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CONSTANT CURRENT SUPPLY

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Fig 1

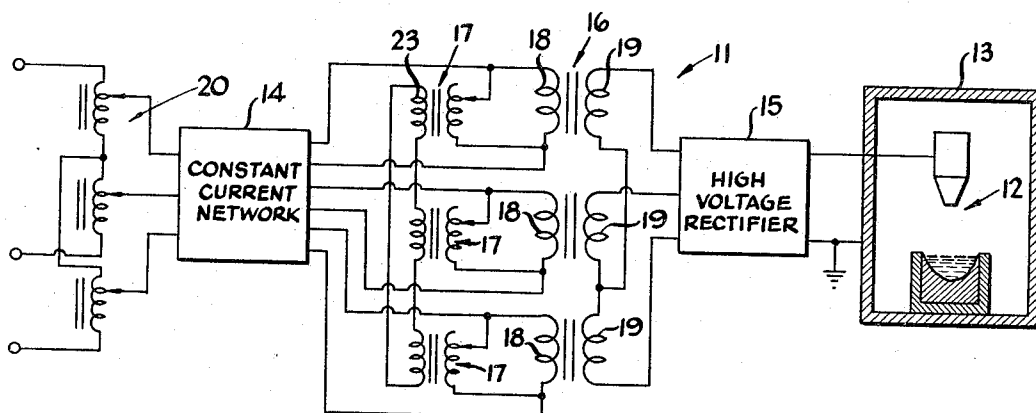
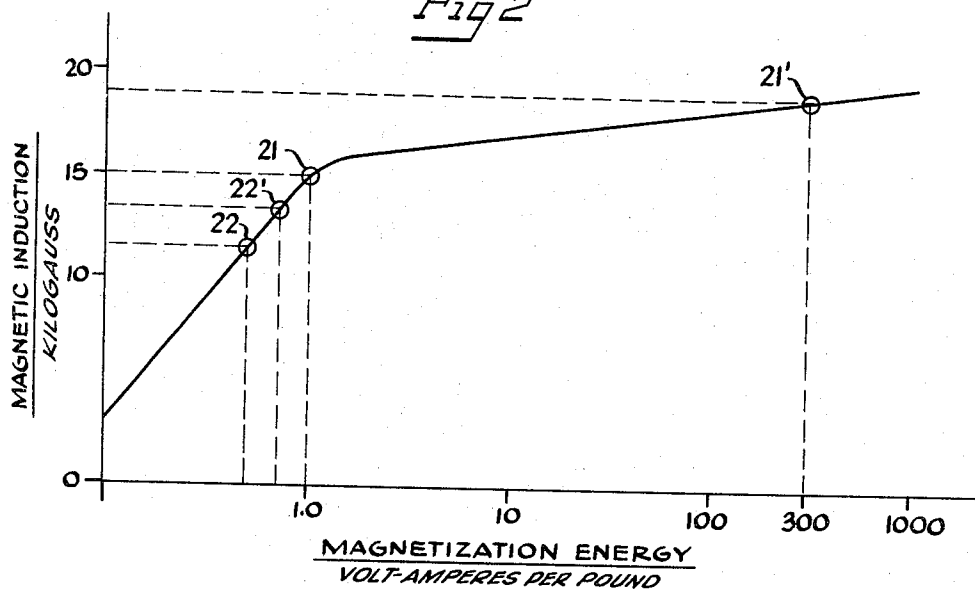


Fig 2



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CONSTANT CURRENT SUPPLY

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This invention generally relates to voltage limiting devices and more particularly to means for limiting undesirable voltage rises in a constant current supply of an electron beam vacuum furnace.

High power three phase constant current power supply systems are extensively utilized in connection with electron beam vacuum furnaces, the electron beam delivered from the filament of an electron gun to a melting crucible or the like being the load of the power supply system. In such power supplies the alternating current output of a monocyclic constant current network is coupled by a transformer to a high voltage rectifier which rectifies the constant alternating current to provide a constant direct current output for delivery to the electron beam load. The electron beam load is quite susceptible to current interruption, whereupon the output voltage of the power supply tends to rise rapidly to excessive, and even dangerous, values which severely stress the coupling transformer as well as the rectifier elements thereof.

Heretofore, various attempts have been made to limit the voltage rise to a safe value. For example, it has been customary to use such safety devices as spark gaps in parallel with the load for limiting the voltage rise. Unfortunately, this has not been an altogether satisfactory expedient, either with respect to complete protection of the equipment against overvoltage, or with respect to prompt re-establishment of the load circuit connections. More particularly, the operation of the spark gaps in itself frequently introduces transients which may disturb the electrical conditions of the whole power supply system for an appreciable time. One other previous approach to the problem has involved the use of the power supply coupling transformer itself as a clamping element on the voltage rise. More particularly, the transformer can be designed to sufficiently saturate upon overvoltage that a ceiling in the voltage rise can be established. However, the transformer in clamping, or limiting the voltage rise to such ceiling draws very high exciting currents from the constant current network. These high, exciting currents tend to produce transients that may damage the transformer.

An object of the present invention is to provide a constant current supply for an electron beam furnace which does not have the disadvantages and limitations of previous constant current power supply systems. Another object of the invention is to provide a constant current supply for an electron beam furnace in which the transformer overvoltage is limited to safe ceiling level without the introduction of transients which would tend to damage the transformer, as well as other circuit elements to which it may be connected. Still another object is the provision of a constant current power supply for an electron beam furnace which is durable in use.

Other objects and advantages of the present invention will become apparent by reference to the following description and accompanying drawings wherein:

FIGURE 1 is a schematic circuit diagram of a three phase constant current power supply system for an electron beam furnace showing various features of the present invention; and

FIGURE 2 is a graphical presentation of a typical magnetization curve for a magnetic core of a transformer and of a shunt reactor associated therewith in accord-

ance with the present invention, illustrating the voltage-limiting action thereof.

Generally, in accordance with the present invention a constant current power supply system 11 is provided for supplying constant current to an electron beam load 12 in a high vacuum furnace 13. The illustrated three phase power supply system includes a three phase constant current network 14, the output of which is supplied to a three phase high voltage rectifier 15 by means of a three phase coupling transformer 16. A magnetic core inductive reactor 17 is connected in shunt or parallel with the respective primary or phase windings 18 of the transformer 16, which reactors function to limit the rise in transformer output voltage to a safe ceiling level to thus protect the equipment against overvoltage. More specifically, the reactors 17 clamp the voltage rise in the transformer secondary windings 19 by absorbing the major portion of the magnetization energy normally delivered to the primary windings 18 to support the voltage rise. Thus, the reactors 17 draw most of the heavy exciting current delivered from the constant current network 14 and accordingly only a small increase in exciting current appears in each transformer primary winding 18. Since the primary winding exciting current is thus limited to a small amount, the secondary output voltage rise, which is supported by the exciting current, is likewise limited.

More specifically, the illustrated three-phase power supply system circuit includes the constant current network 14 which may be of any suitable type such as a conventional monocyclic network. The input of the constant current network 14 is supplied from a Y-connected variable three-phase input transformer 20 to facilitate the ready variation of the constant current output from the network 14. Although the input transformer 20 is depicted in the drawings as being of the autotransformer type, a conventional isolated primary and secondary winding transformer may as well be employed. In this latter instance, the primary windings are preferably delta connected to facilitate harmonic suppression.

The output of the constant current network 14 is, in turn, connected to the primary windings 18 of the three-phase transformer 16 whose secondary windings 19 are Y-connected to the input of the three-phase high-voltage rectifier 15 in the conventional manner. The rectified constant direct current output from the rectifier is supplied to the electron beam load 12 in a high vacuum furnace 13. In order to limit excessive rises in output voltage of the transformer 16, the magnetic core reactors 17 are connected in shunt with the respective primary windings 18 of the transformer 16.

In order that the shunt reactors 17 function as overvoltage limiting devices in the foregoing manner, such reactors are appropriately designed in relation to the transformer with which they are employed. More particularly, the reactors 17 are so designed that the reactor cores operate in the saturated region of the magnetization curve during overvoltage conditions while the transformer core remains below the saturation region. Thus, the reactors draw a higher proportion of the current from the constant current network during the overvoltage condition, thereby limiting the voltage rise in primary and secondary windings of the transformer. This is accomplished by designing the reactors 17 to have operating points for normal output voltage of the network 14 located near or slightly above the knee of the magnetization curve of the reactor cores. The transformer 16 on the other hand is designed to have an operating point for such normal voltage located below the knee of the magnetization curve of the transformer core.

The operation of the shunt reactors 17 in producing a voltage-limiting action will be better understood upon reference to FIGURE 2 which illustrates a typical mag-

netization curve for transformer iron used as the core material in each leg of the transformer 16 and each reactor 17. It is to be noted, however, that dissimilar materials may as well be employed in the transformer and the reactors to provide an analogous voltage limiting action, the use of the same material in both the cores of the transformers and the cores of the reactors being herein employed to provide a single magnetization curve to thereby facilitate ease of illustration. In the plot of FIGURE 2 the vertical coordinate represents the magnetization, or magnetic induction of the iron in kilogauss and the horizontal coordinate represents the corresponding magnetization energy stored by the iron in volt amperes per pound, the vertical scale being linear and the horizontal scale being logarithmic. Each reactor core may be designed for normal operation at an induction, for example, of about 15 kilogauss, which intersects the magnetization curve at point 21 of FIGURE 2 and corresponds to a magnetization energy of about one volt ampere per pound. Each leg of the transformer 16 is designed for normal operation at a lower magnetic induction of, for example, about 11.5 kilogauss, as represented by the operating point 22 on the magnetization curve. The reactor and transformer operating points 21 and 22 correspond to 100 percent voltage throughout the circuit. It is to be noted moreover that the knee of the magnetization curve occurs between about 14½ kilogauss and 16½ kilogauss. It will thus be appreciated that the reactor operating point 21 is located substantially at the knee of the curve, whereas the transformer operating point 22 is downwardly displaced therefrom. In addition, for these operating points the ratio between the corresponding inductions is about 1:3. Now, suppose that the electron beam load 12 is interrupted and the output voltage of transformer 16 begins to rise rapidly. As a result, the operating point of each leg of the transformer may rise to 22', for example, while that for each reactor moves to 21'. The ratio between the magnetic inductions corresponding to the new operating points 21' and 22' will remain substantially equal to the 1:3 ratio existing for the original operating points 21 and 22. However, it will be noted that the magnetization energy stored in each leg of the transformer is still less than 1 volt ampere per pound, thus showing but a slight increase in magnetization current, and therefore in transformer output voltage. The magnetization energy stored in each reactor, on the other hand, has increased to something on the order of 300 volt amperes per pound, thereby designating a substantial increase in magnetization current flowing in the reactor. The reactors thus draw the major portion of magnetization current from the constant current network 14 and prevent the same from appearing in the primary windings of the transformer 16 to thus clamp the output voltage appearing across the secondaries 19 at a safe ceiling level.

Each of the reactors 17 is made variable to facilitate adjustment of the ceiling level to which rises in transformer output voltage are limited. More particularly, upon variation of the reactor inductance placed in shunt with the transformer primary winding, the normal operating point of the reactors may be set to varied locations on the magnetization curve thereof. As a result, the ratio between the respective magnetic inductions of the reactors and transformer, and the proportion of magnetization energy stored in the reactors relative to that stored in the transformers in an overvoltage situation is correspondingly variable, as is therefore the level at which the transformer output voltage is clamped. The reactors 17 may be variable in increments through the provision of taps on the coils thereof or, more preferably, continuously variable as depicted.

The reactors 17 may be provided as separate units, or more preferably as a single unit in which the three reactor windings are wound upon a common core. By providing the reactors as a single unit, some simplification in the construction of the overall circuit results.

The peaks of current drawn by the reactors 17 and the transformer 16 are reduced by providing a path for the third harmonic component thereof. In this connection, the reactors 17 are preferably provided with tertiary windings 23 which are connected in delta, as depicted in FIGURE 1, to provide a path for third harmonic currents. The primary windings 18 of transformer 16, as well as the windings of the reactors 17 may be connected in any desired configuration to the output of the constant current network, and yet a path for third harmonic currents is provided by the tertiary windings 23 of the reactors.

In applications where the primary windings 18 of the transformer 16 can be delta connected, the tertiary windings may be eliminated. The reactors 17 in such applications are connected in shunt therewith. Such a delta connection provides a path for third harmonic components of current and accordingly the peaks of the overall current drawn from the constant current network 14 are reduced.

There is thus provided by the present invention an extremely effective mechanism for limiting excessive voltage rises in the output of a constant current power supply for an electron beam of an electron bombardment high vacuum furnace. The shunt reactor arrangement of the present invention is particularly effective in limiting the output voltage rise of such a constant current power supply when the electron beam is interrupted. As a result, the transformer and associated high voltage rectifier in the constant current power supply are not stressed by excessive voltage rises and accordingly the life thereof knee of said curve for a predetermined normal operating is materially increased. In addition, the shunt reactor arrangement of the present invention may serve other useful purposes while at the same time performing its primary voltage limiting function. For example, the shunt reactor arrangement may function as a narrow range regulator to compensate for fluctuations in the current output from the constant current network which may occur with small changes in line voltage. Moreover, the reactor associated with each transformer primary winding may be connected as an auto transformer between the constant current network and primary winding. By means of such an auto transformer coupling, the reactor may serve as an impedance changing device while at the same time limiting excessive voltage rises.

Various modifications and changes may be made in the disclosed constant current source without departing from the spirit and scope of the invention.

Various features of the invention are set forth in the accompanying claims.

What is claimed is:

1. A constant current power supply for an electron beam furnace, comprising an electron beam load, a constant current network, a magnetic core transformer with a primary winding coupled to the network and a secondary winding coupled to said electron beam load, and a magnetic core inductive reactor having a winding connected in parallel with said primary winding of said transformer so that the same voltage is applied to said reactor winding as is applied to said primary winding, said transformer being designed to have an operating point on the magnetization curve of its core which is below the knee of said curve for a predetermined normal operating voltage, said reactor designed to have an operating point on the magnetization curve of its core closely adjacent the knee thereof for said predetermined normal operating voltage, whereby in response to voltage rises from said predetermined normal operating voltage the core of said transformer is unsaturated and the magnetization current flowing in its primary winding remains relatively constant whereas the core of said reactor is saturated and the winding thereof draws a greatly increased magnetization current to thereby limit said voltage rises to a substantially fixed ceiling.

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2. A constant current power supply for an electron beam furnace comprising an electron beam load, a constant current network, and a three-phase magnetic core transformer with primary windings connected to said constant current network and secondary windings coupled to said electron beam load, and three inductive reactors each having an associated magnetic core and having a winding connected in parallel with a primary winding of said transformer so that the same voltage is applied to said reactor winding as is applied to said primary winding, said core of said transformer being designed to have an operating point at a predetermined normal voltage below the knee of the magnetization curve of the transformer core, said core associated with each reactor being designed to have an operating point at said predetermined normal voltage adjacent the knee of the magnetization curve of the reactor core, each of said reactors having a tertiary winding which tertiary wind-

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ings are connected in a delta configuration to provide a path for third harmonic currents.

3. Apparatus in accordance with claim 1 in which said reactor includes means for varying the inductance thereof to thereby vary the location of its operating point on the magnetization curve of its core and, in turn, vary the ceiling to which voltage rises are limited.

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