# United States Patent

**Bogomolov**

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[54] **METHOD FOR LINEAR ACCELERATION OF HEAVY CHARGED PARTICLES AND DEVICE FOR ITS REALIZATION**


[72] Inventor: **Alexei Sergeevich Bogomolov**, Morskoi prospekt, 16, kv. 40, Novosibirsk, U.S.S.R.



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[51] **Int. Cl.** ....................**H05h 9/02**
[58] **Field of Search** ....................315/5.41, 5.42; 328/233



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*Primary Examiner*—Raymond F. Hossfeld
*Attorney*—Holman & Stern

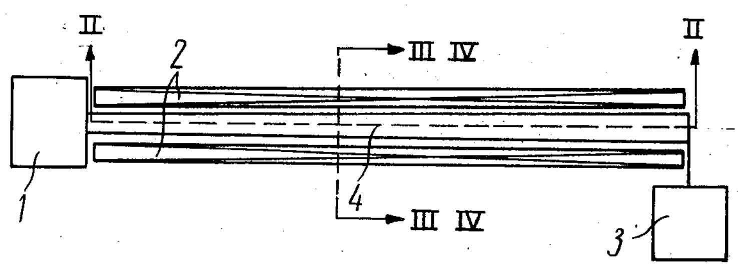


[57] **ABSTRACT**

A method for the linear acceleration of heavy charged particles wherein that there is produced a travelling-wave electromagnetic field which propagates against the accelerated beam and whose reverse spatial harmonic is travelling with a velocity which is in synchronism with the velocity of the accelerated beam, and the accelerated beam interacts with the longitudinal electric component of said electromagnetic field.

A linear heavy-particle accelerator in which the accelerating system is in the form of a waveguide fitted with means to secure synchronism between the velocity of the accelerated beam and the velocity of the reverse spatial harmonic of the travelling-wave electromagnetic field produced by an oscillator. The oscillator and the heavy-particle injector are coupled to the opposite ends of the waveguide.

**3 Claims, 4 Drawing Figures**

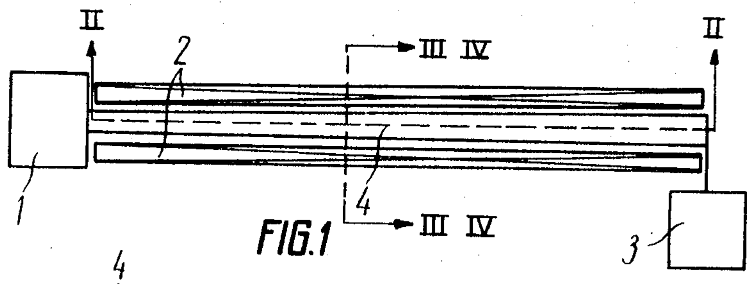



FIG.1

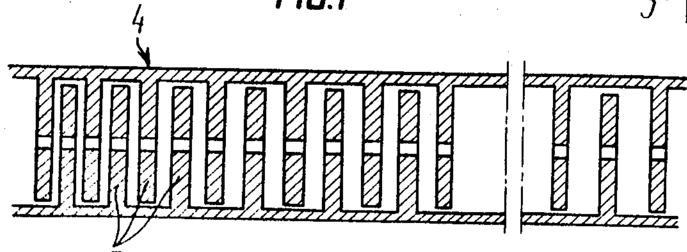



FIG.2

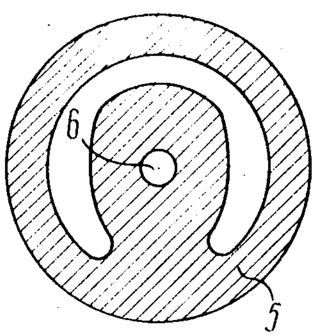



FIG.3

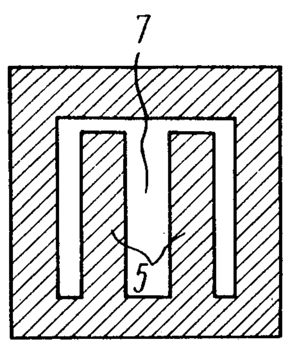



FIG.4

INVENTOR
A. S. BOGOMOLOV
Holman, Glascock, Downing & Seebold
ATTORNEYS

## METHOD FOR LINEAR ACCELERATION OF HEAVY CHARGED PARTICLES AND DEVICE FOR ITS REALIZATION

The invention relates to nuclear physics and, more particularly, to methods for the linear acceleration of heavy charged particles, such as protons, and devices for their realization.

There exists a method for linear acceleration of heavy charged particles by which the accelerated beam interacts with the longitudinal electric component of an electromagnetic field.

There exists a linear proton accelerator, i.e., a device to realize the said method, comprising a proton injector coupled to an accelerating system made in the form of a resonant cavity with a system of drift tubes arranged along the longitudinal axis of the latter, a focusing system, and an oscillator.

The cited method for the acceleration of heavy charged particles operates by the interaction of the accelerated beam with the longitudinal electric component of a standing-wave electromagnetic field. The standing wave electromagnetic field is produced in resonant cavities and the particles are accelerated across the gaps between drift tubes placed inside the cavities. The cavities operate within the VHF band.

The said method provides for the particles' energy gain of about one or two MeV./nucleon per meter of length of the accelerating system and cannot be realized in the UHF band because of the low velocity of the injected heavy particles, at least in the energy region below I00 MeV.

This is why existing linear heavy-particle accelerators are large in size, measuring tens and even hundreds of meters in length and about a meter in diameter.

It is an object of this invention to provide a method for the acceleration of heavy charged particles ensuring a greater energy gain per unit length of the accelerating system and making it possible to accelerate particles from a velocity which is a few hundredths of that of light.

It is another object of this invention to provide a device to realize the said method, which has substantially smaller linear dimensions and diameter in comparison with similar existing devices.

With these and other objects in view, the invention comprises a method for the linear acceleration of heavy charged particles such as protons by the interaction of the accelerated beam with the longitudinal electric component of an electromagnetic field, wherein there is produced, according to the invention, a travelling-wave electromagnetic field which propagates against the accelerated beam and whose reverse spatial harmonic is travelling with a velocity which is in synchronism with that of the accelerated beam.

In a device which realizes the said method for linear acceleration of heavy charged particles, comprising a heavy-particle injector coupled to one end of the accelerating system, a focusing system, and an oscillator, the accelerating system is, according to the invention, made in the form of a waveguide fitted with means to secure synchronism between the velocity of the particles and that of the reverse spatial harmonic of the travelling-wave electromagnetic field set up by the oscillator coupled to the waveguide at the end opposite to that coupled to the injector.

It is preferable to make the said synchronizing means in the form of opposing stubs in the waveguide, arranged with a pitch increasing in the direction away from the input waveguide end coupled to the injector towards the output end in accordance with a specified law of synchronism of the equilibrium particle velocity with the phase velocity of the backward spatial harmonic interacting with the particles.

A linear heavy-particle accelerator built according to the present invention provides for an energy increase of about I0 MeV./nucleon per meter of length of the accelerating system, so that the length of the accelerator may be reduced by an order of magnitude in comparison with existing accelerators.

The invention will be best understood from the following description of a preferred embodiment when read in connection with the accompanying drawings, wherein:

FIG. 1 is a general view of a linear heavy-particle accelerator according to the invention;

FIG. 2 is a longitudinal cross section through an accelerating system according to the invention;

FIG. 3 is a transverse cross section through an accelerating system according to the invention;

FIG. 4 is a transverse cross section through a modified form of the accelerating system according to the invention.

In carrying the invention into effect according to one convenient mode by way of example there is a linear proton accelerator (FIG. 1) comprising a proton injector I which may for instance be a duoplasmatron, a focusing system 2 which may consist of cuter lenses (for example, quadrupole ones), an UHF oscillator 3, and an accelerating system comprising a waveguide 4.

The proton injector I and the UHF oscillator 3 are coupled to the opposite ends of the waveguide 4. Hereinafter, the end of the waveguide 4 coupled to the injector I will be referred to as the input end, and the end coupled to the oscillator 3 will be referred as the output end.

The longitudinal cross section through the waveguide 4 in FIG. 2 shows stubs 5 made from the same material as the waveguide 4 and attached to its internal surface in such a manner that every next stub opposes the preceding one, and the pitch of the stubs 5 is made increasing away from the input end of the waveguide 4 towards the output end in accordance with a specified law of synchronism of the equilibrium particle velocity with the phase velocity of the backward spatial harmonic interacting with the particles.

The above-described arrangement of the studs 5 provides for synchronism between the velocity of the particle being accelerated and the velocity of that reverse spatial harmonic which accelerates the particles, which leads in the final analysis to a greater gain the energy of the accelerated particles.

The same effect can be achieved with a constant pitch between the stubs 5, but they should then be differing in length. In such a case, the length of the stubs 5 should be chosen to satisfy the requirement for synchronism.

FIG. 3 shows a transverse cross section through the waveguide 4. The configuration of the stubs 5 shown is preferable for round waveguides. In this case, the stubs 5 have a small central hole 6 to allow the passage of the accelerated beam.

FIG. 4 shows another modification of the stubs 5. This stub configuration is preferable for rectangular waveguides. In this case the accelerated beam is allowed to pass across the gap 7 between two rows of opposing stubs 5.

The accelerator disclosed herein operates as follows.

The proton beam shaped by the injector 1 enters the waveguide 4 which accepts electromagnetic energy from the oscillator 3 at the opposite end.

As the electromagnetic field propagates along waveguide 4 the construction of which is illustrated in FIG. 2, the electromagnetic field energy is dissipated in the walls and stubs of the waveguide and is converted into the energy of the particle beam due to the interaction of the particles with the longitudinal electric component of the backward spatial harmonic which is in synchronism with the particles being accelerated. The dissipation and conversion of the field energy, together with the electromagnetic field propagation in the direction opposite to the direction of the particle travel, make for the acceleration of the particles in an electromagnetic field having rising (in the direction of the particles travel) amplitude and with the backward spatial harmonic whose velocity, owing to the above-described arrangement of stubs 5, is in synchronism with the velocity of the accelerated particles. For example, with a UHF oscillator, such as a clystron type oscillator with the rated power output 20 to 40 MW., the amplitude of the backward harmonic will be about 100 to 300 kv./cm. at the waveguide end coupled to the UHF oscillator and, say, 1 to 50 kv./cm. at the waveguide end associated with the injector.

The acceleration of the particles in a field of rising amplitude results in a heavy damping of the phase oscillations of the particles and in a reduced phase extent of the bunch of particles. Owing to the reduced phase extent of the bunch and the damping of the phase oscillations of the particles in the bunch, the latter may be accelerated at high values of the equilibrium phase, thereby providing for an efficacious gain of the energy of the accelerated particles. The magnetic field of the focusing system **2** confines the accelerated beam inside the near-axial region of the waveguide **4**.

In the above-described example, only one stage of the accelerator has been described. To obtain larger final values of energy of the accelerated particles, the accelerator may comprise several such stages in cascade.

Advantages of the method for the linear acceleration of heavy charged particles disclosed herein consist in that the energy gain is about I0 MeV./nucleon per meter length of the accelerating system, the impulse current of the accelerated particles is increased five to ten times, and over 90 per cent of the injected particles are captured in acceleration from the continually injected beam.

The dimensions of the linear heavy-particle accelerator disclosed herein are significantly smaller than those of similar existing accelerators.

What is claimed is:

**1**. A method for linear acceleration of heavy particles comprising: injecting a beam of heavy particles at one end of an



elongated waveguide by means of an injector; producing a traveling wave electromagnetic field propagating against a direction of beam injection, and providing stubs in the waveguide with pitches progressively varying in the direction of beam injection to accelerate the beam so that a reverse spatial harmonic of the traveling wave of the electromagnetic field is in synchronism with a velocity of the accelerating beam.

**2**. A linear heavy-particle accelerator comprising: an accelerating system comprising an elongated waveguide; a heavy-particle injector coupled to a first end of said waveguide; an oscillator producing a travelling-wave electromagnetic field and coupled to the waveguide at an end opposite to said first end; means in said waveguide to ensure synchronism between a velocity of the accelerated beam and a velocity of the reverse spatial harmonic of said electromagnetic field; and a focusing system to secure transverse stability of the accelerated beam.

**3**. A linear accelerator as claimed in claim **2**, in which said synchronizing means comprises a plurality of opposing stubs arranged with a pitch which increases away from said first end towards the opposite end in accordance with a law of synchronism of the equilibrium particle velocity with a phase velocity of said reverse spatial harmonic.

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