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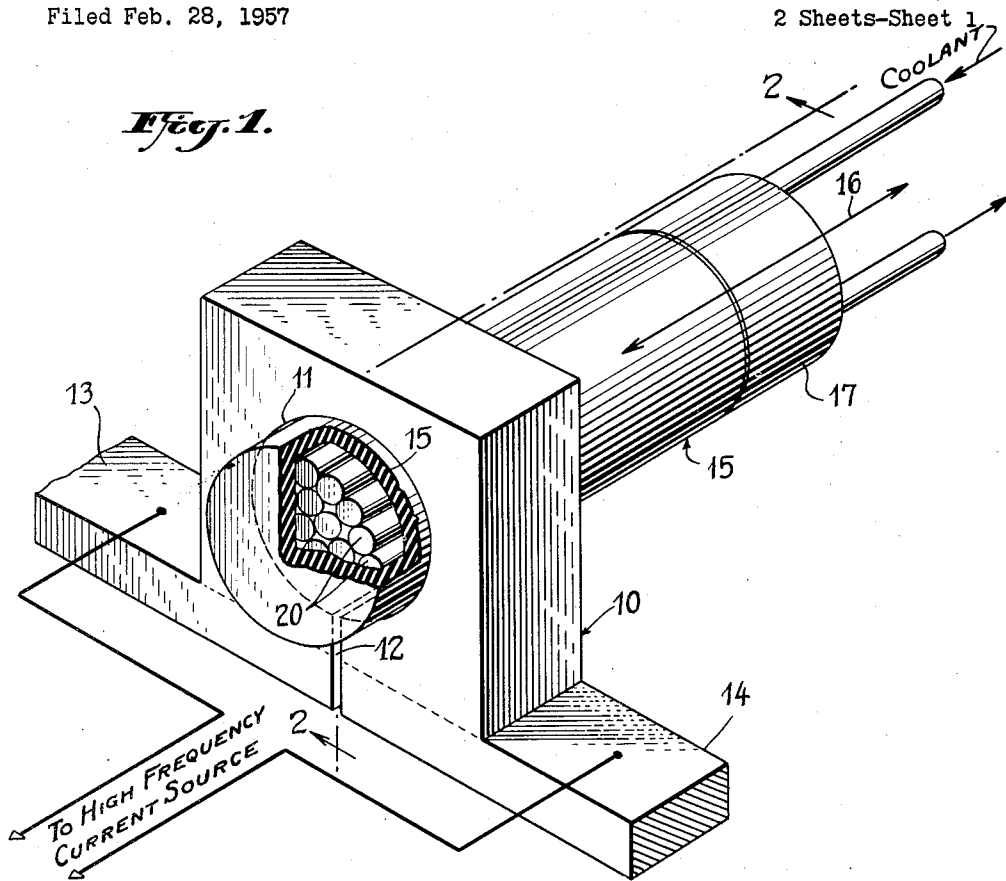
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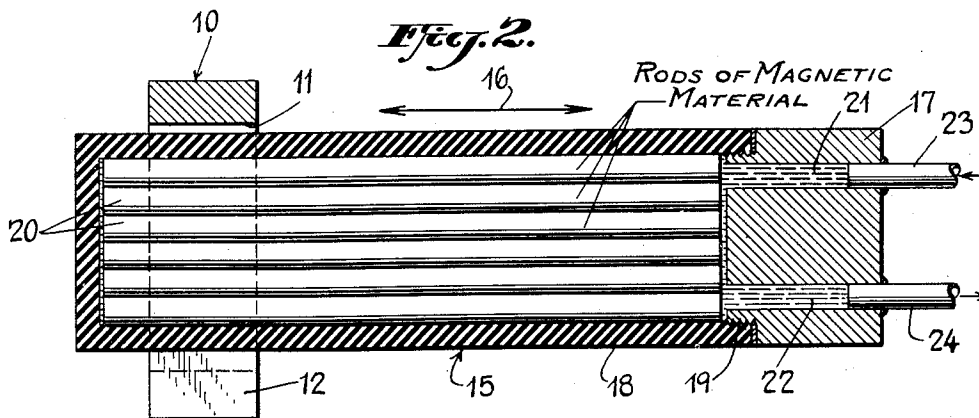
REACTORS FOR HIGH FREQUENCY CURRENT

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Fig. 1.



Figs. 2.



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Fig. 3.

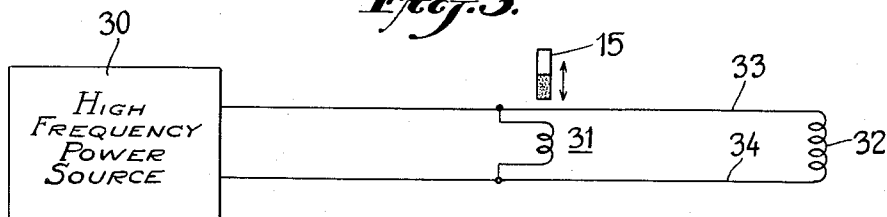


Fig. 4.

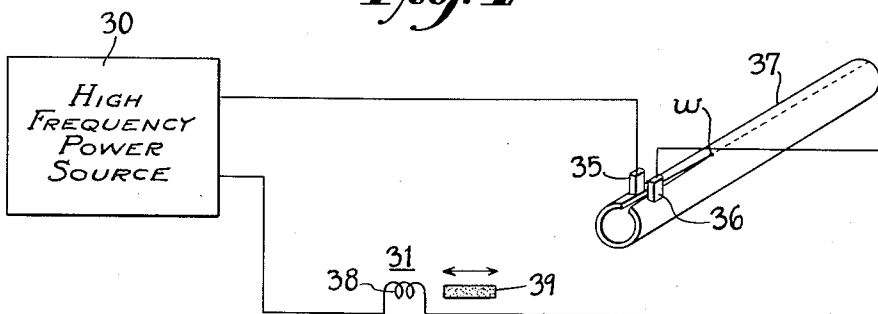
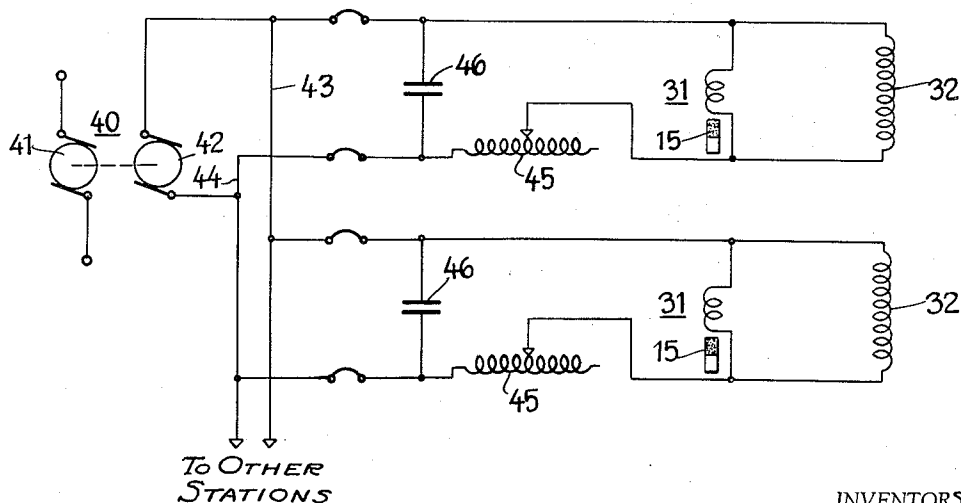


Fig. 5.



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REACTORS FOR HIGH FREQUENCY CURRENT

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13 Claims. (Cl. 219—10.75)

This invention relates to high frequency electrical heating circuits and means and methods for controlling same, and more particularly to means and methods for varying the heating effect produced by such circuits.

In high frequency electrical heating apparatus, the conductors and electrical components are required to handle relatively large currents, and therefore, it is desirable to eliminate adjustable components which employ sliding contacts. On the other hand, continuously and easily variable components which may be accurately set often are required, for example, to control the amount of heat supplied to an object or part and hence, to control the current in the device which causes heating of such object or part.

The current in a circuit may be adjusted without the use of contacts by means of a variable inductive reactor or inductor, and it is well known that the impedance of a reactor, such as a coil of one or more turns, may be varied by means of a magnetic mass or a non-magnetic conductive mass which is adjustable into or out of the magnetic field of the reactor. For example, if a cylinder of copper is moved into the coil without touching its turn or turns, the impedance of the coil may be greatly diminished and in fact reduced down to a very small amount when the space within the coil becomes largely filled by the copper mass. While such an expedient may readily be used to provide a variable reactor for a high frequency power circuit, it permits variation of the reactance only from the maximum amount which the coil will have with no core present, down to a value near zero when the space in and near the coil is largely filled with such a conductive non-magnetic mass, and the reactance of the coil cannot be increased above the value occurring when no such core is present.

If the means for adjusting the impedance of the reactor is a magnetic member, the impedance of the coil may only be increased by such member, and it has been found that in some cases the range of adjustment which may be obtained with either a magnetic member or a non-magnetic conductive member is insufficient for practical purposes. The preferred embodiment of the invention includes means which will permit adjustment of the value of the impedance of a reactor both considerably above as well as below the value which the reactor would have by itself, without any adjusting member or core means therein. The reactor is a coil or turn with a core means therein adjustable generally axially of the coil and with a portion of the length of such core means embodying magnetic material and another portion of the length being of good conductive non-magnetic material such as copper. Thus, when the core means is adjusted to various positions axially, such that the portions thereof within the coil are largely or more or less composed of the non-magnetic material, the reactance can be varied from its normal value down toward zero. When the core means is adjusted to various positions so that considerable portions thereof within the coil are of the magnetic ma-

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terial, the reactance of the device may be changed to various desired values above the normal reactance of the coil itself. By so adjusting the core means so that more or less of both the magnetic and non-magnetic portions are in the coil, various accurately controlled reactance values may be obtained over a range extending from above the normal reactance of the coil down to any desired values below such normal.

When an adjusting member of the type described above is employed in high frequency electrical heating apparatus, special problems arise which are not encountered with circuits carrying relatively small currents, e. g. electrical communication circuits. Thus, because of the relatively large currents involved, it may be necessary to provide water cooling for the adjusting member and because of the small number of reactor turns, the adjusting members should be closely coupled to, and hence closely spaced with respect to, the reactor turns. With close spacing, special care must be taken to prevent contact between the adjusting member and the turns of the reactor. For such uses, the adjusting member or core of the invention is encased in an insulating material such as a synthetic resin, and the core has passageways therein for a cooling fluid, such as water. The core may, for example, be made of a plurality of abutting cylindrical rods of magnetic material, the fluid flowing in the spaces between the rods.

In some installations, it is desirable to supply high frequency power to several heating devices or stations from a single, high frequency, power generator, and in such installations the power supplied to each station should be individually adjustable. If the generator is a high frequency alternator driven by a motor, it is important that the power factor of the load be near unity, and the means for varying the power supplied to each station should have little effect on the power factor. Although a series connection of the adjustable reactor may be satisfactory for use in some cases, a reactor of the type described above having a wide range of adjustment should be connected in parallel with the heating coil if the desired adjustment of heating is to be obtained without unsatisfactory variation of the load power factor.

Various further and more specific objects, features and advantages of the invention will appear from the description given below, taken in connection with the accompanying drawings illustrating by way of example certain preferred forms of the invention.

In the drawings:

Fig. 1 is a combined schematic and perspective view of a preferred embodiment of the invention;

Fig. 2 is a sectional view taken substantially along line 2—2 of Fig. 1;

Fig. 3 is a circuit diagram illustrating one form of high frequency power circuit embodying the invention, the circuit as shown having a work coil adapted to be used for induction heating purposes, for example; and

Figs. 4 and 5 inclusive are circuit diagrams of other high frequency circuits embodying the invention.

Referring now to Figs. 1 and 2, the variable reactor or inductor in the form of a one-turn coil is indicated generally by the numeral 10 and is a body of metal of rectangular cross-section having a central cavity 11, the metal at one side, for example the bottom side, of this block being slit as at 12 to form a gap, the sides of which respectively constitute the "ends" of the single turn. Suitable portions as at 13, 14 may be provided to which the terminals of a portion of a high frequency circuit may be connected as indicated.

An adjusting member or core assembly generally indicated by the numeral 15 is mounted by any suitable adjustable supporting means (not shown) so as to permit

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same to be adjusted in either direction as indicated by the arrows 16, axially with respect to the bore 11 of the coil 10. The core assembly 15 in the example shown is cylindrical and of a diameter small enough so that as mounted and adjusted, the conductive parts thereof at least will not come into contact with the interior surfaces in the bore 11.

As best shown in Fig. 2, the right hand portion 17 of the core assembly comprises a cylinder of non-magnetic and good conductive metal such as copper. A tubular casing 18 of suitable insulation material is secured to one end of the member 17 as by a threaded connection 19. The casing 18 may for example be made of any suitable known form of synthetic resinous material, for example, a phenolic resin and preferably of a form adapted to withstand substantially high temperatures. This casing contains the portion of the core assembly which is formed of magnetic material and in the particular form shown, for example, such magnetic material may take the form of a group of solid rods 20 containing powdered ferro-magnetic material. Such rods 20 or the like may be formed of sintered magnetic oxide, an insulation material, preferably of types now well known per se and which will have a low loss factor and high volume resistivity for example, such as the material marketed under the name Ferramic by General Ceramic & Steatite Corp. It will be understood that other magnetic cores may be used, preferably having a permeability (μ) greater than 1 (preferably substantially greater) and preferably the magnetic particles or elements being in divided form such that any current losses therein will be minimized. For example, finely divided iron carbonyl mixed with a suitable synthetic resinous insulating material may be used.

Since considerable heat normally will be generated in the core assembly, preferably means is provided for cooling the assembly. For example, the metal portion 17 may be formed with cooling fluid passageways as at 21, 22, with conduits as at 23, 24 for connecting same with a suitable source of cooling fluid such as water, which will flow through the cavities and into the spaces about the rods of magnetic material.

When it is desired to provide the greatest amount of reactance possible with the device, then the core assembly is adjusted to a position such that the coil turn will surround the middle of that portion of the core assembly which contains the magnetic material and so that the magnetic material will extend to either side of the bore 11 far enough to be intersected by the greater part of the magnetic field surrounding the turn of the coil 10. Then to obtain lesser values of reactance, the core assembly 15 is moved toward the left. By moving the assembly 15 to such a position that the bore 11 is in part filled by the magnetic core material and in part by the portion 17, the reactance of the device may be reduced to the normal value which it would have if the core assembly 15 were entirely absent. Then, as the assembly 15 is moved further to the left so that the bore becomes more or less filled by the metal portion 17, the reactance is reduced by varying degrees below such normal value.

If the magnetic portion of the core 15 will provide sufficient range of adjustment, as hereinafter described, the portion 17 may be made of insulating material or may be omitted.

As shown in Fig. 3, a high frequency power source 30, which may be, for example, a vacuum tube oscillator or a motor-generator set, is connected to a circuit containing one of the variable reactors 31 made according to the invention, and in which, as indicated, the coil may have several turns within which a core assembly 15 is adapted to be axially adjusted as in the case of the core assembly 15 of Figs. 1 and 2. Preferably, the energy of the power source has a frequency in the range from 9 to 500 kilocycles per second and the coil of the reactor 31 is magnetically uncoupled or isolated from the power source 30. In Fig. 3, the coil of the reactor 31 is shown connected

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in parallel with a heating device in the form of a work coil 32 which, for example, may be used for various induction heating purposes. If desired, the source 30 may include means for changing, in major steps, the amount of power flowing to the work coil 32. The device 31 may be used to secure more of a "vernier" type of adjustment permitting for example adjustments of the current flowing through coil 32 by percentages, say up to 25 percent either above or below an initial or normal amount. When the device 31 is adjusted to lower the reactance thereof, that is to say, by moving the conductive portion 17 of the core assembly 15 into the coil, then, less current will flow through the work coil 32 and more will flow through the coil of the device 31, and if the device 31 is adjusted to increase its reactance, that is, by moving the magnetic portion of the core into the coil, then less current will flow through the coil of the device 31 and more will flow through the work coil 32.

In lieu of an induction heating coil 32, it will be understood that the circuit may for example be connected to supply high frequency power by other means and for other purposes. For example, the coil 32 may be replaced by resistance heating apparatus of the type shown in Fig. 4. The leads 33 and 34 of the power source 30 may be connected to contacts 35 and 36 which engage at opposite sides of a gap in an advancing length of metal tubing 37, so as to heat the edges of such gap by resistance heating as they approach gap closing positions at a weld point *w*. It will be understood that the resistance heating apparatus of Fig. 4 also may be substituted for the induction heating work coil 32 shown in Fig. 5.

Except for the forming of the heating apparatus, which has been described above and which may be replaced by a heating coil 32, the apparatus shown in Fig. 4 differs from the apparatus shown in Fig. 3, primarily in the connection of the variable reactor 31. In the embodiment shown in Fig. 4 the high frequency power source 30 is connected to the heating apparatus in series with the variable reactor 31.

The variable reactor 31 preferably is of the type previously described and comprises a coil 38 and an adjustable member or core 39. The core 39 may have the same form as core 15 described in connection with Figs. 1 and 2 or it may comprise only the magnetic portion of the core assembly 15. When the reactor 31 is connected in series between the power source 30 and the heating apparatus and when the heating apparatus is of the type shown in Fig. 4, it may be possible to obtain sufficient control of the current in the heating apparatus when a core of magnetic material only is employed. In such a case, the non-magnetic conductive portion 17 of the core assembly 15 shown in Figs. 1 and 2 may be omitted. Also, it may be possible to dispense with the apparatus for supplying the cooling fluid illustrated in Figs. 1 and 2.

The operation of the reactor 31, shown in Fig. 4, is different from the operation of the reactor 31 shown in Fig. 3 in that an increase in the reactance of the reactor 31 decreases rather than increases the heating current in the heating apparatus. Otherwise, the operation of the embodiment shown in Fig. 4 is the same as that described above in connection with Fig. 3.

Fig. 5 is a circuit diagram of an installation in which a motor generator set 40 supplies high frequency electrical power to a plurality of heating means or coils 32. The motor 41 of the motor generator set 40 is supplied with electrical power from conventional power lines (not shown) and mechanically drives an alternator or generator 42. The generator 42 provides high frequency electrical power, for example, at a frequency of 9600 cycles per second, to the lines 43 and 44. Each of the heating coils 32 is connected to the lines 43 and 44, and hence to the generator 42, in series with a tapped coil 45 which may be used for coarse adjustment of the amount of power supplied to the heating coils 32.

The generator 42, for reasons well known to those

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skilled in the art, must operate with a load having a power factor which is as near unity as possible. Capacitors 46 connected in parallel with each circuit consisting of the tapped coil 45, a variable reactor 31 and a heating coil 32, form a plurality of parallel resonant circuits with such components which when adjusted for resonance at the frequency of the power supplied by the generator 42 also provides a load on the generator 42 having a power factor substantially equal to unity.

Normally, it is necessary to be able to adjust the heating power supplied to an object within the field of each of the heating coils 32 in small amounts. Adjustment of the power output of the generator 42 will vary the power supplied to all of the coils 32 and coils 45 provide only coarse adjustment and employ movable contacts. Therefore, in order to obtain individual, fine adjustment of the power at each of the stations without the use of contacts a plurality of variable reactors 31 of the type described above are connected in the load circuit, a reactor 31 being connected in parallel with each of the heating coils 32. It has been found that in order to provide the required range of adjustment a core of the type described in Figs. 1 and 2 should also form part of the variable reactor 31. However, when such a variable reactor is employed it should not be connected in series between the associated heating coil 32 and the power source because, in such case, adjustment of the variable reactor 31 will produce fairly large changes in the power factor of the load circuit. On the other hand, when the variable reactor 31 is connected in parallel with the heating coil 32 as illustrated in Fig. 5, the reactor 31 may be adjusted throughout its full range without causing a sufficient change in the power factor of the load circuit to produce unsatisfactory operation of the motor generator set 40.

With each of the above-described circuits, the reactor device embodying the invention makes it possible with a very simple construction to change the amount of power supplied to the work with a fine degree of control without interrupting the current. Thus, these arrangements are well adapted for use for processes where the power used may have to be varied from time to time or from moment to moment without causing troublesome conditions at the power generating source or interfering with other similar circuits connected to the same source.

Although certain particular embodiments of the invention are herein disclosed for purposes of explanation, further modifications thereof, after study of this specification, will be apparent to those skilled in the art to which the invention pertains. Reference should accordingly be had to the appended claims in determining the scope of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. High frequency electrical heating apparatus comprising a source of high frequency electrical power, heating means for transferring electrical energy from said source to an object to be heated, a variable reactor connected to said heating means, said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a hollow member forming a fluid-tight chamber and substantially non-conductive magnetic material disposed within said chamber with fluid passageways therein, said member having fluid passageways therein connecting with said passageways, and means connecting said heating means and said reactor to said source.

2. High frequency electrical heating apparatus comprising a source of high frequency electrical power, heating means for transferring electrical energy from said source to an object to be heated, and means connecting said heating means to said source comprising a variable reactor connected to said heating means and to said source, said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of

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said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow, cylindrical member of insulating material forming a fluid-tight chamber and substantially non-conductive, finely divided magnetic material disposed within said chamber and having fluid passageways therein, at least one of said portions having a fluid passageway therein connecting with said chamber for supplying cooling fluid to said chamber.

3. High frequency electrical heating apparatus comprising a source of high frequency electrical power, heating means for transferring electrical energy from said source to an object to be heated, and means connecting said heating means to said source comprising a variable reactor connected in series between said heating means and said source, said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow, cylindrical member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive, cylindrical rods of finely divided magnetic material mounted in abutting relation within said chamber, at least one of said portions having a fluid passageway therein connecting with said chamber for supplying cooling fluid to said chamber.

4. High frequency electrical heating apparatus comprising a source of high frequency electrical power, heating means for transferring electrical energy from said source to an object to be heated, means connecting said heating means to said source, and a variable reactor connected in parallel with said heating means, said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow, cylindrical member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive, cylindrical rods of finely divided magnetic material mounted in abutting relation within said chamber, at least one of said portions having a fluid passageway therein connecting with said chamber for supplying cooling fluid to said chamber.

5. High frequency electrical heating apparatus comprising a source of high frequency electrical power, a plurality of heating means for transferring electrical power, energy from said source to objects to be heated, means connecting said heating means in parallel with said source, and a plurality of variable reactors, each of said reactors being connected in parallel with one of said heating means and each said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core having a pair of portions disposed longitudinally with respect to each other and each forming a different substantial, longitudinally extending portion of the length of said core, one of said portions being substantially non-conductive and comprising magnetic material and the other of said portions being electrically conductive and comprising substantially non-magnetic material.

6. High frequency electrical heating apparatus comprising a high frequency electrical generator, a plurality of heating means for transferring electrical energy from said generator to objects to be heated, means connecting said heating means in parallel with said generator, and a plurality of variable reactors, each of said reactors be-

ing connected in parallel with one of said heating means and each said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn said core comprising a first portion of non-magnetic material of relatively high electrical conductivity, a second portion mounted in alignment with and secured to said first portion, said second portion comprising a hollow member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive rods of magnetic material mounted within said chamber and with portions thereof in spaced relation, said first portion having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

7. High frequency electrical heating apparatus comprising a high frequency electrical generator, a plurality of heating means for transferring electrical energy from said generator to objects to be heated, means connecting said heating means in parallel with each other and to said generator, and a plurality of variable reactors, each of said reactors being connected in parallel with one of said heating means and each said reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow, cylindrical member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive, cylindrical rods of finely divided magnetic material mounted in abutting relation within said chamber, one of said portions having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

8. A variable reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a hollow member forming a fluid-tight chamber and substantially non-conductive, magnetic material disposed within said chamber and having fluid passageways therein, said member having fluid passageways therein connecting with said passageways in said magnetic material.

9. A variable reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion and a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive rods of magnetic material mounted within said chamber with passageways therebetween, one of said portions having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

10. A variable reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity, a second portion mounted in alignment with and secured to said first portion, said second

portion comprising a hollow member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive rods of magnetic material mounted within said chamber and with portions thereof in spaced relation, one of said portions having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

11. A variable reactor comprising a coil having at least one turn and a core mounted for adjustment axially of said coil and within said turn, said core comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow, cylindrical member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive, cylindrical rods of finely divided magnetic material mounted in abutting relation within said chamber, said first portion having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

12. An adjusting core for a variable inductor comprising a first portion of non-magnetic material of relatively high electrical conductivity and of substantially cylindrical shape, a second portion mounted co-axially with and secured to said first portion, said second portion comprising a hollow cylindrical member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive, cylindrical rods of finely divided magnetic material mounted in abutting relation within said chamber, said first portion having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

13. An adjusting core for a variable inductor comprising a first portion of non-magnetic material of relatively high electrical conductivity, a second portion mounted in alignment with and secured to said first portion, said second portion comprising a hollow member of insulating material forming a fluid-tight chamber and a plurality of substantially non-conductive rods of magnetic material mounted within said chamber with portions thereof in spaced relation, said first portion having fluid passageways therein connecting with said chamber for supplying cooling fluid to said chamber.

References Cited in the file of this patent

UNITED STATES PATENTS

1,642,198	Gerth et al.	Sept. 13, 1927
2,182,341	Hulster	Dec. 5, 1939
2,394,391	Martowicz	Feb. 5, 1946
2,431,425	Sands	Nov. 25, 1947
2,444,259	Jordan	June 29, 1948
2,460,138	Lynn	Jan. 25, 1949
2,470,443	Mittelmann	May 17, 1949
2,570,311	Bohnet et al.	Oct. 9, 1951
2,597,237	Friend	May 20, 1952

FOREIGN PATENTS

993,513	France	Nov. 2, 1951
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