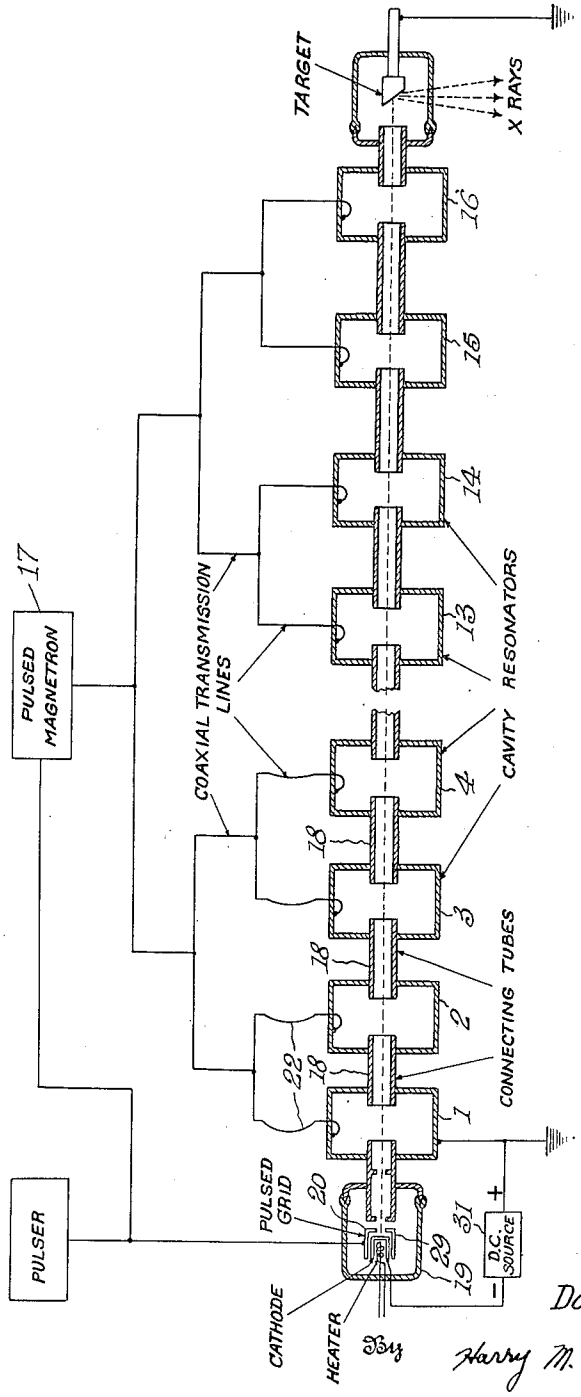
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CAVITY RESONATOR DEVICE FOR PRODUCTION OF HIGH-SPEED ELECTRONS

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CAVITY RESONATOR DEVICE FOR PRODUCTION OF HIGH-SPEED ELECTRONS

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The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to the production of electrons with speeds equal to those produced by electrostatic fields of millions of volts. At present, the chief use of such high speed electrons is for the production of very hard X-rays. Such rays are used mainly for cancer therapy; but also they can be used in important research problems and for the examination of metal castings and other objects too thick for less penetrating X-rays.

It is an object of this invention to provide a device for producing high speed electrons which requires only relative low potentials as compared to certain prior devices.

A further object is the provision of a method and apparatus for producing high speed electrons more efficiently and easily than has heretofore been possible.

These and other objects are attained by the novel method and arrangement of apparatus hereinafter described and briefly speaking, one form of the invention resides in the combination of a plurality of cavity resonators the energizing fields of which are established by a pulsed magnetron and arranged whereby the cavity resonators successively increase the speed and mass of the electrons passing there through, illustrated by the accompanying drawing forming a part of this disclosure. The figure is a schematic diagram showing the arrangement of apparatus in accordance with the invention.

Referring to the block diagram in the accompanying drawings, there are shown sixteen cavity resonators designated by reference numbers 1 thru 16 respectively, all alike and all excited in the same phase by a pulsed magnetron 17, through coaxial transmission lines of equal lengths, made by branching in the same way as for the excitation of a synchronous antenna array.

The tubes 18 projecting into and connecting adjacent cavity resonators are of graded lengths depending upon the speeds of the electrons passing through them. The tubes are all grounded; and the fields between the tubes are of the electro-dynamic type such as cavity resonators, for example and do not involve high-voltage insulation. The electron gun shown diagrammatically at 19 has a cathode 23 which is charged to a high potential, and is kept negative by a direct current source 31. Its emission current is cut off by the grid 26 except during the pulses of the magnetron,

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when synchronous pulses on the grid permit it to shoot electrons into the first resonator. Some of these electrons, arriving in the "wrong" phase, are slowed down in this resonator and give up energy to it; but those which arrive in the "right" phase are speeded up by it.

If the field strengths and distances are properly proportioned, these speeded-up electrons will enter the tube leading to the second resonator before the end of the half cycle of electric field helping them along. In this tube there is no appreciable field, so the electrons spend the next half cycle drifting through field free space in the connecting tube, during which time retarding fields arise in the first resonator. They then emerge into the second resonator during the first half of the next cycle of helping field. They repeat this sort of hiding from hindering fields and coming out into helping fields, all the way through the line of resonators.

To see how the lengths of the connecting tubes should be proportioned, it must be noted that at these very high speeds the ordinary relation of speed to kinetic energy does not hold. Instead, if v is the speed of an electron and c is the speed of light,

$$v^2=c^2\left(1-\frac{1}{\left(1+\frac{V}{V_0}\right)^2}\right)$$

where V_0=509 kilovolts and V measures the kinetic energy, being the potential difference needed in a single field to get this energy. V_0 is twice the potential difference which would give an electron the speed of light if ordinary laws of mechanics extended to such speeds; but from this formula, when $V=V_0$, v^2 is still only ¾ of c^2, or $v=0.87c$. No matter how high V may be, v is always less than c.

For a typical case, assume that the potential of the cathode is $-V_0/2$, or −255 kv., and that each cavity is excited so strongly that its field gives an electron as strong a "push" as the cathode-to-ground field. (It cannot be said that the cavity has the same potential difference, because the laws of potentials do not apply to cavity-resonator fields; so by "push" is meant the line integral of the field through the cavity.) Under these conditions, the electron leaves the first cavity at the same speed as if it has fallen through a potential difference V_0, namely $0.87c$ and this is the speed in the first connecting tube.

In the last connecting tube, after 14 more $V_0/2$ pushes, the kinetic energy is equivalent to a fall through a potential difference $8V_0$. This makes

$v=0.993c$. So the last connecting tube must be long enough to space the centers of the resonators it connects $^{99}/_{87}$, or 1.14 times as far apart as the centers of the first and second cavities. The other distances on centers are, of course, intermediate between these, most of them being more nearly equal to the last than to the first.

To keep the lengths of the concentric lines from the magnetron all equal, the lines may be curved as shown in the diagram, if they all lie in one plane, or the longer ones may be taken out of this plane. With speeds such as herein considered, the phasing should be accurate enough if only the first 3 or 4 of lines 22 are curved and the rest straight and coplanar.

Under the assumed conditions the electron emerges from the last cavity with the same energy as if it had fallen through a potential of $8.5V_0$, or 4.3 million volts. With this energy it strikes the anode block 21, or target, as it is called in X-ray technique, and produces hard X-rays.

Many changes in the dimensions, frequency, voltages, and even the number of resonators, are possible, of course.

The magnetron may be operated at 200 megacycles with high frequency power between 100 and 200 kilowatts during pulses. When 1200 kilowatts are available there is an ample margin for building up the oscillations in each pulse and for driving the free electrons.

The tubes are made too small in diameter to act as wave guides and therefore they act as shields. The apertures projecting into the resonators set up fields which tend to keep the beam of electrons traveling in columns. It is of course possible to initiate flow of electrons in columns by use of electron guns which are well known in the art of radio. Cavity resonators 1 thru 16 are likewise well known in the radio art and are used in the production of microwaves.

For typical dimensions, if the frequency used is 200 mc., as in the example described above, the lengths of the drift tubes may be as follows:

Resonators	Drift Tube Lengths
	Cm.
1 and 2	64.6
2 and 3	68.8
3 and 4	70.8
4 and 5	71.9
5 and 6	72.6
6 and 7	73.1
7 and 8	73.5
8 and 9	73.8
9 and 10	74.0
10 and 11	74.1
11 and 12	74.2
12 and 13	74.3
13 and 14	74.4
14 and 15	74.5
15 and 16	74.5

where the values apply to the case described above in which ½ cycle is allowed for the electrons to pass through each drift tube and ½ cycle to pass through each resonator.

Care must be taken, as noted above, to have the resonators all respond alike to the exciting frequency. The gaps between the ends of the connecting tubes may all be equal and the lengths of the drift tubes must be selected to have a time of transmit equal to that part of the cycle not occupied by electron passage through the gaps in the resonators. If the gaps are long as in the example just described, an allowance must be made, in estimating the "push" defined above, for the fact that each electron takes a finite time to cross each gap. During this time the field and its line integral change, so the "push" is an average of the values the line integral which in the ½ cycle example given above is ½ the maximum value. If now, for example, the gaps are made of such length that an electron in some typical resonator takes only one sixth of a cycle to cross its gap, and it is desired to give it a "push" of 255 kv. in that cavity, the maximum value of the line integral will be 5% greater than 255 kv., or about 268 kv. The longer the gaps are, the more the voltage has to be raised for this cause, to get any required "push," but with this understanding any gap length of this order of magnitude may be used.

The first example given, wherein ½ cycle is allowed for the passage of electrons through the drift tubes and ½ cycle for passage through each resonator is intended for purposes of illustration and to facilitate description of the essential features of the device. In the second example, which is the preferred embodiment of the invention, the resonators are all substantially alike. The drift tubes project through the end walls of the resonators to provide a gap within each resonator in which electron acceleration takes place. The time of transit of electrons across each gap is made much shorter than the time of ½ cycle, preferably ⅙ cycle. During this relatively short interval of electron transit through each gap the line integral of electric field intensity is substantially a maximum. The value of this maximum required for a given electron "push" is therefore much less than for the ½ cycle example, and offers an advantage in obtaining a large output per resonator. The time of electron passage through the drift tubes must be correspondingly longer, that is, of the order of ⅚ cycle. The length of each drift tube, which is proportional to the time of drift, is correspondingly longer. In this example the length of the gap in each resonator may be 20 cm. and the length of the first drift tube may be 108 cm. as compared to 64.6 cm. given in the table. The length of the last drift tube may be 124 cm. as compared with 74.5 cm. The lengths of the intermediate drift tubes increase progressively from 108 cm. to 124 cm. after the manner shown in the table.

Having described my invention, what is claimed is:

1. An accelerator for producing very high velocity electrons comprising, a sequence of evacuated cavity resonators assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces connecting adjacent resonators means adjacent said cavity resonators for injecting electrons into the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, and electrons are accelerated within the resonators during one half cycle of the exciting frequency and drift between resonators during the next half cycle, said accelerative effects being successive and cumulative.

2. An accelerator for producing high energy charged particles comprising a sequence of evacuated cavity resonators assembled on a common axis with intervening spaces between resonators,

drift tubes in the intervening spaces connecting adjacent resonators, means adjacent said cavity resonators for injecting charged particles in the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, and said charged particles are accelerated within the resonators during one half cycle of the exciting frequency and drift between resonators during the next half cycle, said accelerative effects being successive and cumulative.

3. An accelerator for producing very high velocity electrons comprising, a sequence of evacuated cavity resonators assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces connecting adjacent resonators, means adjacent said cavity resonators for injecting electrons axially into the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all cavities are excited in the same phase, said cavity resonators and said drift tubes each having an electron transit time through each resonator and through each drift tube substantially equal to a half cycle period of the exciting frequency, whereby electrons are accelerated within the resonators during one half cycle and drift between resonators during the next half cycle, said accelerative effects being successive and cumulative.

4. An accelerator for producing very high velocity charged particles comprising, a sequence of evacuated cavity resonators assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces connecting adjacent resonators, means adjacent said cavity resonators for injecting charged particles axially into the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said cavity resonators and said drift tubes each having a particle transit time through each resonator and through each drift tube substantially equal to a half cycle period of the exciting frequency, whereby said charged particles are accelerated within the resonators during one half cycle and drift between resonators during the next half cycle, said accelerative effects being successive and cumulative.

5. An accelerator for producing very high speed electrons comprising, a sequence of cylindrical cavity resonators having progressively increasing lengths assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces having progressively increasing lengths connecting adjacent resonators, means adjacent said cavity resonators for injecting high speed electrons axially into the first resonator, means adjacent the last resonator for utilizing the electrons issuing therefrom and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of pulsed high frequency oscillations and coaxial transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having such lengths that all cavities are excited in the same phase, said cavity resonators and said drift tubes each having an electron transit time through each resonator and through each drift tube substantially equal to a half cycle period of the exciting frequency, and electrons are accelerated within the resonators during one half cycle and drift between resonators during the next half cycle, said accelerative effects being successive and cumulative.

6. An accelerator for producing very high speed charged particles comprising, a sequence of cylindrical cavity resonators having progressively increasing lengths assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces having progressively increasing lengths connecting adjacent resonators, means adjacent said cavity resonators for injecting high speed particles axially into the first resonator, means adjacent the last resonator for utilizing the particles issuing therefrom and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of pulsed high frequency oscillations and coaxial transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said cavity resonators and said drift tubes each having a particle transit time through each resonator and through each drift tube substantially equal to a half cycle period of the exciting frequency, and said charged particles are accelerated within the resonators during one half cycle and drift between resonators during the next half cycle, said accelerative effect being successive and cumulative.

7. An electron accelerator for producing high speed electrons comprising a sequence of cylindrical cavity resonators having progressively increasing lengths assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces having progressively increasing lengths connecting adjacent resonators, means adjacent said cavity resonators for intermittently injecting high speed electrons axially into the first resonator, means for exciting axial high intensity electric fields within the resonators, and a target adjacent the last resonator upon which high speed electrons impinge, said exciting means including a source of pulsed high frequency oscillations and coaxial transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said cavity resonators and said drift tubes each having an electron transit time through each resonator and through each drift tube substantially equal to a half cycle period of the exciting frequency, and electrons are accelerated within the resonators during one half cycle and drift between cavities during the next half cycle, said accelerative effects being successive and cumulative.

8. An accelerator for producing very high velocity electrons comprising, a sequence of similar evacuated cavity resonators assembled on a

common axis with intervening spaces between resonators, drift tubes in the intervening spaces connecting adjacent resonators, means adjacent said cavity resonators for injecting electrons into the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said resonators having an electron transit time therethrough less than one half cycle of the exciting frequency, each following drift tube having a time of drift therethrough occupying the remaining part of the cycle, whereby electrons are alternately accelerated in the resonators and drift through the following drift tubes, the accelerative effects being cumulative.

9. An accelerator for producing very high velocity charged particles comprising, a sequence of similar evacuated cavity resonators assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces connecting adjacent resonators, means adjacent said cavity resonators for intermittently injecting charged particles axially into the first resonator, and means for exciting axial high intensity electric fields within the resonators, said exciting means including a source of high frequency oscillations and transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said cavity resonators having a particle transit time therethrough of less than one half cycle of the exciting frequency, each following drift tube having a time of drift therethrough occupying the remaining part of the cycle, whereby the particles are alternately accelerated in the resonators and drift through the following drift tubes, the accelerative effects being cumulative.

10. An electron accelerator for producing high speed electrons comprising, a sequence of identical cylindrical cavity resonators assembled on a common axis with intervening spaces between resonators, drift tubes in the intervening spaces having progressively increasing lengths connecting adjacent resonators, means adjacent said resonators for intermittently injecting high speed electrons axially into the first resonator, means for exciting axial high intensity electric fields within the resonators, and a target adjacent the last resonator upon which high speed electrons impinge, said exciting means including a source of pulsed high frequency oscillations and coaxial transmission lines connected to said source and terminating in coupling loops within the individual resonators, said lines having equal lengths whereby all resonators are excited in the same phase, said resonators and said drift tubes each having an electron transit period through each resonator occupying a small part of a cycle of the exciting frequency and a transit period through the following drift tube occupying the remaining part of the cycle, said accelerative effects being successive and cumulative.

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