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| [45] | Patented | Mar. 2, 1971 |
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| [32] | Priority | Sept. 16, 1966 |
| [33] | | France |
| [31] | | 76732 |

- [54] METHOD AND APPARATUS FOR BOMBARDMENT
OF A TARGET BY MODULATED CIRCULAR
SWEEPING**
6 Claims, 8 Drawing Figs.
- [52] U.S. Cl.**..... **250/49.5,**
235/197, 328/233, 315/23
- [51] Int. Cl.**..... **H01j 37/28,**
G01n 23/00
- [50] Field of Search**..... **250/49.5**
(0), 49.5 (7); 235/197, 198; 315/23; 328/233

[56]

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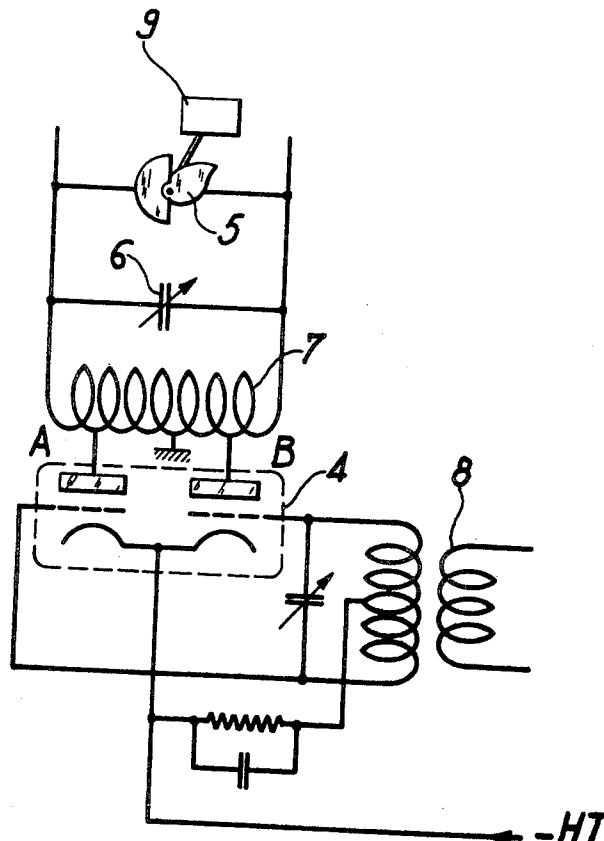
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ABSTRACT: Bombardment of a target is performed by means of a method and apparatus for circularly sweeping said target with a beam of charged particles subjected to the electric fields of two pairs of deflector plates to which are applied sinusoidal voltages displaced in phase by $\pi/2$; specifically, the method consists in forming a well focused particle beam and in modulating said sinusoidal voltages so that they have the form

$$U = U_0(t) \sin. \frac{2\pi t}{T},$$

Wherein U_0 varies as a function of time according to a relation of the form

$$U_0(t) = \sqrt{at + b}.$$



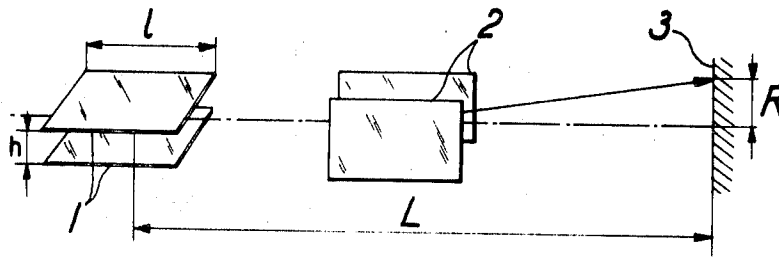


FIG. 1

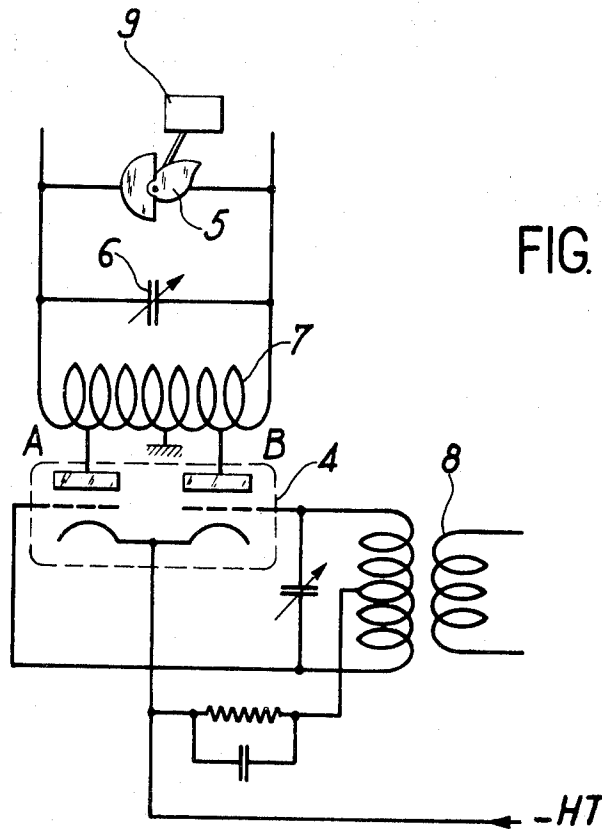


FIG. 2

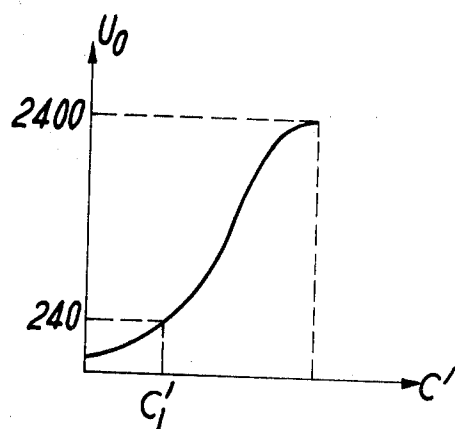


FIG. 3

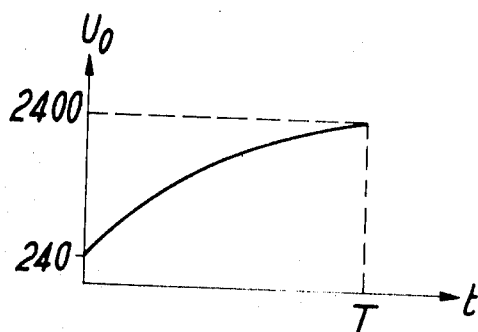


FIG. 4

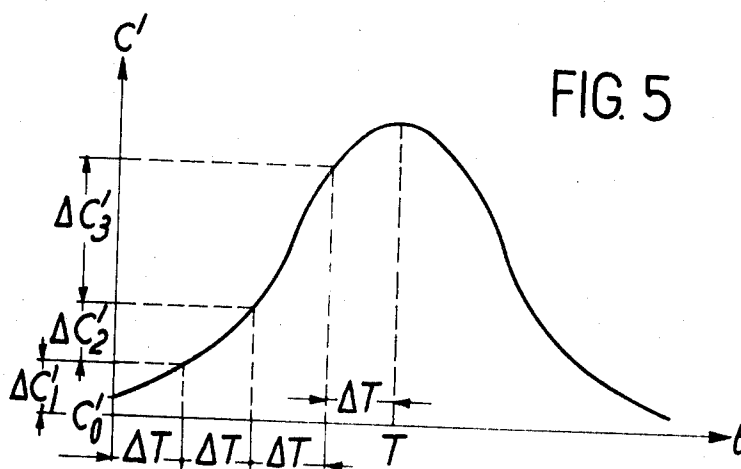


FIG. 5

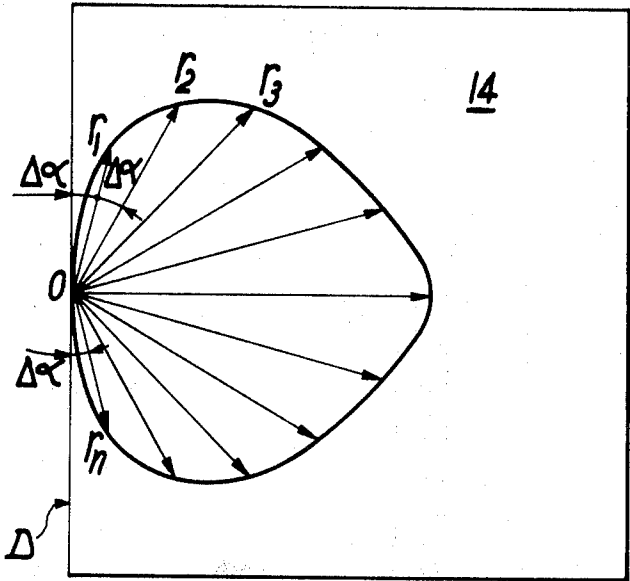


FIG. 6

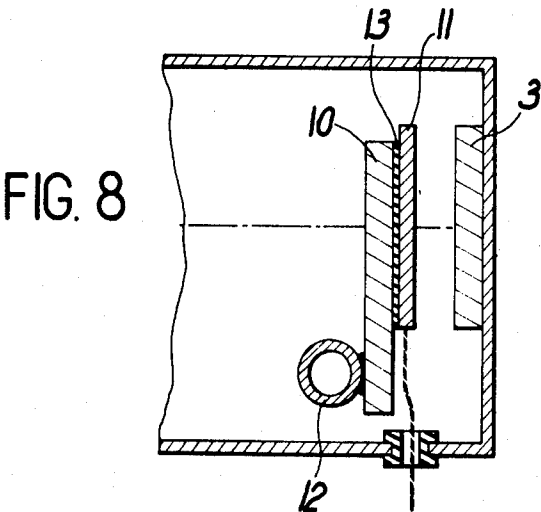
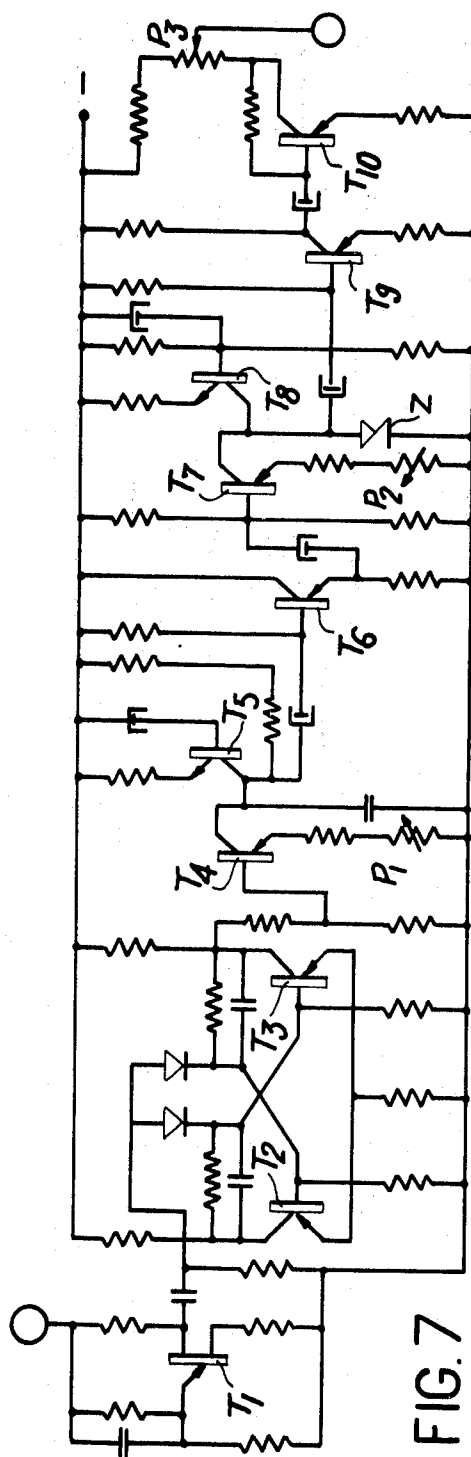


FIG. 8



METHOD AND APPARATUS FOR BOMBARDMENT OF A TARGET BY MODULATED CIRCULAR SWEEPING

This invention relates to a method of bombardment of a target by modulated circular sweeping wherein a bombardment which is uniform in time is carried out over the entire surface of said target by means of a perfectly focused beam of charged particles.

The invention is also concerned with an apparatus for the execution of said method.

It is known that the bombardment of a target placed at the end of travel of a particle accelerator (electrons, protons, deuterons, etc. is intended to produce within this target transmutations which, if the particles with which it is bombarded are light ions (for example deuterons or deuterium nuclei), accordingly release neutrons.

In order to obtain a neutron emission, the target may be bombarded by a deuteron beam which has been defocused so that it has approximately the same diameter as the target. However, this method is unsatisfactory since it results in destruction of the target within a short time on account of lack of homogeneity of the beam.

The aim of the present invention is to prevent rapid destruction of the target by virtue of a bombardment of the target with a beam which, on the one hand, is well focused and which, on the other hand, makes it possible to distribute on said target a flux which is uniform in time, this condition being essential for the purpose of ensuring optimum utilization of the target and obtaining a strong neutron emission.

The present invention provides the method of uniformly bombarding a circular area of a target by a focused beam of charged particles which comprises subjecting said beam to the electric fields of two mutually perpendicularly disposed pairs of deflector plates to which are applied sinusoidal voltages mutually displaced in phase by $\pi/2$, the amplitude U of each of said sinusoidal voltages being modulated so that each has a value defined by the equation

$$U = U_0(t) \sin \frac{2\pi t}{T}$$

wherein U_0 varies as a function of time in accordance with the relation $U_0(t) = \sqrt{at+b}$ and a and b being constants.

The invention also provides apparatus for uniformly bombarding a circular area of a target with a focus beam of charged particles comprising means for focusing said beam of charged particles upon said target, said beam in passing to said target traversing the electric fields of two mutually perpendicularly disposed pairs of deflector plates, means for generating and applying to said pairs of deflector plates sinusoidally varying voltages mutually displaced in phase by $\pi/2$, the amplitude U of each of said voltages varying in accordance with the equation

$$U = U_0(t) \sin \frac{2\pi t}{T}$$

where $U_0(t) = \sqrt{at+b}$, and a and b are constants.

In accordance with a first embodiment of the invention the means for generating the varying voltages includes a variable capacitor which is included in a resonant circuit included in a tuned amplifier (FIG. 1); way of which said sinusoidal voltages are fed to said deflector plates, the moving plate of said capacitor having a contour of which the form is such that as said plate is continuously rotated the capacitance of said capacitor varies cyclically with time in such a manner that the amplitude U_0 of the sinusoidal voltage has a value represented by the expression $U_0(t) = \sqrt{at+b}$, where a and b are constants.

In accordance with a purely electronic embodiment, said function generator comprises a Zener diode which is swept by a triangular current.

As an advantageous optimal feature, a device for checking the focusing and centering of the beam of charged particles used in the apparatus in accordance with the invention is constituted by a metallic diaphragm provided with a cruciform

slot and by a metallic disc having the same diameter as the useful portion of the target, an insulating strip being interposed between said diaphragm and said disc.

Further properties and advantages of the invention will become apparent from the following description which is given with reference to the accompanying drawings and in which two forms of execution of the invention are given by way of explanation but not in any limiting sense.

In these drawings:

FIG. 1 is a diagrammatic view in perspective of a circular sweep system of known type which is intended to receive the apparatus in accordance with the invention (not shown in the FIG.);

FIG. 2 is a diagram of the amplifier of said circular sweep system on which is mounted a variable capacitor constituting a first embodiment of the function generator in accordance with the invention;

FIGS. 3 to 5 show three curves which serve to determine the shape to be given to the contour of the moving plate of the variable capacitor of FIG. 2;

FIG. 6 is a diagram showing the manner in which the contour of the moving plate of said variable capacitor is defined in practice;

FIG. 7 is a circuit diagram of a purely electronic construction of the function generator according to the invention which is intended to produce the desired parabolic variation of U_0 as a function of time and, finally;

FIG. 8 shows a form of construction of the focusing and centering device of the apparatus according to the invention.

The principle of circular sweeping is already known: it consists in subjecting a particle beam to the electric fields of two pairs of deflector plates 1 and 2 (shown in FIG. 1) which are located at right angles to each other and to which are applied sinusoidal voltages which are displaced in phase by $\pi/2$; the target 3 is thus swept circularly.

The principle of the method according to the present invention is as follows:

Since the voltage applied to the pair of deflector plates 1 has the form

$$U = U_0(t) \sin \frac{2\pi t}{T}$$

it is required that the beam should be well focused on the target and that U_0 should be varied as a function of time according to a law such that the flux should be uniform in time over the entire surface of the target 3.

If R designates the radius of sweep of the target 3 at any instant t and R_0 designates the minimum sweep radius, the area which is swept on the target in the case of an infinitely small variation dR of the sweep radius R is $dS = 2\pi R dR$; in fact, the condition of flux which is uniform in time which is characteristic of the present invention is expressed by the relation $dS = K dt$.

From these two relations is derived the condition $2\pi R dR = K dt$, hence by integration $\int 2\pi R dR = Kt + Cte$, that is to say $\pi R^2 = Kt + Cte$ hence

$$R = \sqrt{\frac{Kt}{\pi} + Cte} = \sqrt{K't + R_0^2} \quad (1)$$

K' being independent of the time.

Since the deviation of the beam of particles (for example deuterons) by the pair of plates 1 is electrostatic, the sweep radius is expressed by the standard formula

$$R = \frac{Ll}{2Uh} \cdot U_0 = K'' U_0 \quad (2)$$

wherein L is the distance from the center of the pair of plates 1 to the target 3,

l is the length of the plates 1 (for example 5 cms) and h is the distance between said plates (for example 2 cms).

From relations (1) and (2), we obtain:

$$K'' U_0(t) = \sqrt{K't + R_0^2}$$

that is to say:

$$U_0(t) = \sqrt{K'''t + U_0^2}$$

wherein K''' is independent of the time and U_0 being the minimum value of the voltage $U_0(t)$ which gives a sweep radius R_0 .

In the final analysis, the condition of uniform sweep as a function of time which is characteristic of the invention consists in varying $U_0(t)$ according to the parabolic law

$$U_0(t) = \sqrt{K'''t + U_0^2}$$

The apparatus in accordance with the invention accordingly comprises a function generator which serves to execute the above-mentioned parabolic variation of $U_0(t)$.

In accordance with a first form of construction, said function generator consists of a variable capacitor specially designed for producing said variation of $U_0(t)$ and which is mounted in the amplifier of the circular sweep system.

The desired modulation is effected by producing a variation in the capacitance of said capacitor and consequently in the tuning capacitance of said amplifier.

The amplifier as shown in FIG. 2 comprises an amplifier tube 4, the variable or modulation capacitor 5 which is characteristic of the invention, a second variable capacitor 6, an inductance coil 7, and a voltage step-up transformer 8 supplied by a quartz generator (not shown).

The tuning capacitance is constituted by

1. the modulation capacitance C' of the capacitor 5;
2. the variable capacitance of the capacitor 6 which must make it possible to compensate the capacitance of the deflector plates 1 and 2; and
3. the capacitance of the deflector plates.

The modulation capacitor 5 is driven in rotation by an electric motor 9 at a speed of approximately 3000 r.p.m.

The condition of uniform flux which is characteristic of the invention is satisfied if the condition

$$U_0(t) = \sqrt{K'''t + U_0^2}$$

is fulfilled.

This problem is solved in the following manner:

1. The curve of variation of $U_0(t)$ is plotted as a function of the capacitance C' of the modulation capacitor (as shown in FIG. 3).

In order to obtain U_0 maximum, tuning is effected at optimum value, whereupon the voltage is adjusted until U_0 attains the maximum value (for example 2400 volts).

2. The curve representing the desired variation of U_0 , that is to say the curve

$$U_0(t) = \sqrt{K'''t + U_0^2} \quad (3)$$

(as shown in FIG. 4), is plotted as a function of t .

Taking, for example, as limits of $U_0(t)$ the values 240 volts and 2400 volts, we have in respect of $t = T$, $U_0 = U_0$ maximum = 2400 volts and in respect of $t = 0$, $U_0(t) = U_0 = 240$ volts and relation (3) gives:

$$K''' = \frac{U_0^2 \text{ maximum} - U_0^2}{T} = \frac{2400^2 - 240^2}{T} = \frac{(2.4^2 - 0.24^2) \cdot 1000^2}{T}$$

Relation (3) then becomes:

$$U_0(t) = \sqrt{\frac{5.70 \times 10^6}{T} \cdot t + U_0^2} = \sqrt{\frac{5.70 \times 10^6}{T \cdot t} + 5.76 \cdot 10^4}$$

It is, since $Y_0^2 = 240^2 = 2.4^2 \times 10^4 \rightarrow 5.76 \times 10^4$.

- 3 From the preceding curves, there is deduced the curve which gives the variation in capacitance C' of the modulation capacitor as a function of the time t (FIG. 5); it should be noted that the capacitance C'_0 at the time $t = 0$ (residual capacitance) can be considered as zero inasmuch as it is possible to compensate for this latter with the capacitance of the second variable capacitor 6.

When the curve $C' = f(t)$ has been plotted, the abscissae are divided into n intervals equal to ΔT ($n \Delta T = T$), n being sufficiently great to ensure that the form of the modulation capacitor (the construction of which will be explained hereinafter) is defined with a high degree of accuracy. There correspond to these intervals ΔT on the axis of the ordinates (C') intervals $\Delta C'_1, \Delta C'_2, \Delta C'_3 \dots$

The modulation capacitor 5 is given a form which makes it possible to obtain this variation of C' as a function of time.

It is merely necessary to proceed as follows (FIG. 6): the fixed plate of the modulation capacitor is given the shape of a semicircle, the radius of which is greater than the maximum radius of the moving plate. On the plate 14 from which the moving plate will be cut and which has a straight edge D, there are plotted from a point O of said straight edge, straight lines which divide the plate 14 into n sectors (n having the same value as above).

The angle of each of these sectors is therefore

$$\Delta \alpha = \frac{180^\circ}{n}$$

- 30 There are then plotted on the successive straight lines, starting from the point O, radii $r_1, r_2, r_3 \dots r_n$, the values of which are dependent on the values of the intervals $\Delta C'_1, \Delta C'_2, \Delta C'_3$ as will become apparent hereinafter.

In accordance with a standard formula, it is known that the infinitesimal variation in capacitance of the modulation capacitor 5 is made dependent on the area ΔS_i which is swept by the moving plate by the relation

$$\Delta C'_i = \epsilon_0 \cdot \frac{\Delta S_i}{t} \quad (4)$$

wherein e designates the spacing of the plates of the moving capacitor and ϵ_0 is a constant equal to $10^{-9}/36 \pi$

Moreover, a standard formula of infinitesimal geometry indicates that the area ΔS_i which is swept by a radius r_i plotted on the moving plate in respect of a rotation $\Delta \alpha$ is equal to $\Delta S_i = r_i^2 \Delta \gamma / 2$ (α being a radian), namely that, in the case of α expressed in degrees,

$$\Delta S_i = \frac{\pi}{180} \cdot \frac{r_i^2 \Delta \alpha}{2} = \frac{\pi r_i^2 \Delta \alpha}{360} \quad (5)$$

the relations (4) and (5) thus give

$$\Delta C'_i = \frac{\epsilon_0 \pi r_i^2 \Delta \alpha}{e \cdot 360}$$

whence

$$r_i = \sqrt{\frac{360 e \cdot \Delta C'_i}{\pi \epsilon_0 \cdot \Delta \gamma}} \quad (6)$$

The radii $r_1, r_2 \dots r_n$ plotted in FIG. 6 are given by relation (6), in which; $\Delta C'_i$ is given the values which are plotted on the axis of the ordinates of FIG. 5. We then have between $\Delta C'_i$ and ΔT (ΔT being proportional to $\Delta \alpha$) the relation which corresponds to the curve of FIG. 5.

The radii r_i being thus determined, it merely remains to cut out the plate 14 on which said radii have been drawn, starting from the point O and following the extremities of the different radii r_i .

In the formula (6) which supplies the value of r_i , an arbitrary value can be given to e (spacing of the capacitor plates) provided that said value is greater than the insulation gap (approximately 3 mm.). It should be noted that the degree of accuracy obtained increases with the dimensions.

It is necessary to place the moving plate at a substantial distance from ground in order that there should not be a variable capacitance with ground.

In accordance with a second form of execution, the function generator in accordance with the invention which serves to produce the time-dependent parabolic variation of the form $U_0(t) = \sqrt{at+b}$ is purely electronic and comprises a Zener diode which is swept by a triangular current.

Said Zener diode is chosen so that the knee of its reverse characteristic is sufficiently rounded and is biased in the region of said knee.

A current corresponding to the difference between the collector currents of T_7 and T_8 is passed through the diode Z which is shown in FIG. 7; inasmuch as the collector current of T_8 is constant, the desired result will be obtained if the current of T_7 varies in a triangle.

It is merely necessary for this purpose to ensure that the base of the transistor T_7 is controlled by a triangular voltage generator (T_6), said voltage being obtained from the integration (T_4 and T_5) of the square-wave signals of a bistable multivibrator (T_2 and T_3) controlled by a pulse generator comprising a single-junction transistor T_1 .

The exact form of the modulation voltage is obtained by adjusting on the one hand the height of the triangular voltage which is applied to the base of T_7 (resistor P_1) and, on the other hand, the bias of the Zener diode Z (resistor P_2).

The transistors T_{10} and T_9 operate as amplifiers and the output level is adjustable (potentiometer P_3).

FIG. 8 shows a form of construction of a device for facilitating the checking of the focusing and centering the beam of particles (deuterons) which is projected onto the target 3. The device comprises:

A copper diaphragm 10 which is provided with a cruciform slot and which is designed to swing back in front of the target 3 in such a manner that the center of the cruciform slot is located exactly on the axis of the target. Said diaphragm is insulated by a thin strip 13 of mica (having a thickness of approximately 0.5 mm.) from a copper disc 11 having the same diameter as the useful portion of the target 3 on which the pulses are collected.

The diaphragm 10 is cooled by being in close contact with the shaft 12 through which water is circulated. The distance between the disc 11 and the target 3 must be as small as possible (less than 1 centimeter).

Adjustment of focusing of the beam is carried out as follows: by executing a horizontal sweep of the target followed by a vertical sweep, signals are obtained which represent; two diameters of the beam measured along the two arms of the cruciform slot of the diaphragm 10; adjustment is then affected to make said diameters as small as possible and of equal value.

In order to effect the centering operation, the sweeping is performed in the direction of horizontal deflection and only a single impulse should be seen (the vertical centering voltage being accordingly modified), whereupon the reverse operation is performed and centering is carried out by modifying the

horizontal centering voltage.

We claim:

1. The method of uniformly bombarding a circular area of a target by a focused beam of charged particles which comprises subjecting said beam to the electric fields of two mutually perpendicularly disposed pairs of deflector plates to which are applied sinusoidal voltages mutually displaced in phase by $\pi/2$, the amplitude U of each of said sinusoidal voltages being modulated so that each has a value defined by the equation

$$U = U_0(t) \sin \frac{2\pi t}{T}$$

wherein U_0 varies as a function of time in accordance with the relation $U_0(t) = \sqrt{at+b}$, a and b being constants.

2. Apparatus for uniformly bombarding a circular area of a target with a focused beam of charged particles comprising means for focusing said beam of charged particles upon said target, said beam in passing to said target traversing the electric fields of two mutually perpendicularly disposed pairs of deflector plates, means for generating and applying to said pairs of deflector plates sinusoidally varying voltages mutually displaced in phase by $\pi/2$, the amplitude U of each of said voltages varying in accordance with the equation

$$U = U_0(t) \sin \frac{2\pi t}{T}$$

where $U_0(t) = \sqrt{at+b}$, and a and b are constants.

3. Apparatus in accordance with claim 2 including a device for determining the focusing and centering of the beam of charged particles arranged to be selectively disposed between the source of said beam and said target.

4. Apparatus in accordance with claim 2, wherein the means for generating said varying voltages includes a variable capacitor in a resonant circuit in a tuned amplifier through which said sinusoidal voltages are fed to said deflector plates, the moving plate of said capacitor having a contour of which the form is such that as said plate is continuously rotated the capacitance of said capacitor varies cyclically with time in such a manner that the amplitude U_0 of the sinusoidal voltages has a value represented by the expression $U_0(t) = \sqrt{at+b}$ wherein a and b are constants.

5. Apparatus in accordance with claim 2 wherein said means for varying the amplitude of said sinusoidal voltages includes a Zener diode through which a cyclically varying current of triangular waveform is passed.

6. Apparatus in accordance with claim 2 including a device for determining the focusing and centering said beam selectively positionable to intercept said beam in the neighborhood of the target, said device comprising a metallic diaphragm pierced by a cruciform slot the intersection of which defines the center of the target and a plate insulated from said diaphragm and positioned to receive charged particles passing through said slot.