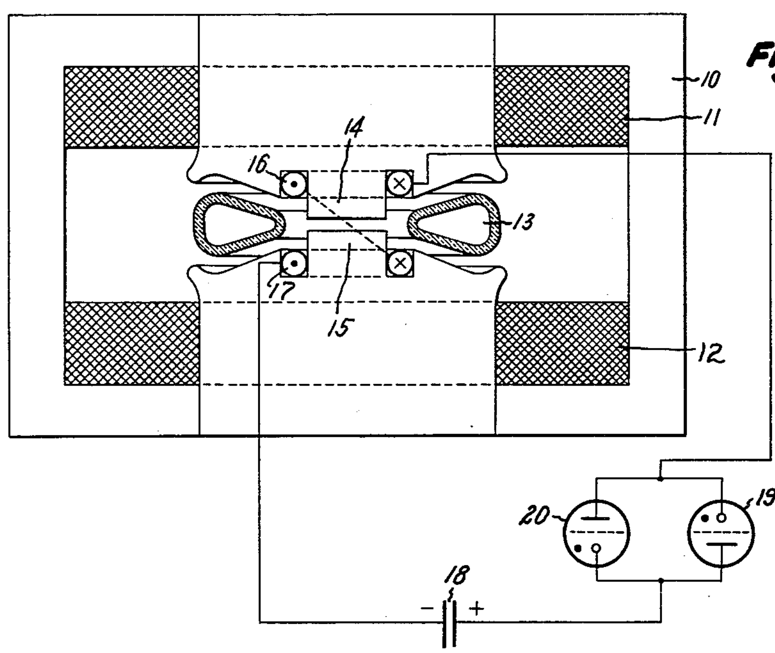

Fig. 1.

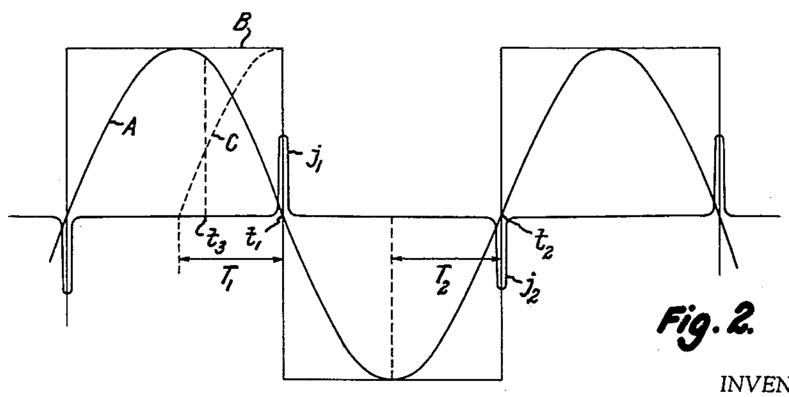

Fig. 2.

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July 10, 1956 R. WIDERÖE 2,754,419

MAGNETIC INDUCTION ACCELERATOR

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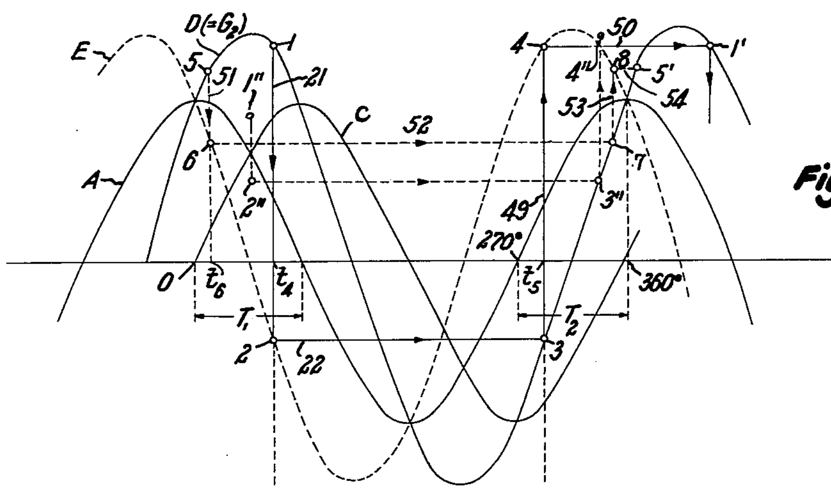

Fig. 3.

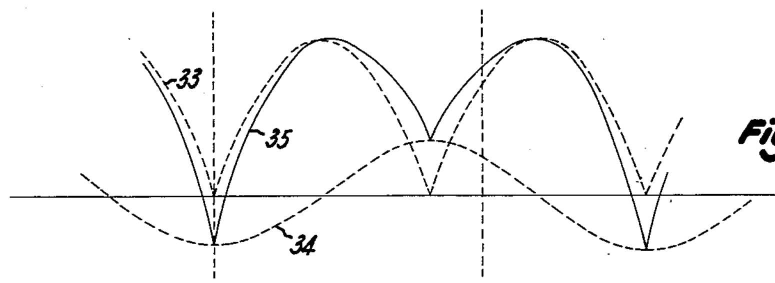

Fig. 5.

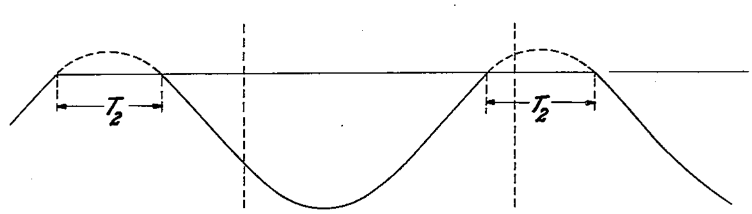

Fig. 6.

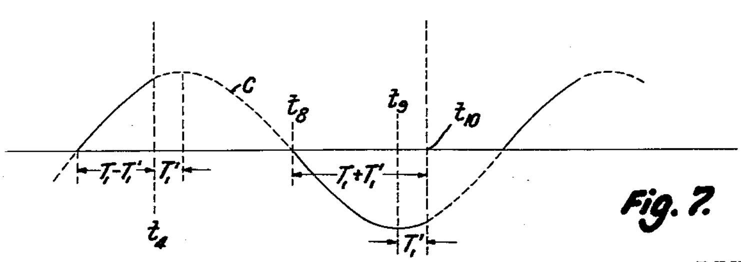

Fig. 7.

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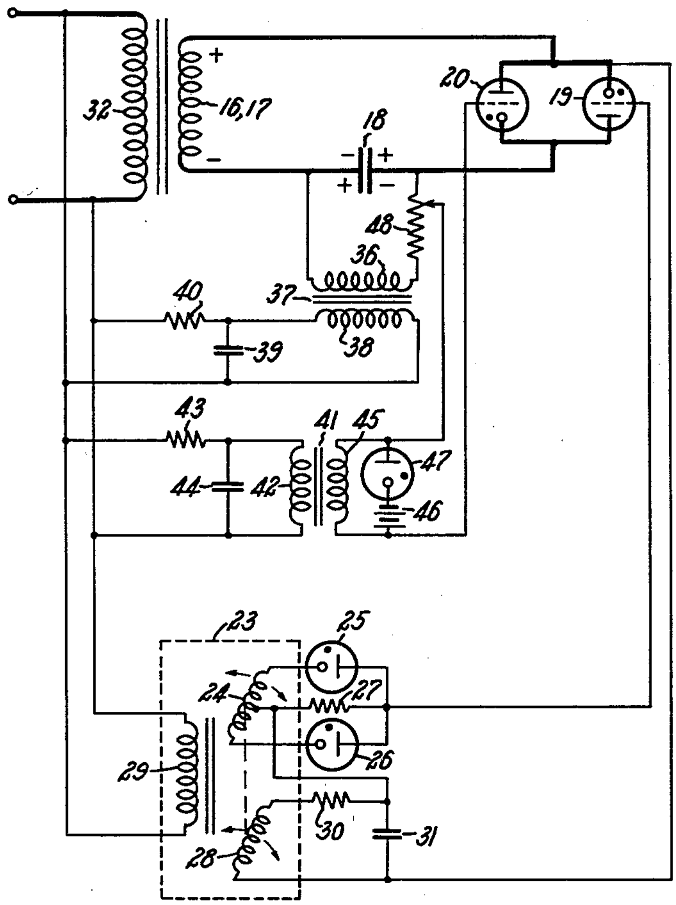

Fig. 4.

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MAGNETIC INDUCTION ACCELERATOR

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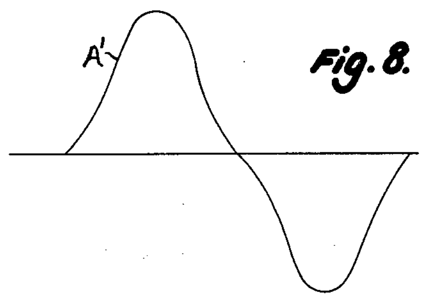

Fig. 8.

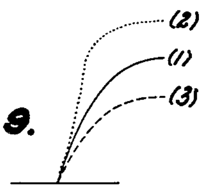

Fig. 9.

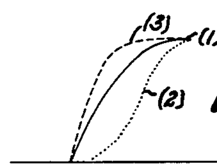

Fig. 10.

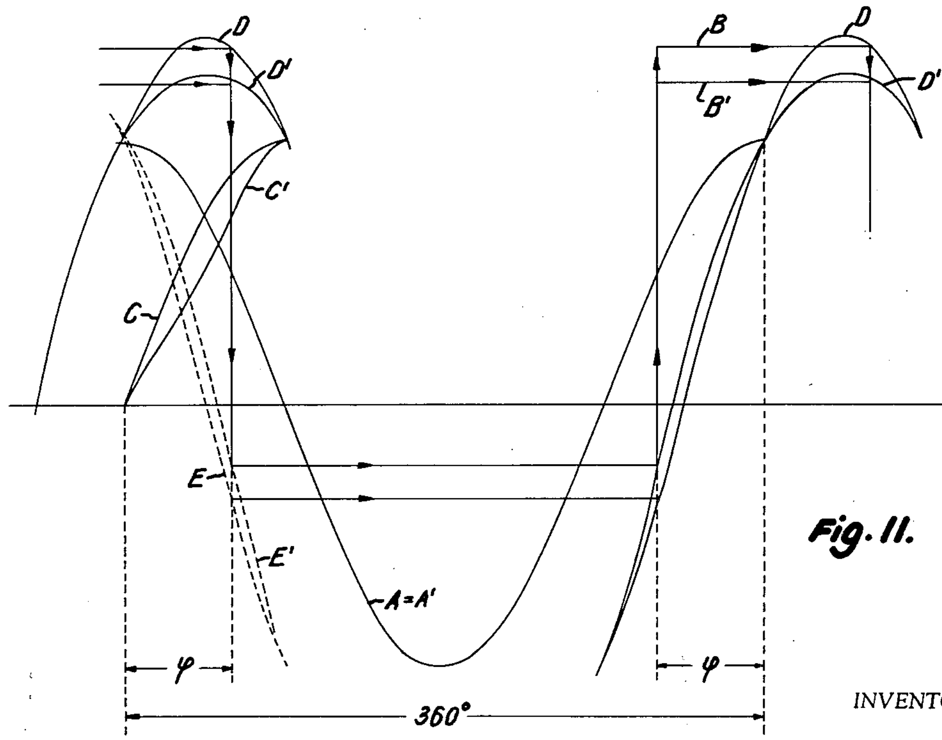

Fig. 11.

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MAGNETIC INDUCTION ACCELERATOR

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Application June 27, 1952, Serial No. 295,852

Claims priority, application Switzerland June 29, 1951

6 Claims. (Cl. 250—27)

The present invention relates to apparatus for imparting high energy to charged particles such as electrons by repeated acceleration to such particles. The particular apparatus referred to is known as a ray transformer or magnetic induction accelerator.

In a magnetic induction accelerator or so-called ray transformator, that is, a device in which the electrons are accelerated in the eddy current field of a magnetic flux up to a velocity or ultimate electron voltage of millions of electron volts, so-called expansion or contraction coils are used for deflecting the electron stream out of the equilibrium orbit. These coils are subjected to the main accelerating flux of the magnetic induction accelerator.

In the type of magnetic induction accelerator to which the present invention pertains, one stream of electrons is shot into an annular tube for acceleration in one direction around the tube at the beginning of the first half-cycle of the main accelerating flux which varies in a generally sinusoidal manner, and a second stream of electrons is shot into the tube for acceleration in the opposite direction around the tube when the main accelerating flux reaches its maximum amplitude in the next half-cycle. The first stream of electrons is ejected from its orbit after a predetermined acceleration and so also is the second stream. The present invention relates to an improved arrangement for ejecting the two electron streams, there being a single capacitor used for the control of the ejection instants of the two streams connected in series with an auxiliary winding surrounding only the induction pole portion of the magnetic circuit and inductively coupled to the main accelerating flux producing winding so as to periodically recharge the capacitor, and the charge on the capacitor being discharged periodically in opposite directions through the auxiliary winding by means of a pair of grid-controlled gas discharge tubes connected in back-to-front relation in circuit between the capacitor and the auxiliary winding. In accordance with the invention, means are so provided for the control grids of the gas discharge tubes that each tube can be "fired," i. e. made conductive at a selected instant, independent of the other, to the end that each electron stream can be ejected at a selected instant of time during its acceleration phase.

In the accompanying drawings which illustrate the invention:

Fig. 1 is a view in central vertical section of a magnetic induction accelerator having an auxiliary winding for effecting an ejection of the electron streams from their orbit after acceleration, there being a capacitor in series with the auxiliary winding and a pair of grid-controlled gas discharge tubes connected in back-to-front relation in circuit between the capacitor and auxiliary winding;

Fig. 2 is a graph illustrating the course of the voltage induced in the auxiliary winding by the flux produced from the main winding of the accelerator, the course of the current flow through the auxiliary winding and the

course of the voltage on the capacitor, in accordance with a known arrangement for operating the gas discharge tubes;

Fig. 3 is a graph similar to that of Fig. 2 illustrating the courses of the voltages, currents and fluxes in accordance with the present invention;

Fig. 4 is a schematic electrical diagram showing the control circuit for the gas discharge tubes in accordance with the present invention;

Figs. 5, 6 and 7 are graphs correlated to Fig. 3 showing the courses of the various components of the grid voltages produced in accordance with the invention to control the firing instants of the gas discharge tubes;

Fig. 8 is a graph showing the course of the voltage induced in the auxiliary winding when the central core portion of the accelerator is magnetized to saturation, the departures from the generally sinusoidal form of curve being much exaggerated;

Figs. 9 and 10 are graphs showing different magnitudes of impulse currents from the capacitor required in the auxiliary winding for ejecting the electron streams in dependence upon different desired ampltiudes of acceleration of the streams; and

Fig. 11 is a graphical presentation of two conditions for expansion of the orbit of the electron streams, one when the central core is saturated and another when the central core is unsaturated.

With reference now to the drawings, Fig. 1 shows schematically a magnetic induction accelerator with a magnetic field structure **10**, two coils **11** and **12** which supply the main flux and at the same time also the so-called control or guiding flux, as well as an annular tube **13** which like the field structure and coils is also shown in section and inside of which the electrons are accelerated. The pole shoes **14** and **15** for the accelerating flux are provided with two expansion or contraction coils **16**, **17** which are connected in series. After the desired electron acceleration has been attained these coils are supplied with a short current impulse, so that the magnetic flux corresponding to this impulse when there is an expansion of the electron orbit acts through the pole shoes **14**, **15** in the same sense as the accelerating flux but through the guiding field space of the magnetic inductor in the opposite sense to the guiding flux (or in case a contraction of the electron orbit is desired the effect is reversed and the magnetic flux acts through the pole shoes **14**, **15** in the opposite sense to the accelerating flux and through the guiding field space in the same sense as the guiding flux), so that the electrons which during the acceleration travel around the equlbiirum orbit deviate from this latter, either in the inward or outward direction, and strike the anti-cathode. Coils **16**, **17** are thus called either expansion or contraction coils depending upon whether the anti-cathode is located on a radius which is greater or smaller than that of the equilibrium orbit. For the sake of simplicity the expression expansion coil is used throughout the following description.

As shown in Fig. 1, the expansion coils are connected in series with a capacitor **18** and two tubes **19**, **20**, the latter being arranged in parallel but with opposed current passing directions i. e. in back-to-front relation. If the curve A in Fig. 2 represents the voltage produced in the expansion coils by the accelerating flux and if it is desired to accelerate the electrons during each accelerating period up to the maximum ultimate electron voltage, there must be a voltage on capacitor **18** corresponding to the rectangular curve B of Fig. 2. The phase position of the ultimate electron voltage is indicated in Fig. 2 by the dotted curve C. It is assumed that the electron acceleration occurs during the quarter wave period T_1 when the induction accelerator has only an electron stream accelerated in one definite direction of gyration, and possibly furthermore during the quarter wave period T_2 if there is a second accelerated stream in the opposite direction of gyration. At the instant t_1 tube **19**, which up to then has been kept non-conductive by means of a suitable sinusoidal grid bias voltage, is fired and capacitor **18** which up to then has a charge with the polarity indicated in Fig. 1 of the drawing, is charged over the cathode-anode gap of tube **19** and the expansion coils **16**, **17** to the opposite polarity. The polarity-reversing current in the form of a current impulse J_1 flows through the expansion coils and thus causes the desired expansion of the orbital path. Half a cycle later, that is at t_2 after a time T_2, tube **20** which up to then has remained non-conductive is fired and the capacitor by means of a fresh current impulse J_2 over the expansion coils has its polarity changed back again to that which it possessed shortly before the instant t_1. If the induction accelerator has a second stream, this is also deflected from the equilibrium orbit to its anti-cathode.

When it is desired to use an arrangement for an induction accelerator having an adjustable ultimate electron voltage, the current impulse J_1 (and also the current impulse J_2 when there are two electron beams travelling in opposite directions) must already occur at some instant depending on the desired ultimate electron voltage and falling within the interval T_1 or T_2 respectively, that is to say before the end of the interval in question. It is obvious that for this purpose the voltage on capacitor **18** will have to differ from the rectangular curve B not only as regards the position in time of the vertical flanks but primarily as regards its amplitude. Namely under the assumption that the iron core of the induction accelerator is unsaturated even when the induction effect is a maximum, it is obviously essential that the ratio of the amplitude of the expansion impulse J_1 to the magnitude of the desired ultimate electron voltage should be constant, so that the electron orbit is always increased by the same amount. If capacitor **18** should discharge itself over the expansion coil from the maximum value shown in Fig. 2, this condition could not be fulfilled, a fact which is readily recognized when for instance the tube **19** is fired at the instant t_3 (Fig. 2). At this instant the electrons have already been accelerated appreciably, namely up to about ⅓ of the maximum possible ultimate voltage, whilst the voltage on the expansion coils has still about the same value which it had at the beginning of the acceleration period T_1. The difference in voltage between capacitor **18** and the coil voltage is thus extremely small and therefore if tube **19** were to be fired at the instant t_3 the resulting expansion impulse would be much too small to enable the electron orbit to be enlarged to strike the anticathode.

These difficulties are overcome by means of the present invention and in order to achieve an adjustable ultimate electron voltage with an arrangement of the kind illustrated in Fig. 1, a method is given whereby expansion impulses of the required magnitude can be produced for any desired ultimate electron voltage.

With this new method, which is later explained by means of a constructional example, the first discharge gap is ignited at an instant which is variable and depends on the desired ultimate voltage, whilst the second discharge gap is ignited as much after the ignition point required for the maximum ultimate voltage of the second stream as the ignition point of the first discharge gap is in advance of the ignition point required for maximum ultimate voltage of the first stream.

A practical example of this method is now explained by means of the curves in Fig. 3. In Fig. 3 reference letter A again indicates the voltage produced in the expansion coils by the accelerating flux. The acceleration interval for the first electron stream is again T_1. The ultimate voltage which can be attained during this interval is given by the ordinates of the sine wave C which coincides with curve C of Fig. 2 and has been drawn with the same amplitude as the curve A. By means of tests with a corresponding arrangement for a magnetic induction accelerator it is for instance possible to prove that the discharge of capacitor **18** (instead of from the voltage value B indicated in Fig. 2 which only applies to accelerations up to a maximum electron voltage) must always occur from a higher voltage value, if the ratio of the expansion current impulse to the prevailing ultimate electron voltage should always be correct. This higher potential for the capacitor, which is referred to later on, lies on curve D and can differ in magnitude, depending on the instant when the electron acceleration ceases during the time T_1. The amplitude of curve D which is determined by the sum ($\sin\tau+\cos\tau$) exceeds the amplitude of curve A by the square root of 2 and D has a phase displacement of exactly 45° relative to A.

A simple calculation shows that when the charge of capacitor **18** during the interval T_1 just has the value of curve D at the firing instant, an expansion current impulse of such magnitude will be obtained that it will have the same ratio to the desired ultimate electron voltage as in Fig. 2 for acceleration up to the maximum possible electron voltage. For this purpose it is assumed that capacitor **18** in the circuit shown in Fig. 4, which is explained later on in detail, is charged with a polarity as indicated by the plus and minus signs shown above the condenser leads. The magnitude of this condenser charge has to correspond to the ordinates of curve D in Fig. 3 at the instant t_4. At the instant t_4 the expansion coil **16**, **17** in Fig. 4 has a potential opposing that of the capacitor, that is a voltage with a polarity indicated in Fig. 4 and a magnitude corresponding to the amplitude of curve A in Fig. 3 at the instant t_4. Capacitor **18** discharges at the instant t_4 through the tube **19** and begins at point **1** on curve D, Fig. 3. The voltage at the capacitor decreases very rapidly according to a steep cosine curve (in Fig. 3 vertical line **21**), intersects curve A and ends (undamped discharge assumed) at point **2** which lies as far below curve A as the point **1** lies above this curve. The charge on capacitor **18** has now the opposite polarity to that which it previously had, that is the charge has the plus and minus signs shown below the capacitor leads. This charge cannot flow back on account of the blocking effect of the discharge gap **19** and the second discharge gap **20** in the capacitor circuit is still non-conductive. The condenser charge thus remains constant at first, that is in the beginning it follows the horizontal line **22** from the instant t_4.

In a general way it is now proved that the total amount of charge variation at the capacitor is proportional to the ultimate electron voltage which is obtained at the firing instant, that is the resulting expansion impulse is also proportional to the ultimate electron voltage. For this purpose it suffices to show that the difference between the ordinates of the amplitude of curves D and A during the interval T_1 is proportional to the prevailing ordinate of curve C. If the starting point for counting the time is made to correspond to the point where curve C passes through the zero line, that is to the peak of curve A, so that the zero point 0 of the time axis is as shown in Fig. 3, curve A will be a simple cosine curve, curve C a simple sine curve and curve D is represented by the expression

$$\sqrt{2}\sin(\tau+45°)$$

if τ indicates the time coordinates. The difference between the ordinates of D and A at any instant during the interval T_1 will thus be

$$\sqrt{2}\sin(\tau+45°)-\cos\tau=\sin\tau$$

that is, proportional to the ultimate electron voltage, because curve C corresponds to sin τ curve. It is thus clear that the capacitor starting voltage depending upon the position of the firing point must always have the value give by curve D in order to achieve an expansion impulse which is always proportional to the selected ultimate electron voltage. The curve of the capacitor voltage for the firing points t_1 and t_2 shown in Fig. 2 agrees with this assertion, because curve D for maximum ultimate electron voltage, that is at the end of interval T_1, has the same ordinate as curve A at the peak point.

Any firing point t_4 within the time interval T_1 can easily be adjusted with the aid of the circuit shown in Fig. 4 for the grid of tube **19**. The grid voltage consists of two voltages in series which are taken from two separate windings of a phase transformer **23**. The first part of the voltage is tapped off from the first secondary winding **24** to which a double-wave rectifier system comprising tubes **25**, **26** and load resistor **27** is connected. The second part of the voltage is obtained from a second secondary winding **28** which is connected rigidly with the first secondary winding **24**, as indicated by the dashed line extending between the two windings, and together with the latter can be rotated relatively to the primary winding **29**. The second secondary winding has a circuit consisting of resistor **30** and a capacitor **31** connected to it for shifting the phase of this secondary voltage by 45°. The voltage on capacitor **31** is in series with the voltage on load resistor **27**. Primary winding **29** is in parallel with the energizing winding **32** of the induction accelerator, the winding **32** corresponding in function to coils **11**, **12** in Fig. 1. From Fig. 5 it is clear that with this grid circuit the position of firing point t_4 can be selected anywhere within the interval T_1. A pulsating direct voltage now occurs at load resistor **27** corresponding to the dotted curve **33**, whilst at capacitor **31** there is a sinusoidal voltage corresponding to the dotted curve **34** and the sum of both these voltages thus appears at grid **19**, that is a voltage according to curve **35**. The peaks of curve **35** serve for firing tube **19** and the phase position of these peaks can be varied within the interval T_1 by means of the phase transformer.

The second discharge gap **20** is now ignited during the time interval T_2 in Fig. 3, this being achieved by means of the total bias voltage consisting of three voltages in series obtained with the circuit shown in Fig. 4.

The first part of this grid voltage is the voltage at capacitor **18**, because the path between the cathode of tube **20** and its control grid first of all contains capacitor **18**. The grid circuit furthermore contains the secondary winding **36** of transformer **37** whose primary winding **38** is connected to a capacitor **39** which is in series with a resistor **40** and is connected to the energizing winding **32** of the induction accelerator. The resistor-capacitor organization **39**, **40** causes the phase of the voltage at the energizing winding **32** to be shifted 45°, so that a voltage occurs at the secondary winding **36** which as regards magnitude and phase corresponds to the curve D in Fig. 3. Curve D in Fig. 3 is also designated by G_2 to indicate that it forms the second part of the grid voltage for tube **20**.

The third part of the grid voltage is shown in Fig. 6 as a function of the time. It consists of a sine wave the upper parts of which corresponding to the interval T_2 and of a quarter cycle duration being cut off. The cut-off part of the sine wave is shown dotted in Fig. 6; the third part of the grid voltage is thus always negative except during the interval T_2 when it is zero. The third part of the grid voltage is thus shown in Fig. 6 by the full-line curve. This bias voltage is produced by means of transformer **41** the primary winding **42** of which is connected over a phase-shifting series connected resistor-capacitor organization **43**, **44** in parallel with the energizing winding **32**, a rectifier **47** with a bias voltage **46** being arranged in parallel with the secondary winding.

The grid circuit of tube **20** thus contains in series arrangement: (*a*) the voltage at capacitor **18**, (*b*) the voltage G_2 which is supplied from winding **36**, and (*c*) the third part of the grid voltage, namely the voltage

according to Fig. 6 which only allows tube **20** to be fired during the interval T_2 and otherwise causes the control grid of this tube to have a blocking effect. The capacitor voltage and the voltage at **36** is reduced by the voltage divider **48** to the magnitude required for the control range of the grid of tube **20**. During the interval T_2, that part of the capacitor voltage which due to voltage divider **48** lies in the grid circuit of tube **20** has a magnitude and polarity corresponding to the horizontal line **22** in Fig. 3. Curve G_2, that is a fraction of the voltage from winding 36 has at the beginning of the interval T_2 a negative value which is considerably greater than the ordinate of line **22**. The third part of the grid voltage, that is the curve in Fig. 6 assumes zero value at the beginning of interval T_2; the blocking effect on tube **20** ceases. When during the interval T_2 curve G_2 intersects the line **22**, that is at the instant t_5, the grid bias voltage of tube **20** becomes positive because the positive capacitive voltage exceeds the negative secondary voltage of winding **36**, so that tube **20** is fired. Capacitor **18** now reverses its charge through expansion coils **16**, **17** and tube **20**, whereby an expansion impulse again occurs in the expansion coil of the same magnitude but in the opposite direction as at t_4. The corresponding voltage jump at capacitor **18** which in Fig. 3 is indicated by the vertical line **49** ends at point **4** which is as far above the instantaneous value of curve A at point t_5 as point **3** is below this curve, that is to say it is at a voltage value which lies just as high as point **1** at the instant t_4 during the firing interval of the first tube **19**, on condition that the polarity reversal of the capacitor occurs without damping. Since tube **20** is now blocked and tube **19** is still non-conductive due to its grid bias voltage, the capacitor voltage now follows a horizontal line again, namely line **50** up to the point **1'** which corresponds to point **1**, and the cycle of operations described above then begins to repeat itself.

If the first discharge gap is ignited at some other instant during the interval T_1, for instance at t_6, capacitor **18** will have a voltage which corresponds to the ordinate of curve D at this instant and the capacitor commences to discharge at point **5**. This discharge, after the capacitor voltage has dropped to a value corresponding to the opposing voltage of coil **16**, **17**, continues down to a voltage value **6** which lies as much below curve A as point **5** lies above this curve, when an undamped discharge is assumed. The change in voltage at the capacitor is indicated in Fig. 3 by the dotted vertical line **51**. It is, however, to be noted that when tube **19** is fired at the instant t_6 the reversal of the capacitor charge is not the same as that which occurs when the tube is fired at t_4, because also at point **6** the capacitor still has such a charge that its right plate is positive with respect to its left plate. From point 6 the capacitor voltage remains contant and follows the dotted line **52** up to point **7** where the negative grid voltage of tube **20** is exceeded by the voltage of secondary winding **36** which from point **7** onwards is greater than the capacitor voltage. A fresh voltage rise up to point 8 now occurs at the capacitor, this being indicated by the dotted line **53**. This voltage jump occurs without a change in the polarity of the capacitor charge and merely results in a change in magnitude of the capacitor voltage. From point **8** the capacitor voltage first of all follows the line **54** up to point **5'** which corresponds to point **5** and where the cycle of operations commences afresh.

It must also be noted that the minimum values reached by the capacitor voltage, that is points **2** and **6** for firing tube **19** at the instants t_4 and t_6 respectively, lie on a sine curve which has a lead of 90° with respect to curve D and also the same amplitude. Curve D has a lag of 45° with respect to the peak of curve A and a lead of 45° with respect to curve C if the phase difference between the wave peaks is measured.

From Fig. 3 it will readily be clear that for each position of the firing instant within the interval T_1, except for the case where the firing point coincides with the end of T_1, the capacitor voltage follows a rectangular curve whose positive and negative half waves are not of equal length. This may appear rather surprising in view of the completely symmetrical circuit consisting of the expansion coils **16**, **17**, capacitor **18** and the two tubes **19**, **20**. The explanation is however that the circuit only operates symmetrically in the one special case referred to, whilst for every position of the firing point within the interval T_1 the second electron stream (if there is one present in the induction accelerator in question), although the same ultimate electron voltage is reached, is subjected to an acceleration which as regards time by now means coincides with the duration of the acceleration of the first stream.

As shown in Fig. 7, if tube **19** is fired at the instant t_4, the first electron stream is accelerated during the interval T_1 less the interval T_1', that is during a time which is less than a quarter of a cycle of the energizing voltage by the amount T_1', whilst the second stream already commences to be accelerated at the instant t_8, thus first of all up to the maximum ultimate electron voltage which is reached at t_9, whereupon a retardation occurs which only ends at the instant t_{10}. At the instant t_{10} the ultimate electron voltage of the second stream is just as high as that of the first stream at the instant t_4. In Fig. 7 the full parts of the sine wave during the acceleration intervals and the dotted portions of the rest of the curve indicate clearly that the apparently symmetrical circuit of Fig. 4 is actually operated unsymmetrically (except of course in the aforementioned special case). Only in this special case where the rectangular curve for the capacitor voltage, as already mentioned, has positive and negative half waves of equal length, does the interval T_1' become zero so that the operation of the circuit is exactly symmetrical.

It is now assumed that there is only one electron stream, namely the one which is accelerated during the whole time T_1 or only part of it. Also in the latter case the circuit shown in Fig. 4 together with all its components is necessary, and the charge-reversal process of capacitor **18** as well as the control of tubes **19**, **20** must occur exactly in the manner described. The expansion impulse which occurs either when the charge of capacitor **18** is reversed at the instant t_5 or when there is a change in the capacitor charge at the instant t_7, serves solely when there is only one stream present in the induction accelerator to restore at capacitor **18** the charge (namely the charge corresponding to points **4** and **8** respectively) which is necessary for interrupting the acceleration at the right instant during T_1 when the next acceleration occurs. Actually the circuit according to the invention possesses the great advantage that without making any alterations to that part of it which serves to produce the expansion impulses, it is possible to have a second electron stream in the induction accelerator if desired so that the output of X-ray energy is double that of a single stream induction accelerator.

It has also to be emphasized that the initial voltage at capacitor **18** automatically adjusts itself to the correct value for any optional position of the firing point within the interval T_1; for this purpose it is not necessary to understand the operating process which has been explained in detail by means of Fig. 3. It is only necessary that in the circuit shown in Fig. 4 the control voltage for the discharge gap **19** should be arranged according to Fig. 5, that is the firing point should be fixed once and for all at some instant during T_1 to correspond with the desired ultimate electron voltage. The correct control for the second discharge gap **20** then adjusts itself quite automatically when the circuit in Fig. 4 is used, no adjustment depending on the selected ultimate electron voltage being necessary.

In this connection it is now shown that in a special case the capacitor **18** depending upon the position of the firing point within the interval T_1 is actually charged to a voltage value which corresponds to the ordinate of curve D at the firing point in question. This can be proved by assuming a value for the initial voltage at capacitor **18** which differs from the voltage value prescribed by curve D and by showing that with this optionally assumed initial voltage value after two changes in the charging of capacitor **18** the resultant voltage more closely approaches the value given by curve D than the optionally assumed initial value of the capacitor voltage. If for instance it is assumed that capacitor **18** has an initial voltage corresponding to point **1″** in Fig. 3. When tube **19** fires, this voltage changes to **2″**, this point being as much below A as point **1″** is above it. At the instant **3″** there is a fresh change in the charge on capacitor **18**, the voltage charge attaining a value which lies as much above curve A as the value at point **3″** lies below it. Point **4″** thus lies much nearer to curve E than point **1″** to curve D and this means that actually for each position of the firing point within the interval T_1 a voltage occurs at capacitor **18** corresponding to curve D, that is to say a capacitor voltage which follows a rectangular curve between the curves D and E.

In connection with the explanation of the curves in Fig. 3 it has been assumed that the iron core of the induction accelerator remains unsaturated even with maximum induction effect. The case is now considered when such an assumption cannot be made. If a certain saturation in the vicinity of the tops of curves A and C is assumed, the conditions which have been described by means of Fig. 3 remain qualitatively unchanged.

Only curves A and C becomes slightly flattened in the vicinity of the maximum and minimum values and this also applies to curve D and therefore also curve G_2 which must correspond to curve D. Careful consideration of the conditions which occur when the accelerator core is saturated leads to the following results: When the central core is magnetized up to saturation curve A in Figs. 2 and 3 becomes deformed as shown at A′ in Fig. 8 to an exaggerated scale. Actually this deformation is so small that it can be neglected. Another and much more important result of the saturation is however the change which occurs in the diameter of the equilibrium orbit of the moving electrons. This orbit becomes reduced because the accelerating field by comparison with the guide field (produced by the unsaturated guide field poles) becomes smaller than in the unsaturated case. If the electrons have to be deflected to the anti-cathode by expanding the equilibrium orbit, then due to the diminution in diameter of the orbit, it is necessary to have a larger expansion impulse than when the central core is unsaturated. If the electrons are deflected by contraction of the orbit, the contraction impulse must be smaller than in the unsaturated case. The impulse currents required for deflecting the electrons in dependence on the desired ultimate voltage are shown in Fig. 9, but referred to the same maximum ultimate voltage. In Figs. 9 and 10 curve **1** refers to the unsaturated case, curve **2** to the case with saturation and expansion of the equilibrium orbit, whilst curve **3** refers to saturation and contraction of the equilibrium orbit.

Fig. 11 gives a graphical representation of conditions for expansion, the same designations being used for the curves as in Figs. 2 and 3. The reference letters with a prime refer to the case of a saturated central core whilst the reference letters without a prime indicate the curves when there is no saturation, that is the curves already shown in Fig. 3 and described in detail. The rectangular curve which indicates the change in capacitor voltage in Fig. 3 for various positions of the ignition point, that is to say various ultimate electron voltages, is also to be found in Fig. 11 for a definite ultimate electron voltage. Fig. 11 also shows that the voltage D′

required for igniting the second discharge gap can for instance be obtained by shifting the phase of the voltage D required for the unsaturated core, because actually only that part of the curve D′ is of interest where it is about to pass through zero in the rising direction. This shows that the angle of the lag of the firing point for the second discharge gap with reference to the firing point required for the maximum ultimate voltage of the second electron stream no longer has to be so accurately fixed as in the unsaturated case, but only has to be approximately so much after the firing point required for the maximum ultimate voltage of the second stream as the firing point of the first discharge gap lies ahead of the firing point which has to be adhered to for the maximum ultimate voltage of the first electron stream.

When, however, the iron core of the induction accelerator is saturated it is also true just as in the case of the unsaturated core that the voltage at capacitor **18** adjusts itself entirely automatically to the required value, and furthermore that when the circuit according to Fig. 4 is employed the second discharge gap **20** is automatically ignited at the correct instant so that the voltage follows a vertical flank of the rectangular voltage curve having the correct magnitude.

The method according to the invention thus deals with producing expansion or contraction impulses for an induction accelerator with variable ultimate electron voltage and with one electron stream or two electron streams gyrating in opposite directions and employing an expansion or contraction coil which is energized by the accelerating flux of the accelerator as well as a capacitor in series with said coil and two grid-controlled discharge gaps in inverse parallel connection, and for the general case this method consists of igniting the first discharge gap periodically at an optionally adjustable instant depending on the desired ultimate voltage, whilst the second discharge gap is ignited at an instant which is about as much after the ignition point which has to be adhered to for the maximum ultimate voltage of the second electron stream as the ignition point of the first discharge gap lies in advance of the ignition point for the maximum ultimate voltage of the first electron stream.

The fact that in this definition of the ignition point for the second discharge gap reference is made to a second electron stream in the induction accelerator corresponds to the fact that it is merely necessary to install in the induction accelerator a device for producing such a second electron beam without having to make any modifications in the method according to the invention for producing the expansion or contraction impulses. Also the circuit for producing these impulses requires no alterations when a change-over is made from a single beam to a double beam induction accelerator where both streams are accelerated to the same ultimate electron voltage.

I claim:

1. The combination with an electron accelerator of the type comprising an annular tube into which streams of electrons are injected in succession for acceleration respectively in opposite directions on an orbit established within said tube, a magnetic structure including a central core portion extending through the central opening within said tube and annular control pole portions confronting one another at said tube, a main winding on said magnetic structure surrounding said control poles, and a source of alternating voltage connected cross said main winding to establish an alternating current therein producing a time varied cycle of magnetic flux of alternating polarity, said flux comprising a first component through said central core portion effecting acceleration of said electrons and a second component through said control poles confining the electron stream during the accelerating period to a path of travel along an orbit of substantially fixed radius; of means for effecting a change in the radius of said electron orbit to discharge each electron stream from

the accelerator, said means comprising, an auxiliary winding surrounding only said central core portion and which is inductively coupled with said main coil so as to cause an alternating voltage to be induced therein, a condenser, first and second grid controlled gaseous discharge tubes connected in parallel in back-to-front relation, means connecting said auxiliary winding, condenser and paralleled valves in a series circuit, means deriving from said source of alternating voltage a control voltage of adjustable phase for the grid of said first tube to ignite the same and render it conductive at an adjustable instant of time in the accelerating period of a first electron stream accelerated when said magnetic flux is of one polarity to discharge a current pulse from said condenser through said auxiliary winding thereby effecting a change in the ratio between said flux components and hence a change in radius of the electron orbit, and means also deriving from said source of alternating voltage a control voltage of an adjustable phase different from the phase of said control voltage for the grid of said first tube for the grid of said second tube to ignite the same and render it conductive at an instant of time as much after the ignition instant required to be adhered to for maximum ultimate electron voltage of the second electron stream accelerated when said magnetic flux is of opposite polarity as the ignition instant of said first tube lies in advance of the ignition instant required to obtain maximum ultimate electron voltage of the first electron stream.

2. Apparatus for effecting a change in radius of the electron orbit as defined in claim 1 wherein said grid control voltage for rendering said first tube conductive is effective only during about one-twentieth of the total period.

3. Apparatus for effecting a change in radius of the electron orbit as defined in claim 1 wherein the means for deriving the control voltage for the grid of said first tube is comprised of an adjustable phase transformer having its primary connected to said source of alternating voltage and said control voltage is constituted by the sum of two voltage components connected in series with the grid of said first tube and which components are derived from the secondary of said transformer, one of said components being constituted by the output of a double-wave rectifier connected to the secondary and the other of said components being constituted by a sinusoidal voltage taken from another secondary and having a phase displacement of 45° relative to said magnetic flux.

4. Apparatus for effecting a change in radius of the electron orbit as defined in claim 3 wherein the secondaries of said transformer are fixed with respect to each other and adjustable jointly with respect to the primary of said transformer.

5. Apparatus for effecting a change in radius of the electron orbit as defined in claim 1 wherein the means for deriving the control voltage for the grid of said second tube is constituted by the sum of three voltage components connected in series with the grid of said second tube, one of said components being the voltage of said condenser, a second component being a sinusoidal voltage derived from the source of said alternating voltage and having a phase displacement of 45° relative to said magnetic flux, and a third component of the same frequency as said second component also derived from said source of alternating voltage, said third component being negative between 0° and 270° of the cycle of the magnetic flux and cut off during the positive portion thereof between 270° and 0°.

6. Apparatus for effecting a change in radius of the electron orbit as defined in claim 5 wherein said second component of said control voltage for the grid of said second tube is produced in the secondary of a transformer whose primary winding is connected to said source of alternating voltage through phase displacement means, and wherein said third component of said control voltage for the grid of said second tube is constituted by the out-

put of a second transformer secondary having a series arranged half wave rectifier and a source of unidirectional voltage connected across said second secondary, said second secondary being energized from a primary winding connected to said source of alternating voltage through phase displacement means.

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