

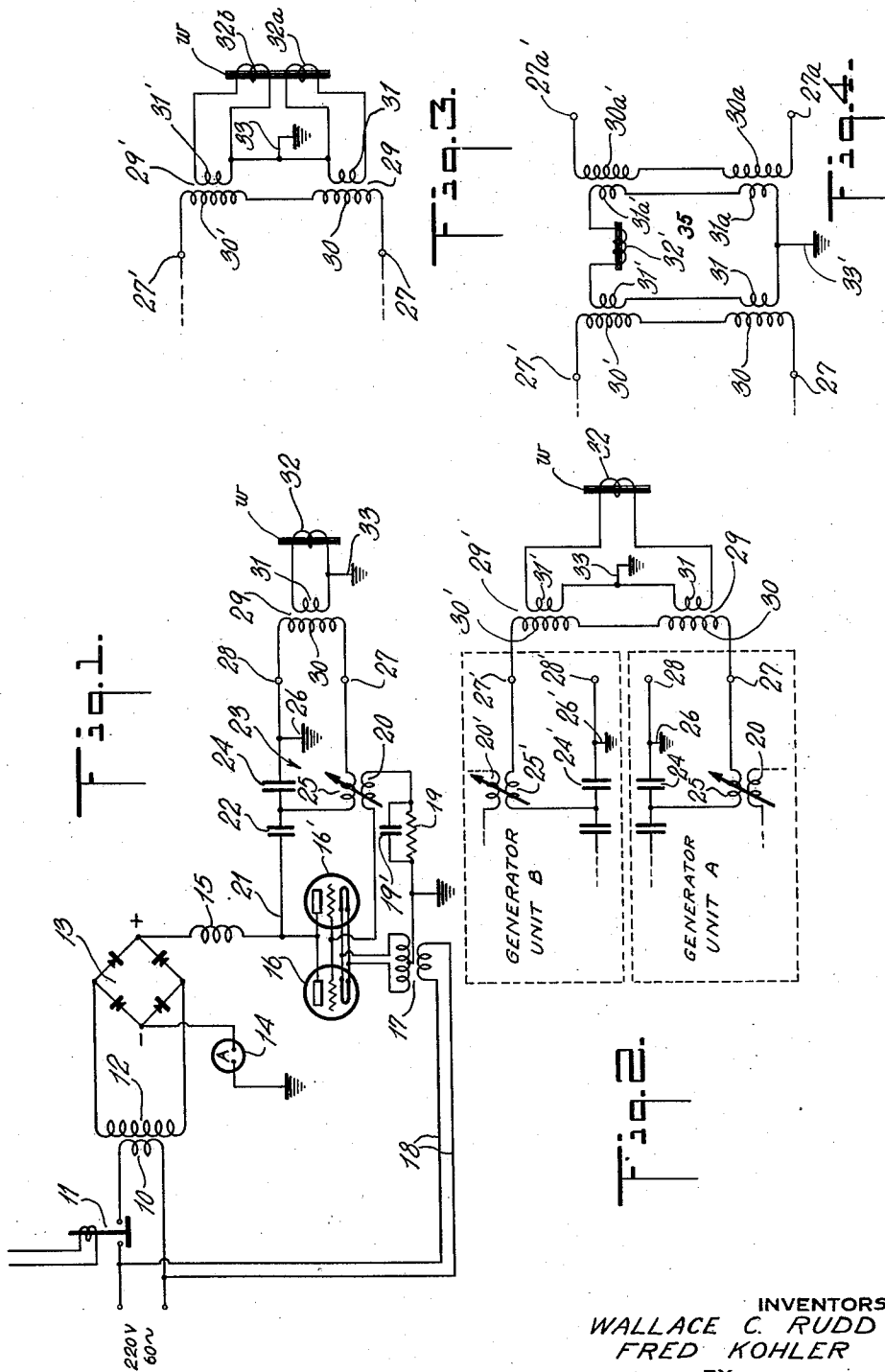
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APPARATUS FOR GENERATING HIGH FREQUENCY CURRENT

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APPARATUS FOR GENERATING HIGH FREQUENCY CURRENT

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This invention relates to apparatus and methods for generating high frequency current for induction heating purposes and the like.

A form of high frequency current generator which has recently come into extensive use for purposes such as inductive heating, comprises a vacuum tube power oscillator connected according to the principles of the Hartley oscillator circuit. That is, an electron discharge device or two or more of such devices connected in parallel, are coupled to a tank circuit to supply increments of energy to such circuit, in accordance with and under the control of the natural frequency of said circuit, thereby maintaining undamped high frequency oscillations therein. Such tank circuit is adapted to include the primary of an output transformer by which the circuit is coupled to a lower voltage work circuit, including a work coil of a small number of turns adapted to carry heavy current for inductive heating purposes and the like. 20 k. w. generator units of this type are now being manufactured on a quantity production basis. Such units including a rectifier and other power supply equipment are mounted in a single portable frame or cabinet, except for the output transformer and work coil circuit and flexible leads therefor. These latter parts are made readily detachable and with flexible connections for convenient use for various types of work, and so that output transformers having various different voltage ratios may be used if desired, depending upon the character of work to be done and the type of heating coil used. Generators of this type are adapted to supply current having a frequency of the order of 400 kilocycles with a peak potential across the leads to the primary of the output transformer of the order of 7000 volts, sufficient power being used for example to produce in the work coil circuit a current of 2000 amperes radio frequency, and with a voltage drop of 300 to 400 across the leads to the work coil.

The heavy currents, high frequencies and high potentials used in the above described equipment, have made it necessary to devote a great deal of time and care to the proper design of the circuits to assure dependable, efficient operation with adequate safety for factory uses. Of course, once this development work has been accomplished for the manufacture of a standard generator of a certain rated capacity, duplicate equipment of the same capacity may be manufactured on a quantity production basis at relatively low cost, and factory workers may be trained to efficiently and safely use such a stand-

ardized machine. However, if increased heating is desired in the work coil, beyond what is obtainable with such a standard generator, it has heretofore been considered necessary to substantially wholly redesign the circuits and equipment, to meet the special requirements of any such greater loads. Although the heat generated in the work coil might be nearly doubled for example by using twice as many oscillator tubes connected in parallel, yet this would involve radical changes in the design of the oscillating circuits and the necessary cooling facilities therefor, to provide for the heavier currents, and these changes in turn would involve still further changes and difficulties due to the consequent alteration in the natural frequency of the circuits. If on the other hand instead of obtaining the increased power by using more tubes in parallel, the tube circuits were redesigned to supply the oscillating currents at higher potentials, the precautions necessary to insure dependable safe factory use of the equipment would become impractical, or involve special design work and special training of the factory workers for each job.

The present invention provides a method and means whereby two or more standardized high frequency generators such as above described, may be operated conjointly so as to effectively add together in one or more work coils, the high frequency magnetic fields made available from the individual generators. The present invention affords means whereby generators of the above indicated types may all be used separately in cases where no more power is required than the rated capacity of a single generator, and yet if at any time, for example, twice as much heat is required in a single work coil, this may be accomplished without any internal changes whatever in the generator units, by merely rearranging the external connections so as to operate two of the generators conjointly and with their high frequency currents in proper cooperative phase relationship.

Due to the fact that the generator units embody separate oscillators with separate independent power supplies, and generally at least some difference in their operating frequencies, it has heretofore been considered impossible or impractical to connect two of such generators for such conjoint operation because of the assumed difficulty of starting and maintaining the generators in proper phase relationship and the possible difficulty and trouble of designing and substituting a new oscillating circuit of suitable frequency and capable of carrying a greatly increased cur-

rent from the two or more generators. However, according to the present invention the component parts and connections of the tank circuits of the generators as used independently, may be so combined when the generators are used conjointly, that the work coil heating effect is doubled, but none of the high potentials on any of the parts is increased with respect to ground potential, the necessary current carrying capacity of none of the high voltage oscillating circuit parts is increased, and the frequency remains about the same or of the same order. Hence no new insulation or safety precautions are necessary, no additional or different equipment is necessary, nor is any additional training required of the workmen who used the equipment.

Various further and more specific objects, features and advantages of the invention will clearly appear from the detailed description given below taken in connection with the accompanying drawing which forms a part of this specification and illustrates by way of example certain preferred forms of the invention. The invention consists in such novel combinations of features, and methods, as may be shown and described in connection with the apparatus herein disclosed.

In the drawing:

Fig. 1 is a schematic diagram illustrating the circuit connections of a single high frequency generator unit such as above referred to, and adapted for use with the invention;

Fig. 2 is a diagram of connections according to the present invention, whereby two of such generator units may be operated conjointly; and

Figs. 3 and 4 are diagrams illustrating alternative embodiments of such connections.

As shown in Fig. 1, the primary 10 of a step-up transformer is connected to a suitable source of power, for example, at 220 volts, 60 cycles, such connection being made through a remotely controlled electromagnetic starting switch as at 11. The terminals of the secondary 12 of the step-up transformer may be connected to the input terminals of a bridge rectifier 13. This rectifier may for example be made up of four mercury vapor rectifiers connected in a well-known way as shown. The negative output terminal of this rectifier as shown may be connected to ground through an ammeter 14, while the positive output terminal is connected through a high frequency choke coil 15 to the plates of a pair of vacuum tube power oscillators as at 16, 16' connected in parallel. The cathodes of these oscillator tubes connected in parallel, as shown, may be maintained in heated condition by current supplied through a transformer 17, the primary of which is supplied with current through connections 18 going back to the original alternating power source. The mid point on the secondary of the transformer 17 may be grounded as shown and connected in series with the oscillator grid-cathode circuit, through a grid resistance 19 and accompanying condenser 19' and tickler coil 20.

A connection 21 runs from the plates of the oscillator tubes through a direct current blocking condenser 22 to a tank circuit 23, which may comprise a tank condenser 24, and an inductance 25 adapted to be variably coupled to the tickler coil 20. As shown, one side of the condenser 24 may be grounded as at 26, the tank circuit running from the other side of such condenser through inductance 25 to a terminal 27 for the generator

unit, the other terminal 28 of which is grounded or may comprise the ground connection.

The equipment of Fig. 1 as thus far described is adapted to be assembled in a portable cabinet or frame which may be moved from place to place where it is desired to be used, whereupon the primary 30 of a desired output transformer 29 is connected to the terminals 27, 28, thereby completing the tank circuit. The secondary 31 of the transformer 29 is adapted to be connected in series with a work coil 32 comprising one, two or more turns encircling or placed adjacent to the work *w* which is to be heated. For safety purposes, one side of the work coil circuit is preferably grounded as at 33.

The circuit of Fig. 1 is designed to operate as follows. Rectified current at a potential for example of 9000 volts average, is supplied from rectifier 13 to the plate-cathode circuit of the power oscillator tubes, through the choke coil 15 and the return circuit through ground from the cathodes. Flow of direct current to the tank circuit is blocked by condenser 22. But upon operation of the starting switch 11, a high potential charge will be applied to the tank circuit 23 through condenser 22, thus initiating damped oscillations in that circuit, of a frequency in accord with the natural frequency of the circuit including whatever output impedance 30 has been selected at the time for connection to the generator. Since the tank circuit is coupled to the tickler coil 20, these damped high frequency oscillations will act to control the grid potential and vary such potential at a frequency in accordance with the natural frequency of the tank circuit and thereby act to vary the increments of energy supplied through connection 21 at the same natural frequency of the tank circuit. Thereafter so long as the source of power is connected, these increments of energy will serve to maintain powerful undamped high frequency oscillations in the tank circuit. The frequency at which the power is supplied to the work circuit may of course be varied within considerable limits by using output transformers of different designs, without requiring any changes in the internal parts of the generator cabinet, since the primaries of such transformers will be connected in the tank circuit, and since the natural frequency of the completed tank circuit controls the frequency of the power being supplied. The frequencies of the standardized generators made in this way, may of course also differ somewhat due to minor constructional differences and the positioning of the flexible output connections. Also output transformers of various ratios may of course be selected to obtain various desired voltage drops across the work coil.

In cases where the amount of heat supplied by the work coil has to be increased up to amounts twice as great as obtainable with the arrangement of Fig. 1, then two of the generator units may be connected for conjoint operation according to the invention in the manner shown in Fig. 2. In this figure, generator unit A is shown having internally of the cabinet, the same portions of a tank circuit as used in Fig. 1. Generator unit B is shown as having internally, portions of a tank circuit which may be the same as corresponding portions of generator unit A, or preferably at least the size or ratings of these elements in unit B are of the same order as corresponding elements in unit A. The corresponding elements of the two generator units are identified in Fig. 2 by the same reference num-

bers which are accompanied by prime marks in the case of unit B.

With the arrangement of Fig. 2, it is noted that the primaries 30, 30' of two output transformers are connected in series across the ungrounded output terminals 27, 27' of the two generators. The other output terminals 28, 28' being both grounded, a high frequency circuit is now provided, composed of the elements of the tank circuits of both generator units, all connected in series and with the primaries of two of the output transformers 29 also connected in series. The primaries 30, 30' are connected into opposite sides of the circuit, i. e., at points which will normally be on opposite sides of a neutral point, the neutral point being determined by the position in the circuit of the ground connections 26, 26'.

In this composite tank circuit the condensers 24, 24' being in series, the effective capacity of the circuit will be substantially one-half that of the capacity of the tank circuit in Fig. 1, assuming that condensers 24, 24' are of about equal capacities. And since the coils 25, 25', 30, 30' are also all in series, the effective inductance of the circuit will be substantially twice that of the tank circuit of Fig. 1, assuming coils 25, 25' are about alike and that transformers 29, 29' are about alike. Hence the natural frequency of this composite tank circuit will remain substantially the same as the tank circuit of Fig. 1. Accordingly, the composite circuit will involve no essential or necessary change in frequency as compared with the tank circuits of the generators as used independently. Since with an oscillator of the type shown in Fig. 1, the natural frequency of the tank circuit determines the frequency at which the vacuum tubes operate, it will be apparent that in the same way the natural frequency of the composite tank circuit of Fig. 2 will serve to determine and control the frequency at which the vacuum tube circuits will operate in both unit A and unit B. In starting the operation of the composite circuit the starting switches for the two generators may be closed either concurrently or at different times if desired. In either case the two generators will immediately start working together and contribute currents which will be in proper phase relationship to cooperate as applied to the opposite sides of the composite tank circuit.

While the total potential drop across the two primary coils 30, 30' in Fig. 2 will be of an order of magnitude which is double that of the generator terminals of Fig. 1, yet the current at any point in the circuit of these coils will be of the same order of magnitude as when the generators are used independently and thus no problem is presented of providing for increased currents in the high voltage oscillating circuits with the connections of Fig. 2. Neither will the potential with respect to ground of any of the parts in Fig. 2 be increased as compared with the connections of Fig. 1, and hence no extra safety precautions need be taken in thus connecting the two generators together, especially since the terminals 27, 27' and connections thereto will be normally widely separated.

With the arrangement of Fig. 2, the two secondaries 31, 31' of the output transformers may be connected in series with the work coil 32 and preferably with a ground connection 33 between the two secondaries. Assuming that the two generators of Fig. 2 are both like that of Fig. 1 as above described, then the voltage drop

across the work coil in Fig. 2 will be substantially double that in Fig. 1, or say 600-800 volts. Hence the work coil heating effect will be substantially doubled as compared with that obtainable in a like work coil in Fig. 1.

In some cases instead of using a heavy heating current in a single work coil, it is desirable to use a pair of work coils which may be more or less separated as desired to cover a more extensive work area. In that case it has been found that more efficient heating may be accomplished if the high frequency currents in such pair of work coils are in synchronism. Fig. 3 shows a pair of work coil circuits with work coils 32a and 32b arranged for this purpose and coupled to a composite oscillating circuit for a pair of generator units, the same as in Fig. 2. In Fig. 3 each of the two work coil circuits may operate in substantially the same way as the work coil circuit of Fig. 1, but the arrangement of Fig. 3 for coupling the two work circuits to a single oscillating circuit so that the work currents will be in synchronism, makes for much more efficient heating than would be the case if the two work coils were supplied with current by wholly independent generators which could not be maintained in synchronism.

While it may be assumed that in most cases the generator units which are to be operated conjointly as per Figs. 2 and 3, will be of like or substantially like construction and normally operate independently at about the same frequency, this is not essential as it has been found possible to obtain equally satisfactory results even though the generators used when operating separately may deliver currents at frequencies which are considerably different. For example, in a typical case, one of the generators may have a frequency in the neighborhood 380 kilocycles and another a frequency above 400 kilocycles, and yet when these two generators are connected with the composite tank circuit, they will readily cooperate at a satisfactory intermediate frequency.

Fig. 4 shows a circuit arrangement whereby four of the generators of the type above referred to may be operated in conjunction with each other, to give a heating effect in a work coil 32' substantially four times greater than obtainable with a single generator as of Fig. 1. In substance the arrangement of Fig. 4 comprises two pairs of generators with the oscillating circuits of each pair connected in series, and with all four generators associated by a single series work coil circuit 35. That is, the ungrounded terminals 27, 27' of two generators are connected in series with two output transformer primaries 30, 30'. Similarly, the output terminals 27a and 27a' of another pair of generators are connected in series with primaries 30a, 30a' of another pair of output transformers. The secondaries 31, 31', 31a, 31a' of these transformers are all connected in series with the work coil 32', a ground connection 33' being applied on the side of the secondary circuit opposite from the work coil.

With this arrangement one terminal of the work coil 32' will be positive while the other terminal is negative, and vice versa, and it will be found that the two pairs of generators will operate in proper phase relationship so that the high frequency currents from all four will cooperate. In this case the composite oscillating circuit including the primaries 30, 30' should preferably have a natural frequency rather close to that of the circuit of primaries 30a, 30a' in order that the generators will not only keep in step, but also

so that the load will be substantially evenly distributed among the four units. By following the same principles as of Fig. 4, it will be apparent that additional pairs of the generator units may be connected to cooperate with a single work coil circuit.

While the invention has been described in detail with respect to certain preferred examples, it will be understood by those skilled in the art after understanding the invention that various changes and modifications may be made without departing from the spirit and scope of the invention, and it is intended therefore in the appended claims to cover all such changes and modifications.

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

1. In combination, a high frequency power generating assembly comprising a portion of a tank circuit including inductance and capacity elements connected in series with output terminals of the generator assembly, whereby such terminals may be connected with the primary of a work circuit transformer to complete the circuit for operation of the generating assembly, such generator assembly further comprising an electron discharge device, a high voltage source of power and connections therefor to said device, and coupling means between said circuit portion and said device, constructed and arranged to supply increments of power to said circuit at a frequency controlled by and in accordance with the natural frequency of the circuit when completed, another similar generator assembly as above specified including an independently connected high voltage source of power, means for connecting said generator units for conjoint and cooperative supply of high frequency current, comprising inductance means for forming a coupling with an inductive heating work circuit or circuits, means for grounding one of said terminals of each generator assembly, said latter inductance means being connected between the ungrounded generator terminals, said oscillatory circuit portions of the two generators and said latter inductance means being thereby connected in series to form a single oscillatory circuit having a natural frequency which controls the frequency of both generator units as conjointly used.

2. Inductive heating apparatus comprising a work coil, two impedance elements in a series circuit therewith, the circuit being grounded at a

point with respect to which the terminals of the work coil are substantially symmetrically positioned, a tank circuit grounded at one point and coupled at each side of a neutral point to said impedance elements respectively, and two vacuum tube power oscillators respectively having plate circuits so coupled to said tank circuit at opposite sides of its grounded point as to supply currents in cooperative phase relationship thereto at the natural frequency of the tank circuit.

3. In combination a pair of high frequency generator units adapted to be each used independently to supply currents of frequencies which are of the same order of magnitude, each of said units comprising a portion of an oscillatory circuit including capacity and inductance elements in series, one end of said circuit portion having a ground connection and the other forming an output terminal for the unit whereby said ends may be connected to an output impedance coupling device to complete the circuit, each of said units also including a vacuum tube power oscillator so coupled to the circuit portion of the unit as to supply current thereto of a frequency in accordance with and under the control of the natural frequency of the circuit when completed, and output impedance means connected between the said terminals of the two units, thereby forming an oscillating circuit including all said elements and having its opposite sides respectively supplied by said oscillators with currents in cooperative phase relationship.

4. Inductive heating apparatus comprising a work coil, an even number of impedance elements in a series circuit therewith, such circuit being grounded at a point with respect to which said elements and also the terminals of the work coil are substantially symmetrically arranged, a plurality of oscillating circuits each coupled respectively to at least one of said elements and each having the same or nearly the same natural frequency, each of said oscillating circuits being grounded at one point, a plurality of pairs of independently energized vacuum tube power oscillators, the oscillators of each of said pairs respectively being so coupled to opposite sides of the grounded point of one of the oscillating circuits as to supply currents in cooperative phase relationship thereto and all at the same frequency.

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