

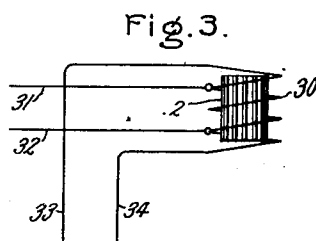
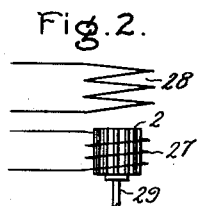
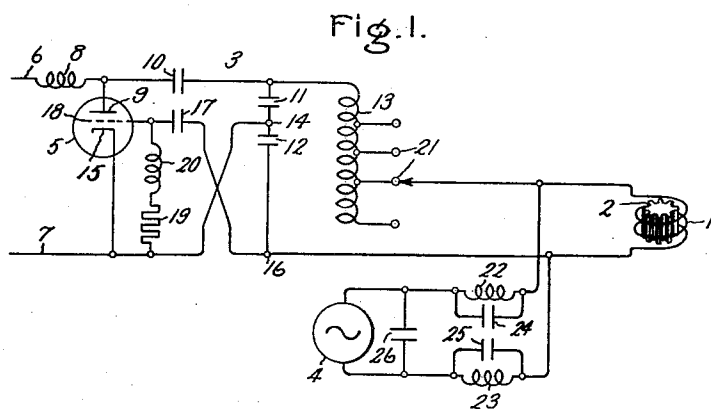
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METHOD OF HIGH-FREQUENCY INDUCTION HEATING

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METHOD OF HIGH-FREQUENCY INDUCTION HEATING

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My invention relates to methods of high frequency heating, more particularly to methods of heating by high frequency electromagnetic induction, and has for its object a simple and reliable method of heating different portions of an irregularly shaped article to a predetermined temperature, such as the base and tip portions of the teeth of a gear for hardening purposes.

In the heating of articles by high frequency induction, I have found a pronounced localized heating effect in different portions of the article by currents of different frequencies. For example, in the heating of metallic gears, such as for annealing or hardening purposes, currents having high frequencies (on the order of 500,000 cycles) tend to heat primarily the surface of the tip or outer end portions of the teeth without bringing the metal at the base portions of the teeth up to the desired temperature. On the other hand, lower frequency currents (on the order of 1,000 to 10,000 cycles) heat the base or root portions of the teeth at a greater rate than the tips.

In accordance with my invention, I utilize a plurality of currents of different frequencies, each suited to give the desired rate of heating of a particular portion of the article or mass of material, so as to effect the heating of the portions of the article simultaneously to the desired temperature or temperatures. In a preferred form of my invention, I energize an induction heating coil with both relatively high frequency currents and relatively low high frequency currents at the same time, these frequencies being chosen to give the desired effective heating of the selected portions of the article by means of the electromagnetic fields set up by the currents of different frequencies, such as the tips of the teeth and the bases of the teeth of a gear. I also provide means for varying the relative values of the high and low frequency currents in the heating coil, or the relative times at which the high and low frequency currents are applied, so as to obtain the desired rates of heating of the outer and inner portions of the article. Also, I may provide separate heating coils supplied with currents of different frequencies with means for transferring the article from one coil to the other.

For a more complete understanding of my invention, reference should be had to the accompanying drawing, Fig. 1 of which is a diagrammatic representation of high frequency heating apparatus embodying my invention; while Figs. 2 and 3 are diagrammatic representations of modified forms of my invention.

Referring to the drawing, I have shown my invention in one form as comprising an induction heating coil 1 in which a suitable article or work piece having cavities and prominences,

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such as a gear 2, is placed for heating to a hardening temperature by reason of the inductive relation of the coil and gear. The coil 1 is connected to two sources of high frequency current, i. e., a suitable source 3 of relatively high frequency current and a suitable source 4 of relatively low high frequency current. It will be understood that the current supplied by the sources 3 and 4 are both high frequency currents in the sense that their frequencies are above 60 cycles. Each current, by means of the single coil, produces its own electromagnetic field passing through the article.

In a typical installation the supply source 3 is preferably an electronic oscillation generator, shown as a Colpitts type generator, and supplies a current of two or three hundred amperes at 3,000 to 4,000 volts having a frequency of approximately 500,000 cycles a second. The generator 4 may, as shown, be a rotary salient pole type generator supplying a current of 500 to 2,000 amperes at 300 volts having a frequency of approximately 1,000 cycles a second.

These frequencies, illustrative of a typical heating application, may vary over wide ranges. For example, the frequency of the generator 3 may vary from 200,000 cycles to 2,000,000 cycles, while the frequency of the generator 4 may vary from 1,000 cycles to 15,000 cycles, a generator 4 of a suitable type to supply the lower frequencies being used, such as an inductor type generator or a spark gap generator. Moreover, the generator 4 may be an electronic generator supplying current at a relatively low frequency of, for example, 50,000 cycles.

As shown, the oscillation generator 3 comprises a suitable electric discharge device 5 having its plate cathode circuit supplied with direct current from a positive supply main 6, and a negative supply main 7 which preferably is grounded. A suitable inductance 8 is connected between the supply main 6 and the anode 9 of the discharge device. The plate or anode 9 is connected through a capacitor 10 to a tank oscillation circuit comprising two capacitors 11 and 12 connected in series with each other and having connected in parallel with them and in series with each other the inductance coil 13 and the induction heating coil 1. A tap 14 between the two capacitors 11 and 12 is connected to the cathode 15 of the discharge device, while the lower terminal 16 of the capacitor 12 is connected through a capacitor 17 to the grid 18 of the discharge device. This latter connection, it will be understood, applies a negative bias to the grid. A suitable leakage resistor 19 and inductance 20 are connected in series with each other between the grid and the cathode.

It will be understood that suitable means (not shown) is provided for supplying the direct cur-

rent to the mains 6 and 7; for example, two-way electric discharge device rectifiers may be used for supplying the direct current at a suitable voltage from an alternating current supply source.

The power supplied from the generator 3 to the heating coil 1 may be adjusted by varying the direct current voltage supplied by the mains 6 and 7 (by means not shown) and also by adjusting the frequency of the supply source. This frequency adjustment is made by connecting the upper end of the heating coil to a suitable one of a plurality of taps 21 on the reactance coil 13.

As shown in Fig. 1, the generator 4 is connected to the same terminals of the coil 1 as the generator 3. However, electric frequency responsive current blocking or filter means is connected in the circuit of the generator 4 for the purpose of preventing the flow of any appreciable high frequency current from the generator 3 through the generator 4. This filter or blocking means comprises two inductance coils 22 and 23 connected in the supply lines from the generator 4 and two capacitors 24 and 25 connected respectively in parallel with the inductance coils. Each of these inductance capacitor circuits 22, 24 and 23, 25 is resonant to the high frequency of the oscillation generator 3 thereby to prevent the flow of the high frequency current through the generator 4. The lower frequency current of the generator 4 passes freely through the inductance coils 22 and 23 to and from the heating coil 1. A capacitor 25 is connected across the generator 4 for the purpose of correcting the power factor of the generator, this power factor being preferably maintained near unity. In the oscillation generator 3 the relatively low frequency current from the generator 4 is blocked by the capacitors 10, 11, 12 and 17.

In the operation of the apparatus, the heating operation is started by closing suitable switches (not shown) in the circuits of the generators 3 and 4. The supply of current from the generator 3 is preferably controlled by establishing and interrupting the supply of direct current power to the mains 6 and 7, while suitable switching means (not shown) is provided in circuit with the generator 4 for disconnecting it from the coil 1. In the heating of the gear 2 for hardening purposes, it is desired to heat both the tip or prominence portions of the teeth, and also the base or cavity portions of the teeth, thereby to provide for the hardening of all working surfaces of the teeth. The high frequency current supplied by the generator 3 heats effectively the tip portions, while the low frequency current from the generator 4 heats effectively the base portions of the teeth. The two heating effects from the single coil 1 are adjusted relatively by selecting a suitable tap 21 on the inductance 13 so that the teeth are heated uniformly throughout to the hardening temperature, at which time the gear is suitably quenched such as by spraying water on it.

Preferably in the heating of gears and the like the gear as shown in the drawing is positioned in the high frequency coil with the axis of the gear substantially parallel and substantially coincident with the axis of the coil, so that the high frequency flux is substantially parallel with the axis of the coil, i. e., the flux is in substantially perpendicular relation to a plane passing through both the tips of the teeth or prominence

portions of the article and the bases of the teeth or cavity portions of the article.

Moreover, in the heating of gears and similar irregularly shaped articles, I contemplate that, if desired, two separate induction heating coils may be used, these coils being connected respectively to the two supply sources 3 and 4. Thus the two coils may be arranged one above the other in axial alignment, as shown in Fig. 2, with the lower frequency supply source 4 connected to the lower coil 27, and the higher frequency supply source connected to the upper coil 28. The gear or other work piece would be inserted first into the lower coil 27 where it would be heated to bring the interior or base portions of the teeth up to the hardening temperature. Then the gear would be raised by means of a suitable support 29 into the upper coil 28 for completion of the heating of the outer tip portions of the teeth to the hardening temperature, and quenching. It is contemplated that the second heating operation in the upper coil would be completed in a very short interval of time because of the preheating of the outer portions of the teeth by the lower coil 27. This heating by the upper coil 28 may, for example, be carried out in one or two seconds, during which time the inner portions of the gear do not cool below the hardening temperature.

In Fig. 3 I have shown a modified form of my invention in which a greater number of turns are provided for the lower frequency current to provide for the generation of the required amount of magnetic flux for the desired heating effect by means of a lower current. In other words, by increasing the number of turns in the coil for the low frequency current, more magnetic flux can be produced with the same current, or a lower current can be used to produce the same magnetic flux. A greater number of turns can be used for the low frequency current than for the high frequency current without prohibitive inductance in the low frequency current path. As shown in Fig. 3, the coil 38 is provided with taps 31 and 32 having connected between them substantially two turns of the coil and to which the higher frequency generator 3 is connected. The terminals 33 and 34 of the coil between which, as shown, are included four turns, are connected to the low frequency supply source. Obviously, any suitable number of turns for each frequency may be used. The high frequency coil, for example, may comprise only one turn.

While I have shown my invention as specifically applied to the heating of a gear for hardening purposes, I contemplate that my invention may be applied to the heating of any suitable material for various purposes. These materials which may be heated are those found suitable for heating by electromagnetic induction by means of currents of practicable frequencies. Such materials are, in general, electrically conductive or semi-conductive and include moist organic or inorganic materials, solutions and glues containing water, high resistivity electric conductors such as carbon, and metals.

The frequencies used will be suitable for the material being heated and will depend upon the resistivity of the material. In general, the higher the resistivity of the material, the higher the frequency required for efficient heating. I contemplate the use of lower frequencies up to 10 megacycles and higher frequencies up to 3,000 megacycles.

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The heating coil may also be used for internal heating purposes, in which application the coil is inserted in a bore or recess in the article such, for example, as in the heating of the teeth of internal gears, internal keyways, or internal splines.

Moreover, the portions to be heated may be selected not only on the basis of location, as the base and tip portions of teeth, but the selectivity may be based on the resistivities of the portions as when the portions are made of different materials.

I also contemplate that my invention may be carried out with the electrode or plate type dielectric heater which comprises two electrodes, usually of plate-like form, between which the article or material to be heated is placed. In this type of heater, an electric field is formed between the electrodes instead of an electromagnetic field formed by an induction heating coil. In accordance with my invention, I connect the two sources of high frequency current of different frequencies to the two electrodes. This electrode type heater may be used, for example, in the cooking of meat between layers of bread forming a sandwich. Thus, a layer of uncooked meat, such as steak or hamburger, may be placed between layers of bread and the sandwich placed between the plates of the dielectric heater. One supply source connected to the plates would supply a current at a suitable lower high frequency and suitable voltage to effect the selective heating of the meat at a desired rate, thereby quickly to cook the meat. The other higher frequency source would supply current at a suitable frequency and voltage to heat the bread selectively at a desired rate and to a desired temperature simultaneously with the heating of the meat.

While I have shown a particular embodiment of my invention, it will be understood, of course, that I do not wish to be limited thereto since many modifications may be made, and I therefore contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The method of inductively heating uniformly the cavity and prominence portions of an article to a predetermined temperature which consists in subjecting the article to a high frequency field in substantially perpendicular relation to a plane passing through both the cavity and prominence portions of the article adapted to heat the cavity portions of the article, simultaneously therewith subjecting the article to a higher frequency field in substantially perpendicular relation to a plane passing through both the cavity and prominence portions of the article adapted to heat the prominence portions of the article, and adjusting the frequency of the higher frequency field to heat the prominence portions of the article at the same rate as the cavity portions to the predetermined temperature.

2. The method of inductively heating the cavity and prominence portions of an article to a predetermined temperature which consists in subjecting the article to two high frequency fields in substantially perpendicular relation to a plane passing through both the cavity and prominence portions of the article produced by high frequency currents of different frequencies, one current having a frequency adapted to heat the cavity portions of the article to the predetermined temperature and the other current having a fre-

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quency at least several times the frequency of the first adapted to heat the prominence portions of the article to the predetermined temperature at the same time that the cavity portions are heated to the predetermined temperature.

3. The method of inductively heating uniformly the cavity and prominence portions of a metallic article to a predetermined temperature which consists in subjecting the article simultaneously to two high frequency electromagnetic fields in substantially perpendicular relation to a plane passing through both the cavity and prominence portions of the article produced by high frequency currents of different frequencies, one current having frequency adapted to heat the cavity portions of the article to the predetermined temperature and the other current having a higher frequency adapted to heat the prominence portions of the article at the same rate as the cavity portions to the predetermined temperature.

4. The method of inductively heating the tip and base portions of gear teeth to a hardening temperature which consists in subjecting the gear to a high frequency electromagnetic field in substantially parallel relation with the axis of the gear teeth adapted to heat the base portions of the teeth, and subjecting the gear to a still higher frequency electromagnetic field in substantially parallel relation with the axis of the gear teeth adapted to heat the tip portions of the teeth to the predetermined temperature at the same time that the base portions are heated to the predetermined temperature.

5. The method of inductively heating uniformly the tip and base portions of metallic gear teeth to a hardening temperature which consists in subjecting the gear simultaneously to two high frequency electromagnetic fields in substantially parallel relation with the axis of the gear teeth produced by high frequency currents of different frequencies, one current having a frequency of up to 50,000 cycles a second adapted to heat the base portions of the teeth of the gear to the hardening temperature, and the other current having a frequency of 200,000 cycles a second or more adapted to heat the tip portions of the teeth to said hardening temperature at the same rate that the base portions are heated to said hardening temperature by the first current.

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