June 22, 1954 S. E. LEONARD 2,681,975

APPARATUS FOR ELECTRICAL HEAT-TREATMENT OF MATERIAL

Filed July 29, 1949 2 Sheets-Sheet 1

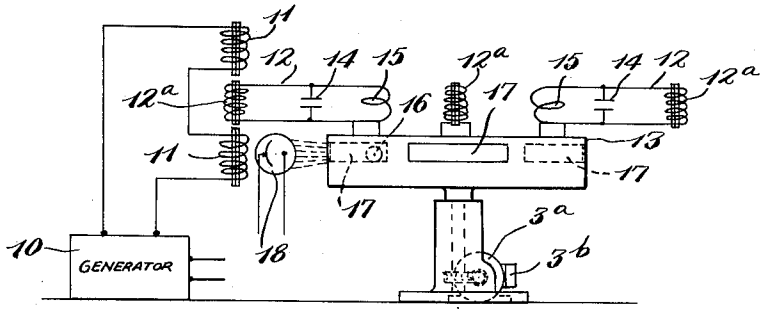


FIG. 1

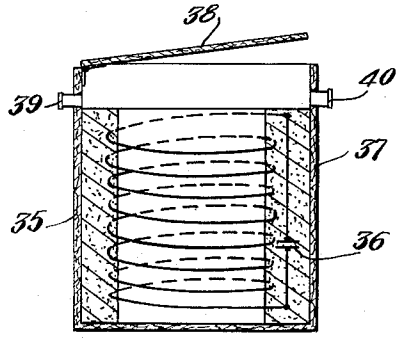


FIG. 7

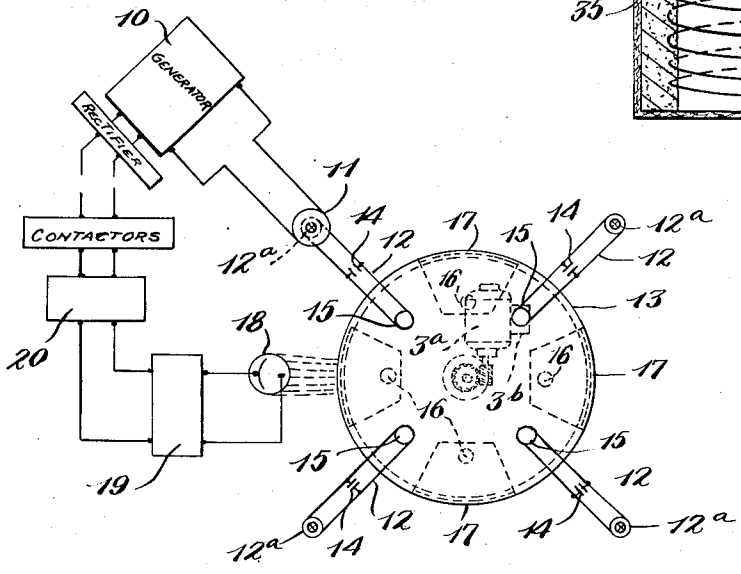


FIG. 2

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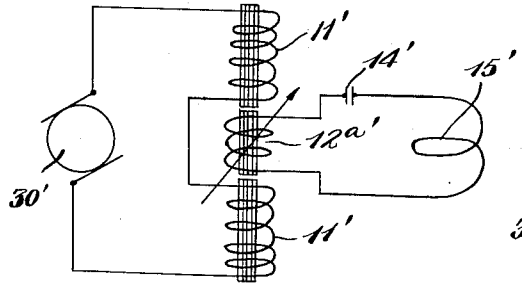


FIG. 3

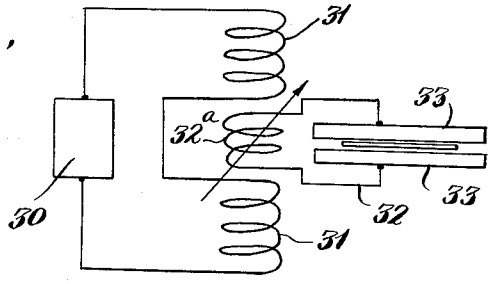


FIG. 4

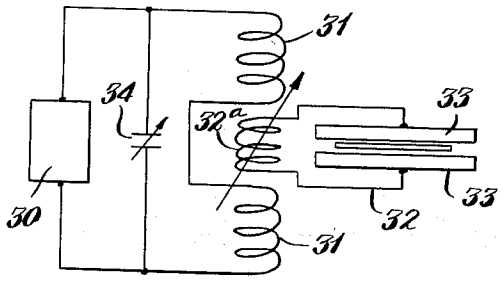


FIG. 5

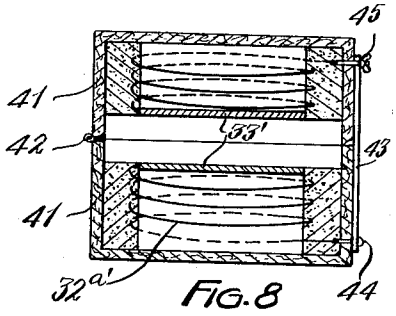


FIG. 8

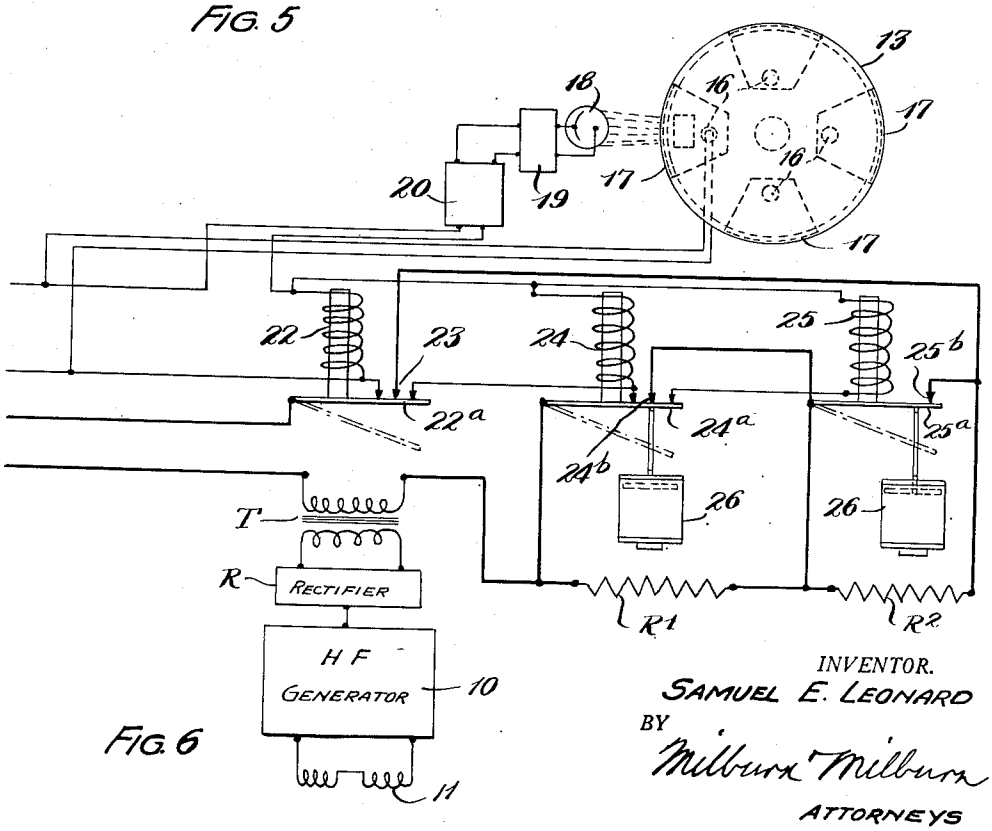


FIG. 6

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APPARATUS FOR ELECTRICAL HEAT-TREATMENT OF MATERIAL

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Application July 29, 1949, Serial No. 107,603

5 Claims. (Cl. 219—10.69)

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This invention relates to the heating of wires, bars and strips of metal, especially iron and steel, and also non-metallic material.

One object of my present invention is to devise means for heating such material by either the induction or the dielectric process.

Another object is to devise an improved means for the heating of such materials in bulk, as for instance in rolls, and in such manner as to be adapted for the present-day method of manufacturing and processing.

Another object is to devise such a system in which there may be employed existing motor generators of the lower frequency induction types as well as of the high frequency types, as for instance the electronic type of generators. More specifically, my present improved system is especially adapted for use in connection with the constant speed motor generator or the frequency-controlled power amplifier type of electronic generator such as is disclosed in my United States Letters Patent No. 2,205,424.

Another object is to devise a new and efficient type of load circuit which makes such a system possible; more specifically, my present invention contemplates the provision of a highly efficient tank work circuit that is coupled to the generator and that is pre-tuned to be resonant at a predetermined frequency suitable to take the work load for the desired results.

Another object is to devise such a system in which the work load may be placed in the induction field or in the capacitive field of the tank work circuit, according to whether the work is of a metallic or non-metallic nature.

Another object is to devise such a system in which the coupling of the tank work circuit to the generator may be variable with respect to mechanical arrangement as well as electrical properties.

More specifically, my purpose is to utilize the relative mechanical movement between the tank work circuit and the generator as a means of satisfying the requisite conditions with respect to electrical coupling in order to thereby provide greater simplicity of structure and increased efficiency as compared with prior systems.

Another object is to devise such a system in which the work may be supplied to and delivered from the same in any suitable manner and in which the operation of the generator may be automatically controlled according to requirements with respect to the work.

Another object is to devise such a system in which the tuning is accomplished in the tank

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work circuit so that there is obtained greater efficiency in heating of the work by virtue of the fact that practically all of the heat will be confined to the work and not in the generator.

Another object is to devise a work circuit which may be recognized as a unit and which is provided with means for receiving the work.

Other objects will appear from the following description and claims when considered together with the accompanying drawings.

It is to be understood that the present form of disclosure is merely for the purpose of illustration and that there might be devised various modifications thereof without departing from the spirit of my invention as herein set forth and claimed.

Fig. 1 is an elevation of the rotatable turntable upon which the work circuits are mounted;

Fig. 2 is a partially diagrammatic plan view of the same arrangement as indicated in Fig. 1 hereof, in which the generator and primary circuit occupy fixed position and in which the annular series of work circuits are mounted upon the rotatable turn-table so as to move the secondary coil of each work circuit into and out of coupling position with respect to the primary coil, reference being had to Fig. 6 for a fuller illustration of the control circuit for the generator.

Fig. 3 is a diagrammatic view illustrating the condenser arranged in series in the tank work circuit and with a motor generator for the primary circuit;

Fig. 4 illustrates diagrammatically an arrangement in which non-metallic material may be heated by the dielectric process and in which there may be employed an electronic generator with very high frequencies;

Fig. 5 illustrates diagrammatically the same arrangement as in Fig. 4 hereof except that in Fig. 5 the primary circuit may be tuned or partially tuned whereas in Fig. 4 the primary is untuned;

Fig. 6 illustrates diagrammatically a system of contactors for automatically controlling the operation of the power source in accordance with the movement of the rotatable turn-table carrying the work;

Fig. 7 illustrates how the work circuit may be embodied in a container for receiving and holding the work and for conveniently placing in position for the heating operation;

Fig. 8 illustrates a combined mold and tank coil that may be built together as a unit.

It is of course understood by those who are fa-

miliar with the art to which the present invention relates, that a pre-tuned tank circuit without the work being inserted therein, reflects no de-tuning effect to the constant frequency generator; but, when the work is inserted in the tank circuit, there are immediately added to the tank circuit certain reactive components which cause a change in the natural period of the tank work circuit. This is especially true in the case of magnetic loads, as for instance iron and steel and other metals with such properties. Under such conditions there are realized also capacity effects as well as resistive changes. Such variations of course must be compensated for.

According to present-day practice, the above-described condition is overcome by throwing the circuit off of resonance or by a change in the power factor of the generator for a period of time until the reactive effects of the load changes and until the resistive effects are sufficiently high to be coupled for maximum power at substantially unity power factor; and this is done by changing capacitors by means of a combined timing arrangement and the operation of contactors which insert capacitors into the generator circuit. This, however, involves considerable mechanism and additional equipment and without attaining maximum efficiency; and it is this present-day condition upon which my present invention is an improvement.

Briefly, one possible arrangement of my present invention contemplates a plurality of tank circuits that are stationary and a generator that may be bodily movable with respect thereto; or, preferably, there is another arrangement in which a plurality of pre-tuned work circuits upon a rotatable turn-table are brought into coupling relation to a generator which remains stationary. Such latter arrangement would permit the proper electrical coupling with marked efficiency and would allow also the work to be loaded and unloaded at the proper points in any suitable manner. Also, there would be provided suitable timing mechanism for permitting and regulating the several operations in proper sequence and in a most efficacious manner, including the operation of the rotatable turn-table, which carries the work, so as to effect the proper movement of the same to and from coupling position, and the energization of the generator at the proper time. Such control means would include interconnection between the rotatable turn-table and the means for effecting energization of the generator in order to turn the generator power on and off at the proper times and thereby avoid generator outputs at times when there is no necessity for the same.

As will be observed, the tank work circuits would be inductively or capacitively coupled to the generator, thereby allowing freedom of mechanical motion of the same with respect to the generator and keeping the tank work circuits at a high efficiency and with a high generator efficiency.

Each of the work circuits is provided with a condenser **14** that serves to tune the secondary coil to resonant frequency or variations thereof, the condenser being here shown in parallel arrangement in the circuit. Each of the work circuits has a coupling coil to the primary circuit of the generator. The work circuit coil **15** may be water-cooled and is adapted to receive the work therewithin.

According to the preferred arrangement of my present invention, reference being now had to Figs. 1 and 2, I provide a stationary generator

10 with the stationary substantially untuned primary circuit with its coil **11**, and a plurality of tuned work circuits which are indicated at **12** and which are mounted upon a rotatable turn-table **13** so as to bring their secondary coils **12***a* successively into coupling with respect to the stationary primary **11**. Each of the work circuits is tuned by means of a condenser **14** which may be arranged in parallel; and there is a work coil **15** in each of the secondaries to receive the work therewithin. Turn-table **13** may be operated by means of an electric motor **3***a* through suitable shaft and gear drive connections and there may be provided any suitable known form of timing means **3***b* for regulating the speed of the motor **3***a* of the turn-table **13** and for controlling the intermittent and temporary stopping of the motor **3***a* and the turn-table so as to permit completion of the heating effect produced by the maximum coupling between the primary and secondary coils **11** and **12***a*, respectively. That is, this automatic control means **3***b* may include means for governing the rate of speed of the motor **3***a* and the turn-table during the period of approaching coupling relation between the primary and secondary coils **11** and **12***a*, respectively, and the period immediately following such coupling relation. For instance, it is contemplated that the secondary coil **12***a* may be moved out of coupling relation at a greater speed than that at which the secondary coil approaches the coupling relation in each instance; and it is contemplated also that, for a brief period, the secondary coil in each instance may stop in completely coupled position in order to perfect the heating operation, as above explained.

Beneath the rotatable turn-table **13** there may be provided a source of radiant energy, referring to Figs. 1, 2 and 6 with the lights **16** for instance, the rays of each of which are adapted to be projected radially out through suitable windows **17** in the circumferential wall of the turn-table and to be impinged upon a photo-electric cell **18** or other similar device that is responsive to radiant energy in an electric circuit. The cell **18** or other such instrumentality is located in an electric circuit which includes also a photo-electric cell amplifier **19** and control relays **20** and leads to a system of electric contactors for controlling the source of power to the primary coil **11** of the power transformer. There may be as many transparent windws **17** as desired and they may be made adjustable circumferentially and otherwise so as to vary their extent in both directions for different patterns according to the given conditions, as for instance in determining the length of time for control of the generator. The portions between the windows **17** are opaque. This circuit, controlled by the photo-electric cell, will include a source of electrical energy to supply a relay **22** which has a hinged armature **22***a* adapted to close the circuit at point **23** so as to energize the solenoid **24** which has a hinged armature **24***a* adapted to close the circuit at point **24***b* and thereby short-circuit the resistance coil R1 in the power generator circuit which includes also the transformer T and rectifier, and also to close the circuit through solenoid **25** whose hinged armature **25***a* will close the circuit at point **25***b*, thereby short-circuiting resistance coil R2. In this way there will be effected a gradual reduction in the resistance in the power generator circuit and hence a gradual increase in the electric power. Each of the solenoid armatures has a dash pot **26** to delay its action and each arma-

ture may return by gravity to open position upon release of the same. With this arrangement, the generator may be energized automatically in accordance with the movement of the work towards and away from the primary coupling coil 11, the windows 17 being so arranged and of such extent that the generator will be energized only when the work coils approach coupling position with respect to the primary coil and while the work coil occupies fully coupled position.

It is to be understood that the primary and secondary induction coils may be of the air core type or of the iron core type, the one form being here indicated in Figs. 4 and 5 for use with high frequency and dielectric work, and the other being illustrated at 11 and 12*a* in Fig. 1 and at 11' and 12*a*' in Fig. 3 for use with low frequency. Also, the condenser for tuning the work circuit may be arranged in parallel, as indicated in Figs. 1, 2 and 5 of the present drawings, or in series as indicated at 14' in Fig. 3. The use of a motor generator is illustrated at 30' in Fig. 3. As above noted, the work circuit is tuned to resonance while the primary circuit is untuned although it may be tuned by a condenser 34, as illustrated in Fig. 5 hereof.

As above stated, it is possible to employ in my present system either a motor generator or an electronic generator. In the case of the motor generator, the initiation and continuation of the relative rotary movement between the same and the work circuit is accompanied by magnetic leakage until the point of the desired maximum coupling is reached; while in the case of the electronic generator, such relative rotary movement is accompanied by electro-magnetic leakage until there is reached the point of maximum coupling between the primary and secondary coils. Thus there is attained the desired resonance between the generator and load and the power incident thereto, with the resultant heating as required.

It might be pointed out that the tank work circuits may be so constructed as to be gas-tight so that there may be employed either a neutral atmosphere or low pressures or other desirable gas conditions. Also, my present system makes it possible to obtain highly efficient work circuits by building electrical tank circuits that are highly efficient.

In Figs. 4 and 5 of the accompanying drawings I have illustrated the possibility of employing my present invention for the purpose of dielectric heating with very high frequency. In each of these illustrations there is indicated an electronic generator 30 with its primary coil 31 of the air core type and the work circuit 32 with its copper movable secondary coil 32*a* of the air core type, which may be water-cooled, and the large capacitor plates 33 which serve to tune the secondary coil to resonant frequency and between which there may be placed the work generally consisting of non-conductive material, as for instance ceramics and the like. The primary circuit may be untuned, as in Fig. 4, or it may be tuned by means of the condenser 34, as in Fig. 5.

For instance, according to my present invention, the tank work circuit may be pre-tuned with respect to the working frequency of the generator, with magnetic load inserted in position in cold condition, and with maximum heating to the "Curie" point. In this case, the generator will load to maximum and then unload due to the increased resistance of the load. This arrangement is desirable for certain annealing as there is no particular load presented to the generator after the point of heating to the "Curie" or non-magnetic point is reached and therefore there is no danger of over-heating or burning of the metal.

Another arrangement with my present invention consists of a tank circuit pre-tuned with respect to the working frequency of the generator without the work in the load circuit. The magnetic work load is then inserted and this is then coupled to the generator. In this case, the generator will produce increasing load to the point of proper load or even over-load and the metal will heat through or past the "Curie" point and even to the point of melting or burning but may be adjusted to the desired temperature above the "Curie" point temperature.

There may also be variations of the above two conditions, according to the coupling and the ratio of the turns of the generator primary coil with respect to the secondary coil in the tank work circuit.

My present invention makes possible also other various advantages. For instance, with a stationary generator and movable tank work circuits, as above described, there may be obtained the advantage of the familiar production line with respect to quantity of work. At the same time, the relative mechanical motion between the generator and the tank work circuits, permits the requisite electrical conditions to be met in an efficient manner. Also, the timing of the relative mechanical motion between the generator and tank circuit, makes it possible to automatically regulate the power to the generator so as to have the power thereto "on" only when required; and my present system permits loading and unloading of the work by means of any suitable mechanical devices outside of the electrical field. With my present invention, it is possible to meet the desired maximum coupling and resonant requirements between the generator and the load, with maximum power transfer, and to shield the tank work circuits within gas-tight chambers or the like for varying conditions; it being also possible to obtain highly desirable results by building highly efficient electrical tank circuits to receive the work.

By virtue of the relative mechanical movement between the generator and the tank circuits, the proper loading conditions of the generator will be met during the time the variable reactive electrical loads are presented until they are comparatively non-magnetic and non-reactive and then they are coupled for full power when in a condition of substantially unity power factor. This arrangement eliminates the necessity of elaborate contactors for changing additional power factor condensers in the motor generator.

In the heating of either metallic or non-metallic bodies, the work circuit may be recognized and handled as a unitary assembly in which the work may be placed for the heating operation. In the case of metallic bodies to be heated, referring to Fig. 7, the work circuit 35 and its condenser 36 may be enclosed within a suitably walled gas-tight electric insulated container 37 which has a closure 38, of electric insulation material, to permit insertion and removal of the work into and out of the space within the coil 35*a* of the work circuit in accordance with the principle above explained, this circuit being embedded within the insulation. This container may be provided with a valved connection 39 for suitable gas supply and a relief valve 40. This

entire container, with the work therein, may be placed within the primary coil so as to assume electric inductive relation for the heating operation, as above explained.

Also in the case of non-metallic bodies to be heated, referring to Fig. 8, it is possible to provide a unitary tank circuit including the split secondary coil **32***a'* connected to the spaced dielectric plates **33'**, these elements being embedded in the electric insulation inside the insulated container **41**. This container consists of two halves hinged together at **42**, with an electroconductor bar **43** pivoted at **44** and adapted to be locked at **45** so as to hold the container closed. When in locked position, this bar serves as a conductor between the coils **32***a'*. The work may be placed in the space between the plates **33'** and the coil of this self-contained unit will be brought into proper inductive relation to the primary coil for the heating operation in the manner above explained. In the case of certain types of ceramic or similar non-metallic work in a dielectric field, this invention has the advantage of reducing the number of molds or forms required, by speeding up the process so as not to tie up the molds for long periods of time.

In view of the recently promulgated Government regulations as to interference by high frequency industrial generators, my present arrangement of a controlled frequency becomes very important since it satisfies the requirements of such regulations.

Thus I have found that pre-tuned tank work circuits of high efficiency can be designed to do a particular piece of work by fitting the work into position in the tank work circuit. With the work in a fixed physical relationship with respect to the tank circuit, both the tank circuit and the work are then moved into the generator field according to a predetermined timing arrangement for the desired result. According to my invention, it is possible to move the successive tank circuits with their work into the generator field in various manners. For instance, the coupling of the tank work circuit to the generator circuit may be initiated at a predetermined rate of speed until maximum coupling is reached, when the relative motion will be stopped for a predetermined time, and then the tank work circuit may be moved out of maximum coupling position at a greater rate of speed, this automatic regulation of the movement and rate of speed of the turn-table being effected by means of a timer indicated in a general way by reference numeral **3***b* in the circuit of the electric motor **3***a* for operating the turn-table. As above noted, this automatic system of control might include also means for automatically energizing and de-energizing the generator according to prescribed power requirements so that the power to the generator will be turned off when the work moves out of fully coupled position.

In my present invention, the motor generator may be of constant fixed frequency type such as the constant speed motor generator and therefore of substantially constant frequency output; or, there may be employed a constant fixed frequency oscillator driving a power amplifier or amplifiers, whose output will thus be a constant fixed frequency.

My present invention will permit the use of pre-tuned tank work circuits of high efficiency adapted to take work in either compact or loose coupled condition; and a system embodying my present invention will accomodate work for either the inductive field or capacitive field or a combination of both inductive and capacitive fields.

When using a motor generator in my present improved system, it works into a partially untuned primary circuit while the tuned secondary or tank work circuit may be moved mechanically into the field of the generator output in such manner that the several factors of speed of such mechanical motion, magnetic leakage, and the design of the coupling pole pieces will permit the generator to work at various degrees of load and reactive components until the magnetic properties of the work diminish and hence the effective load of the work is increased by the developed heat therein, thus increasing its resistance as it approaches the point of maximum coupling; and then when the work circuit reaches the point of maximum coupling, it will remain at such point until the treatment of the work is completed. This greatly simplifies the generator and eliminates the necessity of special contactors for timing and the insertion of additional capacitors in the generator of the motor generator set. Another advantage resides in the fact that changing to resonant conditions takes place in the tank work circuit, thereby creating maximum heat in the work. This eliminates the heating of the motor generator and creates useful and desirable heating of the work in the tank work circuit.

In the case of the electronic generator, the power amplifier or amplifiers may work into an untuned primary circuit, and the tuned secondary or work circuit moves into the field of the generator output in such a way that the speed of relative motion between the circuits, the electro-magnetic leakage and the design of coupling, permit the generator to attack the load, to wipe out the reactive components and to increase the load resistance so that, when maximum coupling is reached, maximum power of the generator is applied until the work is properly treated. Plate voltage is applied to the amplifier or amplifiers at the proper coupling time which is co-ordinated with the mechanical movement of the tank circuits, and there is also automatic regulation of the voltage to the amplifier or amplifiers so as to be increased accordingly as the work approaches and moves into the maximum load position under substantially resonant conditions, in the manner above explained.

To recapitulate, my present invention is adapted for heating materials in bulk, either in compact or loose condition and either by induction or dielectric processes; I have devised a new type of load circuit which may be coupled to generators of different types, the load circuit being tuned to a certain frequency; the coupling of the load circuit to the generator may be variable by virtue of the relative mechanical motion between the two circuits and with the resultant change in reactive components; the generator may remain stationary and the tank circuits may be moved into coupling with respect thereto, as herein illustrated, or the reverse arrangement may be employed; there is obtained a controlled frequency which satisfies the requirements of the recently promulgated Government regulations; with my new method of coupling the work circuit to the generator, the tuning takes place in the tank work circuit while the generator works into an untuned, tuned or partially tuned primary circuit, with the resultant advantage of being able to utilize the heat upon the

work to be heated, instead of permitting part of it to reduce the efficiency of the machine; there may be obtained heats, under control, to the "Curie" point or to temperatures above the "Curie" point; the generator may be energized in accordance with the presence of work in the tank work circuit and according to work requirements; the rate of movement of the work may be varied according to its position with respect to the point of maximum coupling; my present method simplifies the structure by eliminating the use of contactors and capacitors, my present system involving the principle of pre-tuning, with a substantially fixed constant frequency; and my invention is adapted for use in a manner similar to the familiar quantity production line and with comparable incerase in the speed of production over the prior methods which have been employed up to the present time, so far as I am aware.

What I claim is:

1. In a device for heating material, a primary electric circuit having a primary induction coil, an electric generator of substantialy constant frequency for supplying electric power to said primary circuit, and a companion electric circuit pre-tuned for a desired fixed working frequency having a secondary induction coil, said companion circuit including as part thereof coil means for receiving bodily the material therewithin so as to enclose the same and for transmitting electrical energy thereto from said induction coil for heating the material, said generator and primary circuit upon the one hand and said companion circuit including said material-receiving coil means upon the other hand being relatively movable bodily with respect to each other successively through loose and close coupling relationships between said primary and secondary coils, means for effecting such relative movement, and means actuated by the relative position between said generator and primary circuit on the one hand and said companion circuit and material-receiving coil means on the other hand for automatically regulating the supply of power to said generator.

2. In a device for heating material, a stationary primary electric circuit having a primary induction coil, a stationary electric generator of substantially constant frequency for supplying electric power to said primary circuit, and a plurality of pre-tuned companion electric circuits for a desired fixed working frequency and each having a secondary induction coil, each of said companion circuits including as part thereof a work-receiving coil for bodily enclosing the same and for transmitting electrical energy from its induction coil to the work for heating the same, means for bodily moving said companion coils and the work enclosed therewithin as units successively from loose coupling to close coupling relationship with respect to the said primary coil, and means actuated by the position of said companion coils and the work enclosed therewithin with respect to said primary coil for automatically regulating the supply of power to said primary circuit.

3. In a device for heating material, a primary electric circuit having a primary induction coil, an electric generator of substantially constant frequency for supplying electric power to said primary circuit, and a companion electric circuit pre-tuned for a desired fixed working frequency having a secondary induction coil, said companion circuit including as part thereof means for receiving bodily the material therewithin so as to enclose the same and for transmitting electrical energy thereto from said induction coil for heating the material, said primary circuit upon the one hand and said companion circuit including said material-receiving means upon the other hand being relatively movable bodily with respect to each other successively through loose and close coupling relationships between said primary and secondary coils, means for effecting such relative movement, and means actuated by the relative position of said primary circuit upon the one hand and said companion circuit with its material-receiving means upon the other hand with respect to each other for automatically regulating the supply of power to said primary circuit.

4. The same structure as recited in claim 3 hereof and in which said last-named means is electrical.

5. In a device for heating material, a primary circuit having a primary induction coil with means for supplying thereto electric power of substantially constant frequency, and a companion electric circuit pre-tuned for a desired fixed working frequency having a secondary induction coil, said companion circuit including as part thereof means for bodily receiving the material therewithin so as to enclose the same and for transmitting electrical energy thereto from said induction coil for heating the material, said primary circuit upon the one hand and said companion circuit including said material-receiving means upon the other hand being relatively movable bodily with respect to each other succesively through loose and close coupling relationships between said primary and secondary coils, means for effecting such relative movement, and means actuated by the relative position between said primary circuit upon the one hand and said companion circuit with its material-receiving means upon the other hand for automatically regulating the supply of power to said primary circuit.

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