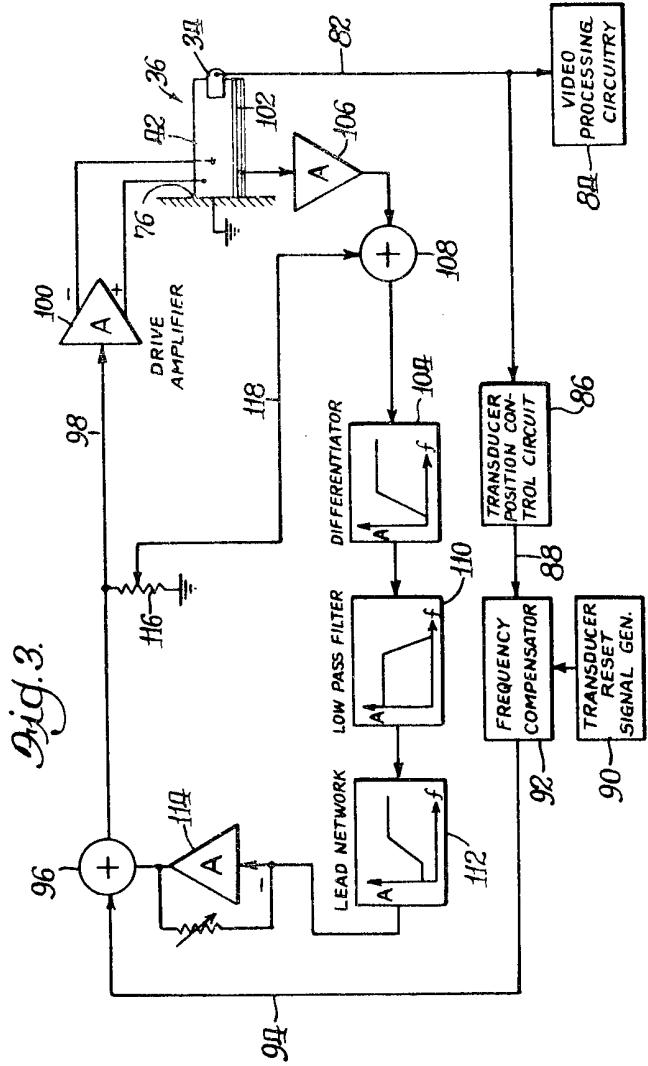
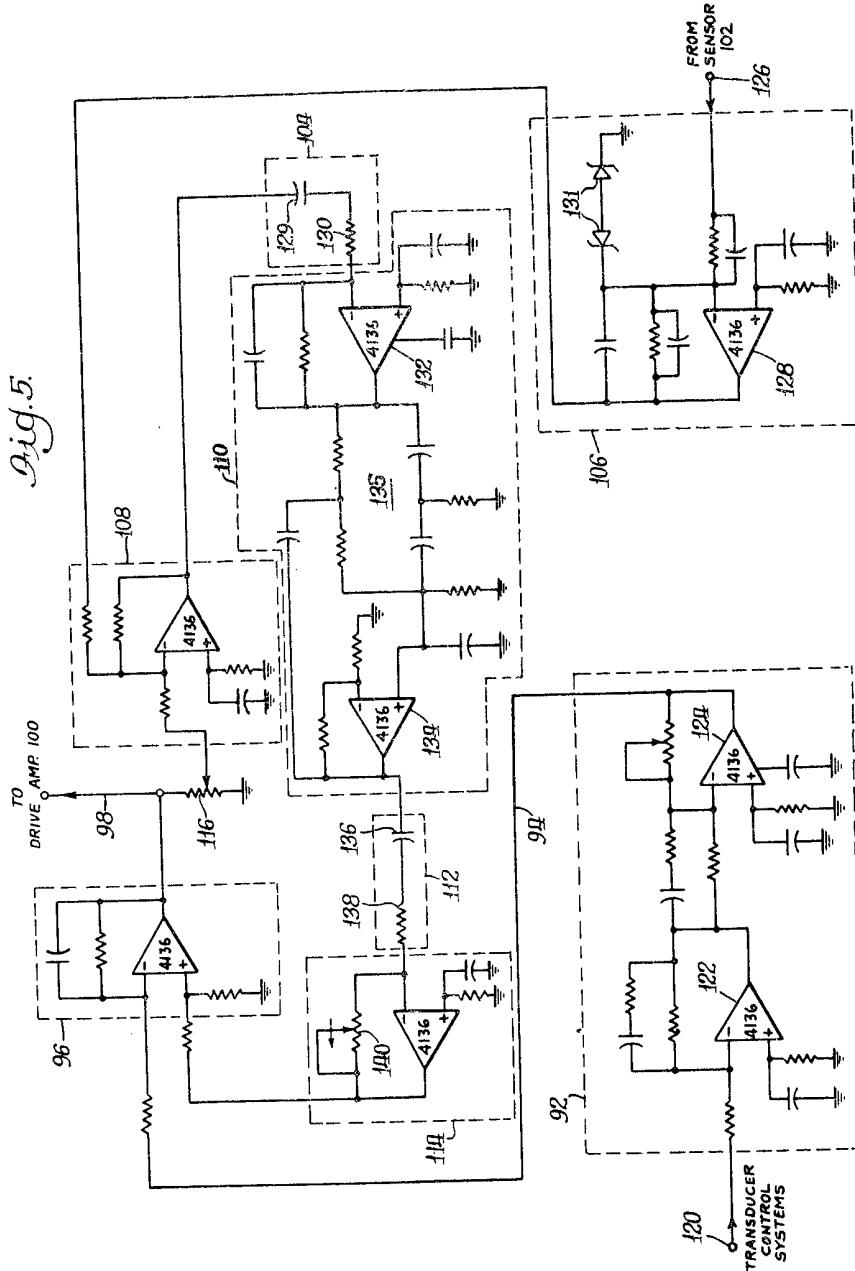
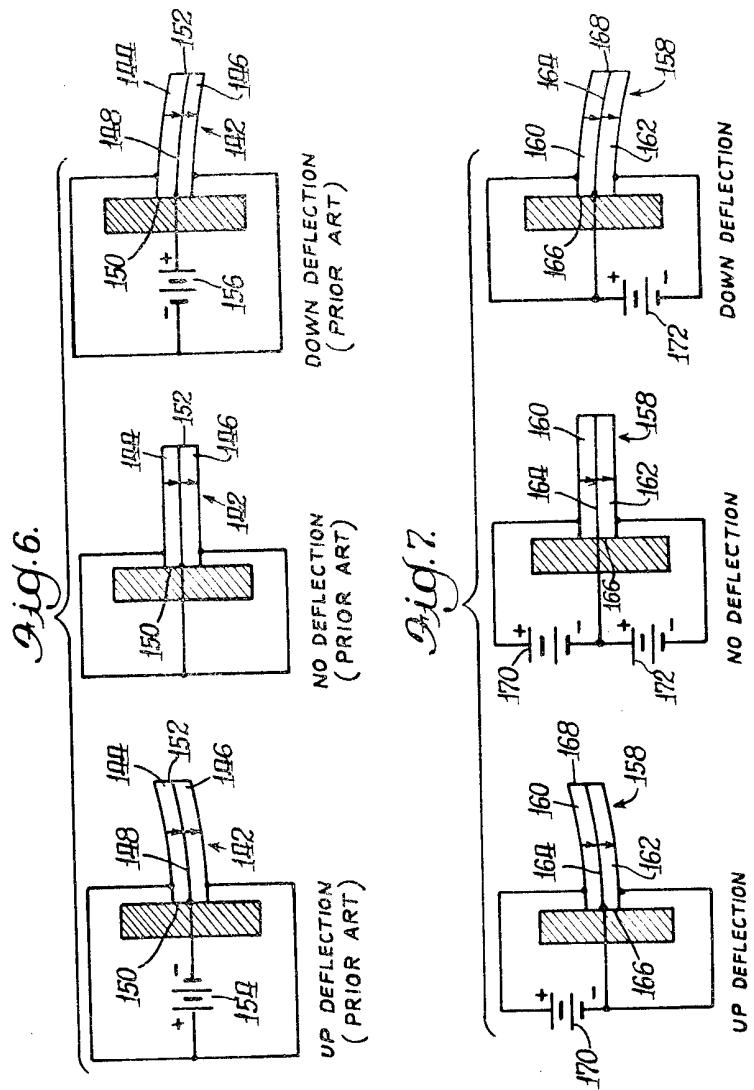


Fig. 5.





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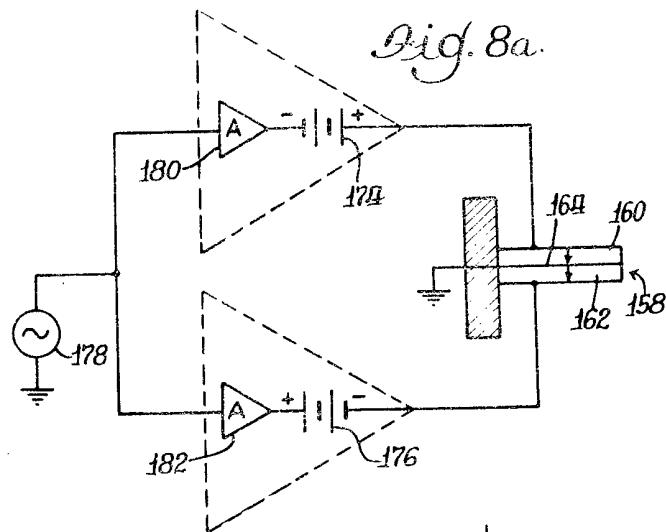
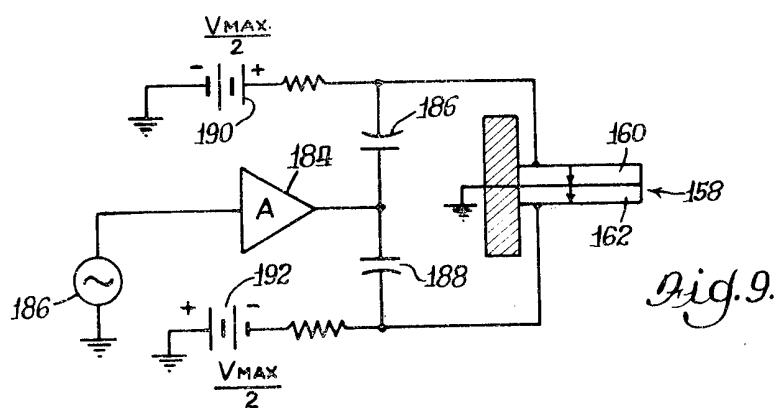
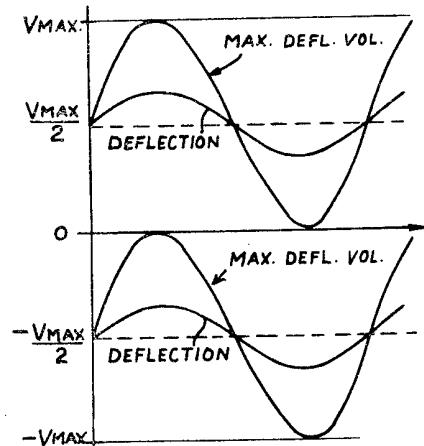


Fig. 8b.



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Fig. 10.

