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RESONATOR PARTICLE SEPARATOR

Filed July 8, 1960

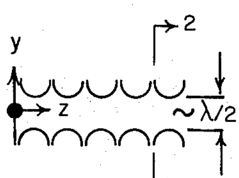

Fig. 1

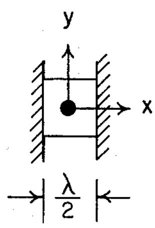

Fig. 2

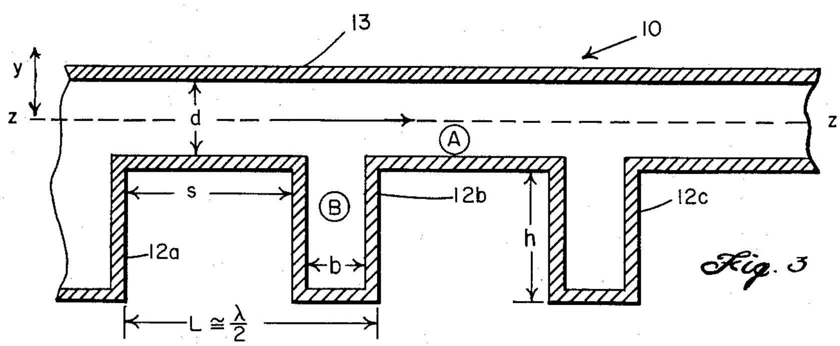

Fig. 3

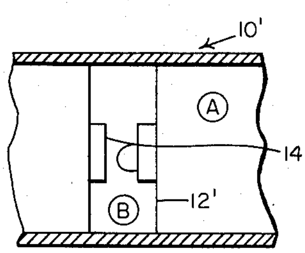

Fig. 4

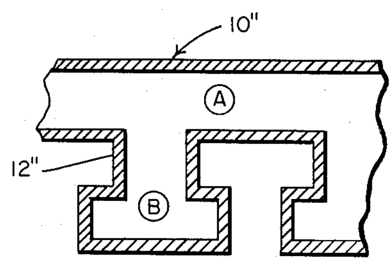

Fig. 5

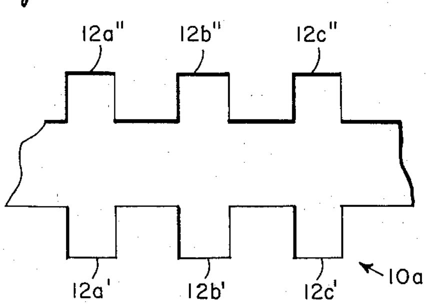

Fig. 6

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RESONATOR PARTICLE SEPARATOR

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This invention relates to radiofrequency resonators and more particularly to resonators for exerting preferential forces on high energy particles.

In high energy particle physics, it is often desirable to separate particles of equal momentum but different mass and having energies on the order of several billion electron volts. In the case of the particles having energies of about one billion electron volts, relatively simple techniques are available for effecting the desired separation. But in the case of particles having about 10 BEV and greater energies, the problem heretofore has not been readily solvable.

Wave guide resonators have heretofore been considered for the separation of high energy particles; however, an inherent difficulty with ordinary wave guide resonators is that they usually have field patterns which include an associated magnetic field component normal to the axis and to the transverse electric field. Because of the interaction of the magnetic and electrical fields in such a wave guide resonator, whereby the deflection caused by the transverse electric field is exactly cancelled by the deflection caused by the transverse magnetic field at the required phase velocity, the electromagnetic waveguide, TE mode, cannot be operated in a travelling wave mode. Therefore, to obtain a net deflection, the waveguide is operated very near "cut off," and the transverse magnetic field is then negligibly small. Since the phase velocity for cut off operation is greater than the particle velocity, the "apparent" phase velocity is reduced by the incorporation of drift tubes into the structure. As a result, it is difficult to realize an aperture greater than about a quarter wave length of the radiofrequency used to energize the wave guide because of the restricting effect of the "drift tubes."

This invention accomplishes the preferential deflection of high energy particles in a wave guide resonator in which there is established for deflection purposes, without the use of drift tubes, a field pattern including a traveling wave of deflecting electric field free from the usual magnetic field component whose effect, if present, would be to cancel the electric deflection. Separation of the particles is accomplished by this traveling wave tranverse electric field. The velocity of the wave down the wave guide is chosen such that the desired particles gradually slip backward or forward along the deflecting wave. The length of the separator may be selected so that the total slip between these particles and the wave is exactly a full wave length. The net effect is that the desired particles spend equal times in fields deflecting them in the two opposite directions and they emerge therefrom with their velocity parallel with the axis. At the same time, the wave velocity has been chosen equal to that of an undesired particle type; thus the field continues to deflect that particle in one or the other direction throughout the length of the separator. Since particles arrive at all phases, both beams are fanned out with maximum intensity at the extremes of the deflection. On emergence, the desired particles from a parallel beam as compared to the undesired particles which have velocity components away from the axis.

A wave guide resonator constructed to utilize the principles of separation described hereinabove, is shown in application Serial Number 16,902, filed March 22, 1960, in the name of John P. Blewett which matured into Patent No. 3,016,458 on January 9, 1963. In that arrangement, the boundary conditions required in accordance with these principles are established by the use of a plurality of discrete, charged members arranged in parallel array. While quite satisfactory for carrying out the separation of the particles as herein described, the present invention is an improved version in which there is provided a wave guide resonator of much simpler construction for the separation of the high energy particles. As pointed out in the theoretical discussion and mathematical analysis forming the basis of this invention in the paper, "A Radio-Frequency Mass Separator for Complete Separation of High Energy Particle Beams" by J. P. Blewett, which appears in the "Proceedings of the International Conference of High-Energy Accelerators and Instrumentation," Geneva, 1959, pages 422–427, published by the European Organization for Nuclear Research, the resonator must establish a boundary condition defined by

$$\sin h\alpha y \sin \alpha z = \text{constant} \qquad (1)$$

By the instant invention these boundary conditions are established by a construction having the advantages of structural simplicity which are readily translatable into lower construction costs. The improved wave guide resonator of the present invention can be fabricated conveniently from an electrically conducting material such as copper and has the form of a rectangular wave guide resonator having transverse stubs disposed in repeating pattern as specifically to be described below. Such a wave guide is readily powered by conventional microwave techniques, and being fully enclosed, does not radiate.

It is thus a first object of this invention to provide apparatus which can be used as a travelling wave structure for the preferential deflection of charged nuclear particle beams.

It is a further object of this invention to provide a resonator in which previous limitations in the use of such resonators to deflect high energy particles are removed.

It is still a further object to provide a resonator which can be used for particle beam separation.

Still another object of this invention is to provide a wave guide of simple construction for the deflection of composite particle beams in which one species of particles having a particular velocity emerges without deflection and all other species of particles having velocities greater or less than the preferred velocity experience deflection and emerge from the resonator with transverse velocity.

The exact nature of this invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification, relating to the accompanying drawing in which:

FIG. 1 shows preferred boundary conditions in accordance with the theoretical principles involved in this invention;

FIG. 2 is a view along 2—2 of FIG. 1;

FIG. 3 shows an elevation view in section of a wave guide constructed in accordance with the principles of this invention;

FIG. 4 is a top sectional view of an alternative embodiment;

FIG. 5 is a side sectional view of still another construction of a guide built according to this invention; and

FIG. 6 is an embodiment similar to FIG. 3.

Referring to the drawing in which like numerals are used to identify like parts throughout the several views, there is shown in FIGS. 1 and 2 the ideal boundary shapes for a wave guide resonator satisfying Equation 1 given above, in which y and z are the dimensions along their respective axes, α is chosen equal to ω/c where ω is $2\pi f$ and c is the velocity of the unwanted particle.

This ideal shaping of a wave guide is described and developed in the previously mentioned publication. As noted in the earlier patent application, the structure utilizing bars to form the boundary conditions shown in FIGS. 1 and 2 is satisfactory but many practical difficulties are involved in the construction of that type of wave guide.

Referring to FIG. 3, there is in accordance with the principles of this invention shown a simplified rectangular wave guide **10** utilizing lateral stubs **12***a*, **12***b*, etc. for accomplishing the boundary shape shown in FIGS. 1 and 2 capable of providing the separation as hereinabove described. Wave guide **10** supports a standing-wave pattern which has the desired traveling wave as one of its components provided the repeat length L is such that

$$2L/\lambda \cong v/c \cong 1 \quad (2)$$

where λ is the imposed wave length and v is the velocity of the desired particle. This structure can also support a simple travelling wave if properly terminated. As such it can be described electrically as a microwave filter having a band pass in the region of resonance as described herein.

The two regions A and B of FIG. 3 have slightly different cross sectional shapes so that the propagation constants Y and Y' of the two regions A and B, respectively, are different. The division is made so that electric energy is stored principally in region A to deflect the particles, and magnetic energy is stored in region B so that it will not deflect the particles. If in region A the dimensions are such that the region is near cut-off ($Y \cong 0$) and the dimensions of region B are chosen such that the region is above cut-off, a resonance can be obtained in the structure for a field pattern that can be used to deflect a particle beam.

A transmission-line solution can be obtained to describe this mode. In region A we can define propagation constant Y and a characteristic impedance Z for a transverse electric (TE) mode such that

$$Y=(2\pi/\lambda)\sqrt{1-(f_c/f)^2} \quad (3)$$

$$Z=\omega\mu d/Y \quad (4)$$

where: f_c=cut-off frequency of region A
f=operating frequency
λ=free space wavelength
μ=permeability of free space
d is the waveguide dimension indicated in FIG. 3.

In region B for propagation in the x direction

$$Y'=(2\pi/\lambda)\sqrt{1-f'_c/f)^2} \quad (5)$$

$$Z'=\omega\mu b/Y \quad (6)$$

where f'_c is the cut-off frequency in region B.

From transmission line theory the resonance relation is approximately

$$2\frac{Y'}{Y}\frac{d}{b}=\tan Y'h \tan Ys/2 \quad (7)$$

which neglects the effects of fringing fields at the junction of regions A and B. Since Y is small and $Y'h$ is almost equal to $\pi/2$ we can write

$$\tan Y'h \tan Ys/2 \cong \frac{1}{\pi/2-Y'h}\frac{Ys}{2} \quad (8)$$

and the resonance condition can be rewritten in the approximate form

$$\frac{4h}{\lambda}\sqrt{1-k^2}=1-\frac{\Delta f}{f_c}\frac{(2s/\lambda)(1-2s/\lambda)}{(2d/\lambda)\sqrt{(1-k^2)}} \quad (9)$$

where: $\Delta f=f-f_c$
$k=f'_c/f_c$

Typical solutions of Equation 9 are as follows:

f_c/f	h/λ	b/λ	d/λ	s/λ	k
0.954	0.275	0.1	0.1	0.4	0.5
0.950	0.276	0.125	0.125	0.375	0.5
0.9995	0.289	0.125	0.125	0.375	0.5

In order to demonstrate how this invention is utilized to select the wave guide dimensions in a particular situation, consider the case where it is desired to deflect π mesons travelling with anti-protons at particle momenta of 6 b.e.v./c. The π mesons are moving at relativistic velocities so that it is necessary to establish a travelling wave at the speed of light to deflect the π mesons. With an excitation frequency selected at 600 mc./sec. in order to obtain an overall wave guide of reasonable dimensions (other frequencies may be selected for economic or other practical considerations), the wave length λ of the travelling wave to be established will be c/f where c is the speed of light, or $300\times10^6/600\times10^6=0.5$ meter.

Substituting the values given in the second typical solution of Equation 9 listed in the table above into Equation 9, values of h, b and d are obtained as follows:

h=14.12 cm.
b=6.25 cm.
d=12.5 cm.

For the overall length of the wave guide, Equation 3 in the above-mentioned paper of J. P. Blewett may be utilized. In the above case, this is computed to be 36 meters.

Of course, it is understood that an alternate structure based upon the configuration of FIG. 3 to give better useful aperture can be constructed by assembling two of the basic structures of FIG. 3 back to back and leaving out the common wall **13**, as shown in FIG. 6. Stubs **12***a'*, **12***b'*, etc, and **12***a''*, **12***b''*, etc. correspond to the stubs in FIG. 3 with a pair of wave guides back to back as noted.

Alternate constructions to that shown in FIGS. 3 and 6 for carrying out the principles of this invention are shown in FIGS. 4 and 5, which embody techniques that may be used to shorten the length of region B (dimension h) to achieve a better mechanical design. The ridged guide resonator **10'** of FIG. 4 provides the same $f'_c/f_c=0.5$ and utilizes ridges **14** which partially fill the volume of stubs **12'**. In FIG. 5 there is shown a step guide resonator **10''** in which there will probably be lower power losses since current concentrations are not as high in this geometry as in the ordinary ridged guide of FIG. 4.

It is thus seen that there has been provided a waveguide structure capable of separating high energy nuclear particles of different masses and equal momentum. The structure is relatively simple in shape and offers greater flexibility in the use of wave guides for the separation of high energy nuclear particles as described above.

Thus it should be understood that the foregoing disclosure relates to only preferred embodiments of the invention and that numerous modifications or alterations may be made therein without departing from the spirit and scope of the invention as hereinafter defined by the appended claims.

We claim:

1. A TE mode wave guide standing wave resonator for removing an unwanted charged particle from a mixture of sub-atomic and nuclear particles of equal momentum and different masses and velocities having energies of 1 b.e.v. and above passing through said resonator by deflecting continuously the unwanted particle in the same direction transverse to its path through said resonator comprising, conductive walls forming a rectangular cross section along x and y mutually perpendicular axes and extending in length along a z axis perpendicular to said x and y axes, said particles travelling through said resonator parallel to said z axis, stubs with rectangular cross-

sections spaced on one wall along the length of said resonator and extending out in length parallel to said y axis, said stubs spaced at a repeat length of $\lambda/2$ where λ is the free space wave length of the travelling wave component of said standing wave moving in one direction down the length of said resonator in the same direction as and at a velocity identical to the velocity of said unwanted particle along its path in said resonator, and the dimensions of said wave guide resonator being in accordance with the relation

$$\frac{4h}{\lambda}\sqrt{1-k^2}=1-\frac{\Delta f}{f_c}\,\frac{(2s/\lambda)(1-2s/\lambda)}{(2d/\lambda)\sqrt{(1-k^2)}}$$

where h is the length of said stubs, k is the ratio f'_c/f_c, f'_c is the cut-off frequency of said stubs, f_c is the cut-off frequency of said wave guide, f is the frequency of said standing wave, Δf is $(f-f_c)$, s is the distance between

stubs measured parallel to said z axis and d is the internal width of said wave guide measured along said y axis to establish said standing wave.

2. The wave guide of claim 1 in which identical stubs are placed on the wall directly opposite the existing stubs and the internal width of said wave guide along the y axis is $2d$.

3. The wave guide of claim 1 in which the internal width thereof along the x axis is $\lambda/2$.

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