United States Patent [19]

Reifenschweiler

[11] **3,836,785**

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[54] **NEUTRON GENERATOR HAVING A TARGET ON WHICH A BEAM OF HYDROGEN IONS IS INCIDENT**

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Related U.S. Application Data

[63] Continuation of Ser. No. 158,389, June 30, 1971, abandoned.

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **250/501,** 250/499, 313/615

[51] **Int. Cl.** **G21g 3/04**

[58] **Field of Search** 250/499, 500, 501; 313/615

[56] **References Cited**

UNITED STATES PATENTS

2,251,190	7/1941	Kallmann et al.	250/84
2,287,619	6/1942	Kallmann et al.	250/84
2,951,945	9/1960	Goodman	250/84.5
3,400,269	9/1968	Holm	250/84.5
3,591,812	7/1971	Detaint	250/84

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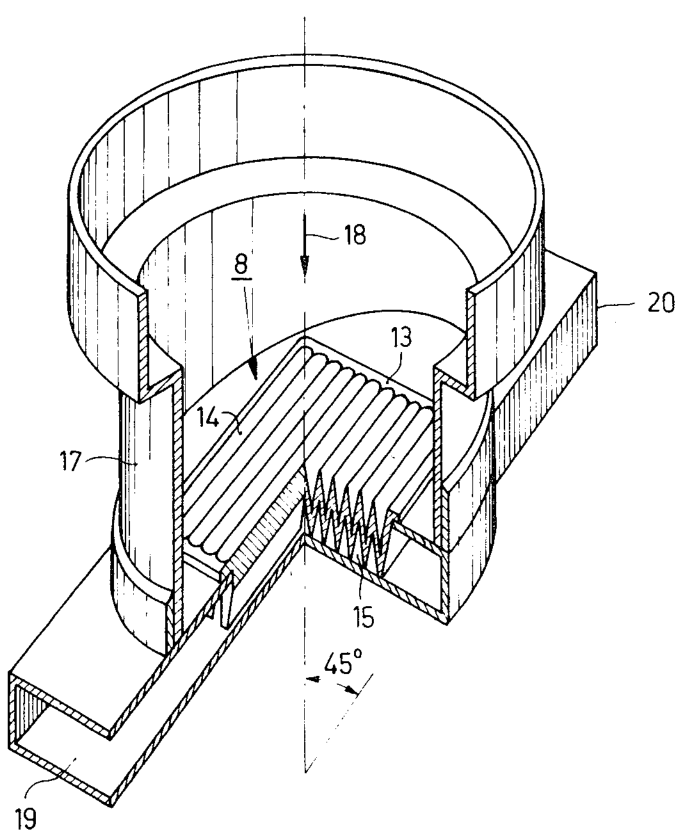
[57] **ABSTRACT**

A target for a neutron generator having a surface formed of a plurality of V-shaped funnels or grovves with edges coinciding at an acute angle for reducing sputtering of the reaction layer by the hydrogen ions incident upon the target surface.

10 Claims, 4 Drawing Figures



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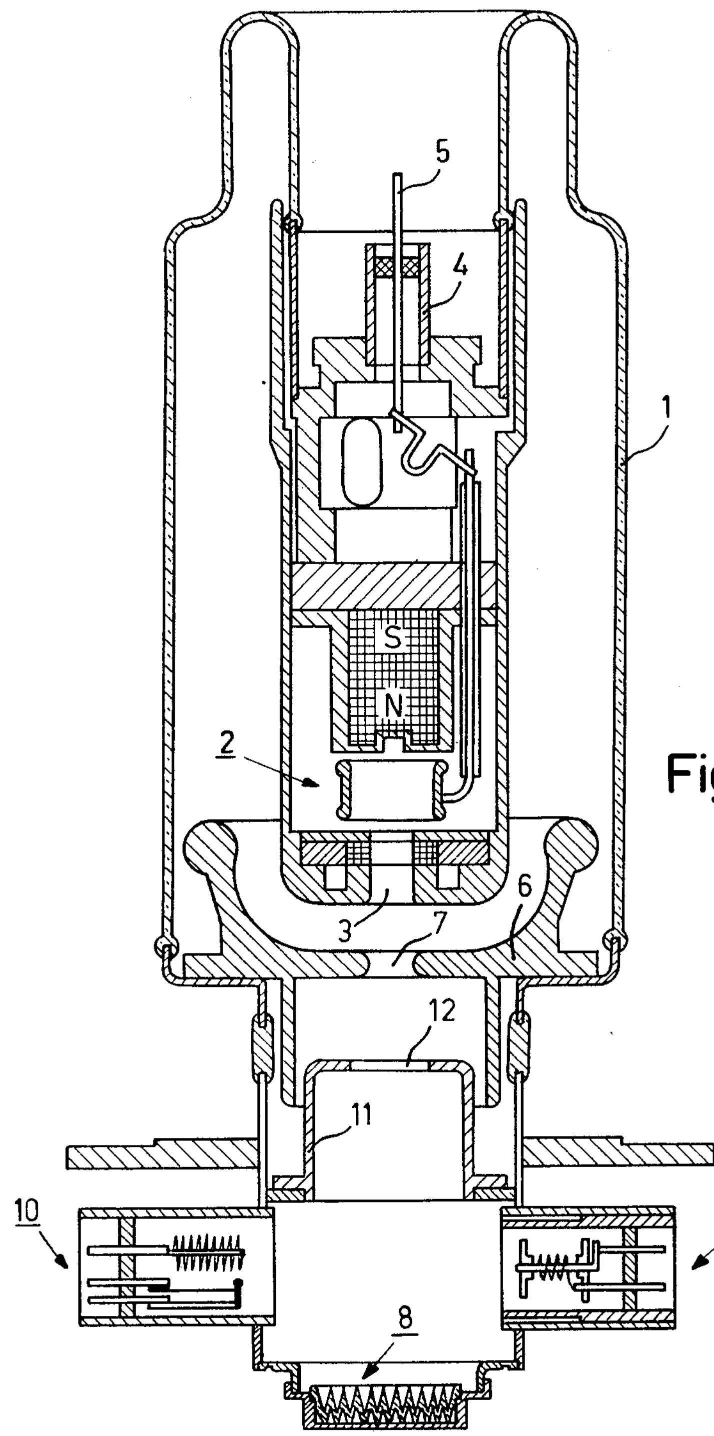

Fig.1

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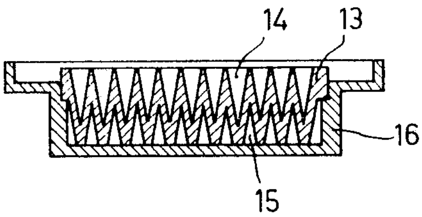

Fig.2

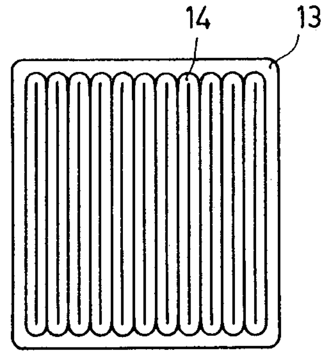

Fig.3

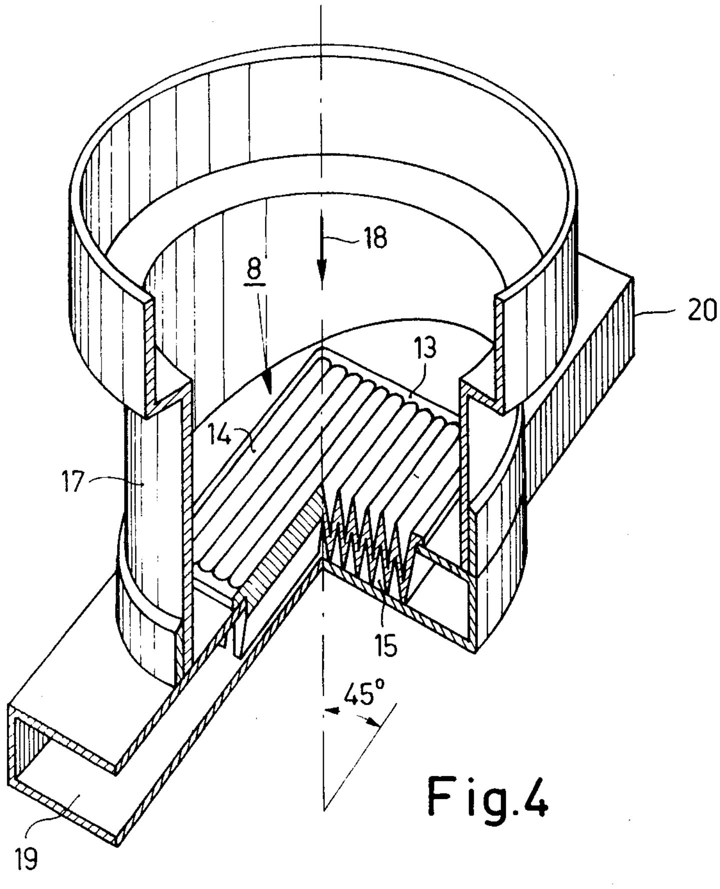

Fig.4

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NEUTRON GENERATOR HAVING A TARGET ON WHICH A BEAM OF HYDROGEN IONS IS INCIDENT

This is a continuation of application Ser. No. 158,389, filed June 30, 1971 now abandoned.

The invention relates to a neutron generator comprising a target on which a beam of hydrogen ions is incident.

Such a neutron generator is described in the article "A high output sealed-off neutron tube with high reliability and long life" in "Modern Trends in Activation Analysis" (1969), pp. 905–910 (Proceedings of the 1968 International Conference). Said neutron generator supplies neutrons with an energy of approximately 14 MeV which result from reactions between nuclei of the heavy isotopes of hydrogen deuterium and tritium. The kinetic energy required for the occurrence of said reactions is obtained by causing a beam of deuterium and tritium ions to traverse a potential difference from 150 to 200 kV. Since the neutron generator described is of the so-called sealed-off type, a storage of deuterium and tritium should be present in the neutron generator, which is sufficient to the end of the life of the generator. For that purpose, a pressure control is present in the generator and is provided with a finely divided titanium powder, which during the manufacture of the generator is saturated with a mixture of 50 percent deuterium and 50 percent tritium. Said pressure control, during operation of the generator, supplies, by heating, the quantity of deuterium and tritium which is necessary to maintain the desirable pressure in the generator. The neutron generator furthermore comprises an ion source of a type which is suitable to operate at the comparatively low pressure which is necessary to be able to maintain the said potential difference. Said ion source ionizes the gas mixture of deuterium and tritium. The ions emanating from the ion source are accelerated and formed into a beam by the said potential difference, then impinge upon a flat target and penetrate into said target with a certain depth of penetration. For the reaction between deuterium and tritium nuclei necessary for the formation of neutrons it is therefore necessary for the target to contain absorbed deuterium and tritium at least in a surface layer in a thickness of approximately the depth of penetration of the ions. Since in a neutron generator of the sealed-off type it is not possible during the life of the generator to replace an exhausted target by a new one, a regenerating target (drive-in target) is used in the neutron generator described. Said drive-in target consists of a base plate of a material having a small diffusion coefficient and absorption coefficient for deuterium and tritium and is provided with a reaction layer having a large absorption coefficient for deuterium and tritium in a thickness of the order of magnitude of the said depth of penetration. Such a target is introduced in the neutron generator without being saturated with deuterium and tritium and, in the first few hours of the life of the generator, absorbs deuterium and tritium from the beam which is incident on the target. The absorbed deuterium and tritium cannot diffuse away to a considerable extent to places in the target which are located more deeply than the thickness of the reaction layer, because the base plate has a small diffusion coefficient and absorption coefficient for deuterium and tritium. The result is that the reaction layer becomes more and more saturated with deuterium and tritium, as a result of which the neutron efficiency starts and remains increasing until an equilibrium is reached between the deuterium and tritium supplied by the beam and the quantity which diffuses from the reaction layer.

From the above it follows that in the known neutron generator described, it is of great importance for the thickness of the reaction layer, which is approximately 3 μm, to remain sufficiently large throughout the life of the generator. A disadvantageous effect is, however, that the material of the very thin reaction layer is sputtered, since the ions impinge upon it at a high speed. The life of the target and hence of the neutron generator is in principle restricted by the sputtering of the reaction layer.

It is the object of the invention to provide a neutron generator having a target in which the disadvantageous influence of the sputtering of the reaction layer is considerably reduced.

According to the invention, in a neutron generator comprising a target on which a beam of hydrogen ions is incident, the target comprises, on the side of the beam, a surface which is formed by a number of funnels facing the beam with their open sides and edges of which of adjacent funnels coincide. By giving the surface of the target such a shape, in which in practice the shape of the funnels is chosen, for example, to be a regular pyramid having a square base and an apex which is smaller than 90°, it is achieved that a very large part of the sputtered particles of the reaction layer remains inside the funnels and impinges again upon another place on the surface thereof. This in contrast with the flat target of the known neutron generator in which an uncharged sputtered particle having a velocity component which is directed away from the target will not return to it anymore. The achieved favourable effect, of course, is the stronger according as the apex of the funnels is more acute. An additional advantage is that the load per surface unit of the target is smaller so that the cooling of the target becomes simpler and dissipation of deuterium and tritium absorbed in the reaction layer occurs less rapidly.

From U.S. Pat. Specification No. 2,251,190 a neutron generator is known having a target on which an ion beam is incident at an acute angle, but for reasons other than those on which the above-mentioned invention is based. From the drawing attached to said patent specification it might be concluded that the target has the shape of one funnel. The invention of this application, however, requires such an acute apex of the funnels that one funnel would become much too long so that structural difficulties and cooling problems occur and the neutron emissive surface also obtains an unfavourable shape.

The U.S. Pat. Specification No. 2,951,945 furthermore describes a neutron generator having a target the surface of which in one of the proposed embodiments is undulated or ribbed. An advantage hereof is said to be that smaller mechanical stresses occur as a result of temperature variations. In this case, however, very shallow grooves are obviously meant which certainly do not have the effect of the invention of this application.

In an alternative construction of a neutron generator according to the invention, the target on the side of the beam has a surface which is constituted by a number of V-shaped grooves, of which edges of adjacent grooves coincide. It is obvious that in this case, with a sufficient acute angle of the V, the effect of the invention is obtained in quite the same manner but in a slightly different construction which, dependent upon the construction of the neutron generator, may have advantages.

An advantageous construction of a neutron generator according to the invention is such that the grooves are straight and extend in parallel. In certain constructions this has important advantages as regards cooling which in this case may consist of parallel ducts between the grooves.

Another advantageous construction of a neutron generator according to the invention is such that the grooves are circular and concentric. This embodiment is very suitable if the outer edge of the target is to be circular.

If the already described construction having circular and concentric grooves is used, it is favourable when the angle of each circular, V-shaped groove has such a value that the dissipation per surface unit as a result of the beam of hydrogen ions is substantially constant throughout the target. Actually the current density of the beam of hydrogen ions is not constant over the cross-section of the beam but generally decreases towards the edge. As a result of this, if each groove would have the same angle, the load of the target in the center is larger than at the edge. This is avoided by using grooves having smaller angles in the center of the target.

In order to take off a beam of neutrons in a direction at right angles to the beam of ions, a very suitable construction is such that the edges of the grooves or the funnels lie in a flat plane which encloses an acute angle with the direction of the beam of ions. As a result of this a larger projected surface area of the target is obtained in the said direction in which the beam of neutrons is to be taken off so that less scattering of said neutrons occurs.

A particularly advantageous construction is such that the acute angle is 45°. As a result of this the projected surface area of the target in the direction of the ion beam and in a direction at right angles thereto can be made equally large so that the neutron generator can be universally used. Actually, neutrons are formed from the reactions substantially without preferred direction so that a spherical distribution exists and a neutron beam can be taken off in any desirable direction and non-desired directions must be screened. The very small preference of neutrons of moving in the direction of the ion beam, on the basis of the law of maintenance of pulse and the direction of the ions incident on the target, can be neglected in connection with the very large difference in kinetic energy between the neutrons, namely approximately 14 MeV, and the ions, namely a few tenths of a MeV.

An advantageous construction of a neutron generator according to the invention is such that the target comprises a support of molybdenum sheet folded in a zig-zag manner. In this manner, straight and parallel V-shaped grooves are obtained in a very simple manner with the extra advantage that the support is also provided with V-shaped grooves on the side remote from the beam, which grooves can advantageously be used for cooling. If the target is secured in the neutron generator in such manner that the edges of the grooves lie in a flat plane which encloses an acute angle with the direction of the beam, the direction of the grooves is preferably chosen to be parallel to the projection of the axis of the beam on the said flat plane.

In order that the invention may be readily carried into effect one embodiment thereof will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 shows a neutron generator according to the invention,

FIG. 2 is a cross-sectional view on a larger scale of the target of the neutron generator shown in FIG. 1,

FIG. 3 is a plan view of the active part of the target shown in FIG. 2, and

FIG. 4 shows the lower part of the neutron generator the target of which encloses an angle of 45° with the ion beam.

The neutron generator shown in FIG. 1 comprises a glass envelope 1, an ion source 2 having an ion emanating aperture 3, a high voltage connection 4, a connection 5 for the anode voltage of the ion source 2, an accelerating electrode 6 having an aperture 7 and a target 8. The neutron generator furthermore comprises a pressure control 9 for the deuterium-tritium filling of the neutron generator, an ionization manometer 10 and a screen electrode 11 having an aperture 12.

By means of an anode voltage from 4 to 8 kV, a deuterium-tritium gas mixture is ionized in the ion source 2, the pressure of which is maintained at a suitable value by the pressure control by supplying gas. The pressure control can supply gas by heating which gas is absorbed in finely divided titanium powder. The ion source 2 is at a positive voltage of 150 to 200 kV relative to the accelerating electrode 6. Ions which are formed in the ion source 2, as a result experience an accelerating electric field and leave the ion source 2 through the aperture 3. The formed ion beam then passes through the aperture 7 in the accelerating electrode 6 and the aperture 12 in the screen electrode 11, and then impinges upon the target 8. The accelerating electrode 6 has a negative potential of a few hundred volts relative to the screen electrode 11 and the target 8 so as to prevent secondary electrons formed on the target from being accelerated towards the ion source 2.

FIG. 2 shows the target on an enlarged scale. This figure will be described together with FIG. 3 which is a plan view, viewed from the side of the ion source, of the active part of the target. The active part 13 of the target is manufactured from a copper plate in which V-shaped straight grooves are milled on both sides. The longitudinal direction of said grooves is at right angles to the plane of the drawing of FIGS. 1 and 2. Eleven grooves, one of which is denoted by 14, are present on the side of the ion source. One of the grooves on the other side is denoted by 15. Cooling water is conducted through said latter grooves. The active part 13 of the target is present in a housing 16 which is secured to the neutron generator in the manner visible in FIG. 1. The housing 16 is also manufactured from copper. The grooves 14 on the side of the ion source are covered with a layer of titanium, approximately 3 μm thick. This layer constitutes the reaction layer since titanium has a large absorption coefficient for hydrogen and must hence remain sufficiently thick. The angle of the groove 14 is approximately 19°. This small angle has for its result that sputtered particles of the reaction layer have a fair chance of impinging elsewhere on the surface of the reaction layer so that the effect of the sputtering is much smaller than without using the invention.

FIG. **4** shows the lowermost part **17** of a neutron generator which comprises a target **8** which encloses an angle of 45° with the direction **18** of the ion beam. The longitudinal direction of the grooves is parallel to a plane through the axis of the ion beam. As a result of this it is achieved that the target has the same projected surface in two mutually perpendicular directions which makes the neutron generator more universally applicable. Reference numerals **19** and **20** denote inlet and outlet apertures, respectively, for cooling water.

As already stated, the grooves **14** and **15** may also be formed by molybdenum sheet folded in a zig-zag manner.

What is claimed is:

1. A neutron generator comprising an envelope, a hydrogen ion source within said envelope, means for activating said ion source to produce hydrogen ions within said envelope, means for forming the ions from said ion source into an ion beam within said envelope and a target within said envelope opposite said ion source for attracting the ions in said ion beam so that the impact of said ions upon the surface of said target produces neutrons, said target surface comprising reaction materials and being formed by a plurality of funnels having open sides and edges coinciding at an acute angle, at least on the side facing said ion beam to reduce the effects of sputtering between said ions and said reaction materials.

2. A neutron generator as claimed in claim **1**, wherein the edges of said funnels lie in a plane at an acute angle with said ion beam.

3. A neutron generator as claimed in claim **2**, wherein the acute angle is approximately 45°.

4. A neutron generator comprising an envelope, a hydrogen ion source within said envelope at one end thereof, means for activating said ion source to produce hydrogen ions within said envelope, means within said envelope for forming ions from said source into an ion beam, and a target within said envelope at the end opposite said ion source for attracting ions in said beam from said ion source so that said ions impact upon the reaction materials of said target thereby resulting in production of neutrons, said target having a surface formed by a plurality of V-shaped grooves having edges coinciding at an acute angle at least on the side facing said ion beam for reducing sputtering between said ion beam and said reaction materials.

5. A neutron generator as claimed in claim **4**, wherein said V-shaped grooves are straight and extend in parallel directions.

6. A neutron generator as claimed in claim **4**, wherein said V-shaped grooves are circular and concentric.

7. A neutron generator as claimed in claim **6**, wherein the angle of each circular, V-shaped groove is such that the dissipation per surface unit resulting from the beam of ions is constant throughout said target.

8. A neutron generator as claimed in claim **5**, wherein said target comprises a supporting molybdenum sheet folded in a zig-zag manner.

9. A neutron generator as claimed in claim **4**, wherein the edges of said grooves lie in a plane at an acute angle with said ion beam.

10. A neutron generator as claimed in claim **9**, wherein said acute angle is approximately 45°.

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