Aug. 24, 1965 **R. L. BELBEOCH** **3,202,817**

POLYENERGETIC PARTICLE DEFLECTING SYSTEM

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Fig. 1.

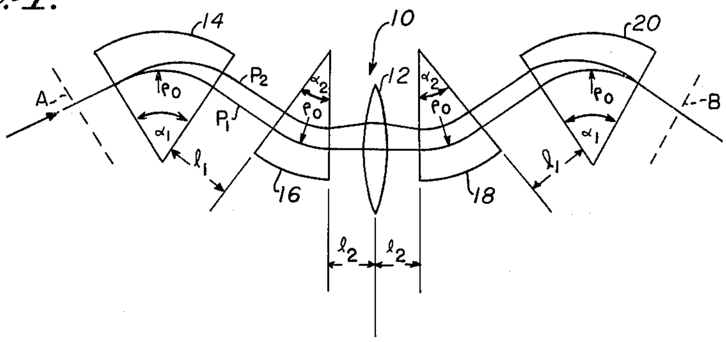

Fig. 2.

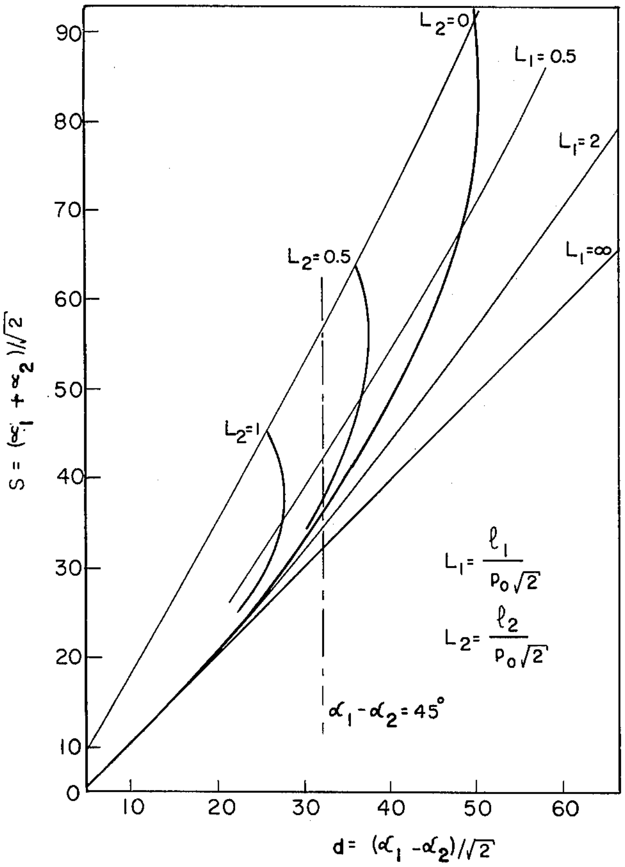

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Fig. 3.

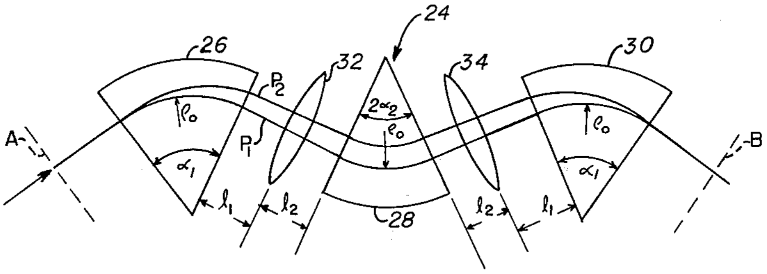
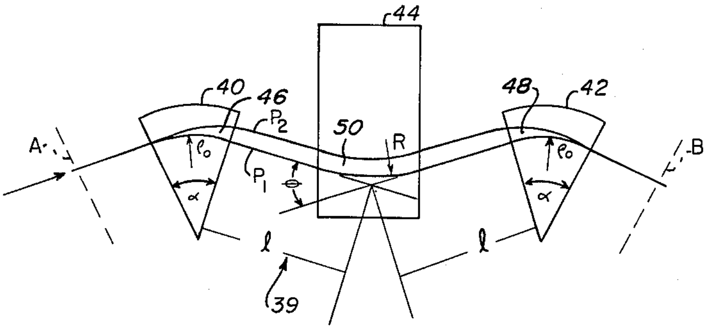


Fig. 4.



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POLYENERGETIC PARTICLE DEFLECTING SYSTEM

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11 Claims. (Cl. 250—41.9)

The present invention relates generally to the controlled deflection of charged particles and, more particularly, to the deflection of electrons or charged particles into, or from, a beam at angles greater than 45°, while conserving the given conditions of parallelism, beam diameter, and longitudinal bunching.

The problem of multiple beam operation in a long linear electron accelerator may be greatly simplified if the electrons can be injected into the machine at some angle with respect to the axis of the accelerator, or at some point therealong. That is, if the electron beam bunching characteristics are maintained before introducing same to the accelerator, it would not be necessary to place the beam injection devices in the main tunnel at the head of the accelerator. Beam injection devices could then be placed to inject at positions along the accelerator, allowing injection of beams of various energies. Multiple injection along the accelerator is preferred since such a design makes feasible the replacement or repair of any defective elements without need for stopping the entire operation of the machine. It is necessary, however, that the deflecting system which introduces the particles to the beam, preserve the parallel characteristic of the beam, and insure that no appreciable debunching occurs in a polyenergetic beam having a momentum spread of the order of 10 percent.

Parallel characteristics of a beam are achieved by prior art systems having zero transverse dispersion for object and image points at an infinite distance, that is, by an achromatic beam deflecting system. Such systems do not introduce the time-of-flight dispersion that is the cause of debunching (or "longitudinal dispersion") for a monoenergetic beam. However, although these systems maintain the transverse optical conditions in a beam having particles of varying energies during the deflection of the beam, some deficiencies are introduced therein. For example, large amounts of debunching may be introduced in a deflected polyenergetic beam. This debunching is the result of the time-of-flight dispersion of particles passing through the system for particles of different energies. Furthermore, this dispersion increases as the angle of deflection of the beam increases. Thus, to maintain a small phase spread in the bunches, only relatively small angles of deflection can be realized in an accelerator injection scheme utilizing an achromatic system of injection.

Since the path length is a function of energy, the choice of a possible system for large angle injection may, therefore, be determined by the debunching coefficient of the system and the energy spread of the beam. While utilizing in part an achromatic system such as described in the prior publication, "Magnetic Systems for Linear Accelerator Beam Injection," M–292, Standford Linear Accelerator Center, R. Belbeoch, the present invention further defines a method and the apparatus for deflecting polyenergetic particles along equal path lengths. In the particular case of deflecting relativistic particles the system can be said to be an isochronous deflecting system, which has equal time-of-flight path lengths. However, for any system dealing with non-relativistic particles, the system is not isochronous, per se, but can be classified as one wherein the path lengths are equal independent of particle energy. Thus, the present invention comprises a deflecting system wherein two or more particles entering the deflection system along initially parallel paths and from the same point will exit along parallel paths at the same time, regardless of their momentum or optical position within the beam. That is, if polyenergetic particles following initially parallel paths emanating from the same point have trajectories between the entrance and exit of the deflecting system such that the net magnetic flux enclosed between the trajectories of the particles equals zero, then the system is one having equal path lengths for particles independent of their energies as set forth in the present invention. Thus, the beam will keep to the first order its entrance properties of parallelism and constant beam diameter, as well as the optimum conditions of longitudinal bunching.

Basically, the concept set forth by the present invention for deflecting a polyenergetic beam of particles comprises compensating for the time-of-flight dispersion caused by bending the beam in one direction (as achieved in an achromatic system) by introducing a beam deflection of the proper magnitude in the opposite direction. That is, the condition for deflecting particles through equal path lengths is provided in a deflection system by changing the sign of the angle of deviation along the central trajectory of a particle beam therein. In particular, the system deflects polyenergetic particles through equal path lengths if the particles are deflected therethrough in accordance with the condition that:

$$l_d - X_0\int_A^B \frac{C(t)}{\rho(t)}dt + \theta_0\int_A^B \frac{S(t)}{\rho(t)}dt + \frac{\Delta p}{p}\int_A^B \frac{D(t)}{\rho(t)}dt + l_0$$

where:

A=the particle entrance plane
B=the particle exit plane
l_d=the difference between the path length of a particle with respect to the central particle path length at plane B
X_0=the lateral distance of a particle path from the central particle trajectory at plane A.
θ_0=the angle of deviation of a particle path with respect to the central particle trajectory at plane A.
p_0=momentum of the particle of central trajectory.
p=momentum of an (arbitrary) particle.
$\Delta p = p - p_0$.
l_0=the difference between the path length of a particle. with respect to the central particle path length at plane A.
$S(t)$=the function of a central particle trajectory or of the path along the system optic axis.
$C(t)$=the function of a particle trajectory with respect to the central particle trajectory.
$D(t)$=the deviation of an arbitrary particle from the central particle path at a position t and having a momentum of $p_0+\Delta p$.
$\rho(t)=1/h(t)$, where $h(t)$ is the curvature of an arbitrary particle on the central particle path at a position t.

Referring to the above equation, l_0 is made equal to zero since the particles are initially bunched; that is, the path length difference between two particles is zero at entrance plane A. Thus, the last term l_0 may be dropped from the equation. The first two terms of the equation define the paths through which particles must be deflected to achieve an achromatic deflection system as known in the art. That is, in order to achieve the necessary characteristics of an achromatic system as defined supra, it is necessary that these two terms be made equal to zero. Thus, the integrals of the first two terms which define the dispersion and parallel characteristics of an achromatic deflection system by the definition of the term achromatic are equal to zero.

In order to obtain the equal particle path lengths (to the first order) set forth in the method of the present invention, that is, to realize the requirement that path lengths be equal for all particles independent of their energy, it is necessary to make the third term of the equation, supra, equal to zero. Since $\Delta p/p$ is a finite value with respect to the deflection system chosen, and is not equal to zero, it follows that the integral

$$\int_A^B \frac{D(t)}{\rho(t)}dt$$

must be made equal to zero.

Therefore, it is an object of the present invention to provide a beam deflection method and apparatus therefor, capable of deflecting a beam of particles of different energy of momentum while conserving the beam properties of parallelism, beam diameter, and longitudinal bunching.

It is another object of the present invention to provide a deflection system for deflecting a beam into, or from, an accelerator at angles greater than 45 degrees.

It is yet another object of the present invention to provide a beam deflecting system wherein beam particles of varying energies are subject to a series of deflecting forces to direct same through predetermined paths or trajectories while maintaining the beam properties of parallelism, beam diameter, and longitudinal bunching.

It is a further object of the present invention to provide a beam deflecting method wherein the beam is deflected by electrostatic or magnetic forces arranged in predetermined patterns and configurations, while maintaining beam particles of varying energies in predetermined conditions of parallelism, constant beam diameter, and longitudinal bunching.

A still further object of the present invention is to provide a beam deflecting system wherein the time-of-flight dispersion for variously charged particles caused by bending the beam in one direction is compensated for by introducing a beam deflection of the desired magnitude in the opposite direction.

Yet another object of the present invention is to provide an isochronous beam deflection system wherein relativistic particles of varying energies comprising the beam will follow equal time-of-flight path lengths through the system.

Yet a further object of the present invention is to provide a beam deflection method wherein the beam is subjected to a series of deflecting forces, preferably magnetic, the series to be arranged in any of several possible patterns to provide the condition that particles entering together regardless of their related energies will exit together.

Still a further object of the present invention is to provide a method for deflecting a polyenergetic beam of particles through a prearranged series of deflecting forces so positioned, that if the entering particles are following initially parallel paths emanating from the same point in a predetermined entrance plane then after the particles are subjected to such deflecting forces they will exit along parallel paths at substantially the same point.

It is still another object of the present invention to provide a method for deflecting a polyenergetic beam of particles through a series of deflecting forces.

Other objects and advantages will be apparent in the following description and claims considered together with the accompanying drawings, in which:

FIGURE 1 is a ray diagram of the paths of two particles of different energies traversing in the horizontal plane, a beam deflecting system which utilizes four bending magnets and one quadrupole magnet as taught by the present invention.

FIGURE 2 is a plot of s versus d as a function of the curves L_1=constant and L_2=constant.

FIGURE 3 is a ray diagram of the paths of two particles of different energies traversing in the horizontal plane, a beam deflecting system which utilizes three bending magnets and two quadrupole magnets as taught by the present invention.

FIGURE 4 is a ray diagram of the paths of two particles of different energies traversing in the horizontal plane, a system which utilizes two bending magnets and one off-center quadrupole magnet as taught by the present invention.

It is to be understood that the above embodiments constitute isochronous deflecting systems when utilized in conjunction with a beam of relativistic particles.

The conditions that must be fulfilled to provide a system through which particles are deflected in equal path lengths independent of energy, can be established by referring primarily to the characteristics of the deflection of particles exposed to the deflecting forces. FIGURE 1 shows an embodiment of a deflection system **10**, for exemplifying the concept of the present invention, utilizing a series of five magneto-optical elements. It is to be understood however, that magnetic or electric deflecting means can be employed. The embodiment utilizes one quadrupole lens, or magnet **12** which is appropriately positioned between four bending magnets **14**, **16**, **18**, and **20**. The bending magnets **14** and **20** are preferably identical as are bending magnets **16** and **18**, the combination thereof being disposed symmetrically in relation to the central quadrupole magnet **12** as shown in the figure.

With such configuration, two relativistic particles P_1 and P_2 having different energies enter the deflection system **10** along a common path simultaneously (at plane A) with respect to time. P_1 is assumed to be the paritcle which follows a central path or trajectory. Initially, the particles P_1 and P_2 are caused to disperse upon entering the first bending magnet **14**, (since a particle of higher energy will have a larger radius of curvature, or will be deflected less than a particle of lower energy, within the same magnetic field) such particles to thereafter follow divergent paths from such first bending magnet through the second bending magnet **16**. Upon passing through bending magnet **16**, the diverging non-mono-energetic particles P_1 and P_2 are subject to a slightly convergent effect but exit from magnet **16** in still a diverging condition. The particle P_1 thereafter passes into substantially the center of the quadrupole magnet **12** and is unaffected thereby. Particle P_2 does not pass through the center of the quadrupole magnet **12** and is bent toward P_1 in a symmetrical relation with respect to quadrupole magnet **12**. Thus, quadrupole magnet **12** does not influence a particle passing through the center thereof, but does influence any particles which attempt to pass therethrough at an eccentric position; such effects of a conventional quadrupole magnet or lens being well known in the art and therefore not further discussed herein. The particles P_1 and P_2 thereafter pass through bending magnet **18** whereby the particles experience a converging effect. The converging particles P_1 and P_2 thereafter pass through bending magnet **20** to further converge and subsequently exit therefrom in a substantially identical path.

For the particular arrangement of the bending magnets and quadrupole magnet in the system **10** of FIGURE 1, the exit path of particles P_1 and P_2 is disposed at a particular angle with respect to the angle of the entrance path thereof; the magnitude of such angle to be determined by the sequence of the magnet components, the distance between these components, the angle of deflection, the radius of curvature of the deflecting magnets and the focal length of the quadrupole magnet. Thus, similar magnets **14** and **20** have an angle of beam deflection, α_1; similar magnets **16** and **18** have an angle of beam deflection, α_2; magnets **14**, **16**, **18**, and **20** all have equal radii of curvature, ρ_0; magnet **14** is situated a distance l_1 from magnet **16**; magnet **16** is situated a distance l_2 from quadrupole magnet **12**, magnet **12** is situated a distance l_2 from magnet **18**; and magnet **18** is situated a distance l_1 from magnet **20**. Thus, magnet **14** bends the beam in an initial direction, magnet **16** bends the beam in an opposite direction, the beam is focused by the quadrupole magnet **12**, is then deflected in the opposite direction by magnet **18**, and finally deflected in the initial direction by the last magnet **20**.

In keeping with the theory set forth by the invention, particles P_1 and P_2 not only exit from the system **10** along the identical exit path (with zero momentum dispersion, and parallel characteristics) but also are located therealong at substantially the same point with respect to time. That is, particles P_1 and P_2 which simultaneously enter the system at entrance plane A simultaneously leave the system at exit plane B along the exit path. Therefore, to obtain the desired characteristics of equal path length for all particles independent of energy, the present invention compensates for the time-of-flight dispersion due to the bending of the beam in one direction by introducing a deflection of the proper magnitude in the opposite direction. Thus, charged particles with larger or smaller momentums will travel the same path lengths; that is will have the same path lengths along the system **10**, and in particular, for a system dealing with relativistic particles, will have the same time-of-flight path length. The particles must generally be subject to those conditions of achromatic systems discussed in the aforementioned reference, in order to achieve a system having the over-all characteristics desired in the present invention. More particularly, the monoenergetic particles entering the system of the present invention along divergent paths from a point, or separate parallel paths, must have trajectories between the entrance and exit of the system such that the net magnetic flux enclosed by two adjacent paths or trajectories of monoenergetic particles must equal zero as explained in the above noted reference.

The construction of the embodiment of FIGURE 1 wherein the mechanism of the present invention is more specifically set forth, is further exemplified by the following, brief theory. The magnets utilized are assumed to be the n-type, wherein $n=\frac{1}{2}$ and the radius of curvature ρ_0 of the central particle orbit is identical in all four magnets.

The following parameters may be used (as definitions of s and d),

$$s\frac{\alpha_1+\alpha_2}{\sqrt{2}} \quad d=\frac{\alpha_1-\alpha_2}{\sqrt{2}}$$

where α_1 and α_2 are the angles through which the beam is deflected within a magnet (as further defined in FIG. 1). If the total deflection angle is assumed to be $2(\alpha_1-\alpha_2)$, the system is defined by four variables, l_1, l_2, $1/f$ and s, and three conditions must be fulfilled.

$$(y|y_0)=(x|x_0)=0$$

$$\left(\theta\middle|\frac{\Delta p}{p_0}\right)=0$$

$$\left(L\middle|\frac{\Delta p}{p_0}\right)=0$$

where

y=Distance from a particle to the central particle orbit or trajectory in the vertical plane

x=Distance from a particle to the central particle orbit in the horizontal plane

θ=Angular divergence of a particle orbit from the central particle orbit

$\Delta p=p-p_0$

p_0=Means momentum of the beam

L=Path length of an arbitrary particle

l_1=Distance between magnets **14**, **16** and also between magnets **18**, **20**

l_2=Distance between magnets **16**, **12** and also between magnets **12**, **18**

f=Focal length of quadrupole magnet **12**

In reality $(y|y_0)=(x|x_0)$ is a fourth condition, which, however, is fulfilled by the inherent characteristics of the $n=\frac{1}{2}$ magnets utilized in the embodiment of FIG. 1. Thus, if $(x|x_0)=0$ and $(y|y_0)=0$, then the system has one degree of freedom remaining. For convenience the parameters in the following relations are changed to:

$$L_1=l_1/\rho_0\sqrt{2}$$

$$L_2=l_2/\rho_0\sqrt{2}$$

$$F=f/\rho_0\sqrt{2}$$

$$\alpha=\alpha_1/\sqrt{2}$$

$$\alpha'=\alpha_2/\sqrt{2}$$

Utilizing the above notations, Equation 1 gives the relations

$$L_1=\frac{s-4\sin s/2\cos d/2+\sin s}{\cos d-\cos s}$$

$$L_2=\frac{\cos s-L_1/2\ (\sin s+\sin d)}{\sin s-L_1/2\ (\cos d-\cos s)}$$

$$1/F=2B\frac{B+2\sin\alpha'}{B+2\sin\alpha}$$

with $B=-\sin(\alpha+\alpha')+L_1\sin\alpha\sin\alpha'$.

The results of the relations are shown in the plot of FIGURE 2, wherein the curves L_1=constant and L_2=constant are plotted in the graph of s versus d. The available region of this plane for which a physical solution exists is inside the curves $L_1=0$ and $L_2=0$.

The parameters for a 90° deflection device constructed in accordance to the invention of FIGURE 1, are given by

$$d=d_0/\sqrt{2}=45^\circ/\sqrt{2}=31^\circ 51'$$

It is necessary to find a compromise between s as great as possible (which means α' great) and L_1L_2 not too small. This is achieved for

$$l_1=\sqrt{2}/4\rho_0$$

$$l_2=3\sqrt{2}/4\rho_0$$

$$\alpha_1=55^\circ 20'$$

$$\alpha_2=10^\circ 20'$$

FIGURE 3 shows a modified embodiment of a beam deflecting system **24** which utilizes three bending magnets **26**, **28**, and **30**, as well as two quadrupole magnets **32** and **34**. The quadrupole magnets **32** and **34** are alternately disposed between the similar bending magnets **26**, **28**, and **30**, the entire deflecting system **24** being symmetrically arranged relative to the central bending magnet **28**. Here again, particles P_1 and P_2 which enter the system along identical paths at substantially the same time, for example, at plane A, exit along substantially identical paths at substantially the same time at plane B. Again particle P_1 is considered the particle of central orbit. Similar magnets **26** and **30** have an angle of beam deflection α_1, and a central beam radius of curvature ρ_0; magnet **28** has an angle of beam deflection, $2\alpha_2$; and a central beam radius of curvature of ρ_0. The spacing of components in the embodiment of FIGURE 3 compares to that of FIGURE 1 in that magnet **26** is disposed a distance l_1 from quadrupole magnet **32**; magnet **32** is a distance l_2 from magnet **28**; magnet **28** is a distance l_2 from quadrupole magnet **34**, and magnet **34** is situated a distance l_1 from magnet **30**.

Again, in the embodiment of FIGURE 3, the deflecting means or forces are arranged in a pattern wherein monoenergetic particles entering the system along parallel or divergent paths have trajectories therethrough such that the net magnetic flux enclosed by two adjacent trajectories or paths of monoenergetic particles between the entrance plane and exit plane B must equal zero. That is, the summation of the flux enclosed between particle paths in magnets 26, 28, 30, 32, and 34 must be equal to zero. In the embodiment of FIGURE 3, the beam is deflected in an initial direction by magnet 26, is focused by quadrupole magnet 32, is thereafter bent in the opposite direction by magnet 28, is again focused by quadrupole magnet 34, and is finally bent again in the initial direction by magnet 30.

FIGURE 4 shows an isochronous beam deflecting system 39 which utilizes two bending magnets 40 and 42 disposed symmetrically about an off-center quadrupole magnet 44. Here again, particles P_1 and P_2 enter at substantially the same time and along an identical path to pass through the system and exit at substantially the same time and along an identical path, the exit path being disposed at a substantial angle to the entrance path. Off-center quadrupole magnet 44 must be of particular design to provide not only a converging effect of particle P_2 with respect to central particle P_1 (in the horizontal plane), but to also provide the bending effects of a bending magnet on the beam. In the deflection system 39 of FIGURE 4, the difference of path length due to the bending of the beam in one direction is compensated for by the introduction of a deflection of the proper magnitude in the opposite direction, thereby providing similar path lengths for particles of varying momentum as taught by the invention. Similar magnets 40 and 42 have an angle of beam deflection of α, and a central beam radius of curvature ρ_0. Magnet 40 is situated a distance l from the off-center quadrupole magnet 44, and magnet 44 is in turn a distance l from magnet 42. Due to the characteristics of an off-center quadrupole magnet, the radius of curvature of a beam passing therethrough is not constant. Thus, the average radius of curvature is equal to R, and the angle of beam deflection through the quadrupole magnet is θ.

Since the quadrupole magnets, such as shown in the FIGURES 1, 3, and 4, have a net convergent effect in the horizontal plane, their addition in the deflecting systems lends versatility to the arrangement of the deflecting magnets. That is, the strengths and relative spacings of the bending magnets may be varied depending upon the particular requirements of the desired deflection system.

Another means of expressing the conditions necessary for achieving the deflection system of the present invention is most evident from FIGURE 4. It may be said that the system deflects particles along equal path lengths independent of their energies when the sum of the flux within the bending magnets and quadrupole magnet equals zero, for polyenergetic particles following initially parallel trajectories or paths emanating from the same point. That is, such a system is attained when the flux (area 46) within magnet 40, plus the flux (area 48) within magnet 42 is of such value and sign that, when added to the flux (area 50) within quadrupole magnet 44, the sum thereof will be equal to zero.

In summation, to obtain a beam deflecting system wherein particles passing therethrough have equal path lengths independent of their energies, it is essential to not only obtain the properties of an achromatic beam deflecting system, i.e., provide the conditions of parallelism and constant beam diameter, but to further provide a condition of longitudinal bunching. Basically, as previously described, such longitudinal bunching is provided in the above-described embodiments by compensating for the time-of-flight dispersion due to the bending of the beam in one direction by introducing a deflection of the proper magnitude in the opposite direction.

While the present invention has been disclosed herein with respect to various preferred embodiments, it will be apparent that numerous variations and modifications may be made within the spirit and scope of the invention and, thus, it is not intended to limit the invention except by the terms of the following claims.

What is claimed is:

1. A method for deflecting a beam of polyenergetic charged particles through equal particle path lengths independent of the particle energies while preserving the bunching characteristics thereof comprising applying a succession of charged particle deflecting forces to said polyenergetic beam; maintaining said succession of deflecting forces with predetermined spacings therebetween and in predetermined orientation with respect to said polyenergetic beam to direct said beam through a predetermined deflection within the region of application of each of said deflecting forces; maintaining the summation of said predetermined deflections within the region of each of said deflecting forces commensurate with said spacings and said orientations to deflect all the monoenergetic particles following initially parallel paths an amount to satisfy the condition that

$$\int_A^B \frac{C(t)}{\rho(t)}dt=0$$

to deflect all the monoenergetic particles following initially divergent paths emanating from a point in a predetermined entrance plane an amount to satisfy the condition that

$$\int_A^B \frac{S(t)}{\rho(t)}dt=0$$

and to deflect all the polyenergetic particles following initially parallel paths emanating from the same point in a predetermined entrance plane an amount to satisfy the condition that

$$\int_A^B \frac{D(t)}{\rho(t)}dt=0$$

where

A is the entrance plane,

B is the exit plane,

t is the distance from the entrance plane A as measured along the central particle path,

$C(t)$ is the deviation of an arbitrary particle from the central particle path at a position t (at the entrance plane A the arbitrary particle is parallel to the central path, that is, the slope of $C(t)$ at $t=0$ [plane A] is zero),

$S(t)$ is the deviation of an arbitrary particle from the central particle path at a position t and having the same momentum as the central particle (at an object or image point $S(t)=0$ by definition),

$D(t)$ is the deviation of an arbitrary particle from the central particle path at a position t having a momentum of $p_0+\Delta p$ where p_0 is the momentum of the central path particle and Δp is the difference of momentum between a particle and the central particle,

$\rho(t)=1/h(t)$ where $h(t)$ is the curvature of an arbitrary particle on the central particle path at a position t.

2. A method for deflecting a beam of polyenergetic charged particles through equal particle path lengths in accordance with claim **1** wherein said step of applying a succession of charged particle deflecting forces to said polyenergetic beam further comprises applying a succession of magnetic fields perpendicular to said beam path by means of n-type bending magnets.

3. The method for deflecting a beam of polyenergetic charged particles in accordance with claim **2** wherein said applied magnetic fields are symmetrically arranged relative to a plane of symmetry of the deflecting system.

4. The method for deflecting a beam of polyenergetic charged particles in accordance with claim **1** wherein said step of applying a succession of charged particle deflecting forces further comprises the steps of applying a divergent deflecting force, applying a focusing deflecting force, and applying a convergent deflecting force.

5. The method for deflecting a beam of polyenergetic charged particles in accordance with claim **4** wherein the angle of deflection applied to said particles by said divergent deflecting force has initially a preselected sign, the angle of deflection applied by said focusing deflecting force has an opposite sign, and the angle of deflection applied by said convergent deflecting force has the initial sign again.

6. The method for deflecting a beam of polyenergetic charged particles in accordance with claim **4** wherein the steps of applying said divergent deflecting force and said convergent deflecting force further comprises applying said divergent deflecting and convergent deflecting forces by means of similar n-type magnets with $n=\frac{1}{2}$, and the step of applying said focusing deflecting force to said beam further comprises applying said focusing deflecting force by means of an off-center quadrupole lens.

7. The method for deflecting a beam of polyenergetic charged particles through equal particle path lengths independent of the particle energies while preserving the bunching characteristics thereof in accordance with claim **1** wherein the step of applying a succession of charged particle deflecting forces to said beam further comprises applying a first divergent deflecting force, applying to a second divergent deflecting force to the deflected diverging particles, subjecting said deflected diverging particles to a focusing force, applying a first convergent deflecting force to said beam of polyenergetic charged particles applying a second convergent deflecting force to said beam of polyenergetic charged particles.

8. The method for deflecting a beam of particles according to claim **7** wherein said first divergent deflecting force directs the particles initially in one direction with respect to the original beam path direction, said second divergent deflecting force directs the particles in an opposite direction with respect to the original beam path direction, said first convergent deflecting force directs the particles in the same opposite direction, and said second convergent deflecting force directs the particles in the initial direction again.

9. The method for deflecting a beam of polyenergetic charged particles through equal path lengths independent of the particle energies while preserving the beam's bunching characteristics in accordance with claim **1** wherein the step of applying a succession of charged particle deflecting forces to said polyenergetic beam further comprises applying a divergent deflecting force to said beam of polyenergetic charged particles, applying a focusing force to said beam, applying a first convergent deflecting force to the diverging particles, applying a focusing force to said converging particles, applying a second convergent deflecting force to said deflected converging particles.

10. The method for deflecting a beam of polyenergetic charged particles according to claim **9** wherein said divergent deflecting force directs the particles initially in one direction with respect to the original beam path direction, said first convergent deflecting force directs the particles in an opposite direction with respect to said original beam path direction, and said second convergent deflecting force finally directs the particles again into the initial direction.

11. A method for deflecting a beam of polyenergetic charged particles initially travelling in parallel trajectories and following paths emanating from a common point through equal particle path lengths independent of the particle energies while preserving the bunching characteristics thereof in a linear charged particle accelerator comprising applying a succession of charged particle deflecting forces to said polyenergetic beam; and maintaining the amount and direction of deflection of said particle paths within the region of application of said forces by regulating said succession of charged particle deflecting forces so that the sum of the flux within the region of the deflecting forces equals zero for said polyenergetic particles following initially parallel trajectories and following paths emanating from a common point.

References Cited by the Examiner

UNITED STATES PATENTS

2,950,388	8/60	White	250—41.9
3,031,596	4/62	Leboutet et al.	250—41.9
3,087,055	4/63	Liebl	250—41.9

RALPH G. NILSON, *Primary Examiner.*