

June 25, 1940.

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2,205,424

INDUCTION APPARATUS

Filed April 8, 1937

3 Sheets-Sheet 1

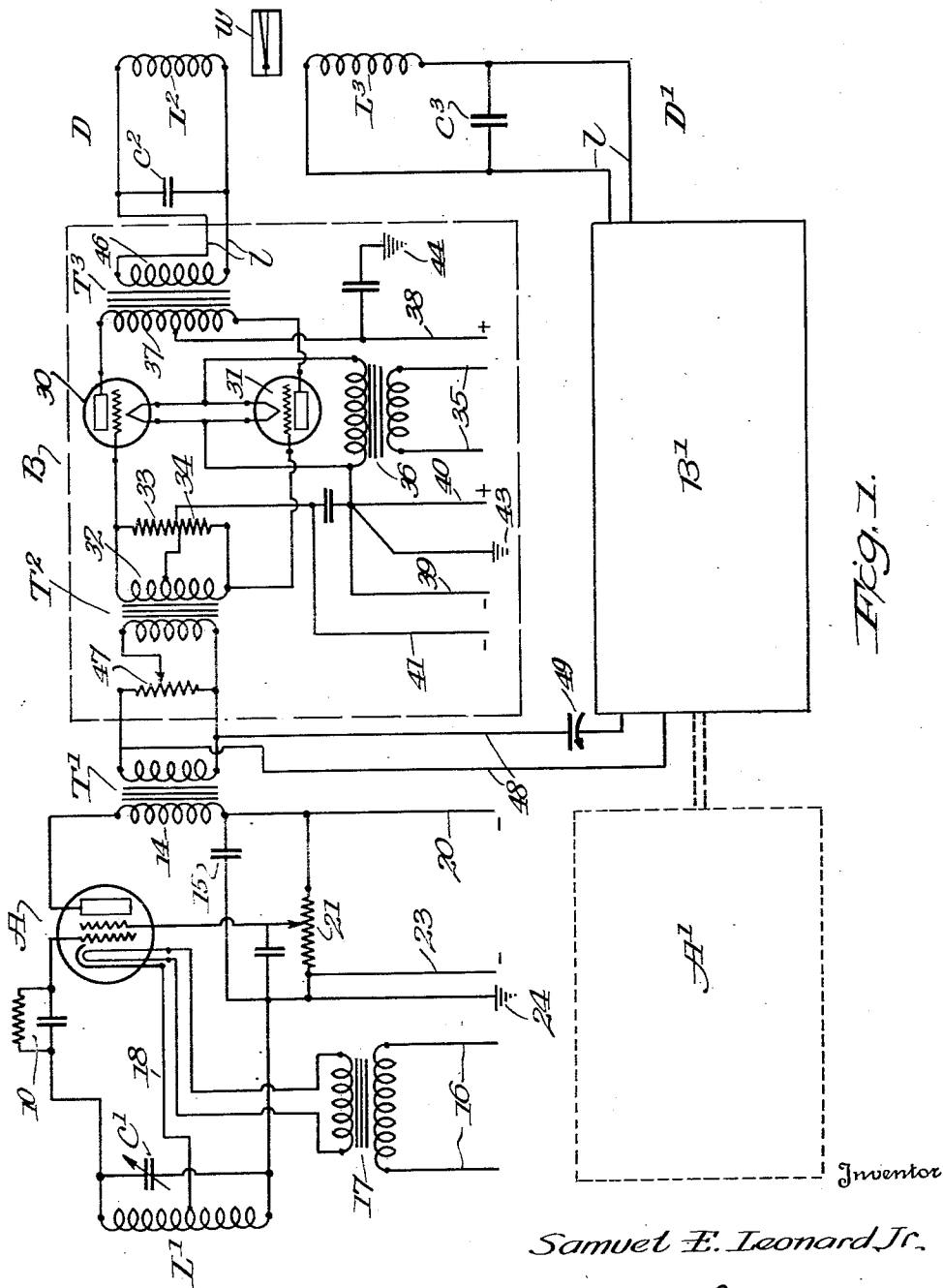


Fig. 1.

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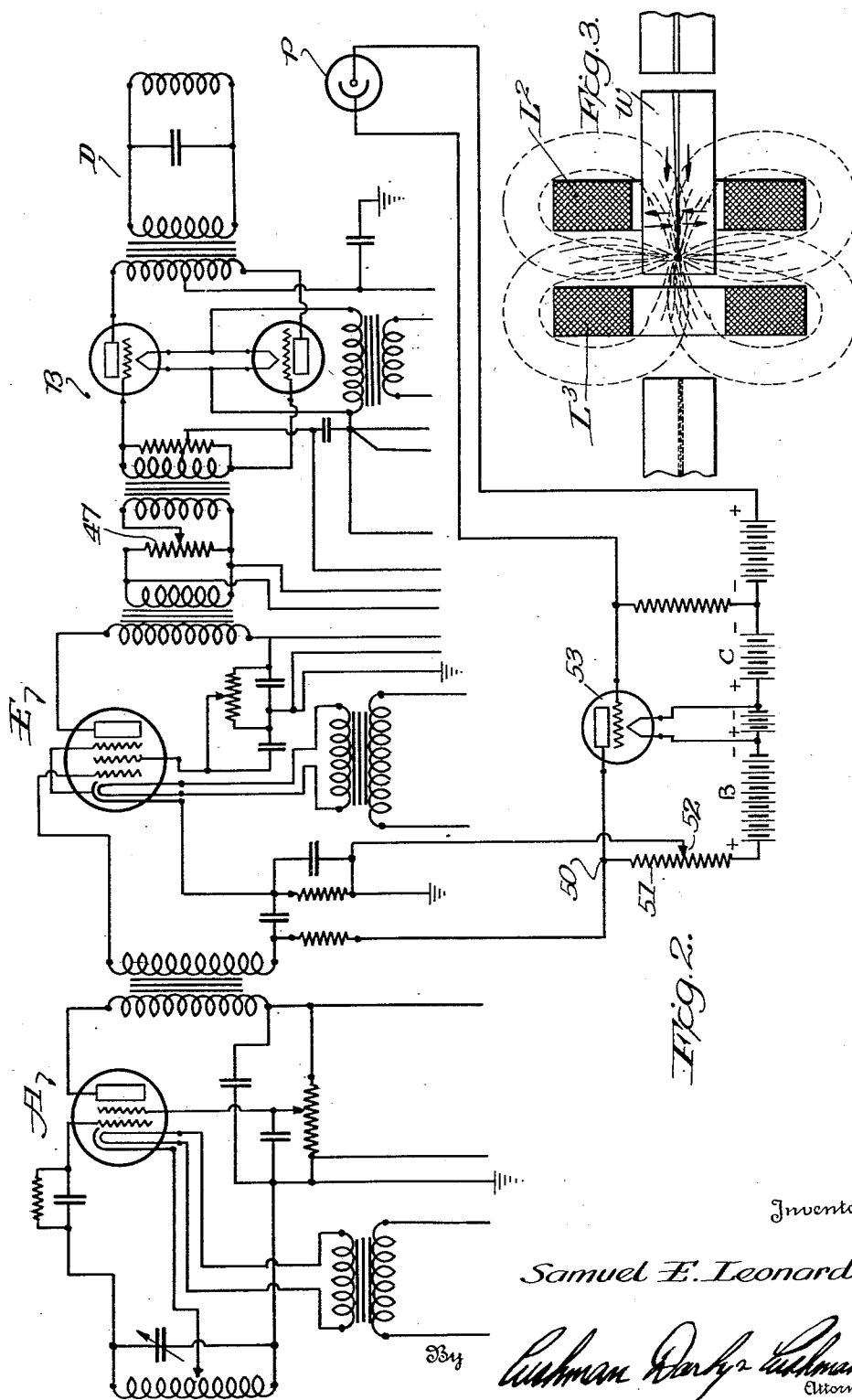
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3 Sheets-Sheet 2



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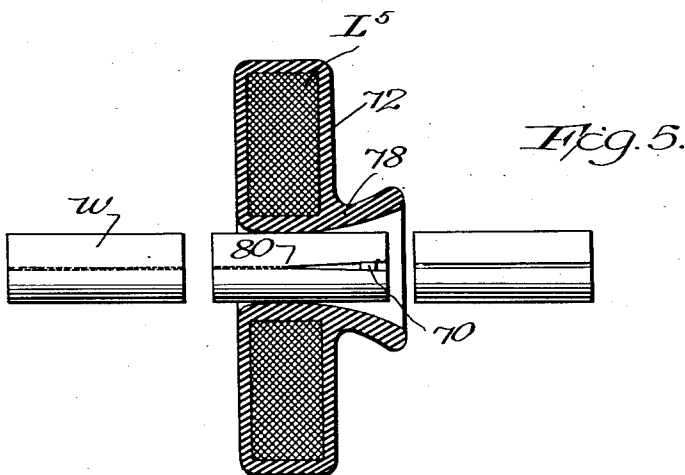
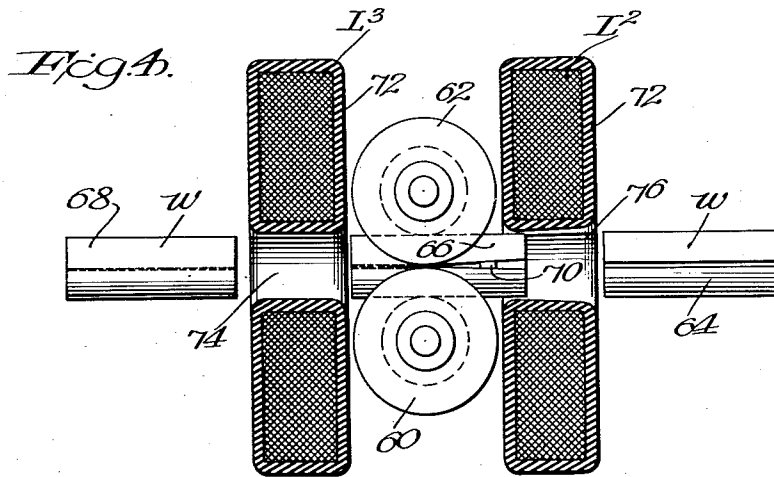
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3 Sheets-Sheet 3



UNITED STATES PATENT OFFICE

2,205,424

INDUCTION APPARATUS

Samuel E. Leonard, Jr., Cleveland, Ohio

Application April 8, 1937, Serial No. 135,800

6 Claims. (Cl. 219—13)

The present invention relates to induction apparatus, particularly such apparatus adapted for induction welding.

5 The principal object of the invention is to provide induction apparatus which are characterized by economy of power consumption as compared with apparatus and methods of similar function now known.

10 Another object of the invention is to provide an induction apparatus comprising a source of alternating current, and a work application circuit including an induction coil in the field of which the work is disposed, said apparatus including means for preventing change of frequency of the alternating current supplied to the coil, by reason of variations in the work application circuit caused by the disposition of the work in the field of the coil.

15 Another object of the invention is to provide an apparatus for inducing electrical currents and heat in the work, including an induction coil in the field of which the work is disposed, which apparatus induces maximum current in the work and maintains the current at a substantially constant maximum value.

20 Another object of the invention is to provide an apparatus of the character described, including a frequency determining oscillator circuit which imposes and maintains a definite frequency on the currents transmitted to the work application induction coil.

25 Ancillary to the above objective, it is a purpose of the present invention to provide an apparatus including a frequency determining oscillator and an induction coil in a work application circuit, said oscillator being protected from the work application circuit so that variations in the latter caused by the insertion of the work in the field of the coil will not vary the frequency imposed on the currents by the frequency determining oscillator.

30 A further object of the invention is to provide an apparatus comprising a work application circuit including an induction coil, and a frequency determining oscillator, which are in resonance with one another, so that maximum currents will flow in said coil and even greater maximum currents will be induced in the work.

35 A further object of the invention is to provide an apparatus comprising a frequency determining oscillator and a work application circuit including an induction coil, the relative reactances of which are such that the work application circuit is placed in resonance with the circuit of the frequency determining oscillator when work

of known characteristics is disposed in the field of the coil.

With respect to the preceding objective, it is a purpose of the invention to provide a power amplifier which automatically adjusts itself to its output conditions without overloading of or damage to the vacuum tubes and associated circuit.

40 A further object of the invention is to provide an apparatus comprising a voltage amplifier or amplifiers and a work application circuit including a coil for inducing heat in the work, having means for varying the heat induced in the work over a wide range by relatively small variations in the voltage applied to the voltage amplifier or amplifiers before amplification.

45 Another object of the invention is to provide an apparatus including a pair of induction coils disposed adjacent to one another so that their fields augment one another, said coils being energized by alternating currents of different frequencies, so that currents of different frequencies will be induced in the work.

50 Another object of the invention is to provide an apparatus including a pair of induction coils disposed adjacent to one another so that their fields augment one another, the frequency of the currents in said coils being maintained constant by a common frequency determining oscillator.

55 Ancillary to the above objective, it is a purpose of the present invention to provide an apparatus including adjacently located induction coils which are supplied with alternating current, having means for shifting the respective currents of the coils substantially 90° out of phase with one another, so that work disposed in the fields of the coils has induced therein currents having closely following impulse peaks.

60 A further object of the invention is to provide an induction heating or welding apparatus equipped with means for selectively or automatically controlling to a fine degree the heat induced in the work.

Included in the above objective, it is a purpose of the invention to provide for substantial changes in the heat induced in the work by only minute changes in the voltage applied to certain amplification stages of the apparatus. The accomplishment of the latter purpose makes practical the utilization of a light-responsive device such as a photo-electric cell as the agency responsive to the condition of the work, this type of device by its very nature responding to heat or color conditions of the work by setting up only

slight variations of current in the circuit of which it is a part.

A particular object of the invention is to provide apparatus and methods for welding the side seams of metal cans or the like by induction, which maintain a uniform weld in spite of disturbances in the welding circuit incident to welding, as well as changes in said circuit due to various factors, such as variations in the thickness of the stock being welded. However, the invention applies equally to the welding of all types of tubular bodies, large or small, as well as the welding of flat plate stock and the like.

Various other objects and advantages of the invention will become apparent as the description thereof progresses. It will be understood that while the present invention applies particularly to induction welding, the invention may be used to advantage in the accomplishment of other kinds of work, such as induction heating and the like. However, certain features of the invention may be limited to use solely in connection with welding.

The above are not all of the important objectives of the invention, and other objects and advantages of the invention will be apparent as the specification progresses.

In the drawings, which are illustrative of the invention and are not intended to restrict the same in any sense.

Figure 1 is a wiring diagram of a simplified form of the invention showing diagrammatically the manner in which the apparatus may be adapted for the use of more than one induction coil.

Figure 2 is a wiring diagram of a modification of the invention, wherein automatic means is provided for controlling the heat applied to the work by the induction coil or coils.

Figure 3 is a diagrammatic view of two induction coils, showing the manner in which their fields augment one another, as well as the disposition of the work with respect to the same.

Figure 4 is a horizontal sectional view of a pair of induction coils, showing the work traversing the fields of the same, with conventional welding devices employed to press the engaging edges of the work together as the work traverses the fields.

Figure 5 is a similar view showing a single coil equipped with a conventional welding device for forcing the edges of the work together, as said work traverses the field of the coil.

It will be understood that the circuits and connections disclosed in the drawings are illustrative only, and other known circuits and connections may be used if desired.

The invention relates to induction devices of the type in which alternating current is supplied to a coil, with the resulting formation of a field around said coil, in which field the work is disposed for the accomplishment of various purposes. Primarily, the present invention is adapted for use in the performance of welding operations, but as hereinbefore mentioned, other similar operations may likewise be accomplished.

In the induction welding of a tube, the tube is passed through a field formed as above, and successive opposed points along the edges of the tube are forced together under pressure as the tube traverses the field. By reason of the transformer action of the coil, currents are caused to flow across the seam of the tube at the points where the edges contact, these currents generally travelling circumferentially of the tube. The

point where the currents cross the seam of the tube is the point of maximum resistance to flow of these currents, and the localized heat caused by this resistance results in a weld when sufficient pressure is applied to the engaging edges.

I have found that by using high frequency currents, particularly currents of frequency above 5000 cycles per second, an effective weld may be produced with a minimum expenditure of power. While the invention is not limited in use to any particular range of frequencies, it can probably be used with the minimum possibility of interference in a range of from 10,000 to 100,000 cycles. Practical welding has been performed at approximately 25,000 cycles in the development of this invention. In prior art devices using the higher frequency currents, as distinguished from currents of commercial frequency, it has not been possible to maintain the current supplied to the induction coil at a uniform frequency, due to disturbances in the coil circuit caused by the work being disposed in the field of the coil, or, in the case of welding, by the flow of the welding currents.

I have overcome such disadvantage inherent in induction welding or similar operations by providing a frequency determining oscillator which controls the frequency of the currents sent to the welding circuit, together with means including a one-way power amplifier circuit for preventing the above mentioned disturbances in the welding circuit from being "thrown back" into the master or frequency determining oscillator to vary the imposed frequency. The present invention greatly differs from prior art systems in which a self oscillator is electrically or inductively coupled directly with the work application circuit, in which systems the frequency of oscillations generated changes in response to changes in the work application circuit when the work is disposed in the field of the coil, or when welding actually commences. This disadvantage of such prior art devices is present when the same are operated at any frequency. The above "throw back" prevention feature is an advantageous characteristic of the present invention when currents of any frequency are employed.

The principal parts of the circuit of the present invention are: the frequency determining oscillator circuit A, the power amplifier circuit B, and the work application or welding circuit D.

The frequency determining oscillator circuit includes a conventional pentode tube having a filament screen grid, control grid, space charge grid and filament. The control grid is connected through a grid leak and condenser combination with an oscillating tuning circuit including the coil L1 and variable tuning condenser C1 disposed in parallel relation with respect to one another. The frequency imposed on the power amplifier, hereinafter described, is determined by the tuning of the L1C1 circuit. The other end of the L1C1 circuit is connected with primary coil 14 of the iron core transformer T1 through the condenser 15. The filament is heated by alternating current from the commercial power leads 16, which leads connect with the filament through a transformer 17 which steps down the voltage of the applied current. A space charge grid is employed in the vacuum tube, being connected into the coil L1 by the lead 18 as shown.

The plate potential is supplied by current which flows through the primary coil 14 from the direct current source 20. The screen grid has a

direct current voltage imposed upon it by being connected to a variable resistance 21 disposed between the positive direct current power lead 20 and the negative direct current power lead 23.

High frequency current is generated in the primary coil 14 of the iron core transformer T1 by the oscillations of the above mentioned thermionic tube. The frequency of the current generated is determined by the tuning of the LC circuit, which may be accomplished in practice by adjustment of the condenser C1. The high frequencies thus generated and which pass through the primary coil 14 are by-passed from the direct current power source through the condenser 15 to the ground 24.

While the above type master or frequency determining oscillator may be used, any other well known type may be employed, such as the Hartley oscillator.

The power amplifier circuit B comprises a pair of thermionic tubes 30 and 31 arranged in push-pull relation. It will be understood that the particular arrangement of the tubes will be a matter of convenience, and only a single tube need be used in each amplifier. Furthermore, while only one amplifier is shown, a plurality of the same may be used if desired. The power amplifier is shown directly coupled to the frequency determining oscillator, but if one or more stages of voltage amplification are used between the power amplifier and the frequency determining oscillator, the latter will be coupled to the former through these stages. Alternating current of amplified voltage is supplied to the grids of tubes 30 and 31 from the secondary 32 of the transformer T2. A pair of resistances 33 and 34 are provided in parallel with the sections of the coil 32 to prevent the amplifier circuit from oscillating at its own frequency. The filaments of the tubes 30 and 31 are energized from commercial power leads 35 through the step down transformer 36. The plates of the tubes 30 and 31 are connected to the primary 37 of an iron core transformer T3. The plates of the tubes 30 and 31 are energized from a positive direct current power lead 38, which is connected intermediately of the ends of the coil 37. The filaments of the tubes 30, 31 are connected with the negative direct current power lead 39.

To increase the efficiency of the amplifier, direct current from a power lead 40 connects with the filament, and a corresponding negative power lead 41 is connected with the grid. Suitable connections 43 and 44 are provided for grounding the alternating currents produced, from the direct current power source leads.

Alternating current of high frequency and amplified voltage is caused to pass through the primary coil 37 of the transformer T3 by the oscillations of the power amplifier circuit, the frequency of the current being at all times controlled and maintained by the frequency imposed by the frequency determining oscillator A on the grids of tubes 30 and 31.

The secondary 46 of the transformer T3 connects with the work application or welding circuit, the latter comprising the condenser C2 and the coil L2 in parallel. The oscillations of the high frequency current in the coil L2 causes a field to be built up around the same in the well-known manner, and it is in this field that the work is disposed for welding or other operations. In order that maximum current may flow in the work application circuit, the same is tuned to resonance with the circuit of the frequency de-

termining oscillator, or preferably the latter circuit is tuned to the natural frequency of the work application circuit.

The frequency determining oscillator A is not directly coupled with the power amplifier B, but these respective circuits are coupled together through the intermediate variable resistance 47 to permit the voltage which is applied to the grids of the vacuum tubes 30 and 31 to be varied. In this manner, the power transferred to the induction coil L2 may be controlled, which in turn provides control of the heat induced in the work W.

In the operation of the entire circuit described, suitable power is applied to the plates of the vacuum tubes of the power amplifier, and this current is changed to alternating current of high frequency by the amplifier, said alternating current having its frequency controlled by the frequency imposed upon the grids of the vacuum tubes 30 and 31 by the frequency determining oscillator. This alternating current of high frequency and amplified voltage is passed to the work application or welding circuit containing the capacity C2 and inductance L2 through the transformer T3, producing a field around the coil L2, in which field the work is disposed to induce welding currents, heat and the like, as described.

The frequency of the induced currents is at all times under control and may be varied at the frequency determining oscillator by adjustment of the capacity C1. Furthermore, the heat induced in the work may be controlled by the resistor 47, adjustment of which will change the voltage amplified by the power amplifier. In connection with the last-named adjustment, substantial amplified corresponding variations in power applied to the work will result from minute changes in the voltage applied to the grids of the amplifier. Thus power control over a wide range is provided by minute voltage variation.

While the inductance and capacity of the circuit of the frequency determining oscillator may be tuned to resonance with the welding circuit containing L2C2, in practice, welding circuits will be constructed having selected values of L2 and C2, these selected values being such that when the work, which will be of known characteristics, is disposed in the field of the coil, it will have such reactance as to tune the welding circuit to resonance with the frequency determining oscillator.

That is to say, the welding circuit in the absence of the work will be somewhat short of resonance, but will be placed in exact resonance when the work of known characteristics is disposed in the field of the coil. By work of "known characteristics" I mean work of relatively uniform composition and mass, whose permeability will be such as effect a predetermined change of magnetic flux of the coil and consequently a known change in its reactance. The work application circuit thus has means comprising its fixed inductance and capacity providing a permanent reactance, and means comprising the work providing a removable reactance.

With this resonant condition, a maximum current will flow in the coil of the welding circuit, and correspondingly increased maximum current will be induced in the work. The elements from which the resonant circuit is constructed, including the coil, are selected so that they have minimum resistance. While the theory of resonance is known, its advantages cannot be availed of in

circuits employing currents of relatively low frequencies, as the extreme size of the capacity and inductance units which would be necessary to provide resonance in the work application circuit would make their use prohibitive.

In the performance of welding, the work may comprise a tubular body W having a longitudinal open side seam to be welded. This tubular body will be passed through the field of the coil L2, and during such passage successive opposed points along the engaging edges of the tubular body will be brought into contact and pressed together as these points pass through the field of the coil. Due to the high frequency used, and the resonant condition of the welding circuit, the current in the coil L2 will immediately rise to its maximum value and the induced current will correspondingly rise to an even higher maximum value. Furthermore, the resistance across the seam of the tube will be immediately increased to a marked degree by heat resulting from the instantaneous flow of heavy current across the seam, thus further increasing the heat, making possible instantaneous and rapid welding of the engaging edges of the tube when sufficient pressure is applied. The welding may be continued for any length of time desired, and only a minimum of current need be supplied to the resonant circuit even though very heavy current will be induced in the work. That is, the power source being in resonance with the work application or welding circuit, only small impulses of current need be applied to the latter to keep it oscillating, so long as these impulses are applied in resonance, and the resonant circuit current maximum is much higher than the maximum of the applied current.

It will thus be seen that the leads to the work need not be of great diameter, as they carry only the small current necessary to keep the resonant circuit oscillating. Consequently the bulk of the apparatus may be kept at a central point and the leads 1 can be made as long as desired to reach the point of work application, without excessive power losses, as in the case of apparatus such as conventional welding systems, in which heavy currents must be continuously carried to the work, thus necessitating heavy leads to avoid power loss.

The work application circuit which is placed in resonance by the presence of the work results in a pronounced advantage in association with the power amplifier disclosed, the latter adjusting itself to its output by only drawing the working current when the work is in the field of the coil, and idling while drawing minimum current when no work is present in said field, and the work application circuit is not in resonance. As a result, plate heating of the power amplifier tubes is held to a minimum, making unnecessary the use of extra large or water cooled tubes.

While effective work may be performed with the use of only a single coil, greater field intensity for a unit power plant may be provided by employing a plurality of coils disposed in adjacent relation to one another in such fashion that their fields augment one another. While any number of additional coils may be employed, for the sake of simplicity I have disclosed only one such coil, and if more than one is used, it will be connected into the system in the same manner hereinafter described in connection with the single additional coil disclosed. In Figure 1, the additional coil is shown at L3, said coil being in a work application circuit D' identical

with circuit D described above. This work application circuit may be coupled with a power amplifier B' identical with the amplifier B described above, and is connected with the secondary of the transformer T' by means of the leads 48. That is, another power amplifier and work application circuit is connected in parallel with the first power amplifier and work application circuit at the transformer T1. The additional power amplifier B' includes a potentiometer similar to 47. The frequency determining oscillator A thus controls the frequency of the currents in the coils of both work application circuits. The leads to the additional coil might be connected with the secondary of the transformer T3, in which case an additional power amplifier would be unnecessary, but the above described manner of connection is preferred.

While effective work may be done by augmenting the intensity of the field of one coil with the field of another, with the currents flowing through the coils in phase, increased heating effect has been found to result by having the currents flowing in the respective coils out of phase. This is accomplished by a variable phase changing condenser 49 disposed in a lead 48, which may be regulated to change the phase as discussed above.

In the use of very high frequencies, particularly for welding purposes, the provision of currents out of phase is effective in quickly raising the work to welding temperature and maintaining it at such temperature. The frequency being so high, the current impulses in each coil will flow one behind another by only a very small fraction of a second, and by having the frequency of current in the augmenting field of the coil L3 out of phase with the current in the coil L2, each current impulse peak from one coil will be followed immediately by a corresponding current impulse peak in the same direction from the other coil, said following current peak reacting in the heated work whose resistivity is higher at that instant due to the effect of the preceding current impulse, causing even greater heating effect and tending to prolong the effect of each current impulse.

If more than one additional coil is used, the circuit of each such additional coil will be provided with a phase changer, so that any desired relative phasing of the currents in the coils may be obtained. For instance, if a total of three coils are used, the currents supplied to the coils could be successively 45° out of phase, thus inducing in the work three successive current impulse peaks at 45° phase intervals.

The use of two induction coils having augmenting fields reduces the cost of equipment, particularly the cost of tubes, at the same time supplying the same amount of power. When only one coil is used, it is necessary to use larger thermionic tubes to deliver the same power, and if this power is considerable, the provision of water-cooled tubes is imperative. In the performance of welding, for instance, it has been demonstrated that the voltage across the welding point is greater with two 300 watt coils substantially 90° out of phase than with a single 600 watt coil. The effect of the induced currents from the respective coils is cumulative, in that an impulse from one coil closely follows an impulse from the other.

In Figure 3, two induction coils are shown in a preferred relative position with respect to one another, and the augmenting effect of the fields

of these coils is illustrated by the lines of force in the usual fashion. It will be noted that between the coils the lines of force from each respective coil have a cumulative effect, thus making the area of maximum field intensity somewhere between the two coils. Thus the provision of two coils, disposed adjacent to one another, results in increased power which can be applied to the work.

In Figure 3, a series of tubes or cans is shown, and in commercial production these cans travel along a mandrel, being fed by any suitable means. The can on the right side of Figure 3 has its side seam completely open and has not yet entered the field of the coils. The next can ahead in the line has passed through the first coil L2, and its leading end is shown positioned between the two coils, in the area of maximum field intensity. When the metal can or tube reaches this position the lines of force of the respective coils will be drawn into the metal of the can, thus further localizing the area of maximum field intensity between the coils. When the can thus enters the field, its permeability changes the flux density and thus varies the inductance of each coil by such a value that the circuits of these coils are placed in resonance with the frequency determining oscillator.

When the can is disposed in the field as in Figure 3, circumferential currents as shown by the arrows are set up in the can body, but these currents do not bridge the seam gap until the edges of the same are in contact. That is to say, these circumferentially induced currents do not become welding currents until the edges of the tube are contacted.

Any appropriate means may be provided between the coils for successively forcing together opposed points along the edge of the side seam of the tube as these points pass through the area of maximum field intensity. Such a device may be a guide such as a bell mouth for the can body, as shown in Figure 5, which constricts the body, thus forcing the edges together as the can traverses the mouth, or pressure rollers such as shown in Figure 4.

It will be understood that when the tube enters the field, the molecules of the metal of the same will be placed in a state of high agitation by the effect of the flux, and the flow of circumferential currents will result in a difference of potential being built up in the respective edges of the can or tube at opposed points. When the opposed points of the edges are contacted in the area of maximum field intensity, a heavy welding current will flow across the same, this current rising instantaneously to an extremely high value by reason of the resonant circuit in which the coils are connected, and also by reason of the single turn transformer effect which results from the tube body having its edges in contact at one point only. The instantaneous high current flow immediately raises the temperature of the metal at this point, thus increasing the resistance to flow of current. This extremely rapid rise of current and resistance brings the metal at its point of contact instantaneously to a welding heat.

By reason of the difference of potential between the edges of the tube, currents will flow longitudinally of the edges of the can, as shown by the arrows, travelling down the length of the edges and across the seam where the edges are in contact.

The welded tube is shown exiting from the coils at the left hand side of Figure 3.

In the use of either a single or double coil, the coil should be of such construction that its field is highly concentrated and localized, so that in welding, only the portion of the work being welded is in the intense field, the remainder of the work being completely outside of, or only on the outskirts of, the intense field. Due to this localization of the field, the entering edges of the can are not subjected to oxidation before reaching the welding point.

The use of a double coil is advantageous in that the first coil, such as L2, prepares the edges of the work for welding by building up a potential difference between the edges just before they reach the welding point.

With equal power applied to the two coils, the area of maximum field intensity should be midway between them as shown. However, an apparatus employing a pair of coils is susceptible to shifting of the area of maximum field intensity from and toward either coil. This may be done by varying the voltage at the first stage of the amplifying system of one or both coils, in the same manner that the heat induced in the work by each coil is controlled. For instance, by moving the contact along the resistance 47, so that less voltage is applied to the transformer T2, voltage applied to the grids of the amplifier tubes 30 and 31 is reduced, consequently reducing power delivered to the coil L2. The field of coil L2 thus collapses somewhat, shifting the area of maximum field intensity toward coil L3. Thus in the heating or welding of work, a control is provided to shift the area of maximum field intensity with respect to the work. It will be evident from Figure 1 that both amplifier B and B' are equipped with a potentiometer such as 47.

The use of the present apparatus employing a plurality of coils will be found to be of great advantage in the art, particularly in the accomplishing of unusual welding jobs which will necessitate the setting up of unusual fields. Various types of fields may be obtained by relatively positioning the two coils in different relation to one another, and by varying the angle of their relative phasing. Furthermore, any number of coils, or pairs of coils out of phase, may be coupled to a common frequency determining oscillator, and operated on the same, or different pieces of work simultaneously. For instance, any number of coils or pairs of coils could be positioned along an extensive piece of work, such as a long tube, to heat or weld it at a plurality of points.

While it is most desirable to employ only a single master or frequency determining oscillator, and to connect the amplifying system of each coil into a common master oscillator, it will be evident that each of the amplifying systems B and B', with their corresponding work application circuits D and D', may be provided with a separate frequency determining oscillator. In that case, the coils L2 and L3 may be disposed closely adjacent to one another, so that their fields will augment one another as described above. Furthermore, with such a modified arrangement, it would be possible to use currents of different frequencies or relative phase relations in the respective coils L2 and L3. The master oscillator A could, for instance, impose a current of one frequency in the coil L2 while a separate master oscillator A' imposes a different frequency in the coil L3. This use of different

frequencies may be desirable in various welding or similar operations, it being evident that currents of at least four frequencies may thus be induced in the work at the same time. That is to say, currents of each of the frequencies of the separate coils L2 and L3 would be present in the work, current of a frequency equaling the sum of the frequencies of the currents in L2 and L3 would likewise be present in the work, as well as current of a frequency equal to the difference of the above mentioned frequencies.

While I have shown the work as passing through the coil or coils, the invention is not restricted to this preferred arrangement, as the coils may be disposed within the work, if the latter is a tubular body, or at the side of the same, or in any desired position so that the work is disposed in the fields of the coil or coils. Furthermore, the coils may be formed or wound to give any desired type or configuration of field.

In Figure 2, a wiring diagram of a circuit of the present invention is disclosed, including automatic means for controlling the heat induced in the work by the coil of the work application circuit.

The general construction of the circuit is the same as heretofore described, including the frequency determining oscillator A, the stage of amplification shown as a power amplifier B, and the work application, or in specific cases the welding circuit D.

It will be understood that any number of stages of voltage amplification may be utilized in the practice of the present invention, and when more than one stage is used, the frequency of the oscillations at each stage will be controlled by the frequency determining oscillator. When the automatic control means of this modification is used, the grids of one of said stages of amplification will be under control of a circuit which is in turn actuated by a device responsive to the condition of the work, as a light-responsive device or photo-electric cell P.

In Figure 2, one of the stages of amplification E includes a variable mu tube which has its control grid connected with one end 50 of the potentiometer 51, so that amplified current flowing in the plate circuit of the photo-electric cell amplifier will cause a variation in the potential of the control grid of the thermionic tube in stage E.

The photo-electric cell P is disposed in any convenient position adjacent to the work W so that the heat or color of the work will vary its resistance, and this variation will be transmitted to the control grid of one of the stages of amplification to control the heat induced in the work as described.

The cell P is connected to the grid of the direct current amplifying tube 53, and as the heat of the work becomes excessive, increased current to the grid of tube 53 increases flow of current in the plate circuit of that tube. The direction of plate current flow will be from point 52 toward point 50, making point 50 relatively negative with respect to point 52, thus lowering the relative potential of the grid of amplifying stage E, which in turn reduces the power amplified. This reduction in power decreases the heat induced in the work, until the latter arrives at a proper heat or color. If the work becomes too cool, obvious reverse operation to that described will cause an increased amount of heat to be induced in the work. Thus the heating of the

work, either for welding or other purposes, is kept uniform.

It will be noted that a substantial correction in induced heat from the coil L2 may be effected by a relatively small variation in grid voltage at one of the stages of amplification. Thus the present apparatus is well adapted for control by means of a photo-electric cell, the currents produced by which are extremely small, as only a minute change in grid potential at the selected amplification stage is necessary in order to produce a substantial change in the heat induced in the work W. This is particularly true when a multiplicity of voltage amplification stages are utilized, and when the photo-electric cell circuit is connected with the grid of the first or one of the earlier stages.

The operation of the photo-electric cell is so rapid that its effect upon the voltage amplified and power sent to the induction coil L2 is substantially instantaneous. Thus, even in performing such rapid operations as the welding of relatively small objects, such as cans, the heat regulation may be instantaneously effected. The heat applied to the work in the case of the welding of cans will not only be corrected for the succeeding can when the cell responds to deficient or excessive heat in one can, but the operation of the automatic control will be so rapid that the heat induced will be corrected before the same can leaves the field of the coil, even though said cans are moving at the very great speed today employed in their manufacture.

In the performance of other classes of work, such as the heating and annealing of objects in furnaces and the like, the heat applied to the work may be accordingly automatically maintained to a fine degree by the apparatus described above, and the heat may be so maintained by the very small currents generated in the photo-electric cell, as only a minute change is necessary in the grid voltage of the earlier stages of amplification to result in a material change in heat applied to the work. This apparatus may be utilized with advantage in the drying of objects coated with lacquer, and the like.

The present apparatus is particularly advantageous for use in welding systems, to maintain a uniform welding heat at all times in spite of variations at the welding point, said variations being caused by the usual electric disturbances at that point. Variations may also be caused by physical changes at the welding point, such as variations in the thickness of the work being operated upon. It will be noted that while minute control of the heat applied to the work is maintained, the circuit is held in stable condition in spite of the voltage variation, as no change of frequency is at any time necessary, nor is any change of frequency possible by reason of disturbances at the welding point by the initiation of the weld or by reason of disposing the work in the field of the coil.

While the device responsive to the condition of the work is shown as a light-responsive cell, other devices such as a thermal-responsive device may be used in lieu thereof.

While the heat-responsive device and its circuit is shown for use in connection with a system employing only a single induction coil, one of the devices may be used to control the voltage amplifier in a system using a plurality of coils as in Figure 1, or a plurality of such devices may be positioned adjacent the work, one for each coil energizing circuit. When a single heat-re-

sponsive device is used for the circuits of more than one coil, the circuit E of Figure 2 might, for instance, be disposed between the circuits A and B of Figure 1, and thus voltage changes caused by the heat or light-responsive device would be amplified to each coil.

In this case, as each amplifier B and B' is equipped with a potentiometer such as 47, the fields of the coils L2 and L3 could be initially selectively adjusted to regulate their fields individually, or to adjust the area of maximum intensity of their combined fields, after which the light-responsive device would control the intensity of the fields of both coils, without destroying their balance as set by the potentiometers 47.

In Figure 4, conventional devices for progressively forcing together opposed points along the edge of a tubular body, such as a can, are shown. The induction coils L2 and L3 are shown disposed adjacent to one another, so that their fields augment one another, and conventional concave pressure rollers 60 and 62 are shown on opposed sides of the seam in the work, and between the coils L2 and L3.

One piece of work is shown at 64 before it enters the coil L2, and it will be noted that the engaging edges of the work are not in contact, and in this position the work will not be in the fields of the coils. At 66, a piece of work is shown after it has entered the fields of the coils, and as said work passes between the pressure rollers 60 and 62, opposed points along the engaging edges of the work are forced together substantially at the time these points reach the area of maximum field intensity of the coils. The edges of the work will be heated to welding temperature, as previously described, and the pressure applied by the rollers 60 and 62 will cause a welding union of said edges. The work with its edges welded will then exit from the coils as shown at 68.

The rollers 60 and 62 are of conventional structure such as disclosed in Patent No. 611,222, to Ries, September 20, 1898, but will preferably be made of insulating material. The coils L2 and L3 may be of any type, and may be wound in such manner that their fields will augment one another at maximum intensity at the point where the rollers 60 and 62 most closely approach one another. The edges of the work may be kept separated until they reach the maximum point of field intensity by a well known device such as a spreader 70, this spreader also preferably being made of insulating material.

The coils L2 and L3 are shown encased in insulating material 72, and are of the air core type as shown at 74 to permit passage of the work therethrough. However, if the coils are disposed in other relative positions with respect to the work, so that the work does not pass through the coils, they may be of the iron core type. It will be noted that the mouth 76 of the coil L2 is beveled, in order to guide the work through the coil and bring the edges close to one another so that the work may be properly engaged by the rollers 60 and 62.

Any suitable means may be employed to feed the work through the coils, such as feeding them therethrough in the case of cans, on a mandrel which extends through the coils. If the work is in the form of an elongated tubular body, a mandrel may or may not be employed as desired.

In Figure 5, a single coil L5 is shown equipped with suitable means for forcing the engaging edges of the work into contact at successive

points, said means comprising a bell mouth constricting device of the type as for instance shown in the above mentioned patent to Ries. This bell mouth 78 may be positioned within the single coil L5, or it may be an integral extension of the insulating casing 72 thereof. In any case, the bell mouth will preferably be composed of insulating material.

With this construction, the work is fed through the coil, and the bell mouth progressively urges the engaging edges toward one another, and the construction of the bell mouth is such that opposed points along the edges of the work are pressed into contact with one another substantially at the center of the coil as at 80, the coil being of a type, or wound in such fashion that its maximum field intensity is at the central point 80. The spreader 70 may be employed to keep the edges of the work apart until opposed points of the edges reach the area of maximum field intensity.

It will be evident that the present invention will permit the continuous welding of the engaging edges of work such as metal tubes or cans, and that this continuous welding may be performed at the high speed now used in the manufacture of this type of work. The speed of the work will be such that as each body of work traverses the point of maximum field intensity, and opposed edges thereof are contacted at this point, instantaneous welding will take place at said point, but the portion of the work welded will be moved beyond the point of maximum field intensity and replaced by another portion in contact before any heat is wasted in heating the entire body of metal of the work.

As mentioned before, the light-responsive device P may be replaced by a heat responsive device such as the well known thermo-electric couple, particularly in induction heating when it is desired to maintain the work at such temperatures that it is not luminous. Such condition may be desired, for instance, in the drying of lacquers and the like on cans. Potential differences caused by heat changes of the work reacting in the thermo-couple may be suitably amplified, and applied to one of the early stages of voltage amplification of the present invention, to bring about a change of heat in the work in a manner similar to that discussed in connection with the light-responsive device P.

The apparatus disclosed herein may be considerably modified without departing from the scope of this invention. Particularly, various types of electrical devices and circuits, such as the thermionic tube circuits disclosed, may be employed to carry out the invention. Furthermore, changes in the method described herein may be made while still practicing the invention.

I claim:

1. In an apparatus for inducing heat in work and controlling the application of the same, a plurality of amplifier stages for generating alternating currents of high frequency, each including a thermionic tube circuit, the final amplification stage constituting a power amplifier, a frequency determining oscillator coupled with the first amplifier stage for imposing a desired frequency thereon, a work application circuit coupled with said power amplifier including a coil which receives the high frequency currents from said power amplifier, said coil producing a field in which the work is disposed, a light-responsive device positioned adjacent said coil, a circuit for said device including an amplifier, and

means connecting the circuit of said device with the grid of the thermionic valve of one of said stages of amplification, whereby the voltage applied to the grid of said valve is varied in accordance with the heat induced in the work in the field of said coil.

2. In an apparatus of the character described, a pair of circuits each comprising a power amplifier including a thermionic tube circuit for generating alternating currents of high frequency, a frequency determining oscillator coupled with said power amplifier for imposing a desired frequency thereon and a work application circuit coupled with said power amplifier including a coil which receives the high frequency currents from said power amplifier, the coil of each of said circuits producing a field in which the work is disposed and said coils being located so that their fields augment one another, and means for maintaining the respective high frequency currents in said coils at such a phase angle with respect to one another that work disposed in said fields has induced therein currents having closely following impulse peaks.

3. In an apparatus of the character described, a pair of circuits each comprising a power amplifier including a thermionic tube circuit for generating alternating currents of high frequency, and a work application circuit coupled with said power amplifier including an induction coil which receives the high frequency currents from said power amplifier, the coil of each of said circuits producing a field in which the work is disposed and said coils being located so that their fields augment one another, a common frequency determining oscillator coupled with the power amplifier of each of said circuits for imposing a desired frequency therein, and a phase changer between said frequency determining oscillator and one of said power amplifiers for maintaining the respective high frequency currents in said coils at such a phase angle with respect to one another that work disposed in said fields has induced therein currents having closely following impulse peaks.

4. In apparatus of the character described, a pair of circuits each comprising a power amplifier including a thermionic tube circuit for generating alternating currents of high frequency, a frequency determining oscillator coupled with said power amplifier for imposing a desired frequency thereon, and a work application circuit coupled with said power amplifier including an induction coil which receives the high

frequency currents from said power amplifier, the coil of each of said work application circuits producing a field in which the work is disposed and being located adjacent one another so that their fields augment one another, and means for shifting the area of maximum field intensity of the combined coils by varying the field intensity of one of said coils.

5. In apparatus of the character described, a pair of circuits each comprising a power amplifier including a thermionic tube circuit for generating alternating currents of high frequency, a frequency determining oscillator coupled with said power amplifier for imposing a desired frequency thereon, said frequency determining oscillator of each circuit being adjusted to impose a different frequency on its respective power amplifier, and a work application circuit coupled with said power amplifier including an induction coil which receives the high frequency currents from said power amplifier, the coil of each of said circuits producing a field through which successive bodies of the work are moved, said work application circuits being adapted to be placed in resonance by each body of work as it passes through the field, said coils being located adjacent one another so that their fields augment one another.

6. In an apparatus for successively inducing heat in rapidly moving bodies of work of known reactance, a power amplifier including a vacuum tube circuit for generating alternating currents of high frequency, a frequency determining oscillator comprising an oscillating circuit coupled with said power amplifier for imposing a desired frequency thereon, an oscillating work application circuit coupled with said power amplifier having reactance means including a tuned coil and condenser which receives the high frequency currents from said power amplifier, said coil producing a field through which successive bodies of the work move at high speed, means for tuning the oscillating circuit of said frequency determining oscillator so that said work application circuit is placed in resonance therewith by each body of the work of known reactance as it moves through the field of said coil, said vacuum tube circuit having means to prevent changes of frequency of the oscillating circuit of said frequency determining oscillator as the bodies of work enter and leave the field of said coil.

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