

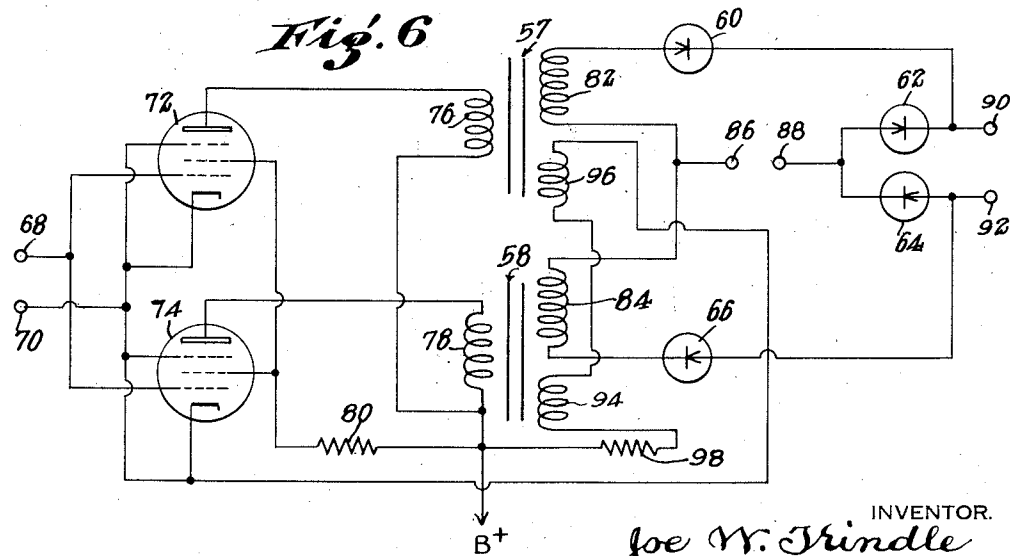
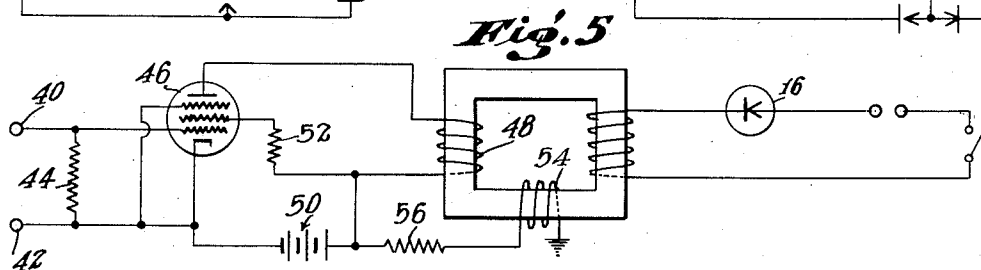
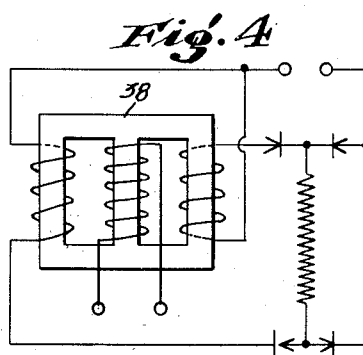
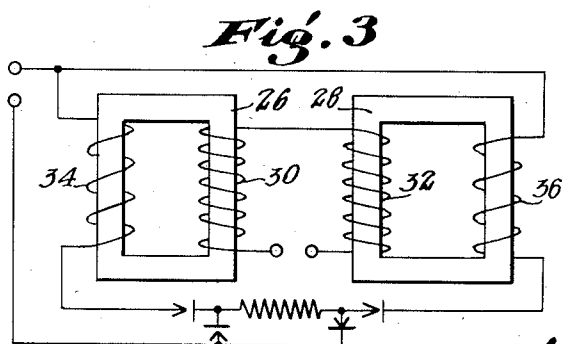
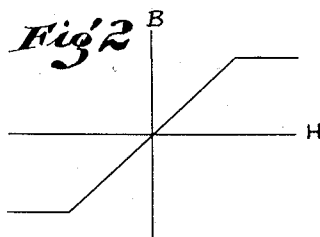
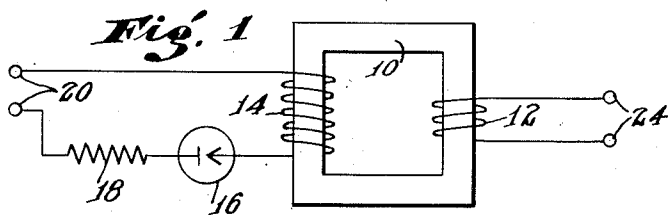
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TRANSDUCTOR

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TRANSDUCTOR

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This invention relates to improvements in transducers, also known as saturable reactors or magnetic amplifiers of the self-saturated type and more particularly to that type of transducer which is designed to control efficiency of a large amount of alternating current power with a small amount of direct current power.

While several types of transducers have heretofore been employed as control devices for regulating the direct current output of power from circuits supplied by an alternating current input, due to certain inherent limitations, such devices have had but a restricted use. Thus, such transducers respond sluggishly to changes in the control current applied with the result that they are unsuitable for many uses wherein a rapid control is desired. For instance, in devices employing servo mechanisms where a relatively small direct current control current must be greatly amplified to obtain sufficient direct current power for the driving motor, it is frequently necessary that the driving motor respond quite rapidly to any changes in the control current. Despite their ruggedness and efficiency, however, known types of transducers cannot be used for this purpose because of their sluggish response.

In addition, for reasons which will be hereinafter explained, certain types of transducers have but limited applications in that their output cannot be reduced to zero.

Accordingly, it is a principal object of this invention to provide a transducer having a rapid response to changes in the control current applied.

It is a further object of this invention to provide such a transducer wherein the power output can be reduced to zero.

It is an additional object of this invention to provide a transducer wherein the current in the control circuit is independent of supply frequency flux changes in the transducer core.

It is still a further object of this invention to provide such a transducer wherein the time constant of the control circuit is made exceedingly small by utilizing magnetic saturation of the core within the control winding.

It is another object of this invention to provide such a transducer of high efficiency, low cost and small size.

Other objects and advantages of the invention will be apparent during the course of the following description.

In the drawings:

Figure 1 illustrates a simplified schematic diagram of a transducer which will be referred to in explaining the operation of the invention;

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Figure 2 is an idealized B-H curve of the transducer shown in Figure 1;

Figure 3 is a schematic diagram showing a modification of the transducer of Figure 1;

Figure 4 is a schematic diagram showing a further modification of the transducer of Figure 1;

Figure 5 is a circuit diagram of a transducer illustrating one embodiment of the present invention; and

Figure 6 is a circuit diagram of a transducer illustrating a second embodiment of the present invention.

Referring first to Figures 1 and 2, the basic principles underlying the operation of transducers will now be explained. Figure 1 shows a core 10 of iron or other material preferably of high permeability, about which is wound a control winding 12 and an anode winding 14. In series with the anode winding 14 are a rectifier 16 and a load resistor 18. A supply voltage of alternating current is supplied to the terminals 20 and a control voltage of direct current is supplied through the terminals 24. Figure 2 represents an idealized B-H curve for the core 10 of the transducer shown in Figure 1. As will be apparent to those skilled in the art, Figure 2 is not a true B-H curve, inasmuch as the shoulder portions of the curve are shown as sharp angles and the hysteresis losses in the core are ignored in that a single curve is utilized to represent both the charging and the discharging of the core. The simplified curve shown is sufficient, however, to illustrate the operating principles of the transducer of Figure 1. The ordinate of the curve is the flux density of the core (B) while the abscissa of the curve represents its magnetic intensity (H). As an alternating current voltage wave is applied to the terminals 20 of the anode circuit, current begins to flow through the anode winding 14. The magnitude of this current is determined by the impedance of the anode windings 14 and the load resistor 18 (ignoring the resistance of rectifier 16). When the core 10 is unsaturated the anode circuit will be highly inductive in that the inductive impedance of the winding 14 is much greater than impedance of the load resistor 18. The current flowing through the anode circuit will therefore be nearly 90 degrees out of phase with the applied voltage. As the anode current rises, the magnetic intensity H of the core will increase until the core becomes saturated. This condition is represented by the upper shoulder of the curve shown in Figure 2. Inasmuch as the inductance L of the anode circuit is proportional to the slope of the B-H curve, when the shoulder of that

curve is passed or in other words when the core 10 becomes saturated, the inductance of the anode winding drops substantially to zero. The impedance of the anode circuit is therefore very greatly reduced being merely the resistance of the load resistor 18. Consequently, the current in the anode circuit rises sharply. The anode circuit is now purely resistive, the anode current is in phase with the impressed voltage, and power is delivered to the load resistor 18. As the applied voltage wave passes through its first half cycle, the current in the anode circuit decreases and the core again becomes unsaturated. During the second half cycle of the impressed voltage wave the anode current decays to zero. Current cannot flow in the opposite direction due to the presence of the rectifier 16 with the result that no power will be delivered to the load after the anode current has decayed to zero. At the completion of a full wave of the supply voltage, the cycle repeats. Thus, during the first half of the supply voltage wave a current is caused to flow in the anode circuit. This current which is 90 degrees out of phase with the impressed voltage gradually increases in magnitude until the transducer "fires" that is, until the core 10 becomes saturated. At this time the inductive impedance of the anode circuit drops to substantially zero, the current in the circuit rises sharply and power is delivered to the load.

It has thus far been assumed that no current has been flowing through the control winding. In a manner which will now be described, a relatively small direct current flowing in the control winding is utilized to control the power output of the anode circuit. As above described, the power output of the anode circuit is negligible until the core 10 becomes saturated at which time the full impressed supply voltage is across the load of the circuit. The output power delivered by the anode circuit to the load is determined by the portion of each cycle of impressed voltage during which the core is saturated. Referring to Figure 2, if a current is flowing in the control winding, the magnetic intensity of the core 10 will be changed. Thus, the initial or starting point on the B—H curve can be controlled by the direction and magnitude of the current in the control winding. Assuming that the control current is flowing in such direction as to raise the initial point on B—H curve, it is apparent that the current in the anode circuit necessary to saturate the core will be reduced. Thus, as the anode current commences to rise during the positive half cycle of the supply voltage, the saturation point, or shoulder of the B—H curve will be more quickly reached, with the result that the transducer will "fire" at an earlier point on the cycle and power will be delivered to the load during a greater portion of the cycle. This will, of course, result in a greater power output. On the other hand, if the current in the control winding is reversed, the initial or starting point on the B—H curve will be lower with the result that a greater current becomes necessary for core saturation. When this condition exists, the transducer will not "fire" until a greater portion of the positive half cycle of the supply voltage has passed. Power will therefore be delivered to the load during a smaller portion of the voltage cycle, with the result that a smaller power output will be realized. Thus, it is seen that the control circuit can be used to determine the period of each cycle of impressed voltage during which

the core is saturated and consequently the amount of power delivered to the load. The transducer acts as a direct current amplifier in that only a very small current need be delivered to the control circuit to effectively control a relatively large amount of direct current power output. This results from the fact that the resistance of the control winding is made exceedingly small so that the power absorbed by the control circuit is small.

The above principles are well-known in the art. When attempts are made to develop practical transducers operating under these principles, however, several difficulties arise. Principal among these difficulties is the fact that the transducer acts as a transformer with the result that it becomes impossible to reduce its output to zero. Thus, the anode circuit acts as a primary while the control circuit acts as a secondary. Flux variations at supply frequency in the core 10, caused by the cyclically varying supply voltage, cause currents in the control circuit. This flow of current in the control winding causes, by Lenz's Law, a similar current to flow in the anode circuit. This anode current in turn flows through the load with the result that the transducer must always deliver some power to the load. It is therefore not possible to design a transducer of the type described above wherein the power output can be reduced to zero. Inasmuch as substantially all applications for which a transducer is suitable require this feature, a simple transducer of the type described above has not been practical.

In order to eliminate the above described transformer action in a transducer, and make possible a zero power output, two transducer circuits have been devised. These are illustrated in Figures 3 and 4. Each of these operates on the same principle. That is, the induction of voltage in the control circuit by flux variations at supply voltage frequencies are avoided by utilizing bucking windings. Referring to Fig. 3, this is accomplished by employing two cores 26 and 28 and two control windings 30 and 32 connected in series. Similarly, a pair of anode windings 34 and 36 are used. The directions of the various windings are so arranged that supply frequency voltages in the control winding 30 resulting from flux variations at supply frequency in the core 26 oppose similar voltage variations induced in the control winding 32. The supply frequency voltages induced in windings 30 and 32 buck each other out with the result that no currents at supply frequency will flow through the control circuit. The circuit of Figure 4 is similar. Here a multi-legged core 38 is employed with the control winding about the middle leg. Parallel anode windings are wound about the other legs of the core, their direction being such that supply frequency flux variations caused in the outer legs of the core by the supply voltage variations oppose and therefore buck each other in the control winding leg of the core. Inasmuch as there are no supply frequency flux variations in that portion of the core about which the control windings are wound, no voltages of supply frequency are induced in the control circuit, and no supply frequency currents flow in such circuit.

The circuits of Figures 3 and 4 have been found satisfactory insofar as the range of control is concerned. That is, the power output of the transducer can be varied from a maximum to zero. Such transducers, however, have an

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inherent limitation in that they respond but sluggishly to changes in the control current. This is due to the fact that the control circuits in these transducers have an inductance which is very high compared to their resistance, hence a relatively long time constant.

As is well known, the time constant of a circuit such as the control circuit of a transducer, is equal to L/R , the circuit inductance divided by the circuit resistance. The control circuits of the transducers above described must have a relatively high inductance in order that a sufficient control range can be realized without using excessively high control current. If the inductance of the control circuit were made small so as to reduce its time constant, a large control current would be required with a resultant increase in the power dissipated in the control circuit and decrease in efficiency. On the other hand, increasing the resistance in the control circuit to a value sufficient to provide a small time constant is not feasible in that such a high value of resistance would be required that the power losses in the control circuit would become impractically large.

It has been found that if the inductance of the control circuit be reduced during but a portion of each cycle of supply voltage, the transducer output will rapidly follow changes in the control voltage applied. Accordingly, in the present invention, and as one of the principal features thereof, a transducer is provided having a control circuit, the inductance of which is reduced to practically zero during a portion of each cycle of the supply voltage. The output of such transducer will consequently follow very rapidly changes in the control current. This reduction of the inductance of the control circuit during a portion of each cycle is accomplished by saturating the portion of the iron core within the control winding. Referring again to Figure 2, as above stated, the inductance of the control circuit is proportional to the slope of the B—H curve. When the operating point on the curve passes the shoulder, in other words when the core becomes saturated, the slope of the B—H curve becomes substantially zero with the result that the circuit inductance becomes substantially zero and the time constant of the circuit is therefore very small. Thus, by utilizing the self saturating characteristic of the transducer, a very short time constant control circuit can be realized. It is of course necessary, in order to accomplish this result that that portion of the core within the control winding be saturated. For reasons now to be explained, this cannot be accomplished with present types of transducers. Thus, referring to the transducer shown in Figure 3, as previously explained, the polarities of windings must be such that supply frequency voltage variations in the control winding 30 resulting from flux changes set up by the voltage variations of the anode winding 34 oppose similar voltage variations induced in the winding 32. Supply frequency voltage changes tending to alter the flux density in the core 26 in one direction must therefore tend to alter the flux density in the core 28 in the other direction with the result that saturation of both cores at the same time cannot result. One of the two series connected control windings must always therefore have an unsaturated core and the control circuit will have a high inductive impedance at all times. Consequently the control winding will have a long time constant. For similar reasons, control winding core

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saturation cannot be utilized in the transducer shown in Figure 4. Thus, in this circuit flux variations caused by the cyclically varying impressed voltage buck in the leg of the core about which the control winding is wound with the result that the flux density in this leg is independent of supply frequency voltage variations. If the flux density in this leg is sufficient to saturate the leg during any portion of the supply voltage cycle, such saturation must exist during the entire cycle with the result that changes in the control current would not affect the transducer output, and the circuit would be inoperative.

In Figure 5 is shown a simplified circuit diagram of a transducer embodying the present invention in which core saturation is utilized to obtain a low time constant control circuit with the result that rapid response to control current changes can be achieved. In addition, a wide output range extending from maximum to zero can be obtained by varying the control current. The novel features of the circuit making possible both of these desirable characteristics are found in the control circuit. The input to the control circuit consists of terminals 40 and 42 with terminal 42 normally being at ground potential. The input current will develop a voltage across the resistor 44 of the pentode tube 46. In the plate circuit of the tube 46 as shown is the control winding 48 and the source of high potential, shown here as a battery 50. A screen dropping resistor 52 is connected between the potential source and the screen of the tube to provide the proper screen voltage. The plate current of the tube 46, hence the current flowing through the control winding 48, is proportional to the voltage applied to the control grid of the tube which in turn is proportional to the applied control current. As is well known, the very high plate resistance of a pentode tube causes such tube to operate as a constant current device whereby the plate current will change only with changes in the applied grid voltage. By utilizing a constant current device in the control circuit, as shown, the desired minimum or zero load characteristic can be accomplished in the simple transducer circuit shown. Thus, as above described, it has heretofore not been possible to employ a simple transducer circuit and accomplish a zero load control due to the transformer action of the circuit. In accordance with the present invention, this is accomplished for the following reasons: Supply frequency flux variations caused by the supply voltage do not cause currents at supply frequency to flow in the control winding (with the result that similar currents flow in the anode circuit) because of the action of the constant current input to the control circuit. Thus, due to the high resistance of the plate circuit of the pentode 46, undesired currents at supply frequency cannot flow through the control winding. The control circuit disclosed in Figure 5 therefore prevents the transducer from acting as a transformer and makes possible a range of control extending to a zero output.

Referring again to Figure 2, it can be seen that in order to provide the full range of control, the initial operating point must be variable from the upper shoulder or maximum output to the lower shoulder or zero output. It is therefore necessary that the direction of flux in the core be reversed as the zero axis is passed. While this can be readily accomplished in the simple transducer shown in Figure 1 by simply reversing the direc-

tion of current flow in the control circuit, in the control circuit shown in Figure 5, this cannot be accomplished inasmuch as the plate current of pentode tube 46 can flow in but one direction. To provide operation over the full range, the bias winding 54 is provided. A current in the bias winding is obtained through the resistor 56 from the battery 50. The direction of the bias winding 54 is such that the flux induced in the transducer core by current flowing through the bias winding will oppose that induced by current in the control circuit. The resistor 56 is chosen of such value that the operating point on the B-H curve will be at the lower shoulder thereof. In this manner, the unidirectional control current can be utilized to regulate the transducer over its full range.

A modified form of the transducer shown in Figure 5 is illustrated in Figure 6. The circuit shown in Figure 6 is essentially a full wave application of that shown in Figure 5. Thus, as previously explained, the simple transducer circuit shown in Figure 1 delivers power to the load only during a portion of alternate half cycles of the supply voltage which for conveniences will be referred to as the positive half cycles. The same is true for the transducer shown in Figure 5. The negative half cycles of the supply voltage cannot cause power to be delivered to the load because of the presence of the rectifier 16 which permits current to flow in but one direction. In the circuit shown in Figure 6, both halves of the supply voltage wave are utilized to deliver power to the load. This is accomplished by utilizing two independent cores indicated at 57 and 58 and a series of rectifiers 60, 62, 64 and 66. A direct current control voltage is applied between the terminals 68 and 70 to the pentode tubes 72 and 74 by means of their control grids which are connected together. In the plate circuit of the tube 72 is the control winding 76 which is wound about a portion of core 57 and in the plate circuit of tube 74 is a control winding 78 which is wound about a portion of core 58. Plate voltage for the tubes is obtained from the high voltage source as shown. Also connected to the high voltage source is a screen dropping resistor 80 which provides the proper operating potential for the screen grids of the two tubes which are connected together. The control windings 76 and 78 are wound about their respective cores in opposite directions with the result that changes in the applied control voltage will cause corresponding changes in the flux density in one core in one direction and a corresponding change of flux density in the other core in the reverse direction.

Referring now to the anode circuit of the transducer shown in Figure 6, it is seen that a pair of anode windings 82 and 84 connected in series are provided, winding 82 being wound about a portion of core 57 and winding 84 being wound about a portion of core 58. As with control windings, windings 82 and 84 are wound in opposite directions. The alternating current supply voltage is applied between terminals 85 and 86 and the transducer output is taken from terminals 90 and 92. One half of the output current flows from the terminal 88, through the rectifier 64, thence through the load, the rectifier 60, the anode winding 82 and back to terminal 86 of the supply source. Similarly, the other half of the output current will flow from the supply terminal 86 through the anode winding 84, through the rectifier 66, thence through the load, through the rectifier 62 back to the

supply terminal 88. During the positive half of the supply voltage cycle, current will be caused to flow through one of the anode windings and during the negative half cycle of the supply voltage current will be caused to flow through the other anode winding. As will be apparent to those versed in the art, direct current power of the same polarity will be delivered to the load during both positive and negative portions of the supply cycle in a manner similar to that of the familiar full wave rectifier circuit.

In order that the zero output may be obtained when the control current is reduced to zero, that is, in order that the starting point on the B-H curve (Fig. 2) will be at the lower shoulder in the absence of any control current, bias windings 94 and 96 are provided. Current of the desired magnitude is obtained from the supply source as shown through a resistor 98.

While the circuit of Figure 6 has been found satisfactory for most purposes, where a very high degree of accuracy is desired or where the direct current supply voltage is apt to vary appreciably, it has been found that good results can be obtained if a voltage regulator is used in the direct current supply voltage circuit. In addition, while the zero output characteristic of the circuit has been found to be very satisfactory, the circuit will inherently have some transformer action between the anode and bias windings of each core. If it be found that this transformer action is sufficient to adversely affect the zero output characteristic of the transducer, it can be eliminated by utilizing the pentode tube as a constant current source to derive the current for the bias winding in a manner identical to that used to eliminate the transformer action between the control and anode windings.

While in the embodiments of the present invention shown in Figures 4 and 5 the elimination of transformer action between the anode and control windings, making possible the utilization of core saturation to achieve a very short time constant control circuit, has been accomplished by using pentode type vacuum tubes in the control circuit, it is to be understood that the invention is not so limited and that other well-known types of constant current devices can be used with good results. In particular, it has been found that satisfactory results have been realized utilizing vacuum tubes of the screen grid types.

It is to be understood that the transducer circuits shown in Figs. 4 and 5 and described herein are for purposes of illustration only, and that various alterations and modifications may be made thereto without departing from the spirit and scope of the invention, and it is desired that any and all such modifications be considered within the purview of the present invention, except as limited by the hereinafter appended claims.

I claim:

1. A transducer comprising a core, an anode circuit including in series relation an anode winding wound about a portion of the said core, a rectifier, means for impressing on said circuit an alternating current supply voltage and output terminals for obtaining from said circuit direct current output power; a control circuit for controlling the transducer power output including a control winding wound about a portion of the said core and a source of control current for said control winding, said source of control current including a multi-electrode dis-

charge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element, means for impressing a direct current control voltage on the control grid of the said discharge tube to control the current in the control circuit, the current in the control circuit being unaffected, due to the high internal impedance of the said discharge tube, by changes in flux density in the said core resulting from changes in the amplitude of the supply voltage at the supply frequency; a bias winding wound about a portion of the said core and means for supplying a direct current biasing current to the said bias winding in such direction that the magnetic flux caused by the said biasing current is in the opposite direction to that caused by the current in the said control winding.

2. A transducer comprising a core, an anode circuit including in series relation an anode winding wound about a portion of the said core, a rectifier, means for impressing on said circuit an alternating current supply voltage and output terminals for obtaining from said circuit direct current output power; a control circuit for controlling the transducer power output including a control winding wound about a portion of the said core and a source of control current for said control winding, said source of control current including a multi-electrode discharge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element, means for impressing a direct current control voltage on the control grid of the said discharge tube to control the current in the control circuit, the current in the control circuit, due to the high internal impedance of the said discharge tube, being unaffected by changes in flux density in the said core resulting from changes in the amplitude of the supply voltage at the supply frequency; a bias winding wound about a portion of the said core and means for supplying a direct current biasing current to the said bias winding in such direction that the magnetic flux caused by the said biasing current is in the opposite direction to that caused by the current in the said control winding, the flux density in that portion of the core about which the control winding is wound being sufficient to saturate said portion during a part of each cycle of supply voltage thereby appreciably reducing the inductive impedance of the control circuit, and imparting to the control circuit a relatively short time constant during such part of the supply voltage cycle, whereby the power output of the transducer will vary rapidly in response to changes in the control current.

3. In a transducer, a pair of cores, an anode circuit comprising a first anode winding wound about a portion of one of the cores, a rectifier, output terminals, a second rectifier, input terminals for impressing an alternating current supply voltage on said circuit, said anode winding and rectifiers constituting a direct current path through said output terminals and through said input terminals, a second anode winding wound about a portion of the other of said cores, a third rectifier and a fourth rectifier, said second anode winding and third and fourth rectifiers constituting a second direct current path through said output terminals and through said input terminals, a control circuit comprising a first control winding wound about a portion of one of the said cores, a second control wind-

ing wound about a portion of the other of said cores, a constant current source for supplying direct current control current to said control windings and means for regulating control current.

4. In a transducer, a pair of cores, an anode circuit comprising a first anode winding wound about a portion of one of the cores, a rectifier, output terminals, a second rectifier, input terminals for impressing an alternating current supply voltage on said circuit, said anode winding and rectifiers constituting a direct current path through said output terminals and through said input terminals, a second anode winding wound about a portion of the other of said cores, a third rectifier and a fourth rectifier, said second anode winding and third and fourth rectifiers constituting a second direct current path through said output terminals and through said input terminals, a control circuit comprising a first control winding wound about a portion of one of the said cores, a constant current source for supplying direct current control current to said first control winding, a second control winding wound about a portion of the other of said cores, a second constant current source for supplying direct current control current to said second control winding, and means for regulating the said control currents.

5. A transducer comprising a pair of cores, an anode circuit including an anode winding wound about a portion of one of said cores and a second anode winding wound about a portion of the other of said cores, said anode windings being connected in series relation, output terminals for obtaining direct current output power from said anode circuit, input terminals for applying an alternating current input voltage to said anode circuit, a plurality of rectifiers providing a full wave rectifier circuit whereby direct current power is delivered to the said output terminals during both halves of each cycle of input voltage, a control circuit for controlling the output power of the transducer including a first control winding wound about a portion of one of the said cores, a source of direct current control current for said first control winding, a second control winding wound about a portion of the other of said cores, a second source of direct current control current for said second control winding, and means for simultaneously regulating the control current from each source, the control current from each of the said sources being responsive to said means but not responsive to supply frequency voltage variations in said control windings.

6. In a transducer, a pair of cores, an anode circuit comprising a first anode winding wound about a portion of one of the cores, a rectifier, output terminals, a second rectifier, input terminals for impressing an alternating current supply voltage on said circuit, said anode winding and rectifiers constituting a direct current path through said output terminals and through said input terminals, a second anode winding wound about a portion of the other of said cores, a third rectifier and a fourth rectifier constituting a second direct current path through said output terminals and through said input terminals, a control circuit including a first control winding wound about portion of one of the said cores, a second control winding wound about a portion of the other of said cores, a constant current source for supplying direct current control current to said control windings, means for regulating the

control current, a first bias winding wound about a portion of one of the said cores, a second bias winding wound about a portion of the other of the said cores and a constant current source of direct current for said bias windings.

7. In a transducer, a pair of cores, an anode circuit comprising a first anode winding wound about a portion of one of the cores, a rectifier, output terminals, a second rectifier, input terminals for impressing an alternating current supply voltage on said circuit, said anode winding and rectifiers constituting a direct current path through said output terminals and through said input terminals, a second anode winding wound about a portion of the other of said cores, a third rectifier and a fourth rectifier, said second anode winding and third and fourth rectifiers constituting a second direct current path through said output terminals and through said input terminals, a control circuit comprising a first control winding wound about a portion of one of the said cores, a constant current source for supplying direct current control current to said first control winding, a second control winding wound about a portion of the other of said cores, a second constant current source for supplying direct current control current to said second control winding, means for regulating the said control currents, a first bias winding wound about a portion of one of the said cores, a second bias winding wound about a portion of the other of the said cores and a constant current source of direct current for said bias windings.

8. A transducer comprising a pair of cores, an anode circuit including an anode winding wound about a portion of one of said cores, a second anode winding wound about a portion of the other of said cores, output terminals for obtaining direct current output power from said anode circuit, input terminals for impressing an alternating current input voltage on said anode circuit, a plurality of rectifiers providing a full wave rectifier circuit whereby direct current power may be delivered to the said output terminals during both halves of each cycle of input voltage, a control circuit for controlling the output power of the transducer including a first control winding wound about a portion of one of the said cores and a second control winding wound about a portion of the other of said cores, a source of current for said control windings comprising a circuit including a multi-electrode discharge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element, means for impressing a direct current control voltage on the control grid of the said discharge tube to regulate the current in the control circuit, the characteristic of the control circuit being such that the current flowing therethrough varies in response to variations in the said control voltage but is unaffected by voltage variations in the said control windings at the frequency of the alternating current input voltage.

9. A transducer comprising a pair of cores, an anode circuit including an anode winding wound about a portion of one of said cores, a second anode winding wound about a portion of the other of said cores, output terminals for obtaining direct current output power from said anode circuit, input terminals for impressing an alternating current input voltage on said anode circuit, a plurality of rectifiers providing a full wave rectifier circuit whereby direct current power may be delivered to the said output ter-

minals during both halves of each cycle of input voltage, a control circuit for controlling the output power of the transducer including a first control winding wound about a portion of one of the said cores and a second control winding wound about a portion of the other of said cores, a source of current for said control windings comprising a circuit including a multi-electrode discharge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element, means for impressing a direct current control voltage on the control grid of the said discharge tube to regulate the current in the control circuit, the characteristic of the control circuit being such that the current flowing therethrough varies in response to variations in the said control voltage but is unaffected by voltage variations in the said control windings at the frequency of the alternating current input voltage, a first bias winding wound about a portion of one of the said cores, a second bias winding wound about a portion of the other of the said cores and a constant current source of direct current for said bias windings.

10. A transducer comprising a pair of cores, an anode circuit including an anode winding wound about a portion of one of said cores, a second anode winding wound about a portion of the other of said cores, output terminals for obtaining direct current output power from said anode circuit, input terminals for impressing an alternating current input voltage on said anode circuit, a plurality of rectifiers providing a full wave rectifier circuit whereby direct current power may be delivered to the said output terminals during both halves of each cycle of input voltage, a control circuit for controlling the output power of the transducer including a first control winding wound about a portion of one of the said cores and a second control winding wound about a portion of the other of said cores, a multi-electrode discharge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element for supplying a direct current control current for said first control winding, a second and similar discharge tube for supplying a direct current control current for said second control winding, the characteristic of the control circuit being such that the current flowing therethrough varies in response to variations in the said control voltage but is unaffected by voltage variations in the said control windings at the frequency of the alternating current input voltage.

11. A transducer comprising a pair of cores, an anode circuit including an anode winding wound about a portion of one of said cores, a second anode winding wound about a portion of the other of said cores, output terminals for obtaining direct current output power from said anode circuit, input terminals for impressing an alternating current input voltage on said anode circuit, a plurality of rectifiers providing a full wave rectifier circuit whereby direct current power may be delivered to the said output terminals during both halves of each cycle of input voltage, a control circuit for controlling the output power of the transducer including a first control winding wound about a portion of one of the said cores and a second control winding wound about a portion of the other of said cores; a circuit including a first multi-electrode discharge tube of the high internal impedance type having a cathode, a plate, a control grid and at least one additional grid element for supplying a direct current

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control current for said first control winding and a second and similar discharge tube for supplying a direct current control current for said second control winding, the characteristic of the control circuit being such that the current flowing therethrough varies in response to variations in the said control voltage but is unaffected by voltage variations in the said control windings at the frequency of the alternating current input voltage, a first bias winding wound about a portion of one of the said cores, a second bias winding wound about a portion of the other of the said cores and a constant current source of direct current for said bias windings.

12. A transducer as set forth in claim 9 wherein the flux density in those portions of each of the cores about which the control windings are wound is sufficient to saturate said portions during a part of each cycle of supply voltage thereby appreciably reducing the inductive impedance of the control circuit and imparting to the control circuit a relatively short time constant during such part of the supply voltage cycle, whereby the power output of the transducers will vary rapidly in response to changes in the applied control voltage.

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13. A transducer as set forth in claim 11 wherein the flux density in those portions of each of the cores about which the control windings are wound is sufficient to saturate said portions during a part of each cycle of supply voltage thereby appreciably reducing the inductive impedance of the control circuit and imparting to the control circuit a relatively short time constant during such part of the supply voltage cycle, whereby the power output of the transducers will vary rapidly in response to changes in the applied control voltage.

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