June 18, 1968 J. C. SCHNURIGER 3,389,283

ELECTRODE STRUCTURE CYCLOTRON HAVING GROUNDED COUPLING PLATES BETWEEN THE DEE RINGS

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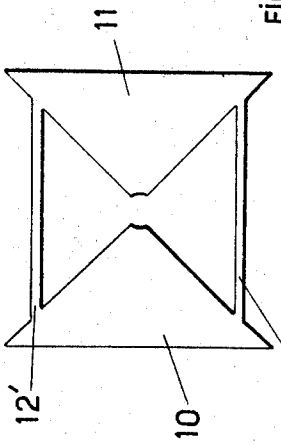
FIG.4



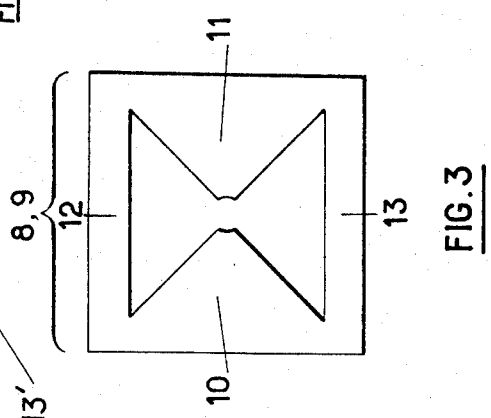


FIG.3

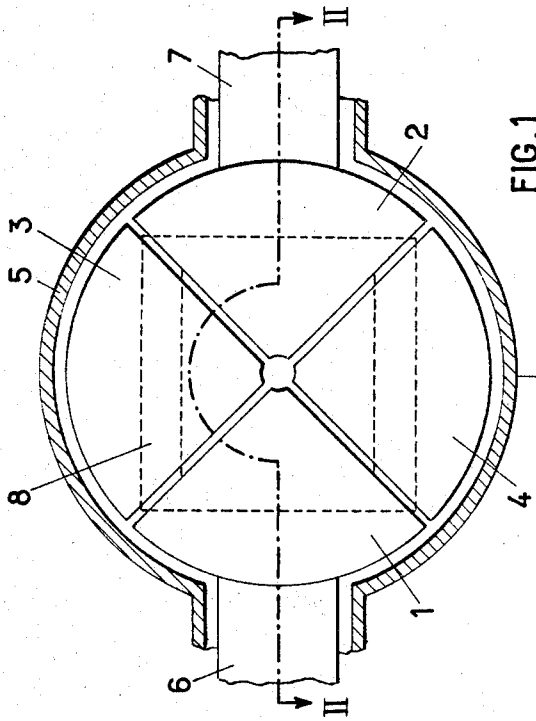


FIG.1

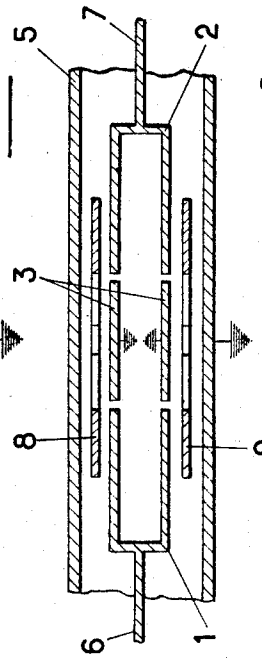


FIG.2

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ELECTRODE STRUCTURE CYCLOTRON HAVING GROUNDED COUPLING PLATES BETWEEN THE DEE-RINGS

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8 Claims. (Cl. 313—62)

ABSTRACT OF THE DISCLOSURE

A cyclotron comprising a pair of sectoral dee electrodes with the sector angle reduced below 180°, separated by grounded electrodes, wherein coupling electrodes, insulated from ground and extending between the surfaces of the dee electrodes and the internal walls of the envelope of the cyclotron are provided with such a shape that the capacitance coupling the electrode to the dee is high with respect to the capacitance coupling the electrode to ground, thereby enhancing the difference between resonant frequencies of the electrical circuit of the cyclotron, when operated in push-push or push-pull mode, respectively.

The present invention relates to cyclotrons, and more particularly to cyclotrons of the type comprising dee electrodes of sectoral shape with the sector angle reduced below 180°, separated by electrodes electrically or galvanically connected to ground.

It is known that such a cyclotron is capable of operating with harmonic acceleration (acceleration realized with a ratio between the period of the excitation frequency and the period of cyclotron rotation of the particles equal to an integral number greater than one), either in that the dee electrodes are excited in phase opposition, producing an operation at the fundamental or at an odd harmonic, or in that they are excited in phase, producing an operation at an even harmonic. To avoid certain disturbances in the operation of the cyclotron, for example, a movement in unison of the orbits of the particles, there exists an interest to separate the resonance frequencies of the system of the dee electrodes corresponding to these two modes of excitation.

It is already known is the prior art to separate these frequencies by coupling the dee electrodes with one another, and one accomplishes this coupling by replacing one of the electrodes connected electrically or galvanically to ground with another electrode, this replacement electrode being galvanically insulated from ground but being substantially at the potential of ground from the point of view of high frequencies, owing to the strong capacitive coupling of this electrode with the evacuated box forming the ground. Nevertheless, since this electrode is positioned between the dee electrodes, its capacity with respect to each of the dee electrodes is relatively small whereas its plain surface parallel to the walls of the evacuated box forms therewith a high capacity, which is necessary anyhow in order that the electrode be at ground from the high frequency point of view. It follows therefrom that the ratio between these two capacities assumes a small value, for example, of the order of 0.1 in practice. However, the desired separation increases with increase in this ratio, and with a ratio of the order of 0.1, one can obtain in practice only a separation, expressed with respect to the average operating frequency, of the order of 1% or less.

Since this figure is insufficient while the suppression of the electric or galvanic ground connection of one of the electrodes introduces a series of inconveniences in the general operation of the cyclotron, it is preferable to maintain this ground connection and to search for another way of realizing the coupling between the dee electrodes by means of separate electrodes having a special configuration because the galvanic ground connection of the electrodes positioned between the dee electrode leads to the practically complete decoupling of the dee electrodes, and consequently without separate electrodes, the separation of the resonant mode is zero or very slight.

The object of the present invention consists in providing coupling means, assuring a strong separation of the modes within a cyclotron whose dee electrodes are separated by electrodes galvanically connected to ground.

According to the present invention, the coupling means are constituted by at least one electrode insulated from ground and extending parallelly to the dee electrode between the latter and the wall of the evacuated box.

According to a further development of the present invention, this electrode possesses a form presenting plain portions having substantially the same contour as the portions of the dee electrodes which face the same, these plain portions being operatively connected by connections or notched parts presenting a relatively reduced surface facing the walls of the evacuated box, thus realizing the relatively high ratio between the capacitances dees-auxiliary electrode and auxiliary electrode-ground.

Accordingly, it is an object of the present invention to provide an electrode structure for cyclotrons of the type described above which obviates, by extremely simple means, the aforementioned shortcomings encountered with the prior art construction.

Another object of the present invention resides in the provision of an electrode structure for cyclotrons which permits by simple means to separate the different modes of resonance of the system of the dee electrodes.

Still another object of the present invention resides in the provision of an auxiliary electrode structure providing coupling means between the dee electrodes and the surrounding walls of the casing which is so constructed and arranged as to assure a relatively high ratio of the capacitance between the auxiliary coupling electrode and the dee electrodes and the capacitance between the auxiliary coupling electrode and the surrounding walls of the evacuated box structure.

Still another object of the present invention resides in the provision of an electrode structure of cyclotrons in which the resonant frequencies of the system corresponding to the different modes of excitation are effectively separated without decoupling the dee electrodes.

These and other objects, features, and advantages of the present invention will become more obvious from the following description when taken in connection with the accompanying drawing which shows, for purposes of illustration only, two embodiments in accordance with the present invention, and wherein:

FIGURE 1 is a partial longitudinal cross sectional view of a cyclotron provided with coupling means according to the present invention,

FIGURE 2 is a partial transverse cross sectional view through the cyclotron of FIGURE 1, taken along the II—II of FIGURE 1,

FIGURE 3 is a plan view on an electrode constituting a coupling means in accordance with the present invention; and

FIGURE 4 is a plan view on a modified embodiment of an electrode forming a coupling means in accordance with the present invention.

Referring now to the drawing wherein like reference numerals are used throughout the various views to designate like parts, and more particularly to FIGURES 1 and 2, there is shown for illustrative purposes in these two figures, a cyclotron having two dee electrodes 1 and 2 of

sectoral shape with the sector angle thereof reduced to 90°, separated by two electrodes 3 and 4 of a shape similar to the dee electrodes 1 and 2 but constituting inactive dee electrodes which are connected to the ground constituted by the evacuated box 5.

The dee electrodes 1 and 2 are supported by beam-like supports 6 and 7, connected to the high frequency circuit of the cyclotron, which has not been shown since its construction is conventional and forms no part of the present invention. Similarly, the conventional pole pieces of the cyclotron also have not been shown for sake of simplicity of the drawing.

According to the present invention, the coupling between the dee electrodes 1 and 2, which are otherwise decoupled by the inactive dee electrodes 3 and 4, electrically or galvanically connected to ground, is realized by means of the auxiliary electrodes 8 and 9, insulated from ground and extending parallelly to the dee electrodes 1 and 2 between the latter and the walls of the evacuated box 5.

FIGURE 3 represents a plan view of each of the auxiliary electrodes 8 and 9. This auxiliary electrode is formed by a rectangular plate suitably cut out in such a manner as to form with the dee electrodes 1 and 2 a relatively strong capacitance and with the evacuated box 5 a relatively slight capacitance. It may be seen from this figure that the cut-out portion leaves the plain triangular portions 10 and 11 which are placed facing the sectoral surfaces of the dee electrodes 1 and 2. These portions, in particular the apices of the triangles 10 and 11, are interconnected by connections or narrow bands 12 and 13 whose surfaces facing the wall 5 are relatively restricted in such a manner that the capacity between the electrode 8 and ground is only slightly higher than the capacity between the electrode 8 and the dee electrodes 1 and 2.

In the modified embodiment of FIGURE 4, the triangles 10 and 11 analogous to that of FIGURE 3 are connected with each other, not by the bands 12 and 13 interconnecting opposite apices thereof, but by bands 12′ and 13′ interconnecting intermediate points of the sides of these triangles. In this manner one may obtain a further relative diminution of the capacity formed between the interconnecting bands 12′ and 13′ and ground.

Calculations and experiments show that one may realize in this manner a ratio between the capacitances (auxiliary electrode-dee electrodes and auxiliary electrode-ground) of the order of 0.7 which corresponds to a separation of the frequencies of the resonant modes greater than 3%.

While I have shown and described two embodiments in accordance with the present invention, it is understood that the same is not limited thereto but is susceptible of numerous changes and modification as known to a person skilled in the art, and I therefore do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are encompassed by the scope of the appended claims.

I claim:

1. In a cyclotron having a grounded evacuated envelope, the combination comprising:
- at least one pair of dee electrodes within said envelope and having each a sectoral shape with the sector angle less than 180°,
- at least one pair of grounded electrodes each separating two of said dee electrodes,
- and means for electrically coupling two of said dee electrodes belonging to a respective pair including at least one auxiliary electrode means insulated from ground and extending parallelly to said dee electrdoes between the surfaces thereof and the internal walls of said envelope.

2. In a cyclotron having a grounded evacuated envelope, the combination comprising:
- at least one pair of dee electrodes within said envelope and having each a sectoral shape with the sector angle less than 180°,
- at least one pair of grounded electrodes each separating two of said dee electrodes,
- and means for electrically coupling two of said dee electrodes belonging to a respective pair including at least one coupling electrode means insulated from ground and extending parallelly to said dee electrodes between the surfaces thereof and the internal walls of said envelope,
- said coupling electrode means being so shaped and positioned that the capacitance formed between said coupling electrode means and said dee electrodes is relatively high with respect to the capacitance formed between said coupling electrode means and ground.

3. In a cyclotron having a grounded evacuated envelope, the combination comprising:
- at least one pair of dee electrodes within said envelope and having each a sectoral shape with the sector angle less than 180°,
- at least one pair of grounded electrodes each separating two of said dee electrodes,
- and means for electrically coupling two of said dee electrodes belonging to a respective pair including at least one coupling electrode means insulated from ground and extending parallelly to said dee electrodes between the surfaces thereof and the internal walls of said envelope,
- said coupling electrode means being so shaped and positioned that the capacitance formed between said coupling electrode means and said dee electrodes is relatively high with respect to the capacitance formed between said coupling means and ground,
- said coupling electrode means having a shape with plain parts of substantially the same contour as the parts of said dee electrodes facing said plain parts, and connections between said plain parts of relatively reduced surface and facing the wall of said envelope.

4. In a cyclotron having a grounded evacuated envelope, the combination comprising:
- at least one pair of dee electrodes within said envelope and having each a sectoral shape with the sector angle less than 180°,
- at least one pair of grounded electrodes each separating two of said dee electrodes,
- and means for electrically coupling two of said dee electrodes belonging to a respective pair including at least one coupling electrode means insulated from ground and extending parallelly to said dee electrodes between the surfaces thereof and the internal walls of said envelopes,
- said coupling electrode means being so shaped and positioned that the capacitance formed between said coupling electrode means and said dee electrodes is relatively high with respect to the capacitance formed between said coupling electrode means and ground,
- said coupling electrode means having a shape with plain parts of substantially the same contour as the parts of said dee electrodes facing said plain parts, and connections between said plain parts of relatively reduced surface and facing the wall of said envelope,
- said coupling electrode means being effectively constituted by a butterfly-shaped aperture provided in a substantially rectangular plain plate.

5. In a cyclotron having a grounded evacuated envelope, the combination comprising:
- at least one pair of dee electrodes within said envelope and having each a sectoral shape with the sector angle less than 180°,
- at least one pair of grounded electrodes each separating two of said dee electrodes,
- and means for electrically coupling two of said dee electrodes belonging to a respective pair including at least one coupling electrode means insulated from ground and extending parallelly to said dee electrodes between the surfaces thereof and the internal walls of said envelope,

said coupling electrode means being so shaped and positioned that the capacitance formed between said coupling electrode means and said dee electrodes is relatively high with respect to the capacitance formed between said coupling electrode means and ground,

said coupling electrode means having a shape with plain parts of substantially the same contour as the parts of said dee electrodes facing said plain parts, and connections between said plain parts of relatively reduced surface and facing the wall of said envelope,

said plain parts being substantially triangularly shaped with metallic bands interconnecting opposite sides of respective triangles.

6. In a cyclotron having a grounded evacuated envelope, at least one pair of dee electrodes within said envelope each having a sectoral shape with the sector angle less than 180°, and at least one pair of grounded decoupling electrodes, each separating two of said dee electrodes,

the improvement essentially consisting of means for effectively separating the resonant frequencies corresponding to different modes of excitation including auxiliary means providing a relatively high ratio of the capacitance between said auxiliary means and said dee electrodes to the capacitance between said auxiliary means and said envelope.

7. In a cyclotron having a grounded evacuated envelope, at least one pair of dee electrodes within said envelope each having a sectoral shape with the sector angle less than 180°, and at least one pair of grounded decoupling electrodes, each separating two of said dee electrodes,

the improvement essentially consisting of means for effectively separating the resonant frequencies corresponding to different modes of excitation including auxiliary means providing a relatively high ratio of the capacitance between said auxiliary means and said dee electrodes to the capacitance between said auxiliary means and said envelope,

said auxiliary means being positioned between said dee electrodes and the internal walls of said envelope.

8. In a cyclotron having a grounded evacuated envelope, at least one pair of dee electrodes within said envelope each having a sectoral shape with the sector angle less than 180°, and at least one pair of grounded decoupling electrodes, each separating two of said dee electrodes,

the improvement essentially consisting of means separate from said decoupling electrodes for effectively separating the resonant frequencies corresponding to different modes of excitation including auxiliary electrode means providing a relatively high ratio of the capacitance between said auxiliary means and said dee electrodes to the capacitance between said auxiliary means and said envelope.

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