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MAGNETIC CORE CURRENT REGULATING CIRCUIT

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FIG. 1

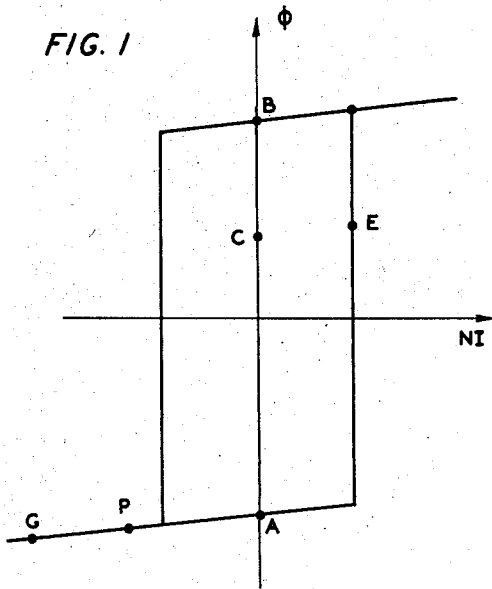


FIG. 2

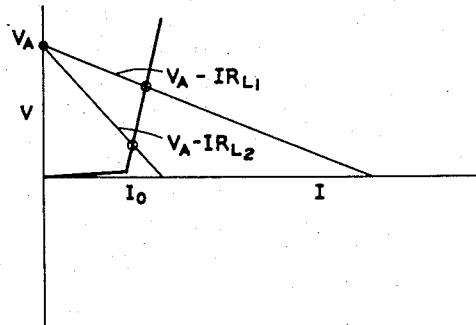


FIG. 3

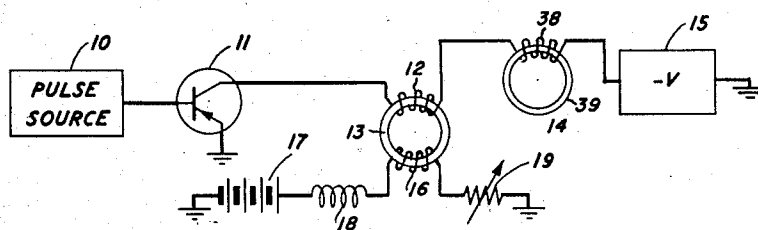
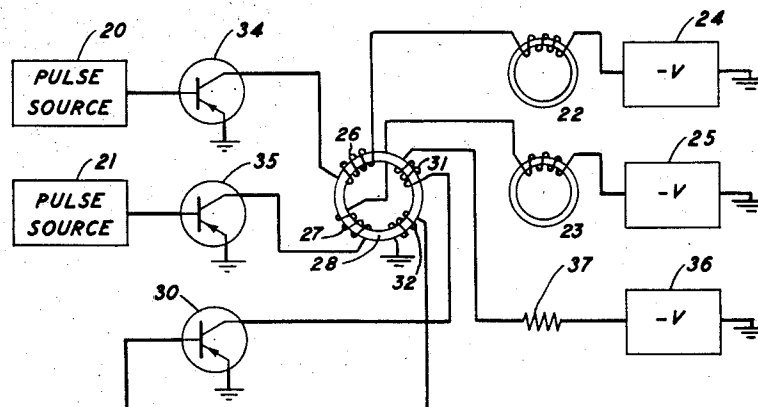


FIG. 4



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MAGNETIC CORE CURRENT REGULATING CIRCUIT

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9 Claims. (Cl. 323—7)

This invention relates to circuits for regulating current applied to a load and, more particularly, to circuits for applying constant current pulses to a varying impedance load.

Constant current sources are frequently required in pulse circuits such as computer systems and are particularly required in computer circuits using magnetic cores. Priorly, constant current sources have been devised using the nonlinear characteristics of a pair of serially connected diodes connected in series opposition between a pulse source and a load. A high voltage source is connected intermediate the two diodes by means of a high resistance. This type circuit delivers a current to the pulse source through one of the diodes and, in response to an incoming pulse, the current formerly delivered through this one diode is cut off and this current is now delivered to the load through the other diode. The series resistance between the high voltage source and the load limits the current. This limiting action, however, is achieved at the expense of wasted power and the requirement of a source of voltage many times higher than that required to be applied across the load.

Magnetically operated load current control devices, commonly called saturable core reactors, are well known in the art. They are essentially a transformer having two or more windings, one of which is serially connected between an alternating current source and a load. The reactance of this series connected winding is under the control of another winding called the control winding. A direct current is fed through the control winding to establish a predetermined flux through the transformer core and the impedance of the series connected winding is directly proportional to this control current. The impedance of this series winding therefore varies linearly with the control winding current. Saturable core reactors, however, exhibit certain limitations with regard to use as current limiting devices. Because of the extensive flux paths of saturable cores, it is difficult to establish a flux through these paths by means of pulses applied at megacycle frequencies. Further, even if a saturable core reactor were designed for use in the megacycle range it would require a relatively large control current to achieve current limiting by maintaining the core in its highly saturated state.

Accordingly, it is an object of this invention to provide a regulated constant current from a relatively low voltage source.

It is another object of this invention to provide a constant current source adapted to drive a variable load, which source consumes a minimum amount of power.

It is a further object of this invention to provide a simplified constant current generator which contains few components.

It is a further object of this invention to provide a current source for driving magnetic core circuits which compensates for changes in the load impedance because of changes in the ambient temperature.

It is another object of this invention to provide a

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current source adapted to produce rectangular current pulses having short rise and fall times.

It is still another object of this invention to provide a generator delivering current pulses of predetermined amplitude independent of the load impedance.

Briefly, I have discovered that, by serially connecting a winding of a square loop magnetic core between a voltage source and a load and preventing the core from completely switching, the core winding presents a bilinear impedance, which impedance can be employed as a current limiter. In accordance with aspects of this invention, a magnetic core having a substantially rectangular hysteresis loop has a winding connected in series with a source of potential and a switch. The switch is adapted to be actuated at a speed which limits the duration of the pulses to a period insufficient completely to reverse the magnetization of the core even though the magnitude of the current is otherwise sufficient to do so. The core and its included winding define a current limiting device which presents a first very low linear impedance to low values of current but, in response to values exceeding a threshold or minimum value, presents a very high linear impedance. Thus, the core winding can be said to exhibit a bilinear impedance. While this current is of insufficient duration completely to reverse the magnetization of the core, the core is partially switched. Continuous current regulation is assured by resetting the core to its initial condition of magnetization before the core is completely switched.

It is a feature of this invention to connect a winding of a magnetic core having a substantially rectangular hysteresis loop in series with a nonlinear load and to deliver current pulses through the winding to the load, which pulses are of insufficient duration completely to reverse the magnetization of the magnetic core.

It is another feature of this invention serially to connect a voltage source, a switch, a magnetic core winding and a nonlinear load and to actuate the switch to permit the voltage source to deliver a current pulse to the load, which pulse is of insufficient duration completely to switch the core. This current is effectively limited by the bilinear impedance of the magnetic core winding.

It is another feature of this invention to employ a single magnetic core as a current regulating device for a plurality of loads by serially connecting these loads to individual pulse sources through individual windings on the current limiting core.

It is another feature of this invention serially to connect a current limiting winding of one magnetic core and a winding of a magnetic core load, which current limiting winding effectively changes its threshold in the same direction and the same magnitude as the load core winding in response to changes in ambient temperature and thus compensates for load threshold variation caused by changes in ambient temperature.

A complete understanding of this invention and of these and various other features thereof may be gained from consideration of the following detailed description and the accompanying drawing in which:

Fig. 1 is an idealized graph of the hysteresis curve of a magnetic core of the type employed with the circuits of Figs. 3 and 4;

Fig. 2 is a plot of the voltage-current characteristics of a constant current source in accordance with this invention;

Fig. 3 depicts, in schematic form, one illustrative embodiment of this invention; and

Fig. 4 depicts, in schematic form, another illustrative embodiment of this invention.

Referring now to Fig. 1, there is depicted a ferromagnetic core hysteresis loop in which the abscissa is the ampere turns of the core while the ordinate is the flux

through the core. Point A represents one state of stable remanent magnetization while point B represents the other stable state of remanent magnetization. Subsequent reference will be made to this graph in order to explain the operation of the various embodiments of this invention.

In accordance with aspects of this invention, a series current limiting circuit includes a pulse voltage source, a winding on a square loop magnetic core and a load. The pulse current flowing in this series circuit is nearly independent of the load impedance due to the switching action of the series core. In order to maintain this current regulation throughout the pulse interval the switching time of the core must be made longer than the pulse from the voltage source. Assuming a rectangular switching waveform for the core, the switching time and voltage are related to the core properties by the equation

$$V\tau = N\Phi \quad (1)$$

where

τ = the time required for switching to take place,
 N = the number of turns of the core winding,
 Φ = the total flux to be switched in the core, and
 V = the voltage across the N turn winding.

To insure current regulation throughout the pulse interval, the actual pulse duration t must be such that

$$V_{\max} t < N\Phi \quad (2)$$

Since V is equal to the voltage of the pulse source minus the load voltage, V will be a maximum when the load voltage is minimum. From the Equation 2 above, it can be seen that partial switching can be obtained through proper design of the number of turns on the winding or by controlling the total flux Φ either by geometrical design or by proper choice of core material. With reference to geometrical design, it is advantageous to use toroidal cores and the cross-sectional area of the core is the most important dimension. The material employed for the core may, for example, be a ferrite or a permalloy tape.

For example, the load may include one or more magnetic core windings serially connected. Normally, these load cores must be completely switched during the pulse interval t , while the current regulating core load must not completely switch in order that current limiting takes place throughout the pulse interval. In order to obtain this difference in switching times the core material selected for the load core may advantageously be one in which switching occurs at a lower value of induced flux.

The switching time of the load core is linearly related to the ampere turn drive as described by M. Karnaugh in an article of the May 1955 Proceedings of the I.R.E., volume 43, No. 5, pages 570 through 583, entitled "Pulse Switching Circuits Using Magnetic Cores."

This relationship is depicted in Fig. 3 of that article. The intercept ν and the slope C^{-1} are related to the dimensions of the core and the magnetic properties of the core material. The current through the load core winding is controlled by the bilinear impedance of the current regulating core winding. The number of turns of the winding on the load core may now be determined to assure complete switching of the load core during the pulse interval, which number of turns, in one embodiment, will exceed the number of turns of the current regulating winding.

Fig. 2 depicts a voltage-current characteristic of a constant current source in accordance with this invention in which the current produced through the load is proportional to the applied voltage and inversely proportional to load impedances such that the current is less than a predetermined value designated as I_0 . Further, beyond the value I_0 the incremental impedance of the current source is high so that for all practical purposes, the pulse current can be considered to be constant. Subsequent reference will be made to this characteristic in explaining the detailed operation of the circuits of Figs. 3 and 4.

Fig. 3 depicts a pulse source 10 connected to the base of transistor 11, the emitter of which is connected to ground. The collector of this transistor is connected to winding 12 of ferromagnetic core 13. The other terminal of winding 12 is connected to one terminal of winding 38 on core 39 of load 14. The other terminal of winding 38 is connected to source 15 of negative potential. Also, on core 13 is winding 16 which is connected to a circuit for resetting the core to its initial state of magnetization. This resetting circuit includes source 17 of potential, inductor 18 and variable resistor 19. As shown in Fig. 3, transistor 11 is a p-n-p junction transistor. However, an n-p-n transistor may be used in this circuit reversing the polarity of source 15.

Assume for the purposes of explaining the operation of the circuit of Fig. 3 that the magnetization of core 13 is that depicted by point A in Fig. 1. A pulse applied to transistor 11 from source 10 causes transistor 11 to become conducting. A pulse of current flows from ground through the emitter, base and collector of transistor 11 to winding 12 of core 13 and finally to source 15. This pulse is of sufficient magnitude to shift the magnetization of the core from point A on Fig. 1 beyond the knee of the curve but of insufficient duration to switch the magnetization to point B of Fig. 1. Assume for the moment that this pulse is sufficient to magnetize the core at point E of Fig. 1 when the pulse from source 10 is terminated; the transistor 11 becomes nonconducting and the load current falls to zero. In response to the termination of load current, the magnetization of core 13 returns to point C of Fig. 1. The current limiting action of the core winding can be understood from the application of the pulse to the voltage-current characteristic of Fig. 2. Core 13 is partially switched by single pulses of current flowing through winding 12. Load 14 may advantageously be a winding of a second ferromagnetic core and the switching characteristics of the load core are such that the load core is switched while core 13 is only partially switched.

While the foregoing explanation of the operation of the circuit of Fig. 3 has been made on the assumption that the magnetic core was initially magnetized at point A on the hysteresis loop of Fig. 1, it might have been maintained at point P or point G on the hysteresis loop by means of a biasing current applied through a biasing winding. The current through this biasing winding performs a dual function. One of these functions is that the value of this current determines the threshold or I_0 point indicated in Fig. 2 of the current limiting winding as seen from the pulse source and the other is that of resetting the core to its quiescent point P or G, whichever point was selected after the partial switching has taken place.

However, some means must be provided for resetting core 13 before it is completely switched to point B of Fig. 1. Core 13 may, however, be of the same geometry and composition as the load core, complete switching of core 13 being inhibited by the combination of a biasing winding and the previously mentioned fast acting transistor switch as shown in Fig. 3. Referring to Fig. 2, the dark lines represent the actual impedance of the current limiting core winding as seen by the current pulses through the transistor switch. The first line segment has only a slight slope indicating a very low linear impedance. At the point designated I_0 , the second line segment begins which has a steep slope indicating a very high linear impedance. V_A is the source voltage and the two light diagonal lines leaving point V_A define load lines. The intersection of the two load lines and the second impedance line are illustrative operating points. The initial application of voltage causes current to flow until the value I_0 is reached. Beyond this value of current the sharp slope of the voltage-current characteristic causes the core winding 12 to present a high linear impedance to the pulse source. Thus, for increases in current beyond I_0 , only a slight increase in current reaches load 14 and, since the slope of this characteristic as herein depicted

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is greatly exaggerated, the current can be considered to be substantially constant. When transistor 11 becomes nonconducting, because of the removal of the pulse from source 10, the magnetic field of winding 13 collapses. The current from source 17 through winding 16 now resets core 13 to point P of Fig. 1. Thus the cycle is ready to be repeated.

From the foregoing explanation, it is apparent that current limiting can be achieved by connecting a winding of a square loop magnetic core in series between a pulse source and a load and preventing the core from being switched. This load may advantageously be another magnetic core winding which in effect presents a first small impedance prior to its switching, a second greater impedance during switching and a third smaller impedance after switching.

If the flux difference between points A and B on the hysteresis loop of Fig. 1 is larger than the quantity

$$\frac{Et}{N}$$

where E is the pulse voltage across the series winding of the current limiting core, t is the pulse duration, and N is the number of turns of this winding, the core need not be reset after each pulse applied to the load but may be reset each second, third or some subsequent number of pulses, provided core 13 is never permitted to switch completely to point B on the hysteresis loop of Fig. 1.

Referring now to Fig. 4, there is depicted a pair of pulse sources 20 and 21 employed to gate transistors 34 and 35, respectively. Serially connected between each of the pulse sources and individual loads 22 and 23 are windings 26 and 27, respectively. These windings are wound on common ferromagnetic core 28. Sources 24 and 25 of negative potential are connected to respective loads 22 and 23. Transistor 30 is connected to windings 31 and 32 on core 28 and comprise a blocking oscillator which resets core 28 after every pulse from sources 20 and 21. This embodiment illustrates that one square loop magnetic core may be utilized as a current limiting device for two or more circuits. It is not necessary to reset the core after each pulse. It need only be reset at sufficiently frequent intervals to prevent the core from being completely switched as was previously explained.

The operation of the circuit of Fig. 4 is quite similar to that of Fig. 3. Either source 20 or source 21 gates its associated transistor. Assuming that source 20 has gated transistor 34, current flows through the transistor emitter, winding 26 and load 22 to source 24. Winding 26 effectively presents the previously described bilinear impedance to this pulse such that a constant current is delivered to load 22 and source 24. Subsequent to this, pulse source 21 gates transistor 35. In a similar manner, current flows through the emitter of transistor 35, winding 27, load 23 and source 25. This current is limited in the same manner as was previously explained in connection with winding 26. In response to the partial reversal of the flux of core 28, pulses are induced in winding 32 in a direction to gate transistor 30. The collector of transistor 30 is connected through winding 31 and resistor 37 to source 36 of negative potential. The gating pulse causes transistor 30 to become conducting and deliver a pulse through winding 31 resetting the magnetization of core 28 to point A of Fig. 1. A more detailed explanation of the operation of transistor switches is disclosed in Transactions of A.I.E.E., volume 74, part 1, March 1955, pages 111-121. The use of blocking oscillators utilizing transistors to pulse cores is disclosed in A. H. Bobeck application Serial No. 555,976, filed December 28, 1955, and an oscillator for resetting a magnetic core is disclosed in H. E. Vaughan application Serial No. 449,222, filed August 11, 1954.

This circuit possesses numerous advantages including compensations for variations in the load due to changes

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in the ambient temperature and characteristics such that rectangular pulses having short rise and fall times can be transmitted to the load.

If the load associated with this current limiting circuit is another square loop magnetic core winding, the impedance of the load changes in response to changes in the ambient temperature. The impedance presented by the current limiting winding will change in the same direction by substantially the same magnitude as the load impedance. Thus, the load current would advantageously vary with temperature in such a manner as to compensate for changes in the magnetic core load characteristic.

Short rise and fall times of the current pulses occur due to the fact that the current limiting winding presents an initially low value of impedance and the only other circuit element controlling the circuit is a transistor switch which rapidly changes from nonconducting to conducting states. The current supplied to the load is therefore a precisely limited rectangular pulse having short rise and fall times, which characteristics make this circuit particularly adapted to drive square loop magnetic core windings.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electrical circuit for regulating the current delivered to a load including a first magnetic core having a first winding thereon, said circuit comprising a source of pulses, a second magnetic core having a second winding thereon and means for resetting said second core, said second winding being serially connected between said source and said first winding, said source including switching means and means for actuating said switching means, said first core being adapted to switch in a shorter time than the time required to switch said second core.
2. A current regulating series circuit in accordance with claim 1 wherein the geometry of said second core is such that the switching time of said second core is longer than the switching time of said first core.
3. A current regulating series circuit in accordance with claim 1 wherein said first winding contains more turns than said second winding.
4. A current regulating circuit in accordance with claim 1 wherein the core materials in said first and said second cores are such that a smaller induced flux is required to switch said first core than is required to switch said second core.
5. A current regulating series circuit in accordance with claim 1 wherein said switching means comprises a transistor having an emitter, a collector and a base, said collector being connected to said second winding, said emitter being connected to a source of reference potential and wherein said switch actuating means includes means for applying a pulse to said base.
6. In an electrical device for regulating the current for a plurality of loads, a magnetic core exhibiting a substantially rectangular hysteresis loop and having a first, a second, a third and a fourth winding thereon, said first, second, and third windings being wound in one direction on said core, said fourth winding being wound in an opposite direction on said core, a first load connected in series between said first-mentioned winding and a source of potential, switching means in circuit with said first load, a second load connected in series between said second winding and a source of potential, second switching means in circuit with said second load, means including said first and said second switching means for permitting partial switching of said core while preventing complete switching of said core, and means for resetting said core.

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7. In an electrical device in accordance with claim 6 wherein said resetting means includes a transistor having a collector and a base and further includes a source of potential, said collector being connected through said fourth winding to said source of potential, said base being connected through said third winding to a source of reference potential, said emitter being connected to a source of reference potential.

8. In an electrical device in accordance with claim 6 wherein said loads include magnetic cores exhibiting rectangular hysteresis loops and further include windings on said last-mentioned cores.

9. An electrical circuit for regulating the magnetic switching of a first magnetic core exhibiting substantially rectangular hysteresis characteristic having a temperature variant coercive threshold and having a winding inductively coupled thereto, a source of pulses, a second magnetic core having a winding thereon and having a sub-

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stantially corresponding temperature variant coercive threshold as said first magnetic core, and circuit means for serially interconnecting said winding on said second magnetic core with said source and said winding on said first magnetic core, said first and second magnetic cores being structurally dissimilar whereby said first core completely switches its state of magnetization while said second core only partially switches and said pulse source limiting the duration of said pulses to effectuate complete switching of said first core but only partial switching of said second core.

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