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HIGH FREQUENCY ELECTRICAL HEATING APPARATUS

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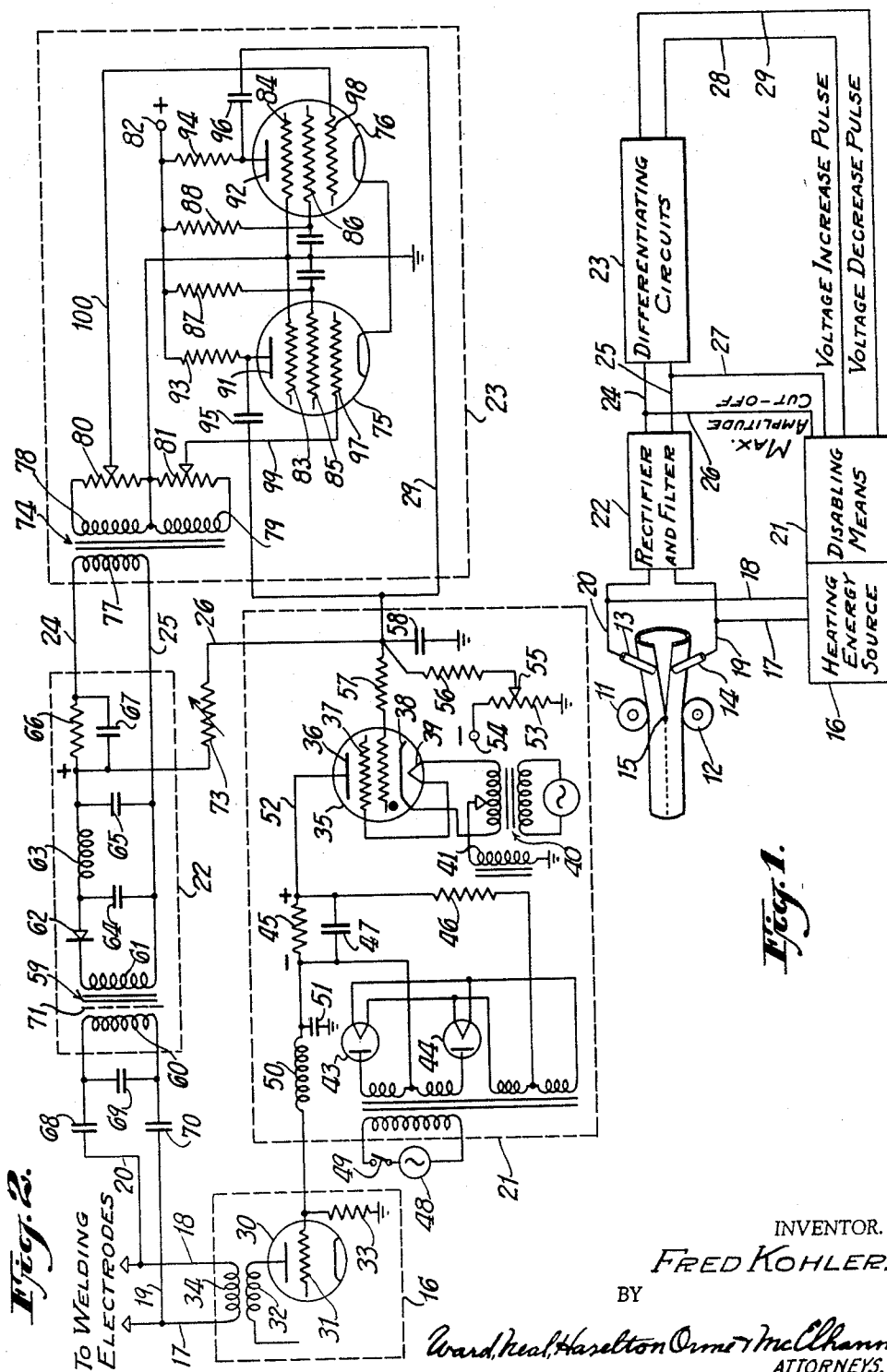


Fig. 2.

TO WELDING ELECTRODES

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HIGH FREQUENCY ELECTRICAL HEATING APPARATUS

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This invention relates to protective apparatus for high frequency heating systems.

In high frequency heating systems which employ electrodes or contactors for transferring or conducting the electrical heating energy from the energy source to the work, arcs of sufficient intensity to damage the electrodes and/or the work are produced between the electrodes and the work from time to time, particularly when the work is moved with respect to the electrodes during heating. Also, under these conditions, the voltage of the energy normally varies at a relatively high rate, e.g. above ten kilocycles per second, as the work is moved due to small intensity, short duration and non-damaging arcs caused by surface irregularities and due to the variation of contact resistance between the work and the electrodes. At times the electrodes may become short-circuited or shunted by a low impedance load which may damage the high frequency energy source due to overloading. Similar effects are encountered in high frequency heating systems employing means other than contacting electrodes for coupling the work to the energy source.

Furthermore, relatively low frequency, non-damaging variations in the energy voltage are caused by thermal effects and supply voltage variations, such variations generally having a fundamental frequency of less than one hundred cycles per second, and from time to time it may be necessary to adjust the supply voltage manually or otherwise to control the heating of the work.

It is important that the high frequency energy source be disabled quickly whenever conditions occur which may cause damage to the electrodes, the work or the source, and it is not desirable that the source be disabled when conditions occur which may cause variations in the voltage of the energy but which will not cause damage to the source and its associated apparatus or the work. Generally, it is not practical to disconnect the electrodes from the work or from the source due to the high currents which must be interrupted and the surge of the source oscillator voltage which may result.

Known types of protective apparatus for high frequency heating systems which rely upon voltage magnitude alone for operation are not satisfactory under the above-mentioned conditions because any of the conditions may produce a voltage change of sufficient magnitude to operate such protective apparatus. In addition, certain types of such apparatus operate only when the voltage at the work increases due to arcing and will not operate when the voltage decreases due to a low impedance shunt or short circuit at the work. If the apparatus operates only when the voltage change is large, to discriminate against smaller, non-damaging conditions, the operation of the protective apparatus may be delayed by the time required for the voltage to reach the operating value.

It has been found that, except for changes in voltage

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to cause adjustment of the heating energy, damaging and non-damaging conditions may be distinguished by the rate at which the voltage of the high frequency energy changes. Thus, it has been found that the voltage of the high frequency energy changes at one rate when the arc intensity is sufficient to cause damage to electrodes or the work and when a short circuit is produced between the electrodes, changes at a higher rate when low intensity non-damaging arcs are formed and when the contact resistance varies and changes at a lower rate when there are thermal and line voltage variations. In accordance with the present invention, the protective apparatus is selectively responsive to the rate of change of the high frequency energy voltage so as to distinguish between damaging and non-damaging conditions. It will be apparent that when the protective apparatus is so responsive, it may be made to respond rapidly when damaging conditions occur and yet it will not respond to non-damaging conditions.

The apparatus of the invention described above will not respond when the voltage is changed manually or otherwise to vary the heating of the work, but it also does not require readjustment when the average level of the voltage of the heating energy is so changed. Although it is not essential, it is desirable that the protective apparatus operate when a maximum safe level of voltage is reached even though the level is approached gradually. Accordingly, in the preferred embodiment of the invention, the protective apparatus includes circuits which cause it to respond when the level of the voltage of the high frequency energy exceeds a predetermined safe level due to causes other than the damaging conditions described above.

In accordance with the preferred embodiment of the invention, a pair of differentiating circuits are coupled to the high frequency energy source through a rectifier and a filter, the filter attenuating energy at the source frequency and passing energy at frequencies below the source frequency. The differentiating circuits in combination with the rectifier and filter provide control signals in response to energy changes caused by high intensity arcs or a short circuit and do not provide control signals with energy changes which occur at a different rate. The control signals as well as the voltage at the output of the filter, which is proportional to the peak of the source voltage, are supplied to disabling apparatus or circuits connected to the high frequency energy source so that the source is disabled whenever the peak voltage exceeds a predetermined level and whenever control signals are produced. It has been found, for example, that satisfactory operation of this embodiment may be obtained if the control signals are produced when the fundamental frequency of the voltage change is in the range from about 100 cycles per second to about 10,000 cycles per second, the upper limit being determined by the source frequency and the upper limit being no greater than about one-fifth to one-tenth of the frequency of the source energy. As used herein, the term "high frequency" refers to a frequency of about fifty kilocycles per second or greater.

It is one object of the invention to provide protective apparatus for high frequency heating equipment which will be responsive when damaging conditions occur and will be substantially unresponsive when changes in operation of the equipment which will not damage the equipment or the work occur.

It is another object of the invention to provide protective apparatus for high frequency heating equipment which will operate as described above and which will operate within a relatively short period of time after damaging conditions arise.

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Other objects and advantages of the invention will be apparent from the following detailed description of the manner in which I now prefer to practice the invention, which description should be considered in connection with the accompanying drawings in which:

Fig. 1 is a combined block and schematic diagram of the preferred embodiment of the invention; and

Fig. 2 is a circuit diagram of the preferred embodiment of the invention.

Fig. 1, which is a combined schematic and block diagram, illustrates the protective apparatus of the invention as it may be employed with a known type of high frequency tube welding apparatus, but it is to be understood that the protective apparatus of the invention may be employed with other types of high frequency heating equipment. Sheet metal 10, which may, for example, be copper, is rolled into tubular form by means of rollers 11 and 12 as it is pulled to the left. A pair of electrodes 13 and 14 contact the surface of the metal 10 causing it to fuse at the abutting edges 15. Heating energy is supplied to the abutting edges 15 from the heating energy source 16 through leads 17—20 and electrodes 13 and 14. The heating energy source 16 comprises a high frequency generator, such as a vacuum tube oscillator, and the energization of the source 16 is controlled by a disabling means 21. The disabling means 21 may be of any conventional type and may, for example, be a gas or a vacuum tube with associated circuits for controlling the bias of the vacuum tube oscillator, a fast-acting switch which controls the energization of the source, a gas tube which, when conducting, de-energizes the vacuum tube oscillator, etc. Preferably, the disabling means is of the type illustrated in Fig. 2 for the purpose of disabling the high frequency or heating energy source 16 within a very short time after a damaging condition occurs. This portion of the apparatus shown in Fig. 1 is well known to those skilled in the art, and therefore, has been shown only schematically, it being understood that other known types of apparatus may be associated therewith to accomplish the desired functions.

The protective apparatus of the invention, which is used in combination with the heating energy source 16 and the disabling means 21, comprises a rectifier and filter 22 and differentiating circuits 23. The rectifier and filter 22 is coupled to the electrodes 13 and 14 by means of the leads 19 and 20 which are in turn coupled to the heating energy source 16 by means of leads 17 and 18. The rectifier and filter 22 rectifies and filters a portion of the high frequency energy but passes energy having frequencies lower than the frequency of the source energy. Preferably the filter portion of the rectifier and filter 22 attenuates energy having a frequency above approximately 10,000 kilocycles per second. The output of the rectifier and filter 22 is coupled by means of leads 24 and 25 to the differentiating circuits 23. The output of the rectifier and filter 22 is also coupled to the disabling means 21 by means of leads 26 and 27. During operation of the apparatus a voltage proportional to the peak level of the high frequency source energy is present between the leads 26 and 27 and if the voltage exceeds a predetermined safe level, the disabling means 21 operates and disables the heating energy source 16. The differentiating circuits 23 supply a voltage increase pulse or control signal to the disabling means 21 by way of the lead 28 when energy of increasing amplitude and having a fundamental frequency within a predetermined band is supplied to the input of the differentiating circuits 23. The differentiating circuits 23 also supply a voltage decrease pulse or control signal to the disabling means 21 by way of the lead 29 when energy of decreasing amplitude and having a fundamental frequency within said predetermined band is supplied to the input of the differentiating circuits 23. The predetermined band is selected so as to distinguish between voltage changes which accompany damaging and non-damaging conditions

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as described above and the band may, under the conditions previously described, extend from approximately 100 cycles per second to about 10,000 cycles per second.

It has been found that with tube welding apparatus of the type described and with movement of the tube 10 at a rate in excess of thirty feet per minute, a frequency band of from 100 cycles per second to 10,000 cycles per second provides satisfactory discrimination between damaging and non-damaging conditions, but it will be apparent to those skilled in the art that dependent upon the degree of discrimination desired and the frequency ranges of the voltage changes accompanying damaging and non-damaging conditions in different installations the frequency range of the energy to which the differentiating circuits are responsive may differ from the frequency band which I have found to be satisfactory, namely 100 cycles per second to 10,000 cycles per second.

It will also be apparent to those skilled in the art that if other protective apparatus is employed or that if it is not desired to use the protective apparatus of the invention for the purpose of controlling the safe peak level of the high frequency energy, the connections 26 and 27 between the output of the rectifier and filter 22 and the disabling means 21 may be omitted. Furthermore, if during operation of the heating apparatus it is found that only increases of amplitude of the energy are encountered when damaging conditions occur, the connection 29 may be omitted or alternatively, if during operation of the heating apparatus only energy amplitude decreases are encountered when damaging conditions occur, the connection 28 may be omitted.

The circuit diagram of the preferred embodiment of the invention is shown in Fig. 2. The heating energy source comprises a vacuum tube oscillator illustrated schematically by the vacuum tube 30 having a control electrode 31, the coil 32 and the resistor 33. Since the vacuum tube oscillator may be of any conventional type, further details thereof have not been shown in Fig. 2. The heating energy is supplied to the welding electrodes by means of the coupling coil 34 and the leads 17 and 18. By the application of a biasing voltage of sufficient magnitude to the control electrode 31, the generation of high frequency energy by the high vacuum tube oscillator may be terminated, and hence the source 16 may be disabled.

The disabling means 21 comprises a gas tube 35 having an anode 36, a control electrode 37, a cathode 38 and a heater 39. Heating energy is supplied to the heater 39 by means of a transformer 40, the center tap of the secondary winding of the transformer 40 being connected to ground through a choke 41. The cathode 38 is connected to one side of the heater 39, and therefore, the cathode 38 is connected to ground through the secondary winding of the transformer 40 and the choke 41.

The anode voltage for the anode 36 of the gas tube 35 as well as the biasing voltage for the control electrode 31 of the vacuum 30 are supplied by means of a conventional rectifier-filter network comprising a transformer 42, a pair of rectifiers 43 and 44, resistors 45 and 46 and a capacitor 47. The primary winding of the transformer 42 is connected to the power source 48 through a switch 49 which may be used to interrupt the flow of current through the gas tube 35 after it has become conducting. The polarity of the voltage at the end of the resistors 45 is indicated by the signs adjacent the ends thereof and the negative end of the resistor 45 is connected to the control electrode 31 through a high frequency choke 50, a high frequency by-passing capacitor 51 being connected to one end of the choke 50. The positive end of the resistor 45 is connected by a lead 52 to the anode of the gas tube 35.

The gas tube 35 is normally maintained in a non-conducting state by a biasing voltage supplied from a source of bias voltage (not shown) connected to the ends of a potentiometer 53, the negative end of the source being

connected to the terminal 54. The adjustable arm 55 of the potentiometer 53 is connected to the control electrode 37 through the resistors 56 and 57. A high frequency bypassing capacitor 58 is connected between the junction point of the resistors 56 and 57 and ground.

When the gas tube 35 is non-conducting, no biasing voltage is applied to the control electrode 31 by the disabling means 21 because in effect there is an open circuit between the positive end of the resistor 45 and ground. However, when a positive voltage of sufficient magnitude is applied to the control electrode 37 in the manner hereinafter described, the gas tube 35 becomes conducting and provides a low impedance path from the positive end of the resistor 45 to ground and thereby applies a negative biasing voltage to the control electrode 31 of sufficient magnitude to disable the vacuum tube oscillator, and hence, the heating energy source 16.

The rectifier and filter 22 comprises an input transformer 59 having primary and secondary windings 60 and 61, respectively, a rectifier 62, a low pass filter including a coil 63 and two capacitors 64 and 65, a resistor 66 and a filtering capacitor 67. The primary winding 60 of the input transformer 59 is coupled to the welding electrodes by means of the leads 19 and 20 and by means of the coupling and voltage dividing network comprising the capacitors 68, 69, and 70. In order to improve the stability and sensitivity of the protective apparatus, it is desirable that the voltage between the ends of the secondary winding 61 correspond only to the voltage between the welding electrodes, and since there normally is a voltage between the welding electrodes and ground, it is desirable to use loose coupling between the primary and secondary windings 60 and 61 and to use a Faraday shield 71 between the windings.

The filter circuit 63-65 attenuates or rejects energy at the source frequency so that substantially no energy at the frequency of the source appears between the output leads 24 and 25. Preferably, also the filter circuit 63-65 attenuates all energy at a frequency above about 10,000 cycles per second, but if desired, the necessary frequency discriminating circuits may be included in or as part of the differentiating circuits 23.

A voltage is developed across the resistor 66 having the polarity indicated at the ends thereof and having a magnitude which is proportional to the peak voltage of the high frequency energy. The filtering capacitor 67 serves the normal filtering function and in addition reduces the magnitude of low frequency voltages appearing between the leads 24 and 25 and by-passes the resistor 66 for high frequencies. The positive end of the resistor 66 is connected by means of leads 26 and 72, the variable resistor 73 and the resistor 57 to the control electrode 57 of the gas tube so that when the magnitude of the voltage across the resistor 66 exceeds a predetermined value or level, the level being determined by the setting of the arm 55 on the potentiometer 53, the gas tube 35 will conduct and the heating energy source 16 will be disabled in the manner described above.

The differentiating circuits 23 comprise a transformer 74 and a pair of vacuum tubes 75 and 76. The transformer 74 comprises a primary winding 77 coupled to the output of the rectifier and filter 22 by the leads 24 and 25 and a pair of secondary windings 78 and 79. Instead of a pair of secondary windings, a single, center tapped, secondary winding having two portions 78 and 79 may be employed. The ends of the winding 78 and 79 of relatively opposite polarity are connected together and are connected to the junction point of a pair of potentiometers 80 and 81. The opposite ends of the winding 78 and 79 are connected to the opposite ends of the potentiometers 80 and 81.

The terminal 82 is connected to a direct current supply (not shown) the positive end of the supply being connected to the terminal 82 and the negative end of the supply being connected to ground. Preferably, the

vacuum tubes 75 and 76 are pentode tubes operated near their saturation points. The suppressor grids 83 and 84 are connected to ground and the screen grids 85 and 86 are connected to the terminal 82 through resistors 87 and 88. The screen grids 85 and 86 are also bypassed to ground by means of capacitors 89 and 90.

The anodes 91 and 92 of the tubes 75 and 76 are connected to the terminal 82 through resistors 93 and 94. The anodes 91 and 92 also are coupled to the control electrode 37 of the gas tube 35 by means of capacitors 95 and 96, the leads 28 and 29 and the resistor 57. The control electrodes 97 and 98 are connected to the arms of the potentiometers 81 and 80 by means of leads 99 and 100, and it will be noted that because of the connections of the windings 78 and 79, the control electrodes 97 and 98 are connected to points of relatively opposite polarity so that a negative-going signal will be applied to either the control electrode 97 or the control electrode 98 regardless of whether the energy supplied to the primary winding 77 is increasing or decreasing.

The vacuum tubes 75 and 76 with their associated circuits act as differentiating amplifiers and by a suitable selection of the circuit constants of these amplifiers and the rectifier and filter circuits, in a manner well known to those skilled in the art, the amplifiers will supply control signals or pulses to the control electrode 37 of the gas tube 35 of sufficient magnitude to render the gas tube 35 conducting only when the rate of change (either increasing or decreasing) of the voltage of the energy of the source 16 or at the electrodes 13 and 14 is within a predetermined range. In accordance with an embodiment of the invention which I have constructed and have found to operate satisfactorily, the circuit constants of the amplifiers and the rectifier and filter circuits were chosen so that control signals of sufficient amplitude to render the gas tube 35 conducting were provided substantially only when the fundamental frequency of the source energy change is within the range from about 100 cycles per second to about 10,000 cycles per second. Furthermore, by the use of such amplifiers and the disabling means shown in Fig. 2, it has been found to be possible to disable the heating energy source 16 within about ten microseconds after a damaging condition occurs. It will be apparent to those skilled in the art that other types of differentiating circuits which will function in a manner similar to the differentiating circuits shown in Fig. 2 may be substituted for the latter differentiating circuits.

Having thus described my invention with particular reference to the preferred form thereof and having shown and described certain modifications, it will be obvious to those skilled in the art to which the invention pertains, after understanding my invention, that various changes and other modifications may be made therein without departing from the spirit and scope of my invention, as defined by the claims appended thereto.

What is claimed as new and desired to be secured by Letter Patent is:

1. In high frequency electrical heating apparatus having a heating energy source for supplying electrical energy at a predetermined frequency to work to be heated, means controlled by said energy for disabling said source when the magnitude of said energy varies from a predetermined value comprising control signal means coupled to said source, said control means being unresponsive to variations in the magnitude of said energy at said predetermined frequency but responsive to variations in the magnitude of said energy at lower frequencies for generating a control signal in response both to an increase and to a decrease in said magnitude and control means connected to said source and to said control signal means for disabling said source in response to said signal.

2. In high frequency electrical heating apparatus having a heating energy source for supplying electrical energy at a predetermined frequency and voltage to work

to be heated, means controlled by said energy for disabling said source when the voltage varies from a predetermined value comprising control signal means coupled to said source which is unresponsive to variations in said voltage at said predetermined frequency but responsive to variations in said voltage at lower frequencies for generating a control signal in response both to an increase and to a decrease in said voltage and control means connected to said source and to said control signal means for disabling said source in response to said signal.

3. High frequency electrical heating apparatus comprising an oscillator for generating high frequency electrical energy, converting means coupled to said source for converting changes in the magnitude of said energy at frequencies lower than said frequency, into control signals when the peak magnitude of said energy increases above a predetermined value and when the peak magnitude of said energy decreases below said predetermined value, and means coupled to said converting means and to said oscillator for cutting-off said oscillator in response to said control signals.

4. High frequency electrical heating apparatus comprising an oscillator for generating high frequency electrical energy, rectifier and filter means coupled to said source for rectifying and filtering energy at said frequency, said filter passing energy at frequencies lower than said frequency, differentiating means connected to said filter for providing a first control signal when the magnitude of said energy increases above a predetermined value for a predetermined time greater than the period of oscillation of said energy and for providing a second control signal when the peak magnitude of said energy decreases below said predetermined value for a predetermined time greater than the period of oscillation of said energy, and means coupled to said differentiating means and to said oscillator for cutting-off said oscillator in response to said control signals.

5. High frequency electrical heating apparatus comprising an oscillator for generating high frequency electrical energy, rectifier and filter means coupled to said source for rectifying and filtering energy at said frequency, said filter passing energy at frequencies lower than said frequency, differentiating means connected to said filter for providing a first control signal when the peak magnitude of said energy increases above a predetermined value for a predetermined time greater than the period of oscillation of said energy and for providing a second control signal when the peak magnitude of said energy decreases below said predetermined value for a predetermined time greater than the period of oscillation of said energy, and means coupled to said differentiating means and to said oscillator for biasing said oscillator to cut-off in response to said control signals.

6. In high frequency heating apparatus having a high frequency oscillator for supplying electrical energy to work to be heated and having means for disabling said oscillator, rectifier means for rectifying said energy, means coupling said rectifier means to said oscillator, filter means coupled to said rectifier for filtering energy at said frequency and for passing energy at frequencies below said frequency, a pair of differentiating circuits coupled to said filter, one of said circuits providing a first control signal when the energy passed by said filter changes from a predetermined value to a higher value and the other of said circuits providing a second control signal when the energy passed by said filter changes from said predetermined value to a lower value, and control means responsive to said control signals and coupled to said differentiating circuits and to said disabling means for operating said disabling means.

7. High frequency heating apparatus according to claim 6 further comprising means coupling said control means to said filter means, said control means also being responsive to energy passed by said filter and having a value

higher than a predetermined value for operating said disabling means.

8. In high frequency heating apparatus having a high frequency oscillator for supplying electrical energy to work to be heated and having means for disabling said oscillator, rectifier means for rectifying said energy, means coupling said rectifier means to said oscillator, filter means coupled to said rectifier for filtering energy at said frequency and for passing energy at frequencies below said frequency, a pair of differentiating circuits coupled to said filter, one of said circuits providing a first control signal when the voltage of the energy passed by said filter changes from a predetermined value to a higher value and the other of said circuits, etc., providing a second control signal when the voltage of the energy passed by said filter changes from said predetermined value to a lower value, and control means responsive to said control signals and coupled to said differentiating circuits and to said disabling means for operating said disabling means.

9. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising energizing means therefor, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having frequencies lower than said source frequency, means coupling said rectifier to said welding electrodes, differentiating means having an input and an output, said differentiating means providing an output control signal with increases and decreases in energy having frequencies within a predetermined band and supplied to the input thereof, means coupling said input to said filter, switching means coupled to said output and to said energizing means, said switching means being operable by said control signal to de-energize said oscillator.

10. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising a vacuum tube having a control electrode, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having a frequency lower than said source frequency, means coupling said rectifier to said welding electrodes, a pair of differentiating amplifiers having inputs and outputs, said amplifiers providing an output signal when energy at frequencies within a predetermined band of frequencies lower than said source frequency is supplied to the inputs thereof, means coupling said one of said inputs to said filter in one polarity and means coupling the other of said inputs to said filter in opposite polarity, a gas tube having a control electrode, means connecting said gas tube to said control electrode of said vacuum tube for causing said vacuum tube to cut-off when said gas tube conducts, biasing means connected to said control electrode of said gas tube for normally maintaining said gas tube nonconductive, and means coupling said control electrode of said gas tube to said outputs for causing said gas tube to conduct when the energy supplied to the inputs of said amplifiers changes from a predetermined value.

11. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising a vacuum tube having a control electrode, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having a frequency lower than said source frequency, means coupling said rectifier to said welding electrodes, a pair of differentiating amplifiers having inputs and outputs, means coupling said one of said inputs to said filter in one polarity and means coupling the other of said inputs to said filter in opposite polarity, a gas tube having a control electrode, means connecting said gas tube to said control electrode of said vacuum tube for causing said vacuum tube to cut-off when said gas tube conducts, bias-

ing means connected to said control electrode of said gas tube for normally maintaining said gas tube nonconductive, means coupling said control electrode of said gas tube to said outputs for causing said gas tube to conduct when the energy supplied to the inputs of said amplifiers changes from a predetermined value and means coupling said control electrode of said gas tube to said filter for causing said gas tube to conduct when the average value of the energy passed by said filter exceeds a predetermined value.

12. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising a vacuum tube having a control electrode, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having a frequency lower than said source frequency, means coupling said rectifier to said welding electrodes, a pair of differentiating amplifiers having inputs and outputs, means coupling said one of said inputs to said filter in one polarity and means coupling the other of said inputs to said filter in opposite polarity, a gas tube having a control electrode, means connecting said gas tube to said control electrode of said vacuum tube for causing said vacuum tube to cut-off when said gas tube conducts, biasing means connected to said control electrode of said gas tube for normally maintaining said gas tube nonconductive, means coupling said control electrode of said gas tube to said outputs for causing said gas tube to conduct when the energy supplied to the inputs of said amplifiers changes from a predetermined value and means coupling said control electrode of said gas tube to said filter for causing said gas tube to conduct when the average value of the energy passed by said filter exceeds a predetermined value.

13. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising a vacuum tube having a control electrode, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having a frequency lower than said source frequency, a first transformer coupling said welding electrodes to said rectifier, a second transformer having a primary winding and a pair of secondary windings, means coupling said filter to said primary winding of said second transformer, a pair of differentiating amplifiers having inputs and outputs, means coupling said one of said inputs to one of said pair of secondary windings in one polarity and means coupling the other of said inputs to the other of said pair of secondary windings in opposite polarity, a gas tube having a control electrode, first biasing means, means connecting said biasing means and said gas tube to said control electrode of said vacuum tube for biasing said vacuum tube to cut-off when said gas tube conducts, sec-

ond biasing means connected to said control electrode of said gas tube for normally maintaining said gas tube nonconductive, means coupling said control electrode of said gas tube to said outputs for causing said gas tube to conduct when the energy supplied to the inputs of said amplifiers changes from a predetermined value and means coupling said control electrode of said gas tube to said filter for causing said gas tube to conduct when the average value of the energy passed by said filter exceeds a predetermined value at least equal to said first-mentioned predetermined value.

14. High frequency welding apparatus comprising a high frequency energy source including an oscillator, said oscillator comprising a vacuum tube having a control electrode, a pair of welding electrodes coupled to said source, a rectifier and a low pass filter connected in series, said filter passing substantially only energy having a frequency lower than said frequency of said source energy, a first transformer having its primary winding coupled to said welding electrodes and having its secondary winding coupled to said rectifier, said transformer having a shield between said primary and secondary windings, a second transformer having a primary winding and a pair of secondary windings, means including a resistor coupling said filter to said primary winding of said second transformer, a pair of differentiating amplifiers having inputs and outputs, means coupling said one of said inputs to one of said pair of secondary windings in one polarity and means coupling the other of said inputs to the other of said pair of secondary windings in opposite polarity, a gas tube having a control electrode, first biasing means, means connecting said biasing means and said gas tube in series with said control electrode of said vacuum tube with the negative end of said biasing means connected to said last-mentioned electrode, second biasing means connected to said control electrode of said gas tube for normally maintaining said gas tube nonconductive, means coupling said control electrode of said gas tube to said outputs for causing said gas tube to conduct when the energy supplied to the inputs of said amplifiers changes from a predetermined value and means coupling said control electrode of said gas tube to said resistor for causing said gas tube to conduct when the average value of the energy passed by said filter exceeds a predetermined value at least equal to said first-mentioned predetermined value.

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