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Miyashita et al.

(54) **ENERGY DEGRADER AND CHARGED PARTICLE BEAM IRRADIATION SYSTEM EQUIPPED THEREWITH**

(71) Applicant: **Sumitomo Heavy Industries, Ltd.**, Tokyo (JP)

(72) Inventors: **Takuya Miyashita**, Ehime (JP); **Takamasa Ueda**, Ehime (JP)

(73) Assignee: **Sumitomo Heavy Industries, Ltd.**, Tokyo (JP)

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(57) **ABSTRACT**

An energy degrader includes a plurality of attenuating members configured to attenuate the energy of an incident charged particle beam, the plurality of attenuating members having different amounts of energy to be attenuated. A low-energy-side attenuating member that is the attenuating member with a larger amount of energy to be attenuated is made of a material having a higher transmittance of the charged particle beam than that of a high-energy-side attenuating member that is the attenuating member with a smaller amount of energy to be attenuated.

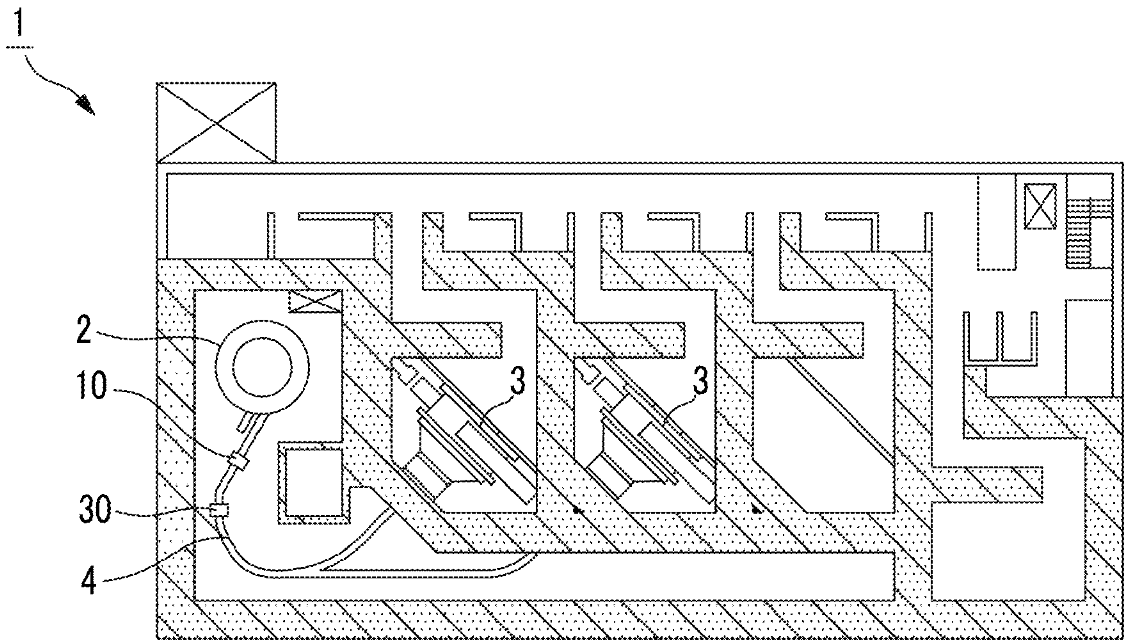


FIG. 1

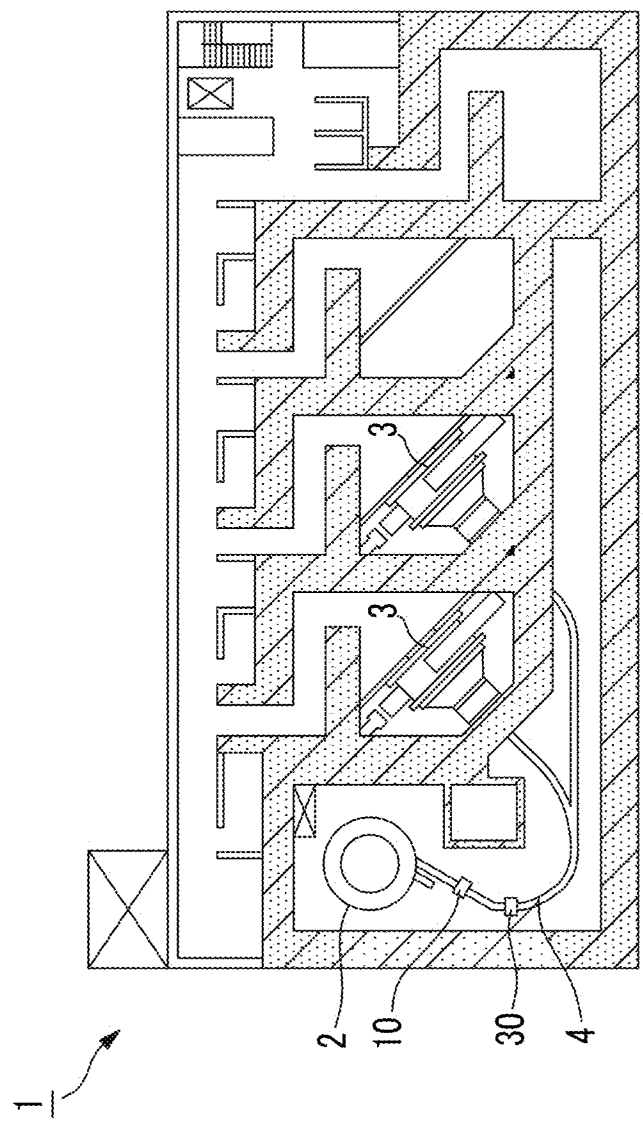


FIG. 2

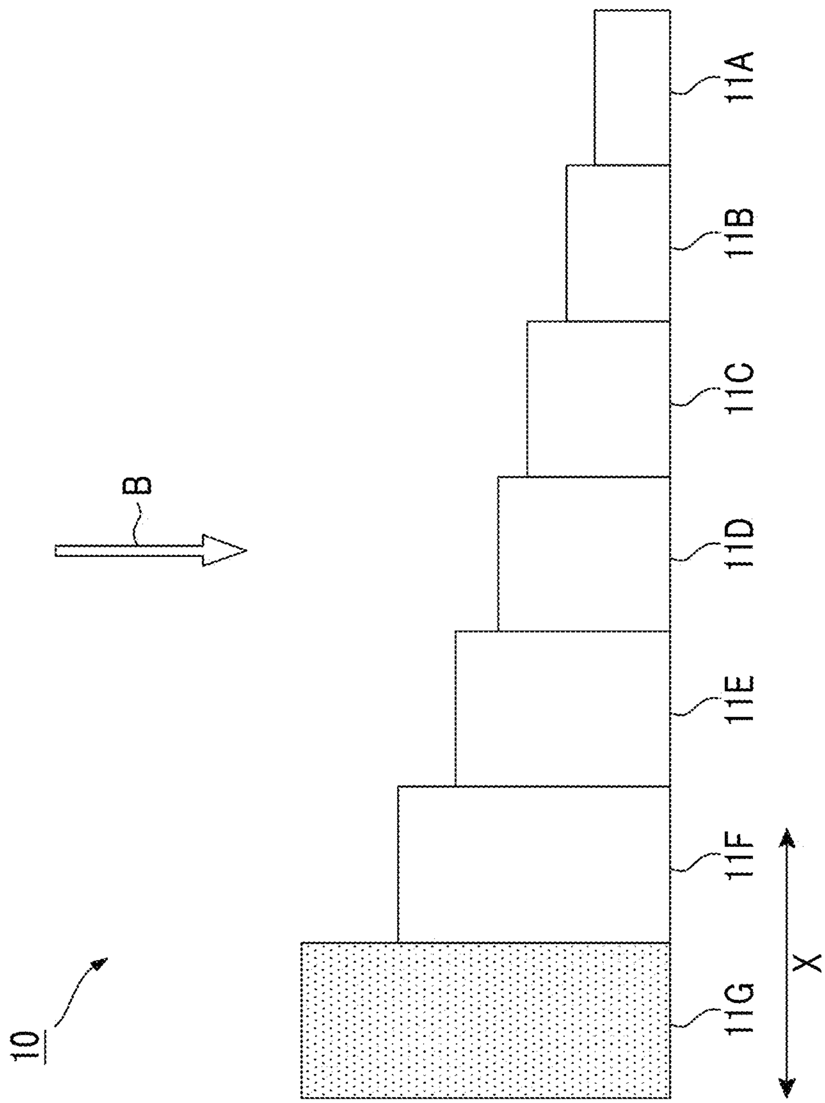


FIG. 3

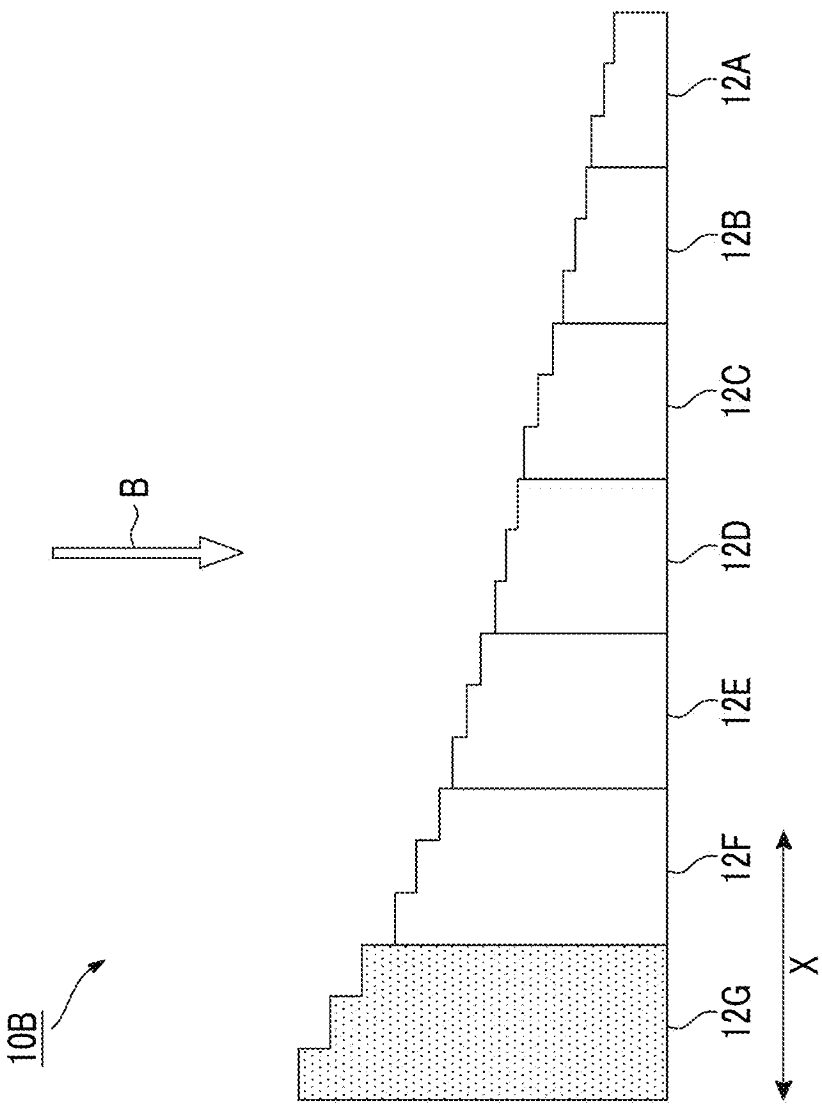


FIG. 4

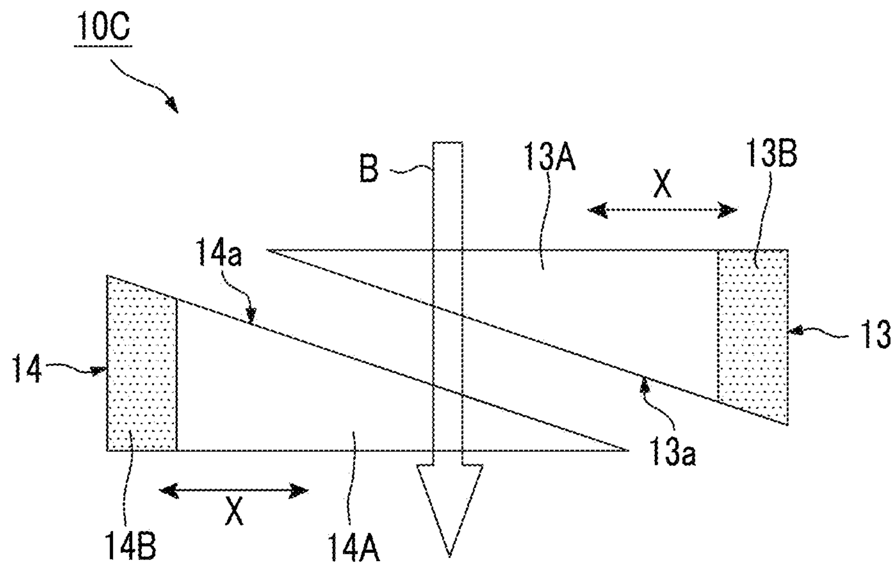
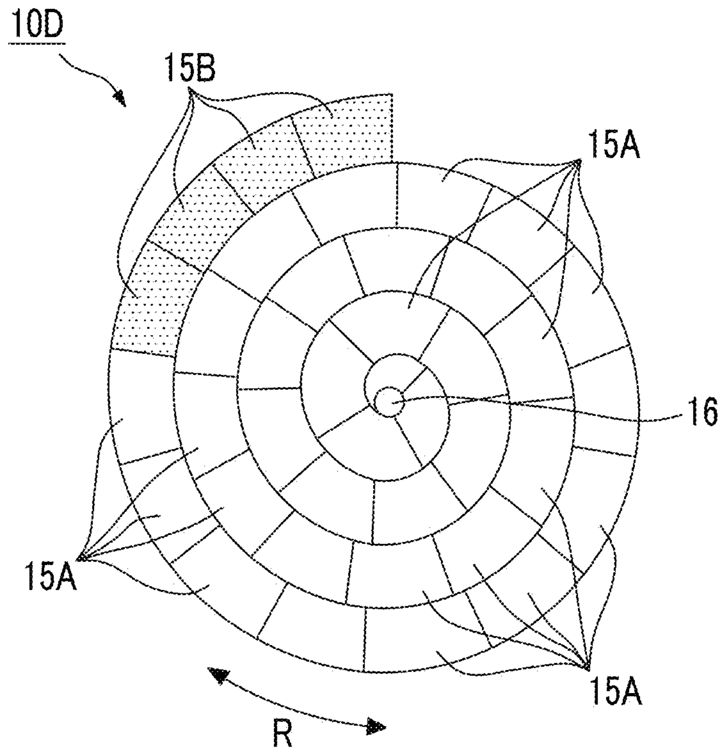


FIG. 5



ENERGY DEGRADER AND CHARGED PARTICLE BEAM IRRADIATION SYSTEM EQUIPPED THEREWITH

INCORPORATION BY REFERENCE

[0001] Priority is claimed to Japanese Patent Application No. 2011-126342, filed Jun. 6, 2011, and International Patent Application No. PCT/JP2012/059585, the entire content of each of which is incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The present invention relates to an energy degrader that attenuates the energy of a charged particle beam, and a charged particle beam irradiation system equipped therewith.

[0004] 2. Description of the Related Art

[0005] There are known facilities that irradiate a patient with a charged particle beam, such as a proton beam, to perform cancer treatment. These types of facilities include a cyclotron (accelerator) that accelerates ions (charged particles) generated by an ion source, a transportation line that transports the charged particles accelerated by the cyclotron, and a rotatable irradiation device (rotating gantry) that irradiates a patient with a charged particle beam from arbitrary directions.

[0006] A degrader in which a beam absorber (attenuating material) is inserted into a beam line (transportation line) to attenuate beam energy is disclosed in a technique described in the related art.

SUMMARY

[0007] According to an embodiment of the present invention, there is provided an energy degrader including a plurality of attenuating members with different amounts of energy to be attenuated configured to attenuate the energy of an incident charged particle beam, the plurality of attenuating members. A low-energy-side attenuating member which is the attenuating member with a larger amount of energy to be attenuated is made of a material having a higher transmittance of the charged particle beam than that of a high-energy-side attenuating member that is the attenuating member with a smaller amount of energy to be attenuated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is an arrangement view of a particle beam treatment system related to an embodiment of the invention.

[0009] FIG. **2** is a schematic view showing an energy degrader related to the embodiment of the invention.

[0010] FIG. **3** is a schematic view showing an energy degrader related to another embodiment of the invention.

[0011] FIG. **4** is a schematic view showing an energy degrader related to a further embodiment of the invention.

[0012] FIG. **5** is a schematic view showing an energy degrader related to a still further embodiment of the invention.

DETAILED DESCRIPTION

[0013] In charged particle beam irradiation systems of the related art, the energy of the charged particle beam is adjusted based on the irradiation position (depth) of a body to be irradiated. An energy degrader having an attenuating material is used for the adjustment of energy of the charged particle beam. Generally, as the attenuating material, graphite that is not easily radioactivated and is inexpensive is adopted. In the related art, the amount of energy to be attenuated is adjusted by changing a length by which the charged particle beam is transmitted through the attenuating material made of the same material.

[0014] Additionally, in recent years, request for using a charged particle beam having lower energy than usual has been increasing. If the attenuating material is thickened in order to increase the amount of energy attenuation, scattering of the charged particle beam becomes large and the number (=transmittance) of charged particles capable of being transmitted through the attenuating material decreases.

[0015] It is desirable to provide an energy degrader that can mitigate a reduction in the transmittance of a low-energy charged particle beam, and a charged particle beam irradiation system equipped therewith.

[0016] In the energy degrader related to the embodiment of the invention, the plurality of attenuating members having different amounts of energy attenuation are provided, and the low-energy-side attenuating member with a larger amount of energy attenuation is formed from a material having a higher transmittance than the high-energy-side attenuating member with a smaller amount of energy attenuation. Therefore, a reduction in the transmittance of the low-energy-side proton beam can be mitigated. As a result, in a low energy region (for example, 70 MeV or lower), a reduction in the number of protons that are transmitted through the attenuating members can be suppressed. When the amount of energy attenuation is large, as compared with a case where the amount of energy attenuation is small, the energy of the charged particle beam after being transmitted through the attenuating members becomes low.

[0017] Additionally, only the low-energy-side attenuating member with the largest amount of energy to be attenuated among the plurality of attenuating members may be made of a material having a high transmittance. In this way, only the attenuating member with the largest amount of energy attenuation can be made of a material having a higher transmittance compared to the other attenuating members.

[0018] Additionally, the low-energy-side attenuating member can be formed from beryllium, and the high-energy-side attenuating member can be formed from graphite. By adopting beryllium as the low-energy-side attenuating member in the aforementioned way, the number of charged particles that are transmitted through and the number of attenuating members can be increased in the low energy region.

[0019] Additionally, according to another embodiment of the invention, there is provided a charged particle beam irradiation system including the above energy degrader and irradiating the charged particle beam. The charged particle beam irradiation system includes an accelerator configured to accelerate charged particles introduced into the energy degrader; and an irradiation device configured to irradiate the charged particle beam having energy attenuated by the energy degrader.

[0020] The charged particle beam irradiation system related to the embodiment of the invention includes the energy degrader that attenuates the energy of an incident charged particle beam. In this energy degrader, the plurality of attenuating members having different amounts of energy attenuation are provided, and the low-energy-side attenuating member with a larger amount of energy attenuation is formed from a material having a higher transmittance than the high-energy-side attenuating member with a smaller amount of energy attenuation. Therefore, the transmittance of the low-energy-side charged particle beam can be improved. As a result, in the low energy region, the number of charged particles that are transmitted through the attenuating members can be increased.

[0021] Hereinafter, preferred embodiments of an energy degrader and a charged particle beam irradiation system equipped therewith related to the invention will be described referring to the drawings. In the present embodiment, a case where a particle beam treatment system is used as the charged particle beam irradiation system.

[0022] Charged Particle Beam Irradiation System

[0023] The particle beam treatment system, which is, for example, a device that is used in cancer treatment, irradiates a tumor (target to be irradiated) inside a patient' s body with a proton beam (charged particle beam).

[0024] As shown in FIG. **1**, the particle beam treatment system **1** includes a cyclotron (particle accelerator) **2** that accelerates ions (positive ions of hydrogen) generated in an ion source (not shown) to generate a proton beam, a rotatable rotating gantry (irradiation device) **3** that irradiates a patient with the proton beam from arbitrary directions, and a transportation line **4** that transports the proton beam (charged-particle beam accelerated by the cyclotron) generated by cyclotron **2** to the rotating gantry **3**.

[0025] The proton beam accelerated by the cyclotron **2** is deflected along the transportation line **4** and transported to the rotating gantry **3**. The transportation line **4** is provided with a deflecting magnet for deflecting the proton beam. Additionally, the transportation line **4** is provided with an energy degrader **10** that attenuates the energy of charged particles (will be described below in detail).

[0026] Moreover, an energy selection system (ESS) **30** is provided at a rear stage (downstream) of the energy degrader **10** in the transportation line **4**. The ESS **30** selectively takes out a proton beam with a desired energy width from the proton beam with a predetermined energy distribution that has been transported. In the ESS **30**, the energy width of the proton beam is selected so as to become a desired range.

[0027] The rotating gantry **3** includes a treatment table on which the patient lies, and an irradiation unit that irradiates a patient with the proton beam. The charged particle beam having energy attenuated by the energy degrader **10** is emitted from the irradiation unit and irradiates to a target region of the patient.

[0028] Energy Degrader

[0029] FIG. **2** is a schematic view showing the energy degrader related to the embodiment of the invention. The energy degrader **10** shown in FIG. **2** is provided on a path (on a beam line) of a proton beam B to attenuate the energy of the proton beam B. The energy degrader **10** includes a plurality of attenuating members **11**A to **11**G that attenuate the energy of the proton beam B to be transmitted. In addition, when it is not necessary to distinguish the attenuating members **11**A to **11**G, these attenuating members are written as the attenuating members **11**.

[0030] In the energy degrader **10**, the attenuating members **11** having mutually different thicknesses are arranged in order of thickness in one direction. In the present embodiment, the attenuating members are arranged so as to increase in thickness in order from the attenuating member **11**A to the attenuating member **11**G in a direction X intersecting the path of the proton beam B. In addition, the term “thickness” means the length of the charged particle beam in its transmission direction. For example, the attenuating members **11** are arranged so that the end surfaces thereof on an outlet side from which the proton beam B is emitted are aligned, and are arranged so that the end surfaces thereof on an opposite inlet side constitute a stair shape. In addition, the attenuating members **11** may not be arranged in order of thickness. Additionally, the attenuating members are arranged so that the end surfaces thereof on the outlet side constitute a stair shape, or may have other arrangements.

[0031] The attenuating members **11** are integrally supported by a supporting member (not shown). Additionally, the energy degrader **10** includes a drive source (for example, a drive motor) that applies a driving force to the attenuating members **11**, guide means (for example, a guide rail) for guiding movement of the attenuating members **11**, or the like. Also, the energy degrader **10** moves the attenuating members **11** that transmits the proton beam B therethrough, on the path of the proton beam B, thereby changing the amount of energy attenuation of the proton beam B. The energy degrader **10** decelerates the proton beam B at different decelerated velocities based on the thicknesses of the attenuating members **11** through which the proton beam B is transmitted. The kinetic energy of the proton beam B is reduced and attenuated.

[0032] Here, in the energy degrader **10**, a low-energy-side attenuating member that is the attenuating member **11** with a larger amount of energy to be attenuated is formed from a material having a higher transmittance of the proton beam B than a high-energy-side attenuating member that is the attenuating member **11** with a smaller amount of energy to be attenuated. In other words, a substance with a small atomic number is adopted for the low-energy-side attenuating member rather than the high-energy-side attenuating member. Since scattering of the proton beam B spreads more greatly as the atomic number of attenuating materials is larger, this results from the decrease in the number of protons capable of being transmitted.

[0033] In the energy degrader **10** of the present embodiment, only the attenuating member **11**G with the largest amount of energy to be attenuated is formed from a material having a higher transmittance than the other attenuating members **11**A to **11**F. The materials of the attenuating members **11** include, for example, carbon (C), beryllium (Be), or the like. In the present embodiment, beryllium that is a stable solid substance with a small atomic number is adopted for the lowest-energy-side attenuating member **11**G, and carbon (graphite) is adopted for the other attenuating members **11**A to **11**F.

[0034] In addition, a material having a higher transmittance than the remaining attenuating members **11**A to **11**E may be adopted for two low-energy-side attenuating members **11**G and **11**F. Additionally, the material having a high transmittance may not be adopted for the lowest-energy-side attenuating member **11**G. For example, a material having a higher transmittance than the remaining attenuating members **11**A to **11**E may be adopted for the low-energy-side attenuating member **11**F, and the lowest-energy-side attenuating member **11**G and the attenuating members **11**A to **11**D may be formed from the same material.

[0035] Operation of Energy Degrader and Particle Beam Treatment System

[0036] In the particle beam treatment system **1**, the proton beam B is accelerated by the cyclotron **2** and the accelerated proton beam B (for example, having an energy range of 230

MeV±several MeV) is introduced into the energy degrader **10**. In the energy degrader **10**, the attenuating members **11** are driven and moved by driving means, and a desired attenuating member **11** is arranged on the path of the proton beam B. The proton beam B passed through this attenuating member **11** is decelerated by the attenuating member **11** and the energy thereof is attenuated (for example, 200 MeV±ten and several MeV).

[0037] The proton beam B passed through the energy degrader **10** is introduced into the ESS **30**. The proton beam B with a desired energy range out of the proton beam B introduced into the ESS **30** is taken out selectively (for example, 200 MeV±1 MeV). The proton beam B with a selected energy width is transported by the transportation line **4**, is introduced into the rotating gantry **3**, and is irradiated to a body to be irradiated. This allows the proton beam B to be irradiated so as to reach a predetermined depth position inside the body to be irradiated. When the proton beam B is irradiated so as to reach a deep position inside the body to be irradiated, the amount of attenuation using the energy degrader **10** is made small, and when the proton beam B is irradiated so as to reach a shallow position inside the body to be irradiated (for example, near a body surface), the amount of attenuation due to the energy degrader **10** is made large.

[0038] According to such energy degrader and particle beam treatment system equipped therewith of the present embodiment, the plurality of attenuating members **11** are included, and the energy of the proton beam B that enters the attenuating members **11** can be attenuated. In the energy degrader **10**, the low-energy-side attenuating member **11**G with a larger amount of energy attenuation is formed from a material having the higher transmittance than a high-energy-side attenuating member with a smaller amount of energy attenuation. Therefore, a reduction in the transmittance of the low-energy-side proton beam B can be mitigated. As a result, in a low energy region, scattering of the proton beam B can be suppressed and a reduction in the number of protons that can be transmitted through the attenuating members **11** can be suppressed.

[0039] Additionally, since only the low-energy-side attenuating member **11**G with the largest amount of energy to be attenuated among the plurality of attenuating members **11** is formed from beryllium that is expensive and has a high transmittance, a reduction in the number of protons that are transmitted through the low-energy-side attenuating member **11**G can be suppressed, while suppressing an increase in the manufacturing cost. That is, a reduction in the number of protons to be irradiated can be suppressed. This enables the proton beam B to be effectively irradiated to the shallow position near the body surface and enables the reliable particle beam treatment system **1** to be realized.

[0040] The following Table 1 shows transmittances at individual levels of energy of the proton beam B. The transmittances in Table 1 are values measured at the outlet of the ESS **30**. All the materials of the attenuating members at this time are the same, and are graphite.

TABLE 1

Energy of Proton Beam [MeV]	Transmittance (ϕ5 mm, 32π) [%]
70	0.36
110	1.66
150	5.54
190	17.29
230	46.50

[0041] The following Table 2 shows the comparison between the materials of the attenuating members with respect to the transmittance of the proton beam B. Measurement is made in cases where the energy of the proton beam B is 70 [MeV] and beam diameters are ϕ5 mm and ϕ2 mm.

TABLE 2

Beam Diameter	Attenuation Rate Material: Carbon (ϕ5 mm, 32π) [%]	Attenuation Rate Material: Beryllium (ϕ5 mm, 32π) [%]
ϕ5 mm	0.358	0.578
ϕ2 mm	0.478	0.744

Second Embodiment

[0042] Next, an energy degrader **10**B related to a second embodiment will be described with reference to FIG. **3**. The energy degrader **10**B shown in FIG. **3** is different from the energy degrader **10** shown in FIG. **2** in that each of the attenuating members **12**A to **12**G have different thicknesses. In this way, each of the attenuating members **12**A to **12**G may be configured to have a plurality of thicknesses.

Third Embodiment

[0043] Next, an energy degrader **10**C related to a third embodiment will be described with reference to FIG. **4**. As shown in FIG. **4**, the energy degrader **10**C has a pair of attenuating members **13** and **14** that are arranged to face each other. The attenuating members **13** and **14** form a wedge shape and are arranged such that mutual inclined surfaces **13***a* and **14***a* face each other. The attenuating members **13** and **14** are configured so as to be movable in an X direction intersecting a traveling direction of the proton beam B. The amount of energy attenuation of the proton beam B is controlled by moving the attenuating members **13** and **14** in the X direction and changing a length by which the proton beam B is transmitted through the attenuating members **13** and **14**. In addition, a configuration may be adopted in which the beam diameter of the proton beam B is controlled by driving any one of the attenuating members **13** and **14** in the traveling direction of the proton beam B to adjust the gap between the attenuating members **13** and **14**.

[0044] The attenuating members **13** and **14** include a plurality of attenuating members **13**A, **13**B, **14**A, and **14**B having different amounts of energy to be attenuated. Here, the low-energy-side attenuating members **13**B and **14**B with larger amounts of energy to be attenuated are formed from a material having a higher transmittance of the proton beam B than the high-energy-side attenuating members **13**A and **14**A with smaller amounts of energy to be attenuated. For example, a material (beryllium) with a high transmittance is adopted only for a portion where the energy of the proton beam B is attenuated to 70 [MeV].

[0045] Even in the energy degrader **10**C of the aforementioned third embodiment, similar to the energy degrader **10** of the above embodiment, in a low energy region, scattering of the proton beam B can be suppressed and a reduction in the number of protons that are transmitted through the attenuating members **13**B and **14**B can be suppressed.

Fourth Embodiment

[0046] Next, an energy degrader **10**D related to a fourth embodiment will be described with reference to FIG. **5**. FIG. **5** is a front view of the energy degrader, and is shown from the traveling direction of the proton beam B. The energy degrader **10**D shown in FIG. **5** includes a plurality of attenuating members **15**A and **15**B having different thicknesses, and the plurality of attenuating members **15**A and **15** are arranged spirally. For example, the plurality of attenuating members **15**A and **15**B are arranged so as to become thin on a central side thereof and become thick on an outer side thereof. For example, the plurality of attenuating members **15**A and **15**B may be arranged so as to become thick on the central side thereof and become thin on the outer side thereof.

[0047] A rotating shaft **16** extending parallel to the traveling direction of the proton beam B is arranged at the center of the energy degrader **10**D. The rotating shaft **16** is configured so as to be rotatable around an axis and movable in the direction intersecting the traveling direction of the proton beam. As the rotating shaft **16** rotates and moves in a predetermined direction, desired attenuating members **15**A and **15**B are arranged on the path of the proton beam.

[0048] Here, even in the energy degrader **10**D of the fourth embodiment, the low-energy-side attenuating member **15**B with a larger amount of energy to be attenuated is formed from a material having a higher transmittance of the proton beam than the high-energy-side attenuating member **15**A with a smaller amount of energy to be attenuated. Even in the energy degrader **10**D of such a fourth embodiment, similar to the energy degrader **10** of the above embodiment, in a low energy region, scattering of the proton beam B can be suppressed and a reduction in the number of protons that are transmitted through the attenuating members **13**B and **14**B can be suppressed.

[0049] Although the invention has been specifically described above on the basis of the embodiments, the invention is not limited to the above embodiments.

[0050] Additionally, the arrangement of the energy degrader **10** is not limited to that immediately after the cyclotron **2**, a configuration may be adopted in which the energy degrader **10** is provided in the irradiation nozzle installed at the rotating gantry **3**.

[0051] Additionally, the accelerator is not limited to the cyclotron **2**, and may be, for example, other accelerators, such as a synchro-cyclotron. Additionally, the charged particle beam is not limited to the proton beam, and may be a carbon beam (baryon beam) or the like.

[0052] Additionally, the material of the low-energy-side attenuating member is not limited to beryllium, and other attenuating materials may be adopted.

[0053] Additionally, the particle beam treatment system **1** may not use the rotating gantry but may use stationary irradiation.

[0054] The energy degrader and the charged particle beam irradiation system equipped therewith of the invention can mitigate a reduction in the transmittance of the low-energy charged particle beam and can suppress a reduction in the number of charged particles that are transmitted through the low-energy-side attenuating member.

[0055] It should be understood that the invention is not limited to the above-described embodiment, but may be modified into various forms on the basis of the spirit of the invention. Additionally, the modifications are included in the scope of the invention.

What is claimed is:

1. An energy degrader comprising:

a plurality of attenuating members configured to attenuate the energy of an incident charged particle beam, the plurality of attenuating members having different amounts of energy to be attenuated,

wherein a low-energy-side attenuating member that is the attenuating member with a larger amount of energy to be attenuated is made of a material having a higher transmittance of the charged particle beam than that of a high-energy-side attenuating member that is the attenuating member with a smaller amount of energy to be attenuated.

2. The energy degrader according to claim **1**,

wherein only the low-energy-side attenuating member with the largest amount of energy to be attenuated among the plurality of attenuating members is made of a material having a high transmittance.

3. The energy degrader according to claim **1**,

wherein the low-energy-side attenuating member is formed from beryllium, and the high-energy-side attenuating member is formed from graphite.

4. A charged particle beam irradiation system including the energy degrader according to claims **1** and irradiating the charged particle beam, the charged particle beam irradiation system comprising:

an accelerator configured to accelerate charged particles introduced into the energy degrader; and

an irradiation device configured to irradiate the charged particle beam having energy attenuated by the energy degrader.

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