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Kaiserswerth et al.

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[54] **RADIO FREQUENCY CHOKE**

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[30] **Foreign Application Priority Data**

Apr. 23, 1971 Germany .... P 21 19 950.8

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[51] **Int. Cl.** **H01f 17/06**, H01f 27/26

[58] **Field of Search** 336/212, 178, 165, 336/234, 233

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[57] **ABSTRACT**

A radio frequency choke for reducing radio frequency interference in switching circuits as for example for gating bi-directional alternating current comprising a composite core with a first portion formed of ferrite material and a second portion formed of laminations of magnetic sheet material. The ferrite and laminated portions may be annular shaped and the radio frequency interference is substantially reduced if an air gap is provided in the ferrite core.

8 Claims, 5 Drawing Figures

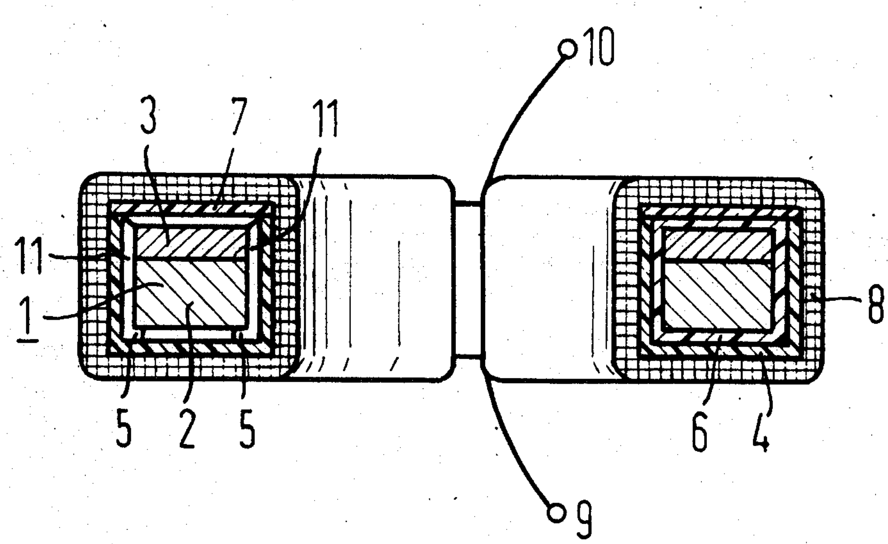


Fig.1

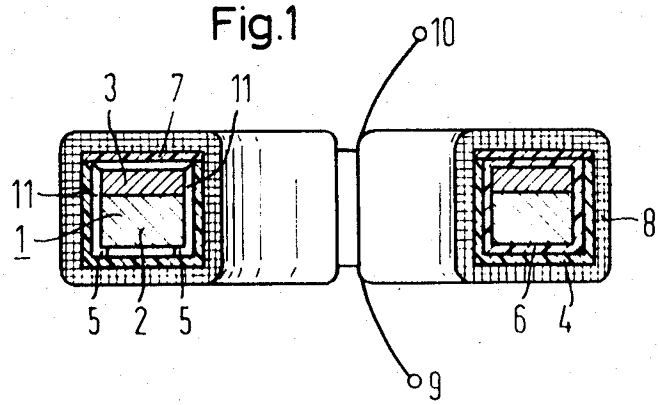


Fig.2

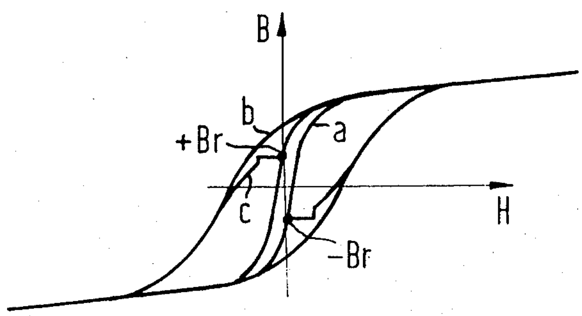


Fig.3

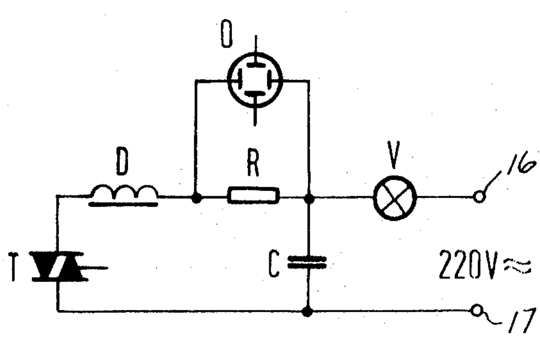


Fig. 5

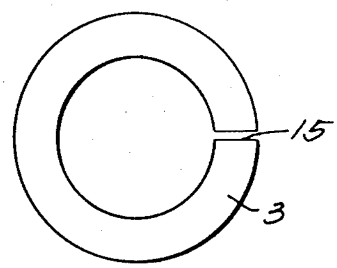
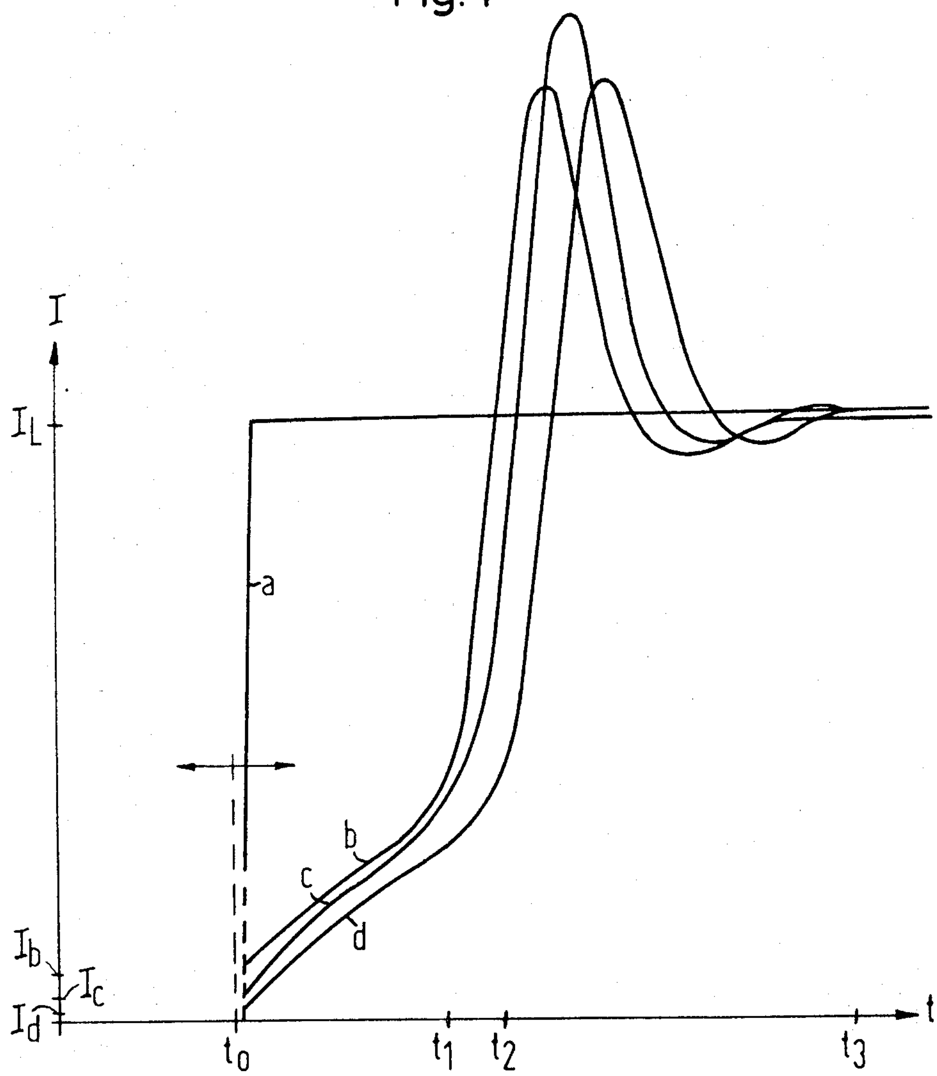


Fig. 4



RADIO FREQUENCY CHOKE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to radio frequency chokes and in particular to a new and novel choke for reducing radio frequency interference.

2. Description of the Prior Art

The use of electronic switches such as silicon controlled rectifiers has developed very rapidly for controlling the application of power to loads such as incandescent bulbs, fluorescent lamps, motors and other devices. Two-way semiconductor switches, sometimes referred to as thyristors and Triacs are known and utilized. A simple circuit for controlling the application of power through such devices in the phase controlled switching circiuit which utilizes very few components.

However, phase controlled switching has the drawback that very high radio frequency interference pulses are produced at the instant when the controlled semiconductor component is switched from its OFF to its ON state. This is because when the circuit is switched on the current jumps from zero to its final full-on value within about one micro second and this process is repeated periodically with each half wave of the supply voltage.

The amplitude of the radio interference pulses which occur in the radio frequencies above 150 kHz depends upon the amplitude of the full-on current as well as on the steepness of its time rise from full-off to full-on. Since the amplitude of the current jump is determined by conditions such as the supply voltage, the active charging rate and the gating angle, it is only possible to lower the steepness of the current jump. Heretofore, an inductance has been connected in series with the controllable semiconductor component and in order to comply with the F.C.C. rules regarding radio frequency interference, a shunt capacitor has also been connected across the power terminals and thus an LC circuit is connected across the power terminals and load.

Such LC circuits reduce radio ferquency interference but a further difficulty is introduced in that when a semiconductor switch is in its ON condition, the choke and capacitor form a parallel circuit which will oscillate at its resonant frequency to furnish additional current through the semiconductor element. The resonant frequency of such parallel circuits is normally in the **5 - 15** kHz range due to the required values for preventing radio frequency interference and it is possible that the frequency of the supply current and the additional oscillatory current from the parallel resonant circuit will combine and result in a zero current and the semiconductor element will switch back to its non-conducting state because the holding current has disappeared. If the gate voltage is still furnished at the gate electrode of the semiconductor element the semiconductor element will again switch to the conduction state after the resonant current has diminished which will again cause radio frequency interference.

This process will repeat itself periodically since the LC combination will be stimulated for oscillation each time the semiconductor component is switched on. If the gating potential is no longer present at the control electrode when the oscillating current from the LC circuit and the supply have combined to drive the current below the holding current the semiconductor switching element will stay off which disconnects the supply current from the load. Thus, with the LC circuit of the prior art the semiconductor switching elements may not operate satisfactorily.

SUMMARY OF THE INVENTION

The present invention comprises a device for preventing radio frequency interference and comprises a choke composed of different core materials. The present invention avoids the difficulties of the prior art by providing a radio frequency choke which has equalizing oscillations which diminish as rapidly as possible while still reducing radio frequency interference in the frequency range between 150 kHz to about 300 MHz.

The present invention comprises a choke for eliminating radio frequency interference for phase gated circuits utilizing semiconductor elements in which the rapid current changes are slowed during switching and which reduces the radio frequency interferences. The choke also dampens equalizing currents that occur in the on condition of the semiconductor elements due to the resonant frequency of the capacitor and choke without interference with the flow of electric power from the power supply to the load.

The choke of the present invention comprises two ring-shaped superimposed partial cores with one partial core comprising laminated iron sheets of magnetizable material and the other partial core comprising a ferrite ring which is formed with an air gap.

The present invention allows the use of inexpensive laminated iron material which has high permeability and thus a low core volume can be utilized so as to dampen the equalizing current of the radio frequency damping combination thus allowing a larger capacitor to be used. The non-linear characteristics of the laminated sheet material are compensated by ferrite material. It has been observed that laminated sheets of magnetic iron material has strong magnetic tolerances but the present invention balances such tolerances by utilizing a ferrite ring formed with an air gap.

Other objects, features and advantages of the invention will be readily apparent from the following description of certain preferred embodiments thereof taken in conjunction with the accompanying drawings although variations and modifications may be effected without departing from the spirit and scope of the novel concepts of the disclosure and in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view through the radio interference choke of the present invention;

FIG. **2** illustrates a magnetization curve of a core;

FIG. **3** is an electrical schematic view of the choke of this invention connected in circuit with a semiconductor device;

FIG. **4** is a graph of current versus time in a gating circuit; and

FIG. **5** is a plan view of a core according to this invention illustrating the gap in the ferrite portion of the core.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention comprises a core for radio interference chokes which are composite devices comprising a first portion of the core which is made of laminated sheet iron. Such sheet iron has been used for example in transformers, transmitters and chokes of the prior art and generally consists of silicon containing iron alloy. The laminated iron sheet may be a non-alloy formed from a deep draw and surprisingly such sheet material which has been discouraged in the past for alternating currents is particularly suited for the production of radio frequency interference chokes. Such material is substantially cheaper than the usual electrosheet material. Also, such material can be processed easier than that of the silicon containing iron alloys.

The choke of the present invention may be formed of rings in which the laminated sheet material is formed into a plurality of rings which are stacked together and the other partial core may be formed of a ferrite ring preferably having an air gap. The ferrite core may be completely separated and be formed of two half ring portions which define a pair of air gaps, however, it has been found advantageous to provide only a single air gap. Also, in order to reduce the noise developed in the core due to magnetostriction, it is desirable that the core not be completely slotted and it may be cut from the inside portion toward the outside. The air gap may be formed radially or in a slanting direction if desired. It is also possible to cut the ferrite ring in several different places.

It is desirable that the ratio of the effective cross section of the ferrite core with respect to the laminated core be not larger than one to one. This will assure that the cost of the radio frequency interference choke according to this invention is low.

In a particular radio frequency choke according to this invention, which carries a current of 2.5 amperes, the outer diameter of the core was 34 mm. and the inner diameter of the core was 20 mm. In such core the ferrite ring of 3 mm. height was utilized and the cross-sectional area of a ferrite core comprised one-third of the entire cross-sectional area of the complete core. An air gap in the range of 0.2 – 0.3 mm. width has proved advantageous in a practical embodiment.

With reference to the drawings, FIG. **1** illustrates in cross-section a radio frequency choke according to the present inventon. The core **1** of the choke comprises a first partial core **2** formed of laminated annular rings of sheet iron and a partial core **3** of ferrite material. The partial core **3** in a practical embodiment had a height of 3 mm. and its effective cross-sectional area was about one-third of the total cross-sectional area of the core **1**.

The choke core **1** is mounted in a coil form **4** which is closed by a top **7** of annular form. The core **1** is mounted on spacers **5** in the coil form **4** and has fin portions **11** which engage the core **1**.

Resin **6** may be cast into the coil form to encapsulate the core **1** in the coil form **4**. The resin **6** remains plastic after the hardening process and may include 40 percent ground quartz so as to improve the heat conductivity within the coil form between the spacers **5**. The resin fills the spaces between the fins **11** and flows between the laminations of the partial core **2** as well as between the partial core **3** and the top lamination of the partial core **2**.

A two-layer winding **8** is wound on the coil form **4** and changes its winding direction after the first layer so that the beginning of the winding designated by numeral **9** is not covered.

The winding **8** surrounds the coil form and terminates at the winding end **10**.

As shown in FIG. **5** an air gap **15** is formed in the partial core **3** of ferrite material. This air gap may be in the range of 0.2 to 0.3 mm. in width.

FIG. **2** illustrates the magnetization curve of a choke comprised of seventeen annular laminations of magnetic sheet material. The flux density B is plotted against the magnetic field intensity H. +B*r* and −B*r* indicate the two static residual points. A narrow hysteresis loop is designated by *a*. A broad hysteresis loop is designated by *b*. The curve a illustrates the hysteresis curve of core material subject to a signal having a frequency r 50 Hz. The curve *b* is the hysteresis curve for a core subject to an exciting frequency of about 1 mHz.

The curve *c* illustrates the condition during the use of a core as a radio frequency choke according to this invention. The core material is at the point +B*r* at a certain instant as long as the semiconductor component element being controlled is non-conductive. When the semiconductor element becomes conductive the current through the semiconductor element will try to jump to its final value within about 1 to 2 micro seconds. The end value of current is generally so large that the core material will be saturated. Due to the high speed at which the magnetic field strength changes, the core material will not follow the quasi static magnetization curve a but must pass through the high frequency magnetization curve *b*. This condition is illustrated by curve *c*. From the static residual point +B*r* the magnetic field strength H jumps without a simultaneous change of the magnetic density B. This means that almost no inductive reactance is encountered by the current during the short period and the choke has only the effect of an air coil for a short time. Also, during this period the resistance does not serve to delay the pulse increase. The addition of the slotted ferrite ring **3** according to this invention substantially improves the characteristic of the choke according to this invention.

FIG. **3** illustrates a schematic view of the invention connected in circuit with a load V which has one side connected to a power terminal **16**. Power terminals **16** and **17** may receive 220 volts A.C., for example. The other side of the load V is connected to a Triac T through a choke D according to this invention and a resistor R. A capacitor C is connected in parallel with the series circuit comprising the Triac T, the choke D and the resistor R. The resistor R may have a small ohmic value and an oscilloscope O may be connected so as to illustrate the current through the choke D.

FIG. **4** is a plot of the switch on conditions of the circuit illustrated in FIG. 3 on an expanded time scale. The current I through the choke D is plotted as the ordinate against time *t* on the abcissa. From an initial time to time t_0 assume that the Triac is in the non-conducting state and that at the time t_0 is transferred to the low impedance condition. If no radio frequency interference choke is connected in circuit with the Triac, the current I jumps from zero to its value I_L within a micro second as shown in curve *a*. Such switching results in very high radio frequency interference pulses being produced due to such steep and high amplitude jumps.

Curves *b*, *c* and *d* illustrate responses utilizing radio frequency chokes having different characteristics. A choke which consists merely of laminated sheet material will produce a response illustrated by curve *b*.

With such a choke at the time t_0 the current I jumps from zero to an initial value of I_b. After the initial value of I_b is reached the current increases relatively slowly along the curve *b* until the core material becomes saturated at a time of t_1. The equalizing current between the choke D and the radio frequency interference capacitor C are superimposed on the charge current I_L and this results in the choke current overshooting above the end value of I_L as illustrated by curve *b*. The equalizing current diminishes rather rapidly due to the high magnetic losses in the core material and the end value I_L occurs at the time of t_3.

Curve *c* illustrates a composite core according to this invention wherein a closed ferrite ring was added to the laminated sheet ring cores. It was merely noted that the initial current at time T_0 was reduced to a value I_c which is about one-half of current I_b without the ferrite portion of the core. Thus radio frequency interference was substantially reduced by the utilization of the ferrite ring in the choke of the invention.

Curve *d* is plotted for a composite core of laminated material and a ferrite core which has been slotted with an air gap of 0.3 mm. width. This reduced the current at time t_0 to a value of I_d as shown and also caused the coil core to be saturated at a later time t_2 which is later than t_1 thus resulting in lower radio frequency interference than with the cores shown in curves *b* and *c*. Also, it has been discovered that curve d is obtained with the ferrite core having a gap even though the laminated sheet material is replaced by cheaper sheet material.

On the other hand, the curves *b* and *c* are subject to substantial changes with a change in the sheet material.

Thus, by the utilization of a ferrite ring with an air gap according to this invention it is possible in a simple and inexpensive manner to equalize the difference in qualities between various sheet materials and still obtain the desired characteristics of the invention.

Although minor modifications might be suggested by those versed in the art, it should be understood that we wish to embody within the scope of the patent warranted hereon all such modifications as reasonably and properly come within the scope of our contribution to the art.

We claim:

1. A radio frequency choke for damping radio frequency interference impulses generated by electronic switches such as silicon controlled rectifiers comprising:

a core formed of two annular core portions which are axially superposed and upon which at least one winding is mounted,

wherein one of said annular core portions is formed of magnetizable, non-alloyed sheet iron material and the other of said annular core portions is formed of ferrite material, and

wherein an air gap is formed in said other of said annular core portions.

2. A radio frequency choke according to claim **1** wherein said iron material is deep-draw sheet iron material.

3. A radio frequency choke according to claim **1** wherein said one of said annular core portions is formed of a plurality of ring-shaped laminations of magnetizable iron material.

4. A radio frequency choke according to claim **1** wherein said air gap in said other core portion extends radially.

5. A radio frequency choke according to claim **1** wherein the ratio of the effective cross-sectional areas of said other core portion to said one core portion is not greater than one to one.

6. A radio frequency choke according to claim **1** wherein said air gap has a width within the range of 0.2 through 0.3 millimeters.

7. A radio frequency choke according to claim **6** wherein the outer diameter of said core is about 34 millimeters and the inner diameter is about 20 millimeters.

8. A radio frequency choke according to claim **6** wherein the height of said other core portion is about 3 millimeters and the ratio of the cross-sectional area of said other core portion to said one core portion is about one to three.

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