

June 12, 1951

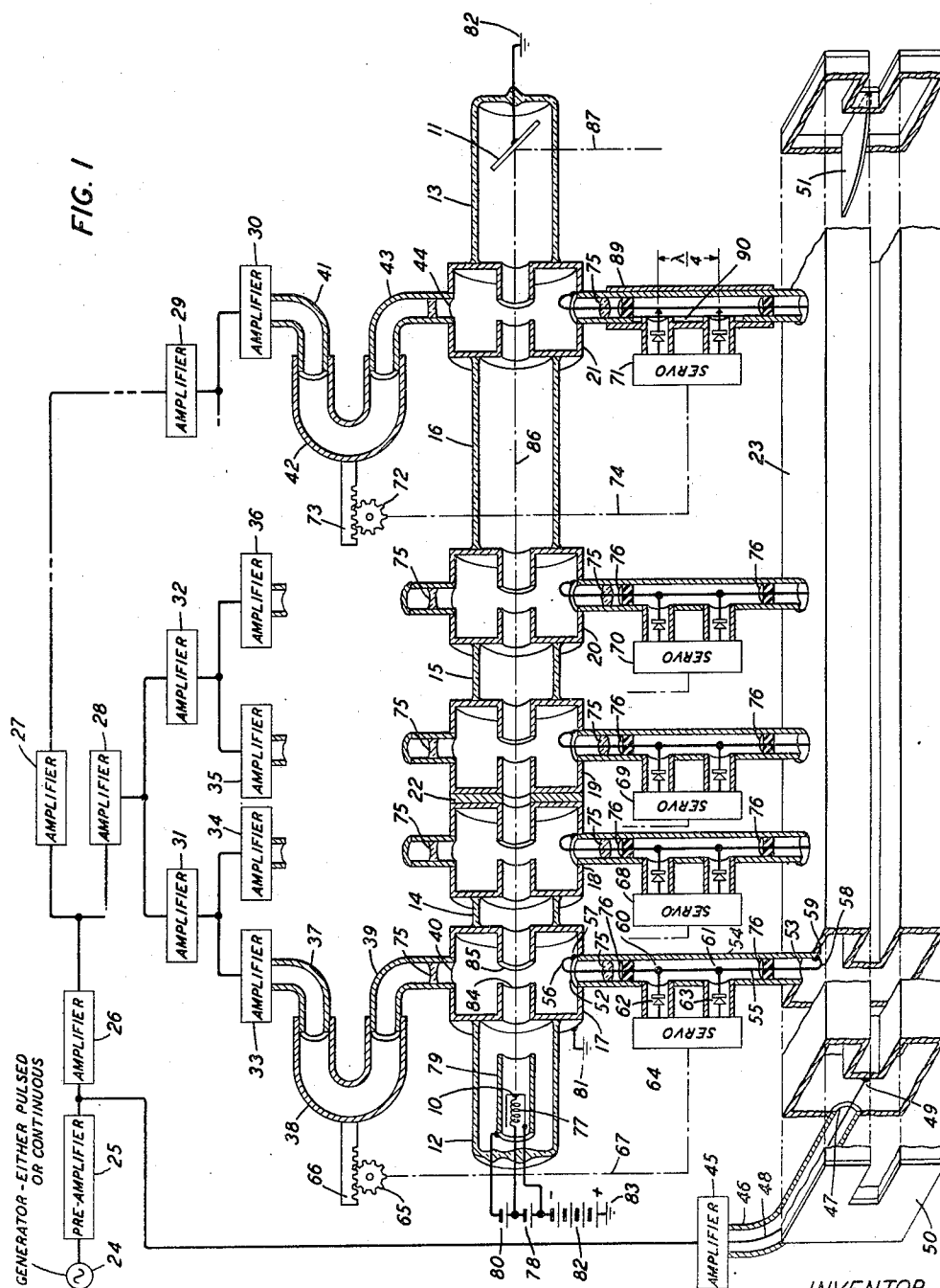
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2,556,978

LINEAR ACCELERATOR FOR CHARGED PARTICLES

Filed Oct. 7, 1948

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

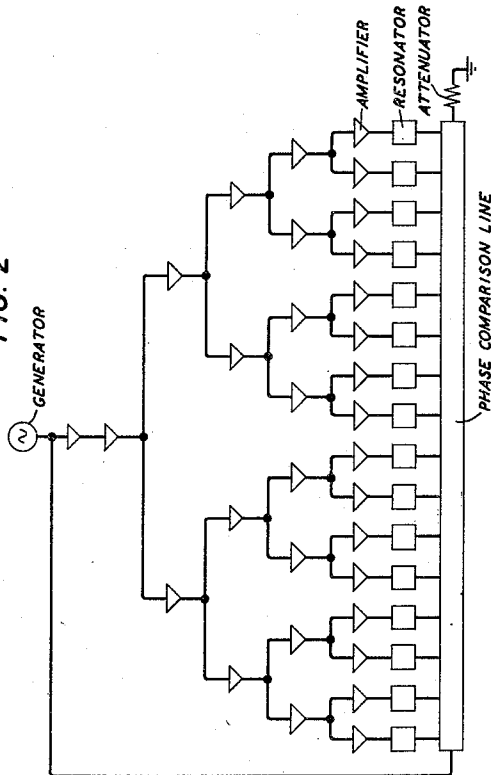


FIG. 3

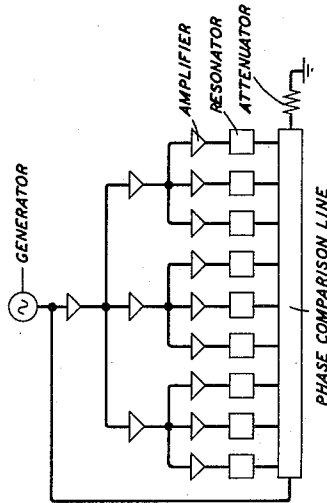


FIG. 4

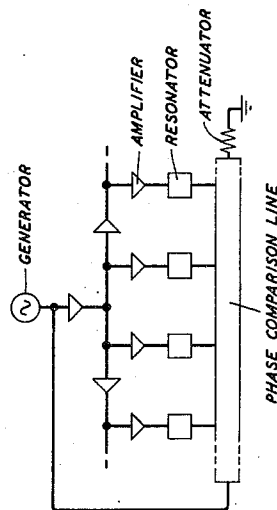
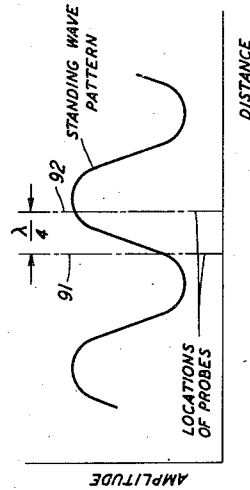


FIG. 5



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LINEAR ACCELERATOR FOR CHARGED PARTICLES

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3 Claims. (Cl. 250-27)

1

This invention relates to arrangements for accelerating electrically charged particles along a path which is not circular, reentrant or repeatedly traversed but which may be linear. More particularly, the invention is directed to an accelerator of the type in which accelerating potentials are developed along the path of the particles through the medium of electromagnetic oscillations or standing waves in a plurality of cavity resonators.

In accordance with the invention, a plurality of cavity resonators are arranged along the electron path, each resonator being provided with apertures through which the electrons may pass to be acted upon by the field in the resonator. To facilitate adjustment of the resonator fields so that they may individually be brought into the proper phase to accelerate the particles a phase reference transmission line is provided. The cavity resonators and the reference line are supplied from a common source of electromagnetic wave. Apparatus is provided for comparing the phase of oscillations in the resonator with the phase of the wave at a point in the transmission line. The supply line between the wave source and the resonator is made adjustable in length so that the phase of oscillations in the resonator may be varied. The length of this supply line is adjusted by means of a servo mechanism controlled by the phase comparison apparatus to stabilize the phase of oscillation in the cavity resonator. Each resonator has its own phase control and when all the phase controls are properly adjusted, the phase of oscillation in each resonator is automatically held to the proper value to secure the maximum acceleration of the particles which pass through the resonators.

It is contemplated that any number of resonators may be employed ranging from a few to a large number, perhaps a thousand or more, arranged along the path of the particles. In most cases the preferred arrangement will be a linear array of resonators coaxially mounted and longitudinally aligned. The resonators may be evenly spaced or irregularly spaced, there being nothing in the principle of operation of the device which requires uniform spacing. The gaps across which the charged particles travel will in general have to be evacuated in order to permit free passage of the particles. In some cases and with some kinds of charged particles the apertures through which the particles are to pass might be covered with thin metal or other foil which would allow the particles to pass without admitting air. The resonators may be stacked together or they

2

may be separated by spacers as desired. If foil is used, it may be supported by metal grills or grids.

If it is desired to use the accelerator with particles of various masses or charges, it is merely necessary to readjust the phases in the resonators to give the proper phase relation for each type of particle employed. The resonators can thus be adjusted to accommodate particles of any charge and mass regardless of the spacing between the resonators and regardless of whether the resonators are spaced evenly or irregularly. It is not necessary to change the phase, frequency or wavelength of the reference line or of the generator to adapt the apparatus to particles of different charges or masses.

The invention is more particularly described hereinafter in conjunction with the accompanying drawing in which:

Fig. 1 is a schematic of an accelerating system in accordance with the invention, showing the resonators and the envelope of the path of the particles as well as parts of the wave guide system in perspective and partly broken away to illustrate suitable structures;

Fig. 2 is a schematic diagram of a system of amplifiers shown connected to a plurality of resonators and to a reference line as employed in the practice of the invention, showing each amplifier output feeding two amplifier inputs to effect the required number of circuit branches;

Fig. 3 is a schematic diagram showing a distribution system in which each preliminary amplifier feeds three amplifiers, instead of two, in the succeeding stage;

Fig. 4 is a schematic diagram showing another arrangement for distributing amplified waves to the resonators; and

Fig. 5 is a diagram useful in the explanation of the phase control system employed in the invention.

Referring to Fig. 1, there are arranged within an evacuated envelope a cathode 10 for emitting electrons and a target 11 upon which electrons may impinge causing the target to emit X-rays. The arrangement shown is illustrative of one embodiment of the invention wherein the charged electric particles are electrons which are to be accelerated for the purpose of bombarding a target to cause the target to emit X-rays. The envelope comprises vitreous cup-like end members 12 and 13, vitreous cylindrical spacing members 14, 15 and 16 and cavity resonators 17, 18, 19, 20 and 21 of which resonators 18 and 19 are joined together by a ring of solder or other metal-

lie spacer 22. Alternatively, the resonators 18 and 19 may be welded together to form a vacuum-tight joint. It is advantageous to have all the resonators identical in size and shape, and in order that they may be driven by a single source of energy they should all resonate at the same frequency.

A generally U-shaped hollow pipe wave guide 23 is provided to serve as a phase reference transmission line and may advantageously extend generally parallel to the electron path between the cathode 10 and the target 11. A generator 24 of suitable design provides electromagnetic waves to energize the cavity resonators and the phase reference line at the resonant frequency of the cavity resonators. The generator may be either continuously operated or pulsed.

An amplifying system is provided between the generator 24 and the respective cavity resonators and includes a preamplifier 25, and a network of other amplifiers 26 to 36, inclusive. The amplifier 26 is connected in tandem with the preamplifier 25 and feeds into amplifiers 27 and 28 in parallel. Amplifier 27 feeds into amplifiers 29 and 30 in tandem. Amplifier 28 feeds into amplifiers 31 and 32 in parallel of which amplifier 31 feeds into amplifiers 33 and 34 in parallel and amplifier 32 feeds into amplifiers 35 and 36 in parallel. Amplifier 33 transmits electromagnetic waves to the resonator 17 through a hollow pipe wave guide 37, a trombone slide section of wave guide 38, and another hollow pipe wave guide 39 entering the resonator 17 through an aperture 40. The trombone slide 38 renders adjustable the effective length of wave guide between the amplifier 33 and the aperture 40 in the resonator 17 and hence determines the phase of the oscillations in the resonator 17. Similar adjustable wave guide facilities should be provided between amplifier 34 and resonator 18, amplifier 35 and resonator 19, and amplifier 36 and resonator 20. Such connections are shown broken away in Fig. 1 in order to simplify the drawing. The amplifier 30 is connected to the resonator 21 through a wave guide 41, a trombone slide section 42, a wave guide section 43, and an aperture 44.

The generator 24 is connected to the reference line 23 through the preamplifier 25, another amplifier 45, and a coaxial transmission line having an outer conductor 46 connected to one wall of the line 23 and communicating with the interior of the line through an aperture 47. The inner conductor 48 of the coaxial transmission line is extended into the interior of the line 23 and connected to an opposite wall thereof at a point 49. One end wall of the line 23 is shown at 50 and for best results the point of connection 49 will be spaced from the inner surface of the wall 50 by a distance of a quarter wavelength at the operating frequency of the wave in the line 23. A tapered attenuator 51 is provided at the far end of the line 23 to absorb energy from waves traveling through the line 23 and substantially prevent a reflected wave from returning toward the point 49.

To effect a phase comparison between waves in the reference line 23 and in the cavity resonator 17, a coaxial line connection is provided between an aperture 52 in the resonator 17 and an aperture 53 in the line 23. This coaxial line has an outer conductor 54 conductively connected to the resonator 17 at the edges of the aperture 52 and to the line 23 at the edges of the aperture 53. The coaxial line has an inner conductor 55 which extends into the resonator 17 in the form of an

inductive loop 56, the end of which is connected conductively to the wall of the resonator at the point 57. The other end of the conductor 55 terminates in an inductive loop 58 extending into the line 23 and conductively joined to the wall of the line at the point 59. Branch coaxial lines are provided at points 60 and 61, which are advantageously spaced a quarter wavelength apart. Each of these branch lines includes a detector such as a crystal detector 62 or 63 and these two branch lines form the input of a servo mechanism 64. The mechanical movement provided by the servo 64 is coupled mechanically to a pinion 65 arranged to drive a rack 66 which is mechanically coupled to the trombone slide element 38. The mechanical coupling between the servo 64 and the pinion 65 is indicated schematically by a dot-dash line 67. Similar servos 68, 69, 70 and 71 are provided for the resonators 18, 19, 20 and 21 respectively, the servo 71 being shown connected to a pinion 72 arranged to drive a rack 73 mechanically coupled to the trombone element 42 through a mechanical coupling shown schematically by the dot-dash line 74.

A plurality of vitreous plugs 75 are shown sealing the apertures 40, 44, 52 and similar apertures around the coaxial inner conductors to complete the continuity of the vacuum envelope. A plurality of wave-transmitting loss-introducing plugs 76 are provided to prevent undue reaction and possible regeneration through loop paths including the line 23 and the cavity resonators.

A heater 77 is provided for heating the cathode 10 by energy from a battery 78. A focusing conductive cylinder 79 is provided around the cathode 10 and may be maintained at a potential difference with respect to the cathode by means of a battery 80, it being advantageous to maintain the cylinder 79 at a somewhat negative potential with respect to the cathode. The metallic system comprising the resonator 17 and connecting metallic members is grounded at 81, and the target 11 is grounded at 82. An electron accelerating potential for providing the initial acceleration of electrons between the cathode 10 and the resonator 17 is provided by means of a battery 83 connected between the cathode 10 and ground 83, the cathode being negative with respect to ground.

It is advantageous that the resonator 17 have a narrow gap as between reentrant portions 84 and 85 and that the other cavity resonators be provided with similar gaps. It is also advantageous that the line 23 have a restricted portion as between the aperture 47 and the point of connection 49 in which region the transmitted wave will develop a high intensity of electric field.

The electron path is shown schematically by a dot-dash line 86 and the principal direction of emission of X-rays from the target 11 is shown schematically by a dot-dash line 87.

In the operation of the arrangement of Fig. 1 electrons emitted by the cathode 10 receive an initial acceleration due to the battery 82 in passing from the cathode to the resonator 17. Electrons which arrive at the gap 84-85 when the electric field across the gap is at a maximum in the proper phase to accelerate electrons and the system is properly adjusted, have their momentum increased additionally at the corresponding gap in each of the succeeding resonators and arrive at the target 11 with greatly increased kinetic energy so that they may produce X-rays, these being emitted principally in the direction of the line 87. The several resonators are driven by

the generator 24 through the network of amplifiers 25 to 36, inclusive. A wave of the same frequency is impressed upon the phase reference line 23 through the amplifiers 25 and 45 and the coaxial lines 46, 49.

By means of the rectifiers 62 and 63 direct current or low frequency potentials are impressed upon the servo mechanism 64 from the separated points 60 and 61 of the line 54. A mechanical output from the servo mechanism 64 is applied as a torque to the pinion 65 to operate the rack 66, thereby moving the trombone slide 38. Motion of the slide 38 continues until the high frequency potentials at the points 60 and 61 become equal when the output of the rectifiers 62 and 63 also become equal and the mechanical output of the servo 64 ceases. The mechanical linkage represented by the dot-dash line 67 must be adjusted in the proper phase to make possible a corrective action. In other words motion of the pinion 65 must be in the correct direction to make the slide 38 move in such a way that the potentials at the points 60 and 61 will be made more nearly equal. The operation of the phase comparison device will then act to maintain constant phase relationship between the oscillations in the resonator 17 and the oscillations in the line 23 at the position of the loop 58. In other words, a standing wave in the line 54 will be held in a stable position with respect to the points 60 and 61. The operation of the phase control may be explained and clarified by reference to Fig. 5 in which the abscissae represent distances along the line 54 and the ordinates represent the amplitude of the standing wave in the line. Vertical dot-dash lines 91 and 92 in this figure represent the position of the connection points 60 and 61, which for best results are approximately a quarter wavelength apart. As shown in Fig. 5, the amplitude of the standing wave is different at the positions of the lines 91 and 92. Adjustment of the slide 38 causes the standing wave pattern to move horizontally with respect to the vertical lines 91 and 92 and when these lines are symmetrically placed with respect to either a maximum or a minimum of the standing wave pattern, the potential is the same and the amplitude of the standing wave pattern is the same at the two points 60 and 61. Hence, the action of the servo mechanism is to keep the standing wave pattern continually adjusted to maintain a maximum or a minimum midway between the points 60 and 61.

Once the respective trombone slides 38, 42, etc. are adjusted to correct initial position and the points of connection 60, 61 and corresponding points on the other phase comparison line are adjusted to the proper position, the relative phases in the respective resonators will thereafter be automatically controlled to the proper values by means of the servo mechanisms. For purposes of the initial adjustment the phase comparison circuits may be arranged to be slidable along the coaxial line between the resonator and the phase comparison line. Such a slidable element is shown in conjunction with the servo mechanism 71 which is attached to a slidable sleeve 89 mounted over a slot 90 in the coaxial transmission line. The sleeve 89 may be adjusted longitudinally along the coaxial line into such a position that when the trombone slide 42 is given a proper initial adjustment the mechanical response of the servo mechanism 71 will be reduced to zero. Similar slidable arrangements may be provided in connection with the servo mechanisms 64, 68, 69 and 70.

To adapt the apparatus to employ particles of a different charge or mass, it is not necessary to make any change in the reference line 23 or in the frequency, wavelength, or phase of the high frequency exciting generator 24. It is only necessary to readjust the axial position of the points 60, 61 with respect to the line 54 and in general to effect the same adjustment on each of the corresponding standing wave lines. This adjustment is made in the case of the points of connection of the servo 71 by moving the slide 89 axially with respect to the slot 90. The system disclosed allows any desired phase with respect to the reference line to be maintained at the gap in any individual resonator by properly choosing the axial location of the points of connection of the detectors for the servos and thereby making the proper initial adjustment of the slide tuners 38, 42, etc. The phase at the gap in each resonator should be set at such value as will give maximum acceleration to a particle passing across the gap. All particles which arrive at the first gap when the phase is right for maximum acceleration will, when all the adjustments are correct, arrive at each succeeding gap at the proper instant to receive maximum acceleration. Particles which arrive at the first gap when the phase is unfavorable will in general fall out of step and on the average will not be accelerated. A proper adjustment of the system is thus seen to be independent of the actual phase velocity in the reference line and independent of the actual phase existing at any point in the reference line at any particular time. Furthermore, the frequency or wavelength in the reference line is not limited by the charge or mass of the charged particles with which it is designed to be used.

In a large installation of the type described where perhaps a thousand or more resonators are provided and extremely high particle energy is desired, it will be feasible to calculate by known transmission theory the optimum phase of oscillation for each of the resonators and to build the connections or wave guides between the respective amplifiers and the resonators of the proper length to give the desired phase at each individual resonator, the respective trombone slides then serving as trimming adjusters. The proper position of the connections 60 and 61 and the corresponding connections for each of the servo mechanisms may also be calculated and these connections may be built in at the proper point and need not be provided with slidable connections. In such a large installation the cost of the computation is expected to be considerably less than the cost of providing a large number of adjustable sleeve fittings. Calculations are made, of course, using a predetermined operating frequency. In the case of a small installation, it may be more feasible to adjust the trombone slide initially to give maximum increase of energy of the charged particles traversing the system and to thereafter adjust the servo mechanism to the proper position along each coaxial line to hold the trombone slide to the optimum setting.

The system of distribution through the amplifiers to the resonators and to the phase comparison line indicated in Fig. 1 is shown in greater detail in Fig. 2 for a system comprising sixteen resonators. It will be appreciated that this scheme of connection can be used with any number of resonators which represent the number 2 raised to the n th power, the number of amplifiers required being $2n$ plus whatever preampli-

fiers are necessary to get the power up to the desired level. The amplifiers can be pulsed simultaneously by turning on the plate voltage of the generator or by removing a bias from some electrodes of the generator which would normally turn off the cathode emission except during the pulse. The advantage of the connection shown in Fig. 2 is that the pulse does not have to pass through very many amplifiers to reach the resonators. The amplifiers themselves may be velocity-modulated tubes, traveling wave tubes, triodes or other amplifiers. A single grounded grid triode is recommended as an amplifier and is capable of giving a peak power of about 1 megawatt at a frequency in the neighborhood of 500 megacycles. Each amplifier needs only a 3-decibel gain as each amplifier drives two like tubes. More gain than that will enable the use of less preamplification to drive the pyramid of amplifiers.

The preamplifier can be excited either by continuous wave radio frequency power or by a pulse signal. This signal is advantageously derived from a crystal-controlled oscillator in conjunction with a frequency multiplier or from some other very stable frequency source.

Fig. 3 shows an alternative connection for the amplifiers in which each amplifier in the pyramid drives three other amplifiers. This means that each amplifier must have a gain of at least 4.8 decibels. Somewhat fewer amplifiers are required for the same number of resonators as compared with the arrangement of Fig. 2.

Another alternative connection of the amplifiers is shown in Fig. 4. The array of resonators may be fed from either end or from any intermediate point according to the scheme of Fig. 4. This arrangement is somewhat less desirable than the others in that it introduces a large number of amplifiers through which the signal must pass to get to the remote end of the accelerator.

What is claimed is:

1. An accelerator comprising means for directing charged particles along a path, a plurality of cavity resonators of the same resonant frequency mounted at successive positions along said path, each said cavity resonator having an inlet and an outlet for said particles, common exciting means for said cavity resonators, individual phase adjusting means for each said resonator, a phase reference transmission line driven by said common exciting means, individual phase comparison means connected between each said resonator and a respective point on said transmission line, and a servo mechanism connected between one of said phase comparison means and the individual phase adjusting means for one of said cavity resonators.

2. An accelerator for charged particles comprising means for directing charged particles along a fixed path, a plurality of syntonous cavity resonators mounted along said path, each said cavity resonator having an inlet and an outlet for said particles, common exciting means for said cavity resonators, a phase reference transmission line, individual wave transmission paths between each cavity resonator and a different point in said phase reference line, means for adjusting the relative phase of oscillations in each said cavity resonator, phase comparing means in each said individual wave transmission path, and a plurality of servo mechanisms each actuated by one of said phase comparing means and coupled to said phase adjusting means of the corresponding cavity resonator.

3. An accelerator for charged particles comprising means for directing charged particles along an established path, a plurality of syntonous cavity resonators mounted along said path, each said cavity resonator having an inlet and an outlet for said particles, phase adjusting means individual to each resonator, a source of electromagnetic waves of syntonous frequency, a pyramidal array of amplifiers for distributing power from said wave source to the respective cavity resonators, a phase reference transmission line adjacent to said cavity resonators, a driving connection between said wave source and said phase reference line, a plurality of phase comparison circuits each connecting one of said cavity resonators with a different point in said phase reference line, a plurality of servo mechanisms, each actuated by the phase comparison circuit connected to a different one of said cavity resonators and each coupled to the corresponding phase adjusting means belonging to the same respective cavity resonator.

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