

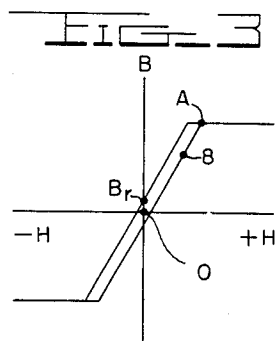
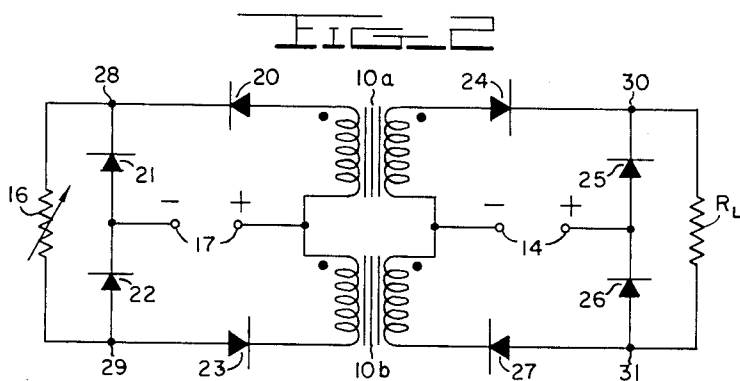
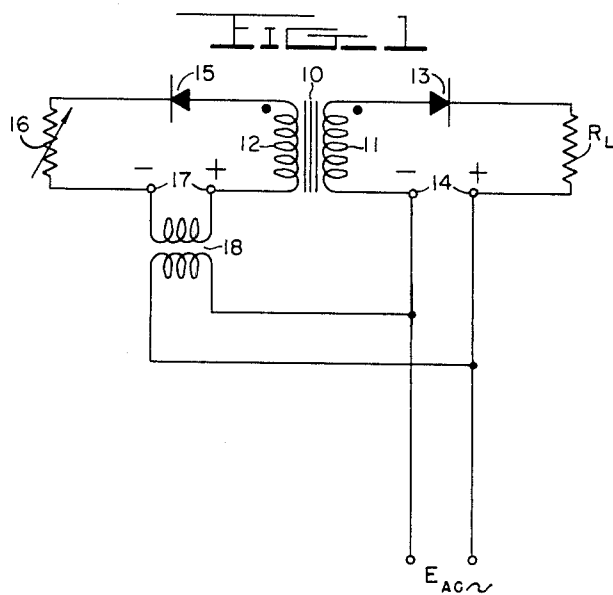
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MAGNETIC AMPLIFIER

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MAGNETIC AMPLIFIER

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This invention relates in general to saturable core reactors, and in particular to magnetic amplifier systems wherein the delivery of direct current power to an electrical load may be controlled by a simple variable resistance, or alternatively by a variable direct current control voltage.

In the field of industrial electronics, the vacuum tube control system is gradually giving way to the more robust, reliable, and efficient magnetic amplifier, particularly in aircraft control systems where such features are of prime importance. In addition to the above-mentioned features, the magnetic amplifier has the further advantage that it is instantly available; that is, it has no heater warm up period which renders the magnetic amplifier control system even more attractive in those applications where such a feature is of significance.

The present day trend in the design of magnetic amplifiers, however, has been to place a great amount of emphasis on the use of high remanent, high permeability cores, usually toroids. These cores are scarce and expensive and therefore detract to a certain extent from the overall desirability of the amplifier. Another disadvantage of certain prior art amplifiers is that their response time, that is the time required for a change in the control circuit to appear at the output of the amplifier has been relatively great.

It is therefore an object of this invention to provide a novel magnetic amplifier having good response characteristics and which utilizes substantially zero remanent, moderately low permeability cores now readily available in the art.

Other objects and features of the present invention will become apparent from a careful consideration of the following detailed description when taken together with the accompanying drawing in which:

Figure 1 is a schematic circuit diagram of one embodiment of the invention,

Figure 2 is a schematic circuit diagram of an alternate embodiment of the present invention, and

Figure 3 shows a typical hysteresis characteristic of the core member used by the present invention.

Referring now in particular to Figure 1 there is shown the circuit details of a half-wave version of the magnetic amplifier provided by the present invention. Included in the amplifier is a core member 10 which has as low a remanent characteristic as possible, preferably zero, and a moderately low permeability characteristic as indicated by the hysteresis characteristic of Figure 3. Wound on core 10 is a load winding 11 and a control winding 12 which may be identical. The load to be driven, shown here for purposes of simplification as a simple resistance labeled R_L , is connected in series with the load winding 11 through a half-wave rectifier designated 13. The load receives its energization from a source of alternating voltage of power line frequencies labeled E_{ac} connected to the power input terminals designated 14. The control circuit has a similar connection in that a control element here shown as a simple variable resistance labeled

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16 is connected to the control winding 12 through a half-wave rectifier 15. Energization of the control circuit is obtained from across a pair of input terminals labeled 17 connected typically through a suitable transformer 18 to the source of alternating voltage E_{ac} .

The phasing of the connection of the supply voltage E_{ac} to the respective power terminals 14 and 17 in the load and control circuits of the amplifier and the phasing of the half-wave rectifiers 13 and 15 is chosen such that current will flow through the load and control windings 11 and 12 respectively during alternate half-cycles of the applied supply voltage E_{ac} . More specifically the phasing of rectifier 13 and the connection of the supply voltage E_{ac} to terminals 14 is arranged so that during alternate half-cycles load current is permitted to flow in the load circuit and at the same time the phasing of rectifier 15 and the connection of the supply voltage E_{ac} to terminals 17 is such that during the half-cycles intermediate the load half-cycles current will be permitted to flow in the control circuit. In the same regard the load and control windings 11 and 12 respectively are wound on core 10 so that the current flowing through the load winding induces a flux in core 10 which has the same direction as the flux induced in the core by current flow through the control winding 12. To this end the load and control windings 11 and 12 are wound as indicated by the dots adjacent one terminal thereof. The dot convention signifies that a voltage applied across one of the windings with a given polarity at the terminal adjacent the dot will induce a voltage of the same polarity at the terminal adjacent the dot in the other winding. Stated otherwise, current flowing through one of the windings in a given direction relative to the terminal adjacent the dot will induce a flux in the core 10 in the same direction as current flowing through the other winding in the same direction with respect to its terminals.

In operation the amount of power delivered to the load R_L is controlled by the setting of variable resistance 16, that is the higher this resistance the lower the output power delivered to the load. As an alternate type of control, resistance 16 could be replaced by a variable D. C. voltage source connected in the control circuit so that it opposes conduction in rectifier 15.

Considering now a typical cycle of operation, first assume that zero power is to be delivered to the load, resistance 16 is set to a value which is much greater than the reactance of the control winding 12 so as to limit the current flowing in the control circuit to a value which is small relative to the magnetization current which must flow in the circuit to saturate the core. In this condition and with the instantaneous polarity of applied E_{ac} voltage to terminals 14 and 17 as indicated in the diagram, rectifier 13 blocks the application of supply voltage E_{ac} from winding 11 but rectifier 15 has the polarity to permit current to flow in the control winding 12. Resistance 16, however, being set to an extremely high value limits the amount of current which flows in the control circuit to a value much less than that required to raise the magnetization level of the core from its normal low remanent level, B_r in Figure 3, to its saturation level typified at A in this figure. In this case the magnetization level of the core during the control half-cycle or the half-cycle in which the control circuit is operative remains substantially at its low remanent unsaturated level designated in the curve of Figure 3 at B_r . During the load half-cycle, however, when the polarities of the voltages applied across terminals 14 and 17 have reversed and rectifier 15 blocks the current in the control circuit and rectifier 13 permits conduction in the load circuit the current permitted to flow in the load circuit is inhibited only by the reactance of winding 11 and the load resistance R_L . The latter is ordinarily of a value much

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smaller than the reactance of winding 11. During this half-cycle then, the magnetization level of the core will be raised from its low value B_r to near its saturation point A, but the voltage E_{ac} and winding 11 are selected so that this half-cycle of voltage acting alone will be insufficient to saturate the core. In this condition then where no power is to be delivered to the load circuit, the magnetization level is substantially unaffected by the control winding 12 and the level of the core is simply shifted up to near saturation level A during the load half-cycle. Consequently only magnetization current is permitted to flow through the load. This current is of course very small and little or no power is delivered to the load resistance R_L .

Now assume that full power is to be delivered to the load R_L . In this condition the control resistance 16 is adjusted to a value which is small relative to the reactance of winding 12. During the control half-cycle then when rectifier 15 permits conduction in the control circuit and rectifier 13 blocks the application of supply voltage to the load winding 11, the control half-cycle raises the magnetization level of the core from the level designated B_r to the saturation value A. At the end of the applied half-cycle of control voltage appearing across terminals 17 the magnetization current flowing in the control winding is at a maximum since this current lags the applied voltage by 90° and the core is saturated. Consequently during the next half-cycle when the polarities of the applied voltages are reversed from that indicated in the diagram, core 10 remains at saturation since a maximum current was flowing at the end of the control half-cycle and full load current is then immediately available for application to the load resistance R_L . In this condition then full power may be delivered to the load. Resistance 16 and the supply voltage appearing across the terminals 17 therefore only need to be sufficient to cause magnetizing current to flow through the control winding 12 if full load is to be derived. Adjustment of resistance 16 to a value intermediate that required for the delivery of full load power to the load circuit and that required for zero delivery of power to the load circuit places the core at intermediate positions on the hysteresis characteristic between B_r and A at the end of the control half-cycle whereby varying amounts of power can be delivered to the load resistance R_L . That is, adjustment of resistance 16 to a value which permits something less than full magnetizing current to flow in the control circuit during its half-cycle will raise the magnetization level of the core at the end of the control half-cycle from typically, say, point B_r to some intermediate level arbitrarily designated B in Figure 3. Then during the next half-cycle only the first portion of the load half-cycle which is required to raise the level from point B upward to point A is lost in raising the core to saturation. The rest of the half-cycle is spent in delivering power to the load resistance R_L .

From the foregoing description it will be recognized that the response of the present amplifier is essentially a half-cycle of applied voltage E_{ac} , since the magnetization level of the core is set during one half-cycle of applied voltage, and load current is permitted to flow during the next half-cycle. Accordingly at power line frequencies of 400 C. P. S. such as are used in aircraft the response time of the amplifier is only 2.5 milliseconds.

The circuit of Figure 1, as previously mentioned, is suitable in that condition where half-cycle power is delivered to the load. If full wave rectified power is to be delivered to the load a circuit such as depicted in Figure 2 may be employed. Here for purposes of simplification the connection of supply voltage E_{ac} to the load and control terminals 14 and 17 have been omitted. In this figure two cores similar to 10 and labeled 10a and 10b are employed. The core load and control windings are respectively connected in parallel to the respective supply terminals 17 and 14 through a rectifier bridge comprising rectifiers 20, 21, 22, 23 in the control circuit and 24, 25,

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26, 27 in the load circuit. In this connection the control resistance 16 is connected across one pair of diagonals 28 and 29 of the control rectifier bridge and the load resistance R_L is connected across one pair of diagonals 30 and 31 in the load rectifier bridge. In the same manner the supply voltages for the control and load circuits are connected across the other pair of diagonals of the control and load rectifier bridges respectively. In operation the control and load rectifier bridges operate to permit load current to flow through the load winding associated with one of the cores and during the same half-cycle to permit control current to flow through the control winding of the other core with this action reversing each half-cycle. More particularly and with the instantaneous applied voltage polarities given in the diagram, control current flows from the positive terminal 17 through the control winding of core 10a, rectifier 20, control resistance 16, rectifier 22 and back to the negative terminal 17. During the same half-cycle load current flows from the positive terminal 14 through rectifier 25, load R_L , rectifier 27 and the load winding of core 10b back to the negative terminal 14. In the next half-cycle the load and control current paths reverse with control current flowing through the rectifier bridge and the control winding of core 10b while load current now flows through the load winding of core 10a. In this way the magnetization level of cores 10a and 10b is being set in the control circuit in alternation whereby full wave power is delivered to the load R_L .

It will be recognized from the foregoing description that one of the main features of the present invention is that its operation depends upon the use of low remanent core material which is readily available in the art. Additionally since only low values of remanence are necessary the core can comprise a conventional shell structure made from one of the many ordinary annealed iron-nickel alloys now available. If the core material itself has a value of remanence too high for good no-load operation, the remanence of the core can be reduced to near zero by forming an air gap in the core structure and for this reason the shell-type core which has an air gap present may be preferred over the toroid structure. The use of a shell-type core structure is further advantageous in that it simplifies the winding of the load and control windings thereon.

Although I have shown and described only certain specific embodiments of my invention it must be understood that I am fully aware of the many modifications thereof. Therefore this invention is not to be restricted except insofar as is indicated by the scope of the present disclosure.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. A magnetic amplifier consisting of, a saturable core member having substantially zero remanence properties, a load winding and a control winding wound on said core, means including said control winding operable to periodically shift the magnetization level of said core from its normally low remanent value toward saturation in one direction, and means including the load winding operable to periodically shift the magnetization level of said core in the same said one direction toward saturation in alternation with the first mentioned shift in magnetization level.

2. A magnetic amplifier consisting of, a saturable core member having substantially zero remanence properties, first means coupled to said core operable to periodically shift the magnetization level thereof from its normally low remanent value toward saturation in one direction, and second means coupled to said core operable to periodically shift the magnetization level thereof in the same said direction toward saturation in alternation with the first mentioned shift in magnetization level.

3. A magnetic amplifier consisting of, a saturable core

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member having substantially zero remanence properties, a control circuit including a control winding wound on said core and means for periodically energizing the same to periodically shift the magnetization level of said core from its normally low remanent value toward saturation in one direction, and a load circuit including a load winding wound on said core and means for periodically energizing the same to periodically shift the magnetization level of said core in the same said direction toward saturation in alternation with the first mentioned shift in magnetization level.

4. A magnetic amplifier consisting of, a source of alternating supply voltage, a saturable core member having substantially zero remanence properties, a load winding and a control winding wound on said core, a control circuit including a control element and a half wave rectifier connected in series with said control winding across said source of voltage so as to periodically shift the magnetization level of said core from its normally low remanent value toward saturation in one direction, and a load circuit including the load to be driven and a half wave rectifier connected in series with said load winding across said source of voltage so as to periodically shift the magnetization level of said core in the same direction in alternation with said first mentioned shift in magnetization level.

5. A magnetic amplifier comprising, a saturable core

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member having substantially zero remanence properties, and magnetizing means coupled to said core consisting of a first winding and means for periodically energizing the same to periodically shift the magnetization level of said core from its normally low remanent point toward saturation in one direction, and a second winding and means for periodically energizing the same in alternation with the first winding to shift the magnetization level of the core in the same said one direction toward saturation.

6. A magnetic amplifier comprising, a saturable core member having substantially zero remanence properties, and magnetizing means coupled to said core consisting of a first means to periodically shift the magnetization level of said core from its normally low remanent point toward saturation in one direction, and a second means operable in alternation with the first means to shift the magnetization level of the core in the same said one direction toward saturation.

References Cited in the file of this patent

Publication entitled "On the Mechanics of Magnetic Amplifier Operation," by R. A. Ramey, AIEE Paper 51-217, May 1951.

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