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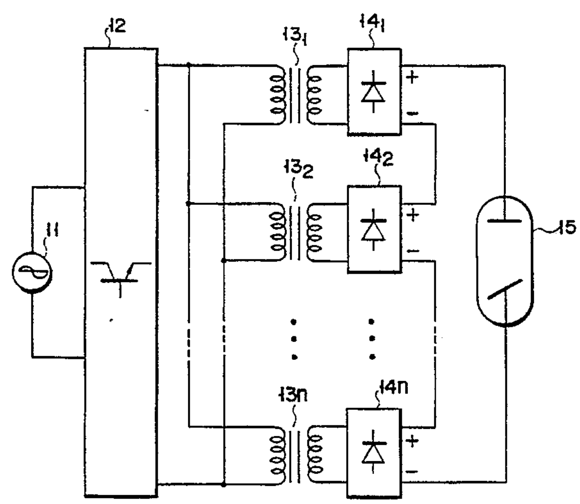
(54) X-ray generator apparatus.

(57) An output voltage of an A.C. power source (11) is input to an frequency converter (12) and the frequency thereof is increased. A plurality of high voltage transformers (13_1, 13_2, ... 13_n) of small capacity each of which has a secondary winding of a small number of turns and which are connected in parallel with one another are connected to an output terminal of the frequency converter (12). Outputs of the high voltage transformers (13_1, 13_2, ... 13_n) are respectively connected to high voltage rectifier circuits (14_1, 14_2, ... 14_n). Outputs of the high voltage rectifier circuits (14_1, 14_2, ... 14_n) are serially coupled, the output voltages thereof are added together, and the addition result is applied to an X-ray tube (15). Combinations of the high voltage transformers (13_1, 13_2, ... 13_n) and the high voltage rectifier circuits (14_1, 14_2, ... 14_n) are molded into units one or a preset number at a time with solid insulating material including gel insulating material.



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X-RAY GENERATOR APPARATUS

The present invention relates to an X-ray generator apparatus having an X-ray tube which generates X-rays when applied with a high voltage obtained by increasing an input A.C. voltage by means of a step-up transformer or the like and rectifying the increased voltage.

An example of this type of conventional X-ray generator apparatus is shown in Fig. 1. In order to enhance the performance and make the device small and lightweight, a frequency converter 2 for converting the frequency of a voltage supplied from an input power source (A.C. power source) is connected to the primary side of a high voltage transformer 3. An output voltage of the frequency converter 2 is increased by the high voltage transformer 3 and an output voltage of the high voltage transformer 3 is rectified by a high voltage rectifier 4. A rectified output of the high voltage rectifier 4 is applied between the anode and cathode of an X-ray tube 5 serving as an X-ray source.

The frequency converter 2 is generally formed of a rectifier for converting an input A.C. voltage to a D.C. voltage, a capacitor for filtering the D.C. voltage, and an inverter for converting the D.C. voltage from the capacitor to an A.C. voltage of a desired frequency. The frequency converter 2 converts the frequency fo (which is a commercial frequency and is generally 50/60 Hz) of the input A.C. voltage to a frequency f1 which is higher than the frequency fo and then applies the voltage to the high voltage transformer 3. As the output frequency f1 of the frequency converter 2 is set to be higher, the size and weight of the frequency converter 2 and high voltage transformer 3 can be reduced. Since the impedances of coils and capacitors generally vary according to the frequency, the capacitance and inductance can be reduced as the frequency is set higher if the impedances are kept unchanged. Since the capacitance and inductance vary in proportion to the size of the capacitor and coil, the size and weight of the frequency converter 2 and high voltage transformer 3 using the coil and capacitor can be reduced as the frequency becomes higher.

However, in the above X-ray generator apparatus, the output frequency f1 of the frequency converter 2 cannot be increased limitlessly and the upper limit thereof is determined by the characteristic of the high voltage transformer 3 for the following reason. Fig. 2 shows an equivalent circuit of the device shown in Fig. 1 in view of the secondary portion of the transformer 3. In Fig. 2, L1, L2 and M respectively denote the primary inductance, secondary inductance and mutual inductance of the high voltage transformer 3. N denotes the turn ratio (the number of turns of the secondary windings/the number of turns of the primary windings) of the transformer 3. In this case, in order to obtain a high output voltage, the high voltage transformer 3 is so designed that the number of turns of the secondary winding is set to be very larger than that of the primary winding, and thus the secondary inductance L2 is very larger than the primary inductance L1 and mutual inductance M. Therefore, the inductance of the secondary portion of the high voltage transformer 3 which is actually equal to (L2 - M) as shown in Fig. 2 can be regarded as being equal to the secondary inductance L2 by neglecting M, and in the following explanation, it is assumed that the inductance of the secondary portion is equal to L2. Further, assuming that the equivalent impedance of a the X-ray tube 5 is Rx and the terminal voltage of the X-ray tube 5 is Ex and the rectifier 4 is omitted from being consideration since it does not relate to the terminal voltage Ex, then the secondary inductance L2 is serially connected to the impedance Rx. If the output frequency of the frequency converter 2 is f1, an impedance Z2 due to the secondary impedance L2 can be expressed by the following equation and it is understood that it varies in proportion to the output frequency f1 of the frequency converter 2:

$$Z2 = 2\pi \cdot f1 \cdot L2 \quad (1)$$

Further, the voltage Ex applied to the X-ray tube 5 is expressed as follows:

$$Ex = E2 \cdot Rx / (Rx + Z2) \quad (2)$$

Since the turn ratio N is very large and thus the inductance $(L1 - M)/N^2$ can be neglected, a terminal voltage E2 of the mutual inductance M is expressed as follows using an output voltage E1 of the frequency converter 2:

$$E2 = E1 \cdot N \quad (3)$$

As is clearly understood from the equations (1) and (2), the impedance Z2 becomes higher as the output frequency f1 of the frequency converter 2 becomes higher, causing a problem that the voltage Ex applied to the X-ray tube 5 is lowered. For this reason, the output frequency f1 of the conventional frequency converter 2 has an upper limit of approximately 10 KHz and a higher frequency exceeding the upper limit cannot be attained. If the frequency is set to approximately 10 KHz, it is difficult to greatly reduce the size and weight of the transformer and rectifier circuit and noise may be generated from the transformer 3. The reason why the output frequency f1 of the frequency converter 2 can be increased only to approximately 10 KHz at most is that the secondary inductance L2 of the high voltage transformer 3 is very large.

In order to solve the above problem, it has been proposed to modify the primary portion of the high voltage transformer 3 as shown in Figs. 3 and 4. In the circuit of Fig. 3, a capacitor C1 is serially connected to the primary winding of the high voltage transformer 3 to attain a series resonance operation on the primary portion. In the circuit of Fig. 4, a capacitor C2 is connected in parallel with the primary winding of the high voltage transformer 3 to attain a parallel resonance operation on the primary portion. However, in either circuit, a voltage on the primary portion of the high voltage transformer 3 is equivalently increased by the series resonance or parallel resonance operation. The inductance L1 of the primary portion is originally small and the resonance voltage is low, and therefore, in order to obtain the same voltage applied to X-ray tube 5 as that obtained in a case wherein no resonance circuit is connected, it is only possible to increase the output frequency of the frequency converter 2 to two or three times the output frequency set in a case wherein no resonance circuit is connected.

Further, in United State Patent No. 4,545,005 (Mudde), the secondary winding of the high voltage transformer is divided into a plurality of sub-windings to increase the frequency of the high voltage transformer, the sub-windings are connected to rectifier circuits are serially coupled and applied to an X-ray tube. However, the high voltage transformer is not divided and the high voltage transformer can be regarded as being a single transformer, and an output of one frequency converter is simply connected to a single high voltage transformer. Therefore, like the conventional case shown in Fig. 1, it is only possible to increase the frequency to approximately 10 KHz at most.

Further, in United State Patent No. 4,317,039 (Romandi), plural frequency converters and plural high voltage transformers are used, but in this conventional case, the object thereof is to reduce ripples and the object is attained by setting the phases of the plural frequency converters different from one another. Therefore, this reference does not aim to increase the frequency of the transformer and discloses that the frequency lies in the medium frequency range and amounts to approximately six to seven KHz.

An object of the present invention is to provide an X-ray generator apparatus in which the frequency of a voltage from an A.C. power source is increased by a frequency converter, then the voltage is increased by means of a transformer, and the increased voltage is rectified by means of a rectifier and applied to an X-ray tube, and in which the output frequency of the frequency converter is increased and the size and weight of the transformer and rectifier are reduced.

An X-ray generator apparatus according to the present invention comprises frequency converter means connected to an A.C. power source, for increasing the frequency of an A.C. voltage; plural transformer means connected to an output of the frequency converter means, for increasing the output A.C. voltage from the frequency converter means; and rectifier means for converting the output A.C. voltages from the plural transformer means to D.C. voltages, serially adding all of the D.C. voltages, and applying the result of addition of the D.C. voltages to an X-ray tube.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a block diagram of an example of the conventional X-ray generator apparatus;

Fig. 2 is an equivalent circuit diagram of the device shown in Fig. 1;

Fig. 3 is a diagram showing another example of the conventional device;

Fig. 4 is a diagram showing still another example of the conventional device;

Fig. 5 is a block diagram of a first embodiment of an X-ray generator apparatus according to the present invention;

Figs. 6A and 6B are equivalent circuits of a portion ranging from the secondary winding of a high voltage transformer to the X-ray tube in the conventional device of Fig. 1 and the first embodiment;

Fig. 7 is a diagram showing the characteristic of the first embodiment;

Fig. 8 is a diagram showing a first modification of the first embodiment;

Fig. 9 is a diagram showing a second modification of the first embodiment;

Fig. 10 is a diagram showing a third modification of the first embodiment;

Fig. 11 is a block diagram of a second embodiment of an X-ray generator apparatus according to the present invention;

Fig. 12 is an equivalent circuit of a portion ranging from the secondary winding of each high voltage transformer to the X-ray tube in the second embodiment; and

Fig. 13 is a diagram showing the characteristic of the second embodiment.

There will now be described an embodiment of an X-ray generator apparatus according to the present invention with reference to the accompanying drawings. Fig. 5 is a block diagram showing the construction of a first embodiment. An A.C. power source 11 serving as an input power source is connected to the input terminal of an frequency converter 12. The frequency converter 12 increases the frequency of an A.C. voltage supplied from the A.C. power source 11. High voltage transformers 13_1, 13_2, ... 13_n are connected in parallel with one another between output terminals of the frequency converter 12. That is, one end of the primary winding of each of the high voltage transformers 13_1, 13_2, ... 13_n is connected to one of the output terminals of the frequency converter 12 and the other end of the primary winding of each of the high voltage transformers 13_1, 13_2, ... 13_n is connected to the other output terminal of the frequency converter 12. The secondary windings of the high voltage transformers 13_1, 13_2, ... 13_n are respectively connected to high voltage rectifiers 14_1, 14_2, ... 14_n. The output terminals of the high voltage rectifiers 14_1, 14_2, ... 14_n are serially connected and the result of serial addition obtained by the series connection is applied to an X-ray tube 15. That is, the positive output terminals of the high voltage rectifiers 14_1 is connected to the anode of the X-ray tube 15, the negative output terminals of the high voltage rectifiers 14_1, 14_2, ... 14_{n-1} are connected to the positive output terminals of the high voltage rectifiers 14_2, 14_3, ... 14_n, and the negative output terminal of the high voltage rectifier 14_n is connected to the cathode of the X-ray tube 15.

In this case, the number of turns of each of the primary windings of the high voltage transformers 13_1, 13_2, ... 13_n is set to be equal to that of the primary winding of the conventional high voltage transformer 3 shown in Fig. 1 and the number of turns of each of the secondary windings of the high voltage transformers 13_1, 13_2, ... 13_n is set to 1/n of that of the secondary winding of the conventional high voltage transformer 3 in order to simplify the description.

Next, the operation of this embodiment is explained. Fig. 6A is an equivalent circuit diagram of a secondary portion (a portion from the secondary winding to the X-ray tube with the rectifier being neglected) of the conventional transformer 3 of Fig. 1. Fig. 6B is also the equivalent circuit diagram of the secondary portions of the transformers 13_1, 13_2, ... 13_n of the first embodiment shown in Fig. 5. In general, the number of turns of the secondary winding of each of the high voltage transformers 3, 13_1, 13_2, ... 13_n is extremely larger than that of the primary winding thereof, and the secondary inductance L2 is set to a large value. Therefore, the equivalent circuit diagrams can be expressed only by the secondary inductance L2 as shown in Figs. 6A and 6B. The frequency converter is generally on/off operated by the switching pulse and outputs a pulse signal. Therefore, the voltage E2 is also expressed by a pulse.

If, in Fig. 6A, $L2 / Rx = \tau a$, then the voltage Ex applied to the X-ray tube 5 is expressed by using the time constant τa as follows and rises as shown by a curve A in Fig. 7. The reference time t = 0 with respect to time t in Fig. 7 is a timing at which the voltage E2 starts to rise.

$Ex = E2 (1 - e^{-t/\tau a})$ (4)

That is, if it is assumed that the pulse width of the voltage E2 is τa, the tube voltage Ex is set to a maximum value (0.63 E2) at the time of $t = \tau a$.

On the other hand, in the device of this embodiment shown in Fig. 5, the number of turns of the secondary winding of each of the high voltage transformers 13_1, 13_2, ... 13_n is set to 1/n of that of the high voltage transformer 3 in the conventional device (Fig. 1). Since the inductance of a coil varies in proportion to the square of the number of turns, the secondary inductance becomes $L2/n^2$ and the secondary voltage becomes E2/n in each of the high voltage transformers 13_1, 13_2, ... 13_n. Further, the load of each of the high voltage transformers 13_1, 13_2, ... 13_n is substantially the same as a value obtained by dividing the load Rx in the conventional device by n, that is, it becomes Rx/n. As a result, the equivalent circuit diagram of the embodiment of Fig. 5 can be expressed as shown in Fig. 6A.

In secondary portion of each of the high voltage transformers 13_1, 13_2, ... 13_n, the time constant τb is expressed as follows according to the above description with reference to Fig. 6A:

$\tau b = (L2 / n^2) / (Rx / n)$
$= (L2 / Rx) / n$
$= \tau a / n$ (5)

A voltage E3 applied to the load Rx/n is expressed as follows:

$E3 = E2 (1 - e^{-t/\tau b}) / n$ (6)

The voltage Ex applied to the X-ray tube 15 is given as follows by serially adding the terminal voltages E3 of the loads:

$Ex = n \cdot E3$
$= E2 (1 - e^{-t/\tau b})$ (7)

That is, as shown by a curve B in Fig. 7, at the time of $t = \tau b$, the tube voltage Ex is set to 0.63 E2 which has been reached at the time of $t = \tau a$ in the conventional device. In this case, since $\tau b = \tau a/n$ as shown by the equation (5), the time constant in the device of this embodiment (Fig. 5) is set to 1/n of that of the conventional device (Fig. 1), and therefore, it is understood that the frequency of the transformers 13_1, 13_2, ... 13_n can be increased by n times since the same voltage is obtained if the pulse width of the output of the frequency converter 12 is set to τb.

the conventional high voltage transformer shown in Fig. 6A, even if the switching pulse width of the frequency converter 2 is simply changed from τa to 1/n times (= τb) to increase the frequency, the peak value of the tube voltage Ex expressed by the equation (4) becomes smaller as shown by a curve C in Fig. 7 and the application power simply becomes small as indicated by a hatched portion.

As described above, according to the first embodiment, the high voltage transformer is divided into a plurality (for example, n) of transformers 13_1, 13_2, ... 13_n having a small capacity (the number of turns of the primary winding is kept unchanged and the number of turns of the secondary winding is reduced to 1/n times the original value), the primary windings of the divided transformers 13_1, 13_2, ... 13_n are connected in parallel with one another between the output terminals of the frequency converter 12 and a voltage obtained by serially adding together the rectification results of the outputs of the respective transformers is applied to the X-ray tube 15. Thus, the secondary inductance of each of the transformers 13_1, 13_2, ... 13_n can be reduced to $1/n^2$ times the original value, and as a result, the upper limit of the output frequency of the frequency converter 12 is increased by n times. Therefore, the apparatus including the frequency converter 12 can be made small and lightweight. Since the output frequency of the frequency converter 12 can be increased up to approximately 100 KHz or to a frequency which exceeds the audio frequency, generation of noise which is a problem in the conventional device can be prevented. Further, since the output control of the frequency converter 12 can be effected at a higher speed as the output frequency thereof increases, a high voltage applied to the X-ray tube 15 can be more precisely set by using the feedback operation. Further, since high voltage wave ripples become smaller as the frequency becomes higher, a flat high voltage wave can be obtained. In addition, the rising characteristic of the tube voltage can be improved as shown by the curve B of Fig. 7, it becomes easy to apply a high voltage in a pulse form to the X-ray tube 15 and generate X-rays only at necessary timings, thereby making it possible to reduoe the amount of X-ray radiation to an object. It is preferable to form the cores of the high voltage transformers 13_1 13_2, ... 13_n by using ferrite or the like which has a good frequency characteristic in order to attain the high operation frequency. Further, it is also possible to serially connect the outputs of the high voltage transformers 13_1, 13_2, ... 13_n instead of connecting the transformers 13_1, 13_2, ... 13_n to the respective rectifiers 14_1, 14_2, ... 14_n and rectify the serially coupled voltages by means of a single rectifier. In addition, it is possible to connect resonant capacitors in series or in parallel on the primary portion of each of the high voltage transformers 13_1, 13_2, ... 13_n. The frequency converter can change the output voltage in addition to the output frequency by means of a pulse width modulation (PWM) for changing the pulse width of the switching pulse.

Next, modifications relating to the improvement of the first embodiment are explained. In the conventional X-ray generator apparatus, the high voltage transformer and high voltage rectifier are disposed in a container filled with insulating oil. Since the container is substantially entirely filled with insulating oil, the volume and weight thereof become very large. In this case, the maintenance therefor is troublesome and there occurs a problem that oil leaks out of the container and stains the surrounding. In the first embodiment, since the transformer is divided into a plurality of transformers of small capacities the high voltage transformer and high voltage rectifier are disposed in a container of small capacity and can be molded into one unit with solid insulation material including gel insulating material. Injection type insulating material such as epoxy and material such as silicone gel which is solidified but has a physical property between those of the fluid and solid can be given as examples of the above insulating material. Since silicone gel has a good high frequency characteristic, it can be preferably used as the insulating material for the device constructed to attain a high frequency. Each molding unit may be constructed by a single transformer 13_1 and a single rectifier 14_1 as shown in Fig. 8 or by a plurality of transformers 13_1 to 13_i and a plurality of rectifiers 14_1 and 14_i as shown in Fig. 9. Further, as shown in Fig. 10, only the secondary winding of the transformer 13_1 and the rectifier 14_1 are molded and it is not always necessary to mold the primary winding of the transformer. Although not shown in the drawing, the high voltage transformer and the rectifier may be separately molded and they are connected by connectors or cables. Thus, various combinations of the molds can be selectively made.

Unlike the conventional device in which a large-high voltage transformer and rectifier are disposed in one container, use of the above molded units makes it unnecessary to fill insulating oil into an unnecessary space, so that a small and lightweight X-ray generator apparatus can be realized which can be easily assembled by combining the units and in which replacement can be effected for each molded unit to attain easy maintenance. Further, since the dielectric breakdown voltage of solid insulating material is higher than that of insulating oil, a high insulation efficiency can be attained and the size and weight can be easily reduced. The small and lightweight X-ray generator apparatus requires only a small installation space in a hospital or the like and can be easily transported.

Next, a second embodiment is explained. Fig. 11 is a block diagram of the second embodiment. Portions which are the same as those of the first embodiment are denoted by the same reference numerals and the detail description thereof is omitted. In the first embodiment, only one frequency converter 12 is provided, but in the second embodiment an frequency converter is also divided into n frequency converters like a transformer. Inverters 12_1, 12_2 ... 12_n which are connected in parallel with one another are connected to the A.C. power source 11. Outputs of the frequency converters 12_1, 12_2, ... 12_n are supplied to rectifiers 14_1, 14_2, ... 14_n via high voltage transformers 13_1 13_2, ... 13_n. Capacitors C_R are respectively connected in series with the secondary windings of the high voltage transformers 13_1, 13_2, ... 13_n to constitute series resonant circuits on the secondary portion of the transformers.

Also, in this embodiment, the same effect as that of the first embodiment can be obtained. Further, in a case where a part of the frequency converters 12_1, 12_2, ... 12_n is set into the rest or nonoperative state outputs of those of the high voltage transformers 13_1, 13_2, ... 13_n which are connected to the remaining frequency converters are bypassed the high voltage transformers which are connected to the frequency converters set in the rest state and applied to the X-ray tube 15. Therefore, the tube voltage can be roughly controlled by controlling the number of frequency converters which are set in the rest state. Moreover, if the frequency converters are PWM-controlled, the tube voltage can be precisely controlled.

Further, according to the second embodiment, since a number of frequency converters are used, even if a part of the frequency converters becomes defective, the defective frequency converters are set into the rest state and other frequency converters which are otherwise set in the rest or nonoperative state can be used instead of the defective frequency converters. Therefore, it becomes possible to prevent the whole X-ray generator apparatus from being set into the inoperative state. The maximum output is lowered by an amount corresponding to the number of defective frequency converters, but it is seldom to use the maximum output and the device can be used without receiving practical interference while the defective frequency converter is being replaced.

The resonance capacitor C_R is connected to the secondary winding of each of the high voltage transformers 13_1, 13_2, ... 13_n to cause an LC series resonance so as to prevent the voltage applied to the X-ray tube 15 from being lowered and to further increase the frequency of the frequency converters.

Next, the characteristic of the second embodiment is explained. An equivalent circuit of the secondary portion of one of the high voltage transformers 13 is shown in Fig. 12. Since the frequency converter 12 effects a switching operation for the rectangular wave, the secondary voltage E2 takes a rectangular waveform in the first embodiment shown in Fig. 6A, but takes substantially a sine waveform in the second embodiment in which the secondary portion is set in the resonant condition. Assuming that the frequency of the sine wave is f and $\omega = 2\pi f$, and if the capacitance of the capacitor C_R is so determined as to set up the condition of $\omega L2 = 1/\omega C_R$ at the frequency f according to the general theory of series resonance, then the impedance on the secondary portion becomes only Rx. Therefore, even if the frequency f is set at a high frequency, influence of the secondary inductance L2 to the tube voltage Ex can be neglected as shown in Fig. 12. However, voltages across L2 and C_R in Fig. 12 have inverted phases and cancel each other but $E_L = E2 \cdot \omega L2 / Rx$ and $Ec = E2 / (\omega C_R \cdot Rx)$ are obtained, and in general, they becomes relatively larger than E2. Therefore, in the conventional device shown in Fig. 6A, resonance cannot be attained on the secondary portion when the dielectric voltage of the transformer and capacitor and the insulating measure are taken into consideration.

However, in the present invention, since the high voltage transformer is divided into n portions, E2 and L2 in the respective resonant circuits can be reduced to $E2/n$ and $L2/n^2$ as shown in Fig. 6B as in the first embodiment. In particular, L2 varies inversely with the square of the dividing number n, it becomes extremely small. In this way, since the voltages E_L and E_C across L2 and C_R can be suppressed to small values, the advantage of the resonance on the secondary portion of the transformer can be effectively used.

As described above, in a case where only the high voltage transformer is divided as in the first embodiment, the secondary inductance L2 becomes smaller, making it possible to attain a high frequency operation. However, in a case where the resonance circuit is formed on the secondary portion of the transformer as in the second embodiment, influence by the secondary inductance L2 can be completely neglected, making it possible to attain a higher frequency operation. Alternatively, in a case where the device is operated at the same frequency as that obtained where no resonance circuit is formed on the secondary portion, the dividing number can be reduced within the permissibie range of the breakdown voltage of the transformer and the capacitor. Since the primary voltage becomes a sine wave due to the resonance circuit in the secondary portion, it is possible to turn on or turn off switching transistors in the frequency converters at the time of the current does not flow therethrough. Therefore, the heat radiation of the apparatus can be suppressed, thereby increasing the efficiency of the apparatus. The secondary resonance is not limited to the series resonance described above but may be a parallel resonance attained by connecting a capacitor in parallel with the secondary winding of the high voltage transformer.

Fig. 13 shows the characteristic of the voltage applied to the X-ray tube 15 obtained when the secondary portion is set in the resonant mode. In Fig. 13, solid lines indicate Ex, and curves A and B among them respectively indicate the case of the conventional device and the case wherein the transformer is divided into n portions like the curves A and B of Fig. 7, and a curve D indicates a characteristic obtained when the high voltage transformer of the second embodiment is divided and the secondary portion is set in the resonant mode.

According to the second embodiment, the raising characteristic of the curves A and B which is suppressed by the secondary inductance of the transformer is improved by means of the resonance as indicated by the curve D. Therefore, a higher frequency operation can be attained, and the voltage applied to the X-ray tube can be further increased. Fig. 13, fr indicates the resonant frequency. Further, broken line curves indicate the voltages obtained by multiplying the terminal voltages E_L and E_C of the secondary inductance L2 and the capacitor C_R with the dividing number n.

As described above, the operation frequency can be further enhanced and the dividing number can be reduced by use of the secondary resonance in comparison with a case wherein the high voltage transformer is simply divided.

Further, the modifications explained with reference to the first embodiment can also be applied in the second embodiment, and like the first embodiment, the transformers and rectifiers can be selectively molded into respective units with solid insulation material. It is not necessary to respectively connect the transformers to the frequency converters. It is possible to connect several transformers to a single frequency converter.

As described above, according to the X-ray generator apparatus of the present invention, the output frequency of the frequency converter can be increased by dividing the transformer for increasing an output A.C. voltage of the frequency converter which increases the frequency of an A.C. voltage into a plurality of transformers of small capacity in which the number of turns of the secondary winding is smaller than that of the original transformer, adding outputs of the transformers together, and applying the result of addition to the X-ray tube. As a result, the apparatus can be made small and lightweight, the control speed of the voltage can be enhanced if the frequency is increased, and the output voltage can be precisely controlled by feeding back the output. Further, the assembling and maintenance can be simplified by molding the divided transformers and the rectifiers into respective units with solid insulating material (including gel insulating material). In addition, ripple components included in the output voltage can be easily suppressed and stabilized by the high frequency operation and the X-rays can be easily generated in a pulse form. When the frequency is increased, the frequency of the switching pulse .of the frequency so that noise can be prevented from being generated. Further, if a plurality of transformers are respectively connected to a plurality of frequency converters, each frequency converter can be easily and independently controlled so that the precision of generation of the X-rays can be enhanced, and even if one or some frequency converters become defective, the apparatus can be continuously operated by using the remaining frequency converters. The frequency can be further increased by connecting the capacitor to the secondary winding of the transformer to form an LC resonance circuit and effect the resonance operation.

Claims

1. An X-ray generator apparatus connected to an A.C. power source and for applying a D.C. voltage to an X-ray tube, comprising:
frequency converting means (12) connected to said A.C. power source, for receiving an A.C. voltage from said A.C. power source and increasing the frequency of an input A.C. voltage;
transformer means (13) connected to said frequency converting means, for receiving an output voltage of said frequency converting means and increasing the input voltage; and
rectifier means (14) for rectifying an output of said transformer means and applying a D.C. voltage to said X-ray tube, and characterized in that
said transformer means comprises a plurality of transformer means (13_1, 13_2, ... 13_n) connected in parallel to an output of said frequency converting means (12), for receiving an output voltage of said frequency converting means (12) and increasing the input voltage; and
rectifier means (14_1 14_2, ... 14_n) rectifies the outputs of said plurality of transformer means (13_1, 13_2, ... 13_n) and applying a D.C. voltage corresponding to the sum of the outputs of said transformer means to said X-ray tube.

2. An apparatus according to claim 1, characterized in that
said frequency converting means comprises a plurality of frequency converting means (12_1, 12_2, ... 12_n) connected in parallel to said A.C. power source, for receiving an A.C. voltage from said A.C. power source and increasing the frequency of an input A.C. voltage; and

said plurality of transformer means (13_1, 13_2 ... 13_n) are connected to outputs of said plurality of frequency converting means (12_1, 12_2, ... 12_n).

3. An apparatus according to claim 1 or 2, characterized in that said rectifier means includes a plurality of rectifiers (14_1, 14_2, ... 14_n) respectively connected to output terminals of said plurality of transformer means (13_1 13_2 ... 13_n).

4. An apparatus according to claim 1, 2, or 3, characterized in that said plurality of transformer means respectively include resonance circuits (C_R).

5. An apparatus according to claim 4, characterized in that each of said resonance circuits (C_R) is connected to a secondary winding of a corresponding one of said transformer means.

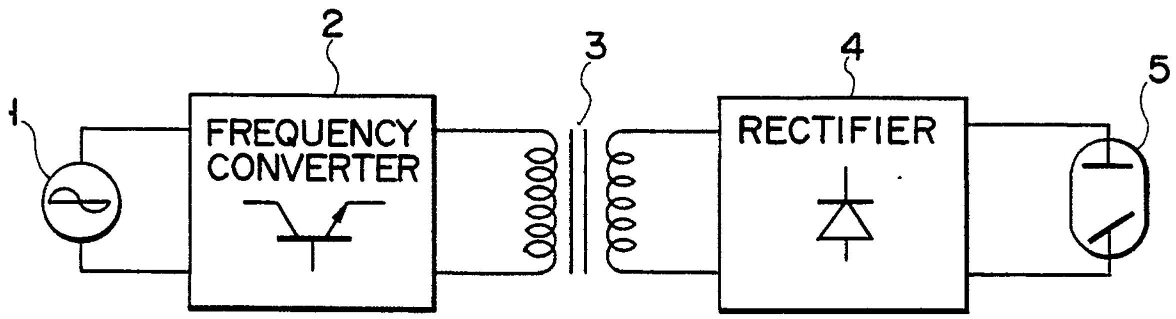
6. An apparatus according to claim 1 or 2, characterized in that at least secondary windings of said plurality of transformer means and said rectifier means are molded with solid or gel insulating material.

7. An apparatus according to claim 3, characterized in that combinations of at least secondary windings of said plurality of transformer means and said plurality of rectifiers are molded one or a preset number at a time with solid or gel insulating material.

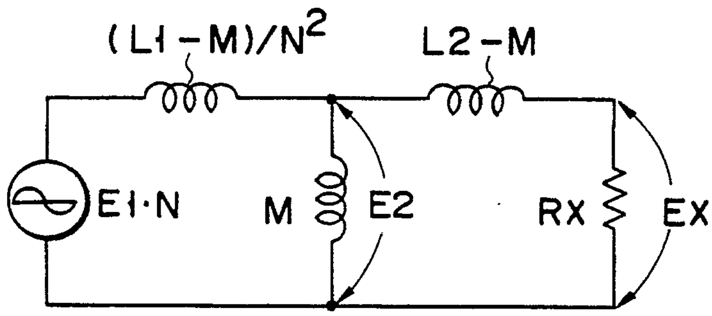
8. An apparatus according to claim 1 or 2, characterized in that each of said plurality of transformer means includes a primary winding, secondary winding and cores on which the primary and secondary windings are wound, and said cores are formed of ferrite.

9. An apparatus according to claim 1 or 2, characterized in that said frequency converting means includes means for controlling a pulse width or pulse interval of switching pulses applied to a switching transistor included in the frequency converting means in order to control the output voltage of the frequency converting means.

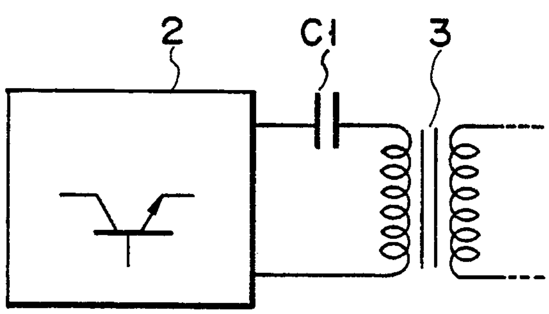
10. An apparatus according to claim 2, characterized in that said plurality of transformer means are respectively connected to said plurality of frequency converting means.



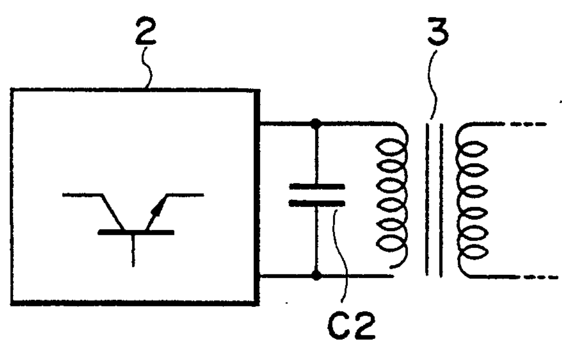
F I G. 1



F I G. 2



F I G. 3



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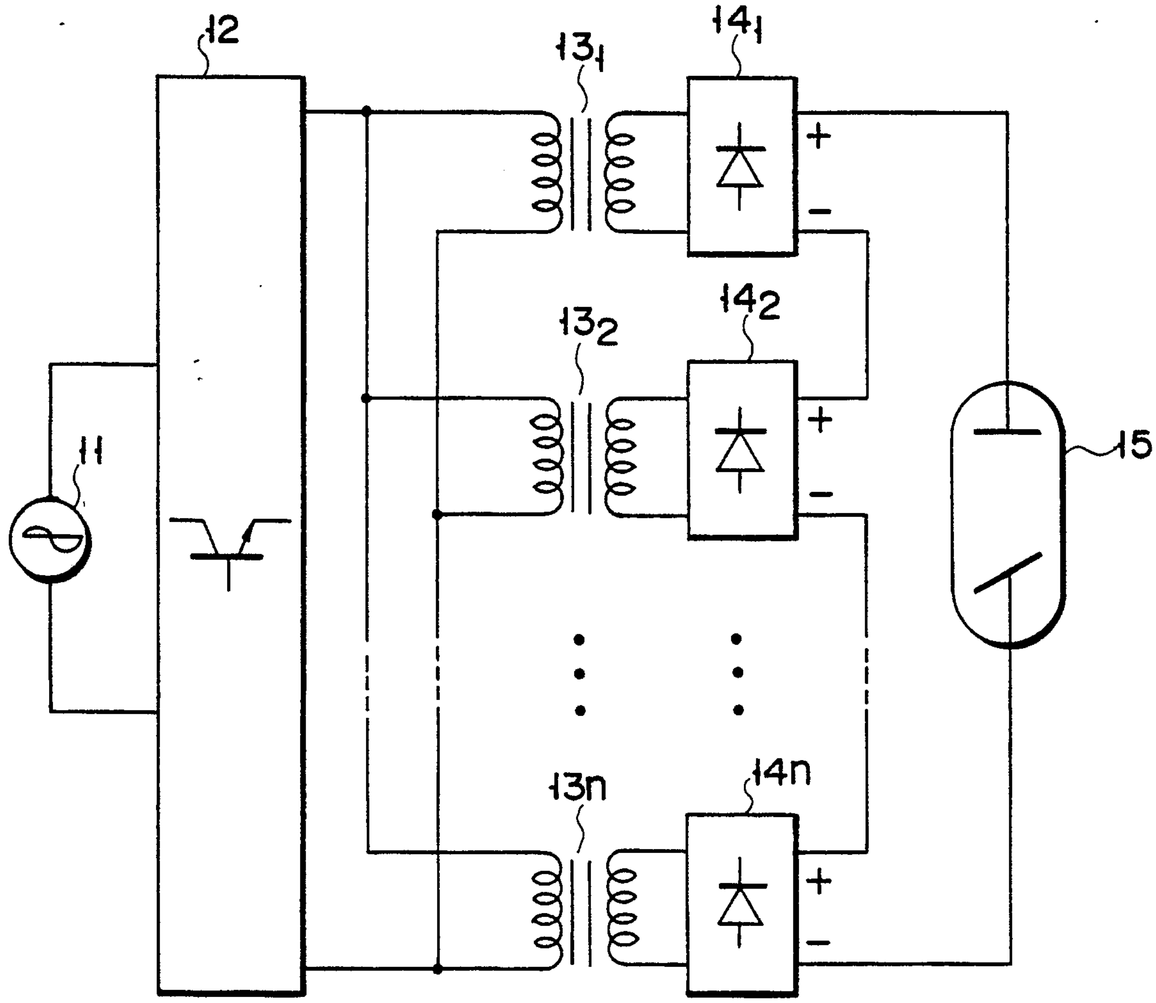


FIG. 5

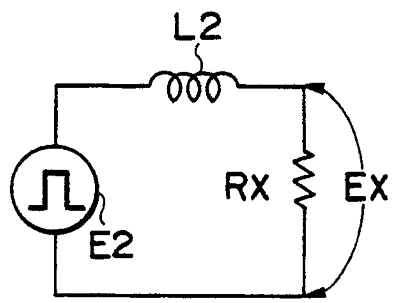


FIG. 6A

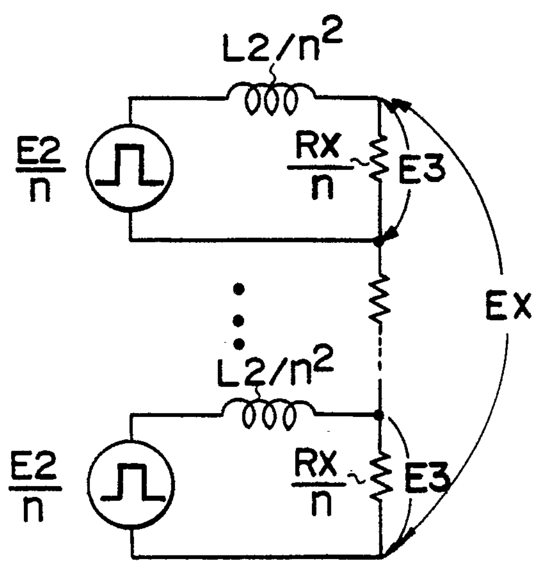
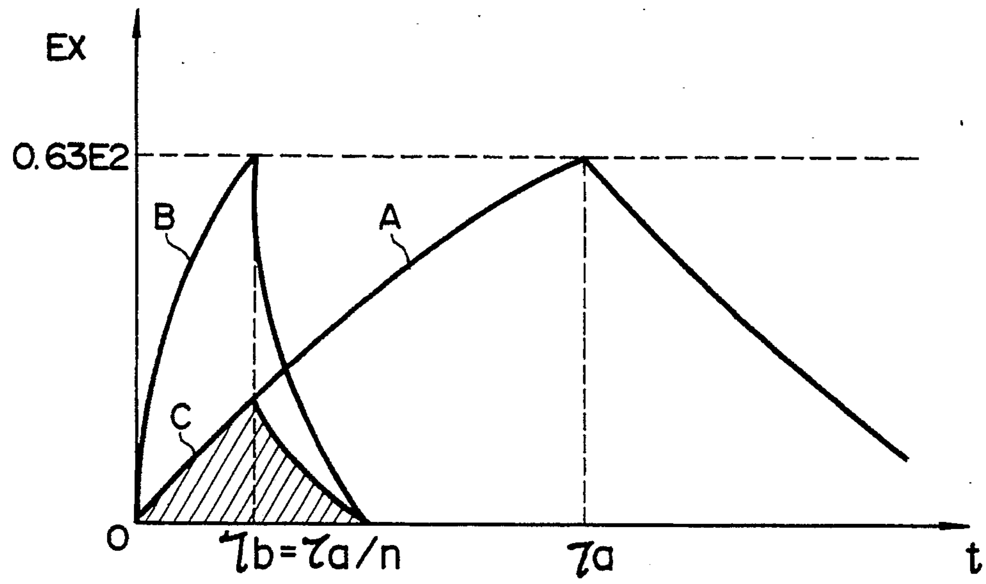
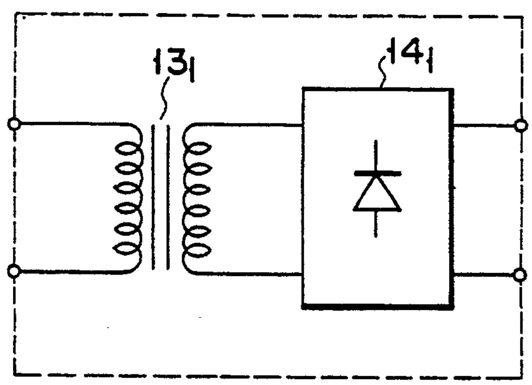


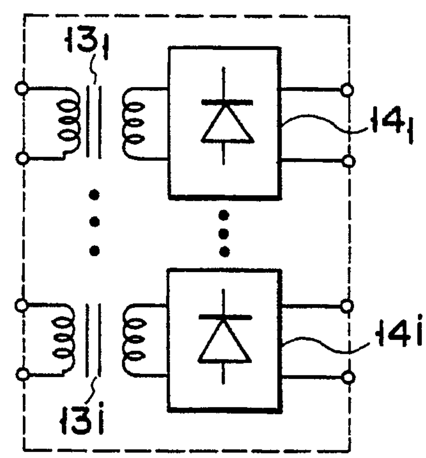
FIG. 6B



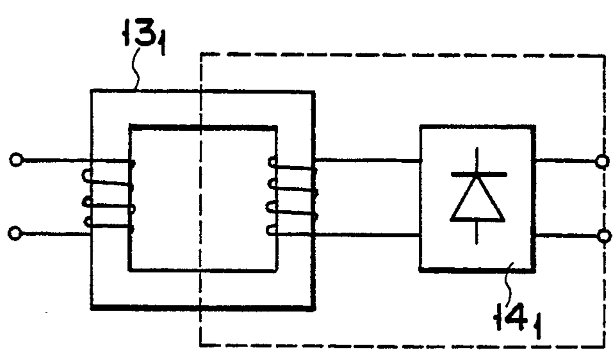
F I G. 7



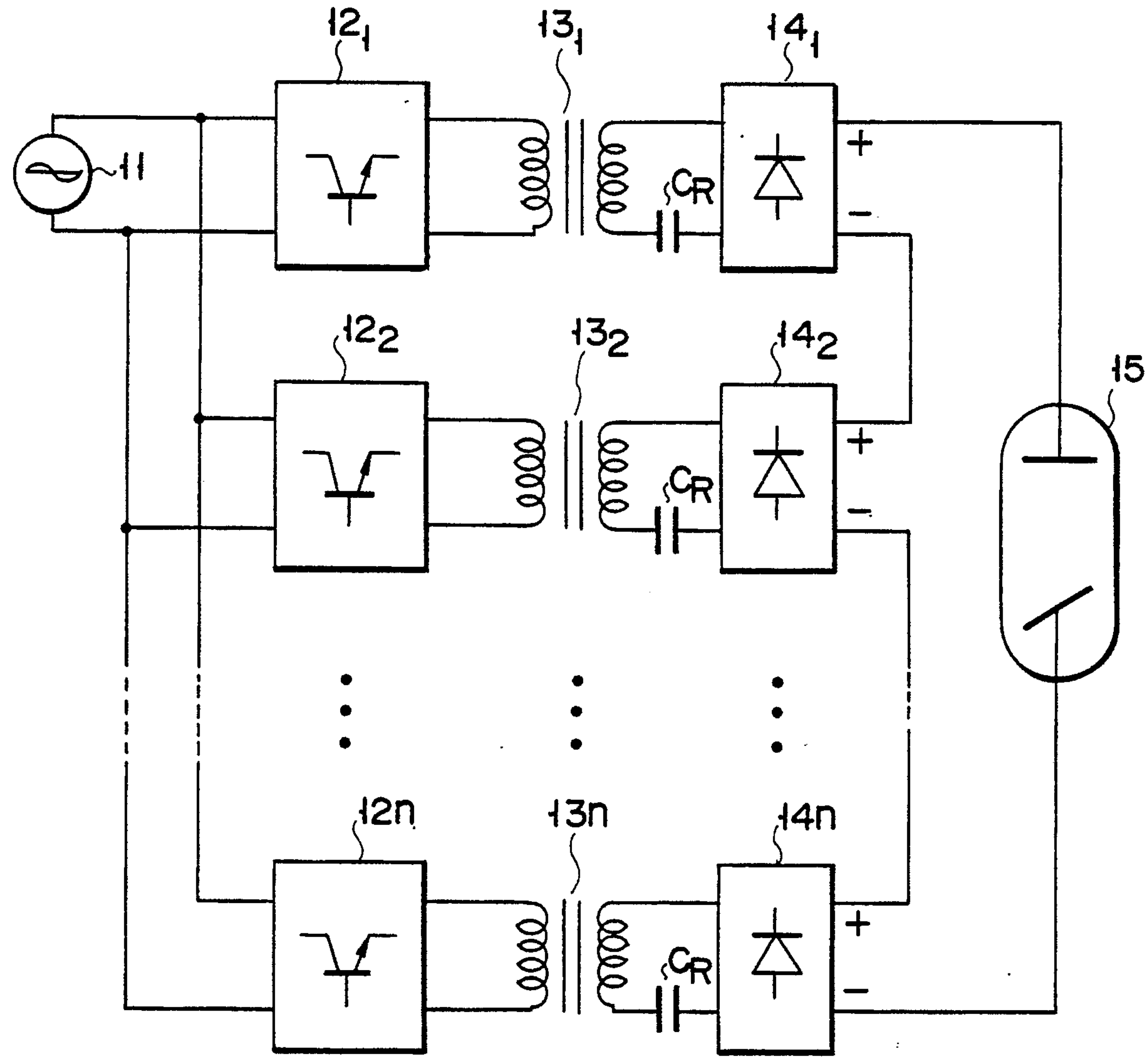
F I G. 8



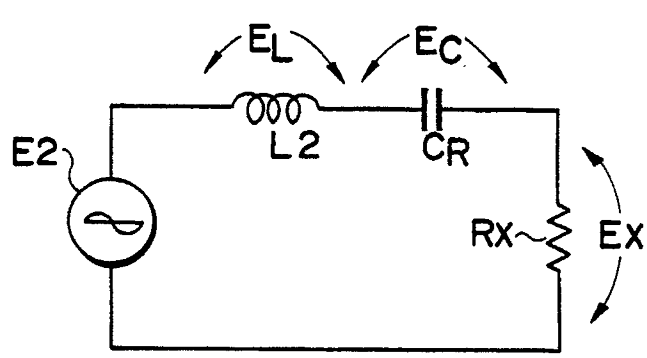
F I G. 9



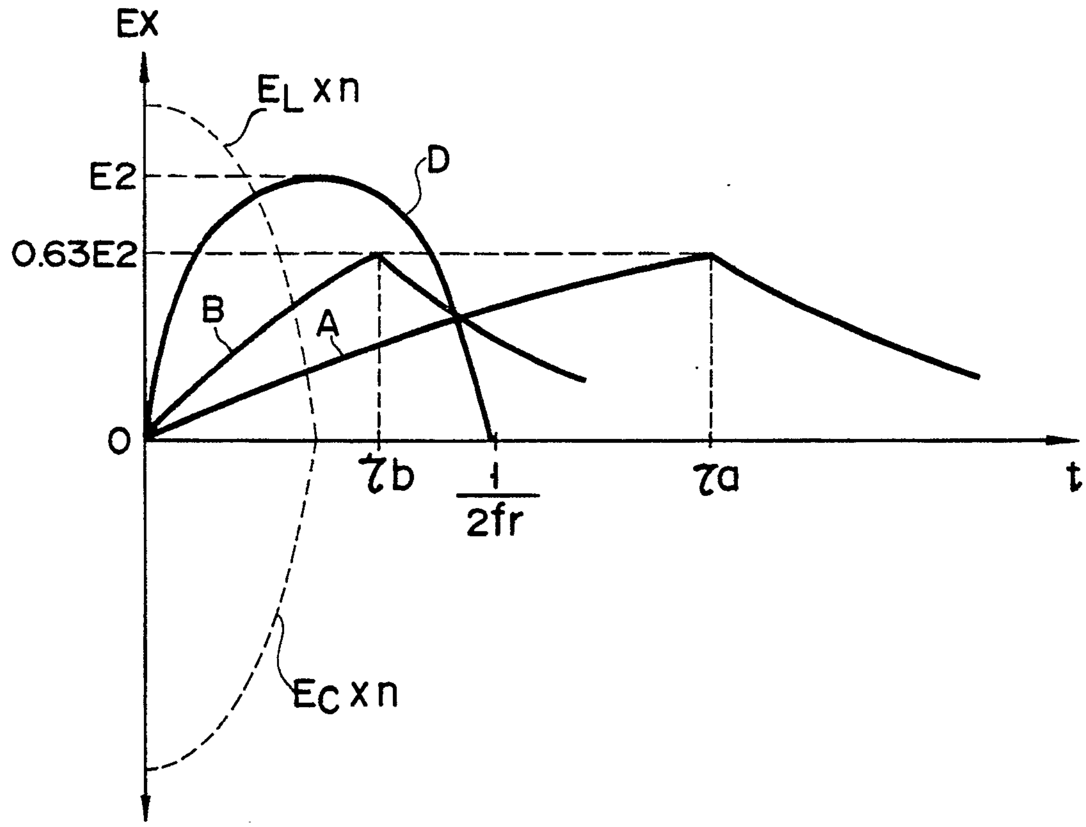
F I G. 10



F I G. 11



F I G. 12



F I G. 13