embodiment as well.

[0072]

Note that residual magnetization of the permanent magnets is about 1 tesla at the maximum at present and is weaker than saturation magnetization (about 2 tesla in a case of iron) of the ferromagnetic material. Therefore, in a case where the main magnet A101 has a high magnetic field intensity (equal to or greater than 2 tesla, for example), there is a concern that the volume of the canceling magnetic field generation devices M214 may increase in order to appropriately cancel out the disturbance magnetic field. In addition, since magnetism of the permanent magnets such as a neodymium magnets or ferrite magnets changes depending on the temperature, it is necessary to consider stability of the magnetic field at the time of adjustment and operation. In addition, some permanent magnets are materials that are easily damaged and have low workablity, and it is thus difficult to use them for the canceling magnetic field generation devices M214 that require to be finely worked for their shapes. Therefore, it is more convenient to form the canceling magnetic field generation devices M214 using a ferromagnetic material as in the first embodiment.

[0073]

FIG. 9 is a diagram illustrating another example of a canceling magnetic field generation device formed of a permanent magnet.

[0074]

The canceling magnetic field generation device M242 illustrated in FIG. 9 is integrally formed and attached to an extraction channel partitioning wall portion M207a unlike the canceling magnetic field generation devices M241 that are formed of a pair of permanent magnets spaced apart from each other with the central plane M233 sandwiched therebetween as illustrated in FIG. 8. In addition, the canceling magnetic field generation device M242 is arranged to have a polarity opposite to that of a disturbance magnetic field generated by the extraction channel M207. Specifically, the canceling magnetic field generation device M242 is arranged to have a magnetic moment opposite to a magnetic moment that the extraction channel partitioning wall portion M207a has. Even in this case, it is possible to reduce the disturbance magnetic field generated by the extraction channel M207 with a canceling magnetic field of the canceling magnetic field generation device M241.

[0075]

Note that in the example of FIG. 9, the canceling magnetic field generation device M242 is located close to the extraction channel partitioning wall portion M207a, and there is thus a concern that an extraction channel magnetic field on the radially outer side is also reduced by the canceling magnetic field generation device M242, and it becomes difficult to deflect the beam to the extraction trajectory. For this reason, it is necessary to design the extraction channel M207 and the canceling magnetic field generation device M214 such that sufficient beam deflection can be obtained. In addition, since the thickness of the canceling magnetic field generation device M242 is added to the extraction channel partitioning wall portion M207a, a larger turn separation is required. As a result, it is substantially necessary to move the inlet of the extraction channel M207 away by the amount corresponding to the thickness of the canceling magnetic field generation device M242, and there is thus a concern that this may lead to degradation of beam extraction efficiency. Therefore, it is more convenient to use the canceling magnetic field generation device M214 formed of a ferromagnetic material as in the first embodiment.

[0076]

Since it is possible to achieve the reduction with the canceling magnetic field of the canceling magnetic field generation device M241 even if the canceling magnetic field generation devices M241 and M242 formed of permanent magnets are used as in the present embodiment as described above, it is possible to efficiently and satisfactorily extract beams with all energies to be extracted.

Third embodiment

[0077]

The present embodiment is different from the first embodiment in that an accelerator A100 includes canceling magnetic field generation devices formed of coils instead of the canceling magnetic field generation devices M214 formed of the ferromagnetic material.

[0078]

FIG. 10 is a diagram illustrating an example of the canceling magnetic field generation device according to the present embodiment and schematically illustrates a longitudinal section along a vertical plane of a main magnet A101 in the vicinity of a central plane M233.

[0079]

A canceling magnetic field generation device M250 illustrated in FIG. 10 includes a core portion M251 and a peeler magnetic field generation coil M252. The core portion M251 may be formed of a ferromagnetic body such as iron, or may be a coil bobbin formed of a resin having electrical insulation properties or the like. The peeler magnetic field generation coil M252 is a coil wound around the core portion M251.

[0080]

Also, a plurality of (in the drawing, a pair of) canceling magnetic field generation devices M250 are arranged plane-symmetrically with respect to the central plane M233 such that a beam traveling region is sandwiched therebetween. In addition, the canceling magnetic field generation devices M250 are arranged and controlled to have the same polarity as that of a magnetic field generated by the main magnet A101, that is, a polarity opposite to that of a disturbance magnetic field generated by an extraction channel M207. Note that control (for example, adjustment of the current to be supplied) of the peeler magnetic field generation coil M252 is performed by, for example, a control apparatus A140. In this manner, it is possible to reduce the disturbance magnetic field generated by the extraction channel M207 with a canceling magnetic field generated by the canceling magnetic field generation devices M250 similarly to the first embodiment in the present embodiment as well.

[0081]

The intensity of the magnetic field generated in the peeler magnetic field region by the extraction channel M207 is about several hundreds of millitesla in a case of a main magnet of about 2 tesla. In order to generate a magnetic field of several hundreds of millitesla only by a coil, a large capacity power source, a hollow conductor, a feedthrough, and the like are required, and there is thus a concern that this may lead to an increase in size of the device that generates the canceling magnetic field. Therefore, the canceling magnetic field is adjusted by winding the peeler magnetic field generation coil M252 around the core portion M251 in the present embodiment. In this case, the canceling magnetic field can be adjusted by changing the current to be supplied to the peeler magnetic field generation coil M252. In other words, it is possible to adjust a beam extraction ability during operation of the accelerator A100, for example, by using the canceling magnetic field generation devices M250. For this reason, it is possible to shorten a period of time required for beam adjustment and to absorb a decrease in beam extraction efficiency due to mixing of the disturbance magnetic field after the main magnet is disassembled for maintenance.

[0082]

FIG. 11 is a diagram illustrating an example of the canceling magnetic field generation device M250. In FIG. 11, only one of the pair of canceling magnetic field generation devices M250 arranged on the upper and lower sides with the central plane M233 sandwiched therebetween is illustrated. Also, FIG. 11(a) is a plan view seen from a side opposite to the central plane M233, FIG. 11(b) is a plan view seen from the right side of FIG. 10, FIG. 11(c) is a plan view seen from a direction perpendicular to FIG. 3, and FIG. 11(d) is a perspective view seen from the side of the central plane M233.

[0083]

As illustrated in FIG. 11, the core portion M251 of the canceling magnetic field generation device M250 has a curved shape along the peeler magnetic field region M205. Also, the peeler magnetic field generation coil M252 is wound around the core portion M251 in a clockwise or counterclockwise direction around a direction substantially perpendicular to the central plane M233 as an axis.

[0084]

As described above, the canceling magnetic field generation devices M250 are formed of coils, and it is possible to adjust the beam extraction ability of the beam during operation of the accelerator A100 and to thereby facilitate adjustment to efficiently and satisfactorily extracting the beam in the present embodiment.

[0085]

Each embodiment of the present disclosure described above is an example for explaining the present disclosure, and the scope of the present disclosure is not intended only to those embodiments. Those skilled in the art can practice the present disclosure in various other aspects without departing from the scope of the present disclosure.

Reference Signs List

[0086]

A100 accelerator

A101 main magnet

A102 ion source system

A103 extraction port

A110 beam transport line

A133 irradiation device

A140 control apparatus

M201 yoke

M202 main magnetic pole

M203 coil

M204 RF kicker

M205 peeler magnetic field region

M206 regenerator magnetic field region

M207 extraction channel

M207a extraction channel partitioning wall portion

M207b extraction channel adjustment portion

M208 extraction port through-hole

M209 acceleration electrode through-hole

M210 acceleration electrode

M211 rotating capacitor

M212 rotating capacitor driving power machine

M214, M241, M242, M250 canceling magnetic field generation device

M251 core portion

M252 peeler magnetic field generation coil

CLAIMS

[Claim 1]

An accelerator that accelerates an ion beam while causing the ion beam to circulate by a main magnetic field and an acceleration radiofrequency electric field, the accelerator comprising:

a main magnetic field generation device that applies the main magnetic field to a space between a plurality of main magnetic poles arranged to face each other;

a beam displacement device that causes the ion beam circulating in a main magnetic field region to which the main magnetic field is applied to be displaced to outside of the main magnetic field region;

an extraction channel magnetic field generation device that generates an extraction channel magnetic field to extract the ion beam that has been moved to the outside; and

a canceling magnetic field generation device that is provided to be closer to an inner peripheral side than the extraction channel magnetic field generation device and generates a canceling magnetic field with a polarity opposite to a polarity of the extraction channel magnetic field.

[Claim 2]

The accelerator according to claim 1, wherein the extraction channel magnetic field generation device is provided in an outer peripheral portion of a peeler magnetic field region where a peeler magnetic field that by disturbing the ion beam that has been displaced to an outer periphery of the main magnetic field region, which is outside of the main magnetic field region, causes the ion beam to move outward is generated.

[Claim 3]

The accelerator according to claim 2, wherein the canceling magnetic field generation device is provided above the peeler magnetic field region.

[Claim 4]

The accelerator according to claim 1, wherein the extraction channel magnetic field generation device includes a partitioning wall portion that passes through a traveling plane through which the ion beam travels and extends in a direction substantially perpendicularly intersecting the traveling plane.

[Claim 5]

The accelerator according to claim 1, wherein a plurality of the canceling magnetic field generation devices are plane-symmetrically arranged with respect to a traveling plane through which the ion beam travels.

[Claim 6]

The accelerator according to claim 1, wherein the canceling magnetic field generation device is arranged at a position spaced apart from the main magnetic pole in an axial direction perpendicularly intersecting a traveling plane through which the ion beam travels in the space.

[Claim 7]

The accelerator according to claim 1, wherein the canceling magnetic field generation device is a ferromagnetic body, a permanent magnet, or a coil.

[Claim 8]

The accelerator according to claim 7, wherein

the canceling magnetic field generation device is a ferromagnetic body, and

the ferromagnetic body is iron.

[Claim 9]

The accelerator according to claim 7, wherein

the canceling magnetic field generation device is a coil, and

a control apparatus that adjusts a current to be supplied to the coil is further included.

[Claim 10]

The accelerator according to claim 4, wherein

the canceling magnetic field generation device is a permanent magnet, and

the permanent magnet is attached to the partitioning wall portion.

[Claim 11]

The accelerator according to claim 2, wherein a shape of the canceling magnetic field generation device is defined in accordance with a magnetic field distribution of the extraction channel magnetic field generated in the peeler magnetic field region.

[Claim 12]

The accelerator according to claim 1, wherein the beam displacement device generates a peeler magnetic field that by disturbing the ion beam that has been displaced to an outer periphery of the main magnetic field region, which is outside of the main magnetic field region, causes the ion beam to move outward.

[Claim 13]

The accelerator according to claim 12, wherein

the beam displacement device generates a regenerator magnetic field that by disturbing the ion beam that has been displaced to an outer periphery of the main magnetic field region, which is outside of the main magnetic field region, causes the ion beam to move inward, and

the peeler magnetic field is generated on an upstream side, and the regenerator magnetic field is generated on a downstream side, with respect to a beam traveling direction.

[Claim 14]

A particle therapy apparatus comprising:

an accelerator that accelerates an ion beam while causing the ion beam to circulate by a main magnetic field and an acceleration radiofrequency electric field; and

an irradiation device that performs irradiation with the ion beam extracted from the accelerator,

wherein the accelerator includes

a main magnetic field generation device that applies the main magnetic field to a space between a plurality of main magnetic poles arranged to face each other,

a beam displacement device that causes the ion beam circulating in a main magnetic field region to which the main magnetic field is applied to be displaced to outside of the main magnetic field region,

an extraction channel magnetic field generation device that generates an extraction channel magnetic field to extract the ion beam that has been moved to the outside, and

a canceling magnetic field generation device that is provided to be closer to an inner peripheral side than the extraction channel magnetic field generation device and generates a canceling magnetic field with a polarity opposite to a polarity of the extraction channel magnetic field.

ABSTRACT

An accelerator capable of efficiently and satisfactorily extracting a beam is provided. A main magnet A101 applies a main magnetic field to a space between a plurality of main magnetic poles M202 arranged to face each other. An RF kicker M204 causes a beam circulating in a main magnetic field region to which the main magnetic field is applied to be displaced to outside of the main magnetic field region. An extraction channel magnetic field to extract the beam is generated. A canceling magnetic field generation device M214 is provided to be closer to an inner peripheral side than an extraction channel M207 and generates a canceling magnetic field with a polarity opposite to that of a disturbance magnetic field produced by an extraction channel.