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(54) APPARATUS AND METHOD OF INDUCTION-HARDENING MACHINE COMPONENTS WITH PRECISE POWER OUTPUT CONTROL

GERÄT UND VERFAHREN ZUM INDUKTIONSHÄRTEN VON MASCHINENBESTANDTEILEN MIT GENAUER AUSGANGSLEISTUNGSREGELUNG

APPAREIL ET PROCEDE DE TREMPE PAR INDUCTION DE PIECES DE MACHINE, COMPRENANT LA REGULATION PRECISE DE LA PUISSANCE EMISE

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- **No further relevant documents disclosed**

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Description

FIELD OF THE INVENTION

The present invention relates generally to the technology of induction heating and more particularly to the use of induction heating devices for case-hardening of machine components such as gears.

Machine components such as gears, splined shaves and sprockets are frequently subjected to high torque loads, frictional wear and impact loading. Gears of this type are typically used in power transmission drive trains. An apparatus and method for induction-hardening of such machine components is disclosed in US-A-4,845,328 to Storm et al.

The Storm et al. patent and this application are both owned by the same assignee, Contour Hardening Inc., of Indianapolis, Indiana.

As is well known in the art, a known device for gear teeth hardening includes a dual-frequency arrangement for induction heating wherein a low frequency current is used for preheating the gear teeth and then a high frequency (Radio Frequency) current is then used for final heating prior to quench hardening of the gear teeth. The dual frequency induction hardening concept is described in the article "Induction Gear Hardening by the Dual-Frequency Method" which appeared in Heat Treating Magazine, Vol. 19, No. 6, published in June, 1987.

As explained in the article, dual-frequency heating employs both high and low frequency heat sources. The gear is first induction heated with a relatively low frequency source (3-10 kHz), providing the energy required to preheat the mass of the gear teeth. This step is followed immediately by induction heating with a high-frequency source which typically ranges from 100-300 kHz depending on the gear size and diametral pitch of the gear teeth. The high-frequency source will rapidly final heat the entire tooth contour surface to a case hardening temperature. The gears are then quenched to a desired hardness and tempered.

Induction heating is the fastest known way of heating an iron alloy gear. In some applications a pre-heat low frequency heat process precedes the final heat RF heating. Heating times for the high-frequency RF heating step typically range from 0.10 to 2.0 seconds. In induction heating, the gear is mounted on a spindle and spun while positioned within the induction heating coil. A quick pulse of power is supplied to the induction heating coil which achieves an optimum final heat of the gear teeth. Next, the piece is manually or automatically moved into a water-based quench. Because induction hardening puts only the necessary amount of heat into the part, case depth requirements and distortion specifications are met with great accuracy.

Within the induction heating process, whether dual- or single frequency, and regardless of the type of part and its material, the part characteristics dictate the optimum design of both the induction heating coil or coils and the most appropriate machine settings. In particular, the amount of time that the high-frequency power signal is supplied to the induction heating coil to generate the final heat is a most critical parameter. The exact amount of heat required to harden the gear is directly related to the precise amount of time that the power signal is supplied to the induction heater coil.

Traditionally, there are two systems well-known in the art for supplying power to an induction heater coil as described above. The first system utilizes what is known in the art as a "solid state" generator approach wherein high power amplification devices such as transistors, be they bipolar or CMOS, are used in the high-frequency RF generator to supply a high-frequency oscillator signal to the induction heater coil. An alternate approach is to use a vacuum tube RF generator and utilize thyristor type devices to switch power on and off to the high-frequency, high power vacuum tube oscillator circuit. The output of either oscillator circuit is coupled to the induction heater coil by way of a transformer. Some experts in the art of induction heating coil machines designed for case hardening metallic structures have heretofore preferred the solid state high-frequency RF generators for their exact timed control of power delivery to the induction heater coil. A vacuum tube RF generator typically receives its input power subject to the on/off timing characteristics of thyristor devices such as silicon controlled rectifiers (SCR's) which are also known in their JEDEC description as reverse blocking triode thyristors. The power delivery timing variance created by the SCR is intrinsic in the operation of such devices. Specifically, once an SCR is "turned on" for a partial cycle, even though the on/off signal supplied to the gate is removed or deactivated, the SCR will continue to conduct current so long as the anode to cathode terminals are biased with a positive voltage. In the worst case of a 60-cycle power signal being transferred by the SCR, this results in over an 8 millisecond additional power signal transmitted by the SCR, since half of a 60-cycle waveform is 8.33 milliseconds in duration.

It is recognized that the vacuum tube RF generator is preferred by some in the induction heating art for its characteristic power delivery curve in supplying power to an induction heater coil. Additionally, since SCR's are the device of choice for repeated high power switching circuits, a technique for accurately controlling SCR's to deliver specific quantities of power to a high-power vacuum tube RF generator is needed.

An example of such an induction hardening apparatus is disclosed in US-A-4,317,975, which discloses an induction heating apparatus using a gate-controlled switching device for detecting each zero-crossing of a high-frequency energization current. This zero-crossing data is thereafter used to provide multiple trigger signals to a configuration of SCRs to thereby produce a heating signal.

A method and apparatus for more accurately controlling the timed power output of a silicon controlled rec-

tifier power supply is needed for accurately controlling the power signal supplied to induction heater coils used in case hardening devices.

One object of the present invention is to provide an improved induction hardening machine.

Another object of the present invention is to provide a method for more accurately controlling the power signal supplied to induction heater coils of an induction hardening machine to precisely control the power supplied and thus the heating of a gear during case hardening.

According to one aspect of this invention there is provided an induction hardening machine as claimed in claim 1. According to another aspect of this invention there is provided a method for accurately controlling heating of a gear as claimed in claim 2.

These and other objects of the present invention will become more apparent from the following description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a typical embodiment of an induction-hardening system according to the present invention

FIG. 2 is a timing diagram showing variations in the active or "on" state of an SCR with respect to certain input conditions applied to the gate of the SCR.

FIG. 3 is a graph depicting a deviation in power output signals produced by power switching SCR circuits of the present invention as compared with prior art devices.

FIG. 4 is a block diagram of another embodiment of an induction-hardening system according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Referring now to FIG. 1, an induction-hardening system 10 according to the present invention is shown. Switch SW1 provides an activation signal to the system processor 12 for inv king or initiating the case hardening of a gear. System processor 12 is programmed by the user with timing parameters for controlling the power signal supplied to the induction heater coil. Processor 12 supplies an on/off power switching signal to power switching SCR circuit 14. System processor 12 receives a zero crossing indicator input signal from zero crossing detector 16. One phase b_1 from 3*b* high voltage power source 18 is supplied to an input of zero crossing detector 16. The 3*b* high-voltage power source 18 supplies three phases of high voltage power to the power switching SCR circuits 14. Power switching SCR circuits 14, when activated, supply either half-wave or full-wave AC power signals to the primary windings of step-up transformer 22. Transformer 22 steps up the AC power signals b_1, b_2 and b_3, typically 480 volts three-phase signals, to a voltage level sufficiently high that rectifier and filter 24 produces a 24,000 volts DC signal at its output.

The 24,000 volts DC signal at the output of rectifier filter 24 is the power source for a vacuum tube type high-energy RF oscillator 26. The output of the high-energy oscillator 26 is AC coupled to the induction heater coil 28 via windings 29. Induction heater coil 28 supplies a case-hardening heating signal to the gear teeth of gear 30 when an RF signal is supplied to its input.

The components 22, 24 and 26 of the system 10 are part of RF generator 20 which is a high-frequency, high-power RF generator. The RF generator 20 is an off-the-shelf system supplied by Pillar industries, Inc., N92 W15800 Megal Drive, Menomonee Falls, Wisconsin 53051. The RF generator 20 is referred to as a "450/600 kilowatt RF Generator".

The particular geometry and physical attributes of gear 30 dictate the precise amount of time that power switching SCR circuits 14 are "turned on" by system processor 12 in order to produce the appropriate case hardening result. In some instances, the amount of time that the SCR circuits 14 are turned on is as small a time period as 0.10 seconds to accomplish the desired heating and case hardening of gear 30. with this condition in mind, it is easy to see why the prior art devices which did not include zero crossing detector 16, were unable to accurately control the amount of power signal or total power supplied to the induction heater coil 28.

The system processor 12 of the present invention typically includes a computer having adequate memory and computing capability, and a programming input device such as a CRT/keyboard device. Additionally the processor 12 has mass storage devices such as floppy or hard disk drives for use in storing and recalling control programs. Operationally speaking, an operator programs the system processor 12 through a keyboard for a particular "on-time" or heat time which is the exact time that the power switching SCR circuits 14 shall be turned on to supply a fixed quantity of high-frequency power signal to the induction heater coil 28. In response to the programmed "on time" information, the system processor 12 will compute a complement value for the specific "on time" which is equal to the difference between the "on time" divided by 8.33 milliseconds (the period of a 60 Hz waveform). The remainder from this calculation is subtracted from 8.33 milliseconds to produce a time value which is the delay time that the processor 12 should delay after detecting a zero crossing of the 60 Hz signal present at the input of detector 16 prior to activating the

SCR circuits 14 to supply power to the RF generator. The time delay calculation is designed so that the end of the on or conducting period for the SCR devices corresponds exactly with or just prior to a zero crossing of the power signal b_1 supplied to the input of zero crossing detector 16. Thus, the SCR's, which remain in the conducting state so long as the anode to cathode terminals are forward biased, will not remain on a substantial period of time after the system processor 12 signals the SCR circuits 14 to turn off by deactivating the input to the circuits 14.

It is well known in the art that SCR circuits 14 may supply a half-wave or full-wave 3*b* output signal to the transformer 22. If the signal is half-wave in nature, the divide-by factor described above (8.33 milliseconds) becomes 16.67 milliseconds and the remainder is subtracted from 16.67 milliseconds. Additionally, negative-slope zero crossovers must be detected to determine the appropriate timing reference points for activating a half-wave output SCR circuit. Thus, the "on time" desired is divided by 16.67, and any remainder therefrom is subtracted from 16.67. The result of the subtraction process is the delay period required after a negative-slope zero crossover of the power signal prior to activating the SCR circuits 14 for half-wave outputs therefrom. Although the other phases (b_2 and b_3) of the SCR circuits 14 may remain "on" after the input to circuits 14 is deactivated, the above technique produces an accurate and repeatable power output from SCR circuits 14.

Referring now to FIG. 2, a timing diagram showing variations in active or "on" state of an SCR with respect to certain gate signal conditions is shown. Curve 40 is a standard sine wave power signal representing the b_1 signal at the input of detector 16. Curve 40 is a 60 Hz signal plotted with respect to time. Curves 42 and 46 represent the signal produced by the system processor 12 and supplied to the gate input of the SCR circuits 14. Curves 42 and 46 are the "on time" desired to produce a predetermined amount of heat in a particular gear 30 to be induction hardened.

The circuits 14 are activated or caused to supply a power signal to generator 20 at the point in time which is the off-on transition of the curve 42. At the end of the "on time" of curve 42, or time T_D, the signal changes from the "on" state to the "off" state. The precise timing of the on-off transition does not occur near a zero crossing of curve 40. Since the activation signal represented by curve 42 does not return to the "off" state until after the zero crossing at time T_C, the power signal which is supplied to the RF generator 20, represented by curve 44, is continuously "on" until time T_e, which may be as much as 8.33 milliseconds after the on-off transition of curve 42. Thus, if the on signal produced by system processor 12 begins at time T_B and continues until time T_D, the total power signal supplied to the RF generator will last from time T_B until time T_E on the graph, for a total time period of T_2.

In order to precisely control the power supplied to the induction heater coil, and thus achieve more accurate control of the induction hardening process, the system according to the present invention computes a time delay beyond a zero crossing (here the zero crossing at T_0) for turning on the SCR circuits 14 so that the SCR activation signal, represented by curve 46, will change from the "on" state to the "off" state at or just prior to a zero crossing of curve 40. For example, in order to eliminate the additional "on time" of the power signal 44 as compared to the gate on-time input signal represented by curve 42 which switches the SCR circuits, the system processor 12 will compute a time T_3 which corresponds to the desired "on time" T_1 divided by 8.33 milliseconds and subtract the remainder from 8.33 milliseconds to produce time T_3. Then, the system processor delays activating SCR circuits 14 a period of time T_3 after a zero crossing so that the activation curve 46, which coincidentally is exactly equal in "on time" duration to curve 42, changes from the "on" to the "off" state at time T_C, which corresponds with a zero crossing of the power signal curve 40.

Since the curve 46 is so closely related at time T_C to a zero crossing, an accurate amount of "on time" of the SCR circuits 14 is achieved, thereby accurately controlling the amount of time that power is supplied to RF generator 20 with precision not heretofore known with SCR circuits. In so doing, the amount of power which is supplied to induction heater coil 28 is accurately controlled. Thus, a tube type RF generator, which is preferred by some skilled in the art over the solid state semiconductor type high-frequency RF generators, may be used to produce an accurate quantity of power signal and a correspondingly precise quantity of power supplied to the induction heater coil 28.

Although only one phase (b_1) of the power source 18 is shown in FIG. 2, it should be apparent to one skilled in the art that in a 3*b* system all three phases are related by 120 degrees. Thus, a fixed amount of additional power signal will be supplied by the other phases (b_2 and b_3) of the power source 18 beyond the time T_C with the activation signal represented by curve 46. Nevertheless, the additional power supplied by the other two phases will be a constant quantity since the deactivation signal occurs at a predetermined time and phase relative to the other power phases. Therefore, the amount of power delivered to the gear 30 by the system 10 is repeatable by establishing a fixed timing reference (with respect to one phase) for switching on and off a 3*b* power source.

Referring now to FIG. 3, a graph of the power output of the RF generator 20 is shown. The maximum power output of the generator 20, represented by curve 50, can be adjusted vertically to achieve higher or lower total instantaneous power output. The variance in "on time", represented by times T_1 and T_2, as a result of the intrinsic functionality of SCR circuits is shown at the bottom of the graph. If the SCR circuits remain on for a length of time T_2 as opposed to T_1, which is the desired "on time", the additional power represented by the shaded portion 52

underneath the curve 50 is supplied to the heater coil 28 in addition to the actual desired power, represented by the unshaded portion underneath the curve 50 and extending up to the end of time T1. The additional amount of power supplied to the induction heater coil 28 causes excessive heating of the gear 30.

As is seen in the graph of FIG. 3, timing variations make for greater variations in the case hardening process, particularly when the "on time" T1 is approximately 0.10 seconds. The maximum difference between times T2 and T1 can be as much as 8.33 milliseconds, and thus the power represented by area 52 can represent as much as 8-10% difference in power supplied to the induction heater coil 28 when a 0.10 second power signal is desired for heater coil 28. Another recognized fact is that once the gear 30 has been heated, the additional heating time represented by the area 52 can seriously increase the heat of the gear, as the heat transfer properties of the gear are non-linear and cause heat to transfer deeper into the gear face once the gear is heated around the perimeter. Thus, it is highly desirable to control the power supplied to the induction heater coil 28 via the technique shown and described above.

Referring now to FIG. 4, another embodiment of an induction-hardening system 110 according to the present invention is shown. Switch SW2 provides a reset/start signal to single pulse timer circuit 116. AC power source 118 supplies an AC signal to phase angle detector 112 and power switching devices 114. Phase angle detector 112 provides a series of pulses to an input of single pulse timer circuit 116. Each pulse from detector 112 corresponds to the detection of a predetermined phase angle of the AC power signal from power source 118. Upon receiving a reset/start signal from switch SW2, single pulse timer circuit 116 is triggered or activated by the next pulse from detector 112 to produce a pulse or signal having a predetermined duration. The predetermined duration pulse enables the power switching devices 114. Thus, the initiation of the heating cycle as a result of the closure of switch SW2 is delayed until a predetermined phase angle is detected by phase angle detector 112. Phase angle detector 112 provides a phase detector means for detecting a predetermined phase angle in the power signal from AC power source 118.

As in the previous embodiment, the RF generator 120 receives a power signal from the power switching devices 114 and in response thereto supplies a high frequency, high power signal to the induction heater coil 128 via windings 129. Windings 129 provide impedance matching between the output of the RF generator 120 and the induction heater coil 128. Single-phase and multi-phase power supplies are contemplated.

The phase angle detector 112 is implemented using a triac phase angle controller Part No. TDA1185A manufactured by Motorola Incorporated of Phoenix, Arizona. The TDA1185A device is programmable to produce an output signal corresponding to detection of a predetermined phase angle of the AC signal. This predetermined phase angle is variable with the TDA1185A device in accordance with an external set voltage representing the conduction angle desired. (See discussion of control signals, infra.) Since the TDA1185A device detects firing angles only on the positive half of the AC signal, should a firing angle on the negative half of the AC signal be desired, an inverting operational amplifier may be inserted between the AC power source and the phase angle detector 112 to invert the AC signal, and thus provide an input signal to the phase angle detector 112 such that activation in the negative half of the AC signal may occur.

Signal pulse timer circuit 116 is implemented using a retriggerable monostable multivibrator integrated circuit, part No. 74LS123 manufactured by Texas Instruments. The 74LS123 is a rising-edge triggered device and thus the pulses produced by the phase angle detector 112 can be used to trigger the production of an output pulse from the timer circuit 116. The signal produced by switch SW2 provides a retrigger, enable or rearming signal to the timer circuit 116. Since the 74LS123 device can be configured to produce an output pulse from less than 1 millisecond to a very large time duration, such as hours, the combination of the phase angle detector 112 and the timer circuit 116 provides infinitely variable control of the timing functions necessary to activate power switching devices 114 in accordance with the previously described conditions calling for a supply of a specific duration power signal to the RF generator 120.

Optional control signals, represented by broken lines 132 and 134, provide phase angle selection and pulse width duration signals to detector 112 and circuit 116, respectively. Specifically, the phase angle control signal, present on signal path 134 and supplied to an input of detector 112, provides phase angle selection information to detector 112. In response to the signal on signal path 134, detector 112 produces an output pulse corresponding in time to the occurrence of the desired phase angle established by the signal on signal path 134. Likewise, the duration control signal present on signal path 132 controls the time duration of the pulse produced by circuit 116. The signal on signal path 132 is typically implemented via a potentiometer/capacitor combination establishing a decaying signal well known with such circuits.

The device 110 of FIG. 4 includes several components which are identical with components of the device 10 of FIG. 1. In particular, the AC power source 118 corresponds with the three-phase high voltage power source 18, power switching devices 114 correspond with power switching SCR circuits 14, RF generator 120 corresponds with RF generator 20, induction heater coil 128 corresponds with induction heater coil 28, and gear 130 corresponds with gear 30. Triacs or Silicon Controlled Rectifiers (SCR's) are contemplated as the power switching devices in block 114.

Operationally speaking, the pulses produced at the output of phase angle detector 112 correspond in time with a predetermined phase angle of the AC signal indi-

cated by time line T_B in FIG. 2. Likewise, the output pulse produced by timer circuit 116 will correspond with time T_2. Thus, the difficulties of energizing an AC power source with precise timing and power output control are overcome by the embodiment of FIG. 1 wherein a time delay after a zero crossing is used to determine turn on time of the power signal, or as in the embodiment of FIG. 4, a particular phase angle is detected to determine the point in time when an activation signal is desired for activating the power switching devices. With both embodiments of the invention, a predetermined timing reference point relative to the AC power signal is located or detected prior to the activation of the power switching devices to produce an activation signal which will subside before or simultaneously with a subsequent zero crossing of the power signal so that the power switching devices will be turned off or switched off at a precise predetermined time, typically a zero crossing as is the case with most thyristors .

Alternately, it is also contemplated that the phase angle detector 112 and timer circuit 116 are portions of a microcomputer based controller (not shown) wherein an A/D converter (not shown) is used to monitor the amplitude (which corresponds with the phase angle) of the signal from source 118. Further, user-changeable software enables control of the desired phase angle detected and the width of the control pulse supplied to the power switching devices 114.

Claims

1. An induction-hardening machine (10) for contour hardening of a gear (30) comprising:

   an AC power source (18) for producing an AC power signal;
   a zero-crossing detector (16) connected to said AC power source (18) for detecting zero crossings of said AC power signal and producing a zero-crossing signal corresponding thereto;
   a high-frequency generator (20) having a power input and an output for producing a high-frequency high-power signal in response to a signal supplied to said power input;
   a high-frequency induction heater coil (28) sized to fit said gear (30) and connected to said output of said generator (20), said coil (28) generating a high-frequency electrical signal through said gear (30);
   thyristor power switching means (14) having an activation input, a power input connected to said AC power source (18), and a power output, said power switching means (14) supplying an AC power signal to said power input of said high-frequency generator (20) in response to a signal supplied to said activation input; characterised by

   processor means (12), connected to said zero-crossing detector (16) and said thyristor power switching means (14) activation input, for computing activation times and supplying a corresponding activation signal to said activation input, wherein said processor means (12) includes:

      1) means for entering a desired activation time;
      2) means for computing a delay time so that the sum of the activation time and the delay time corresponds to a minimum whole number multiple of the period of said AC power signal; and
      3) input means for receiving a user supplied manual cycle start input signal;

   said processor (12) responding to a cycle start input signal by detecting a zero crossing signal and delaying a period of time equal to said delay time before supplying an activation signal to said activation input so that the activation signal is extinguished substantially simultaneously with a subsequent zero crossing of said AC power signal.

2. A method for accurately controlling heating of a gear (30) from an induction-hardening device (10), the induction-hardening device (10) including an AC power source (18), thyristor power switching means (14) having an activation input for producing a power signal in response to a signal appearing at the activation input, an RF generator (20) responsive to said power signal to produce a high-frequency, high-power signal, and an induction heater coil (28) connected to said RF generator (20) and producing an electrical signal in the gear (30) in response to the high-frequency, high-power signal, said method characterised by the steps of:

   determining a desired activation time for supplying power to the induction heater coil (28) based upon the geometry of the gear (30);
   dividing the desired activation time by one-half the period of the AC power supply signal to produce a remainder quantity;
   subtracting the remainder quantity from one-half the period of the AC power supply signal to produce a delay time;
   detecting a zero crossing of said AC power supply signal; and
   supplying an activation signal to the activation input of said thyristor power switching means (14) for a time period corresponding to said activation time after a time equal to said delay time has expired.

Patentansprüche

1. Gerät (10) zum Induktionshärten für das Formhärten eines Zahnrades (30) aufweisend:

   eine AC-Leistungsquelle (18) zur Erzeugung eines AC-Leistungssignals;
   einen Nullpunkt-Durchgangsdetektor (16), der an die AC-Leistungsquelle (18) zur Bestimmung von Nullpunkt-Durchgängen des AC-Leistungssignals und zur Erzeugung eines damit übereinstimmenden Nullpunkt-Durchgangssignals;
   einen Hochfrequenzgenerator (20) mit einem Leistungseingang und einem Ausgang zur Erzeugung eines hochfrequenten Hochleistungssignals in Reaktion auf ein an dem Leistungseingang anliegendes Signal;
   eine Hochfrequenzinduktionserhitzungsspule (28), die so bemessen ist, daß sie das Zahnrad (30) aufnimmt, und an den Ausgang des Generators (20) angeschlossen ist, wobei die Spule (28) ein hochfrequentes elektrisches Signal durch das Zahnrad (30) erzeugt;
   eine Thyristor-Leistungschaltvorrichtung (14) mit einem Aktivierungseingang, einem Leistungseingang, der an die AC-Leistungsquelle (18) angeschlossen ist, und einem Leistungsausgang, wobei die Leistungsschaltvorrichtung (14) ein AC-Leistungssignal dem Leistungseingang des Hochfrequenzgenerators (20) als Reaktion auf ein Signal, das dem Aktivierungseingang zugeführt wird, zuführt; **gekennzeichnet durch**
   eine Prozessorvorrichtung (12), die an den Nullpunkt-Durchgangsdetektor (16) und den Aktivierungseingang der Thyristor-Leistungsschaltvorrichtung (14) angeschlossen ist, zur Berechnung von Aktivierungszeiten und zur Zuführung eines entsprechenden Aktivierungssignals zu dem Aktivierungseingang, wobei die Prozessorvorrichtung (12) aufweist:

      1) eine Vorrichtung zur Eingabe einer gewünschten Aktivierungszeit;
      2) eine Vorrichtung zur Berechnung einer Verzögerungszeit, so daß die Summe der Aktivierungszeit und der Verzögerungszeit einem kleinsten ganzzahligem Vielfachen der Periode des AC-Leistungssignals entspricht; und
      3) Eingabemittel zum Empfangen eines manuellen vom Benutzer zugeführten Eingangssignals für einen Zyklusstart; wobei der Prozessor (12) als Reaktion auf ein Eingangssignal für einen Zyklusstart ein Nullpunkt-Durchgangssignal bestimmt und für eine Zeitperiode, die gleich der Verzögerungszeit ist, verzögert, bevor er ein Aktivierungssignal dem Aktivierungseingang zuführt, so daß das Aktivierungssignal im wesentlichen gleichzeitig mit einem nachfolgenden Nullpunkt-Durchgang des AC-Leistungssignals ausgelöscht wird.

2. Verfahren zur genauen Regelung der Erhitzung eines Zahnrads (30) durch ein Gerät (10) zum Induktionshärten, wobei das Gerät (10) zum Induktionshärten eine AC-Leistungsquelle (18), eine Thyristor-Leistungsschaltvorrichtung (14) mit einem Aktivierungseingang zur Erzeugung eines Leistungssignals als Reaktion auf ein an dem Aktivierungseingang erscheinendes Signal, einen RF-Generator (20), der für das Leistungssignal empfänglich ist, um ein hochfrequentes Hochleistungssignal zu erzeugen, und eine Induktionserhitzungsspule (28) aufweist, die an den RF-Generator (20) angeschlossen ist und ein elektrisches Signal in dem Zahnrad (30) als Reaktion auf das hochfrequente Hochleistungssignal erzeugt, wobei das Verfahren durch folgende Schritte gekennzeichnet ist:

   Bestimmen einer gewünschten Aktivierungszeit für die Zuführung von Leistung zu der Induktionserhitzungsspule (28) in Abhängigkeit von der Geometrie des Zahnrades (30);
   Teilen der erwünschten Aktivierungszeit durch die Hälfte der Periode des AC-Leistungszuführsignals, um eine Restmenge zu erzeugen;
   Abziehen der Restmenge von einer Hälfte der Periode des AC-Leistungszuführsignals, um eine Verzögerungszeit zu erzeugen; Bestimmen eines Nullpunkt-Durchgangs des AC-Leistungszuführsignals; und
   Zuführen eines Aktivierungssignals zu dem Aktivierungseingang der Thyristor-Leistungsschaltvorrichtung (14) für eine Zeitdauer, die mit der Aktivierungszeit übereinstimmt, nachdem eine Zeit verstrichen ist, die gleich der Verzögerungszeit ist.

Revendications

1. Une machine de chauffage par induction (10) pour la trempe d'un contour d'un engrenage (30) comprenant :

   une source d'énergie électrique à courant alternatif (18) pour produire un signal d'énergie électrique à courant alternatif ;

   un détecteur de passage par zéro (16) relié à ladite source d'énergie électrique à courant alternatif (18) pour détecter les passages par zéro dudit signal d'énergie électrique à courant

alternatif et produire un signal de passage par zéro correspondant à celui-ci ;

un générateur haute fréquence (20) présentant une entrée de puissance et une sortie pour produire un signal haute fréquence de puissance élevée en réponse à un signal fourni à ladite entrée de puissance ;

une bobine de chauffage par induction haute fréquence (28) dimensionnée pour s'adapter audit engrenage (30) et reliée à ladite sortie dudit générateur (20), ladite bobine (28) produisant un signal électrique haute fréquence à travers ledit engrenage (30) ;

un moyen de commutation de puissance à thyristors (14) présentant une entrée d'activation, une entrée de puissance reliée à ladite source d'énergie électrique à courant alternatif (18), et une sortie de puissance, ledit moyen de commutation de puissance (14) fournissant un signal d'énergie électrique à courant alternatif à ladite entrée de puissance dudit générateur haute fréquence (20) en réponse à un signal fourni à ladite entrée d'activation ; caractérisée par

un moyen à processeur (12), relié audit détecteur de passage par zéro (16) et à ladite entrée d'activation du moyen de commutation de puissance à thyristors (14), pour calculer des temps d'activation et appliquer un signal d'activation correspondant à ladite entrée d'activation, dans lequel ledit moyen à processeur (12) comprend :

1) un moyen pour entrer un temps d'activation désiré ;

2) un moyen pour calculer un temps de retard tel que la somme du temps d'activation et du temps de retard correspond à un nombre entier minimum multiple de la période dudit signal d'énergie électrique à courant alternatif ; et

3) un moyen d'entrée pour recevoir un signal d'entrée de démarrage d'un cycle manuel fourni par un utilisateur ;

ledit processeur (12) répondant à un signal d'entrée de démarrage d'un cycle en détectant un signal de passage par zéro et en retardant une période de temps égale audit temps de retard avant d'appliquer un signal d'activation à ladite entrée d'activation de sorte que le signal d'activation est éteint sensiblement en même temps qu'un passage ultérieur par zéro dudit signal d'énergie électrique à courant alternatif.

2. Un procédé pour commander avec précision le chauffage d'un engrenage (30) à partir d'un dispositif de trempe par induction (10), le dispositif de trempe par induction (10) comprenant une source d'énergie électrique à courant alternatif (18), un moyen de commutation de puissance à thyristors (14) présentant une entrée d'activation pour produire un signal de puissance en réponse à un signal apparaissant à l'entrée d'activation, un générateur HF (20) répondant audit signal de puissance pour produire un signal haute fréquence de puissance élevée, et une bobine de chauffage par induction (28) reliée audit générateur HF (20) et produisant un signal électrique dans l'engrenage (30) en réponse au signal haute fréquence de puissance élevée, ledit procédé caractérisé par les opérations consistant à :

déterminer un temps d'activation désiré pour appliquer de la puissance à la bobine de chauffage par induction (28) sur la base de la géométrie de l'engrenage (30) ;

diviser le temps d'activation désiré par la moitié de la période du signal d'énergie électrique à courant alternatif afin de produire une valeur formant reste ;

soustraire la valeur formant reste de la moitié de la période du signal d'énergie électrique à courant alternatif afin de produire un temps de retard ;

détecter un passage par zéro dudit signal d'énergie électrique à courant alternatif ; et

appliquer un signal d'activation à l'entrée d'activation dudit moyen de commutation de puissance à thyristors (14) pendant une période de temps correspondant audit temps d'activation après que se soit écoulé un temps égal audit temps de retard.

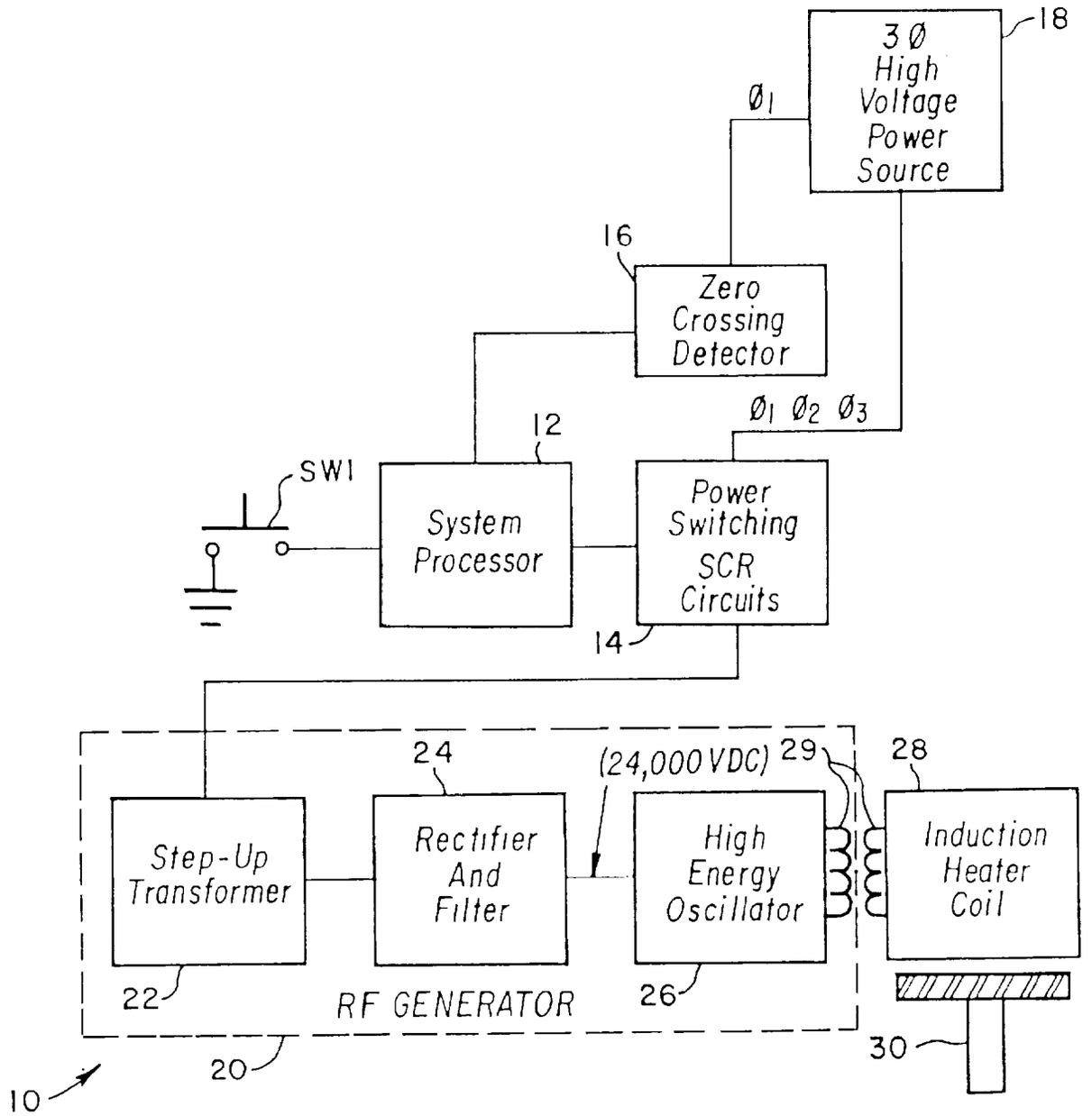

3 Ø
High
Voltage
Power
Source
18
Ø1
16
Zero
Crossing
Detector
Ø1 Ø2 Ø3
12
SW1
System
Processor
Power
Switching
SCR
Circuits
14
24
(24,000VDC)
29
28
Step-Up
Transformer
Rectifier
And
Filter
High
Energy
Oscillator
Induction
Heater
Coil
22
RF GENERATOR
26
30
20
10

Fig.1

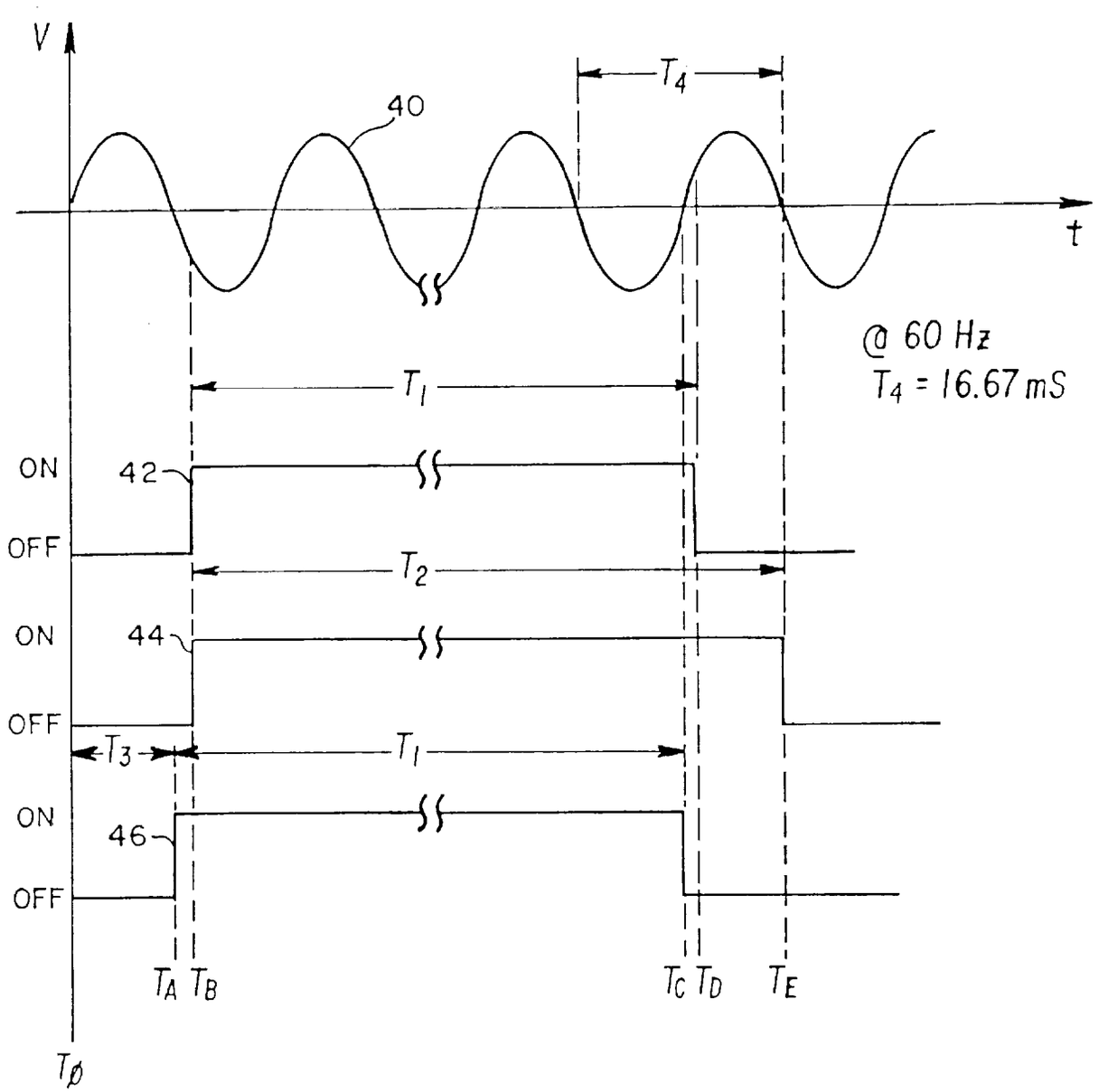

V
40
T_4
t
@ 60 Hz
T_4 = 16.67 mS
T_1
ON
42
OFF
T_2
ON
44
OFF
T_3
T_1
ON
46
OFF
T_A T_B
T_C T_D T_E
T_ϕ

Fig.2

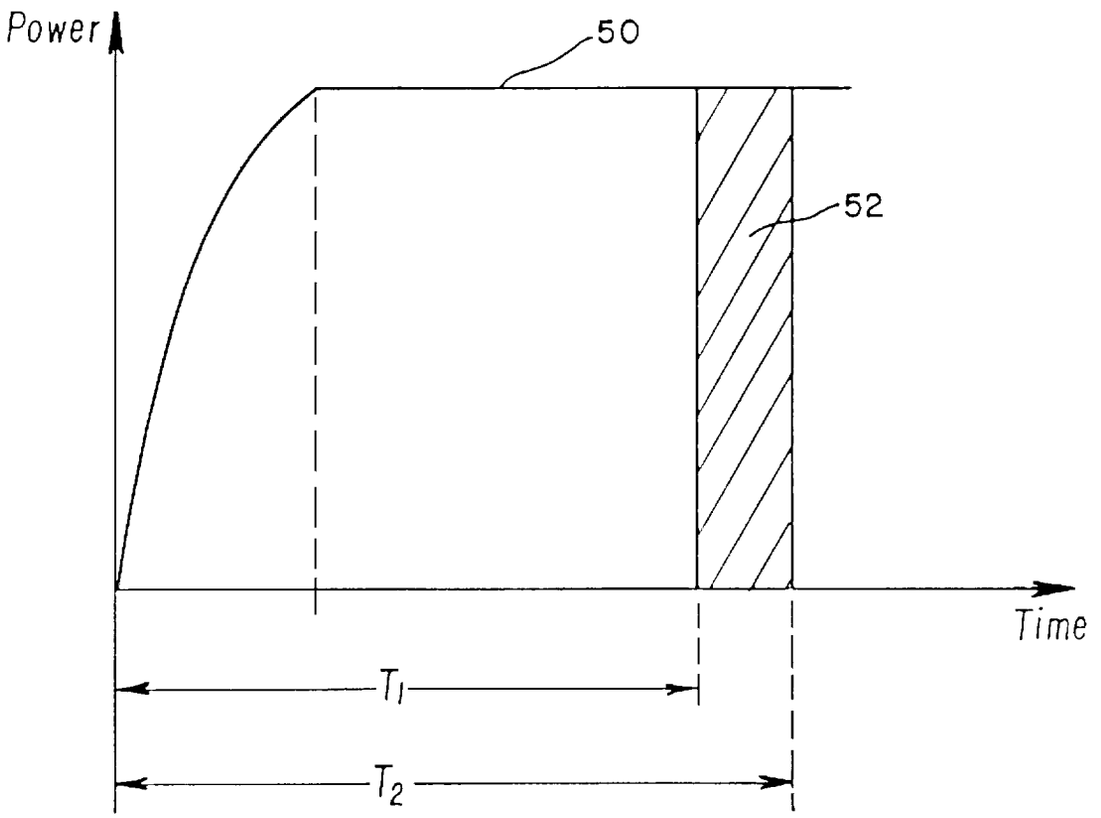


Fig.3

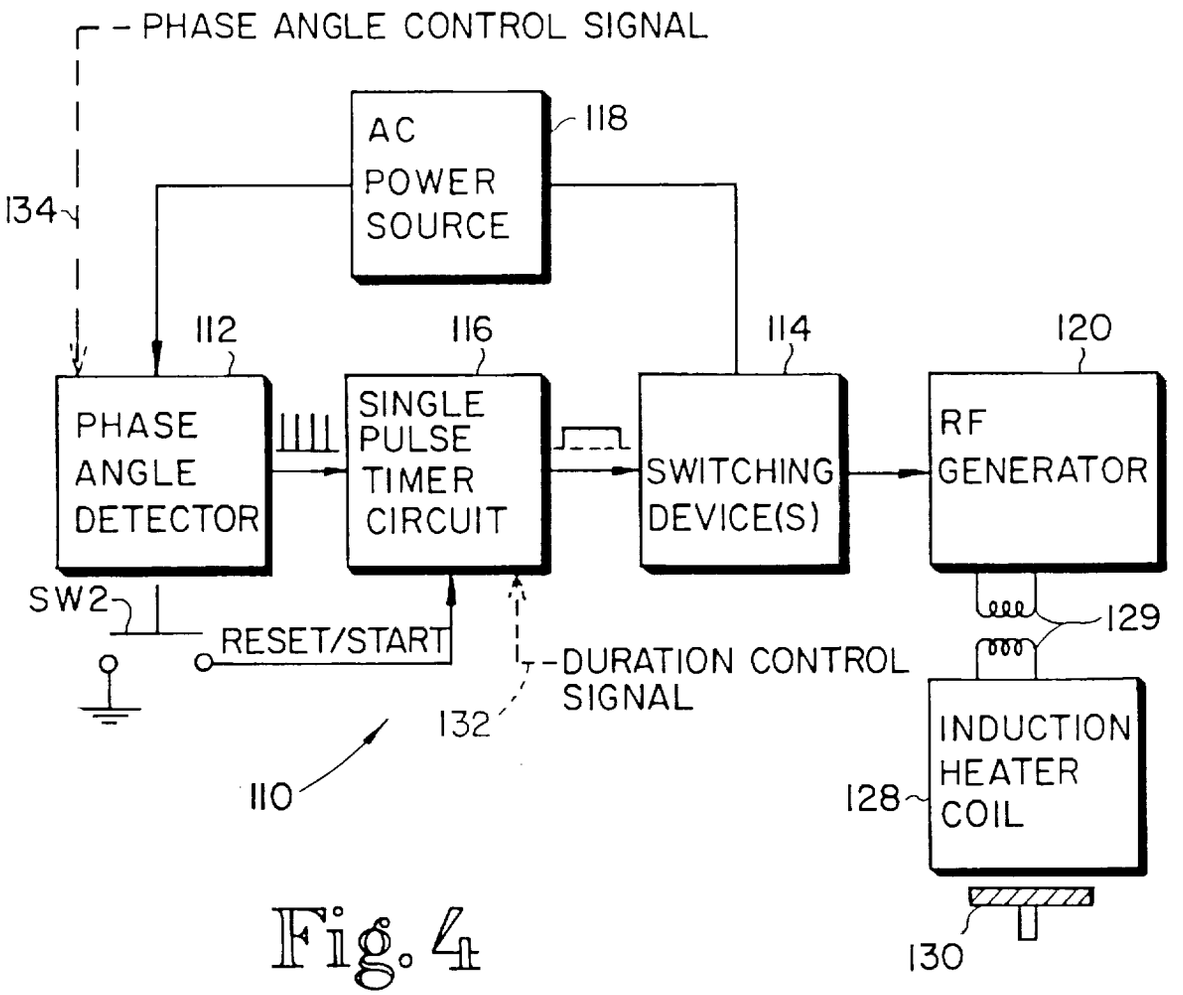

PHASE ANGLE CONTROL SIGNAL
AC POWER SOURCE
118
134
112
116
114
120
PHASE ANGLE DETECTOR
SINGLE PULSE TIMER CIRCUIT
SWITCHING DEVICE(S)
RF GENERATOR
SW2
RESET/START
DURATION CONTROL SIGNAL
132
129
110
INDUCTION HEATER COIL
128
130

Fig. 4