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Wierts et al.

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[54] **SHORT HIGH-FREQUENCY RESONATOR HAVING A LARGE FREQUENCY RANGE FOR CYCLOTRONS**

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Related U.S. Application Data

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[30] **Foreign Application Priority Data**

Apr. 29, 1970 Netherlands 7006247

[52] **U.S. Cl.** ..... **333/82 B,** 328/234, 315/5.41

[51] **Int. Cl.** **H01p 7/00**

[58] **Field of Search** ..... 315/5.41, 5.42; 333/82 B; 328/234

[56] **References Cited**

UNITED STATES PATENTS

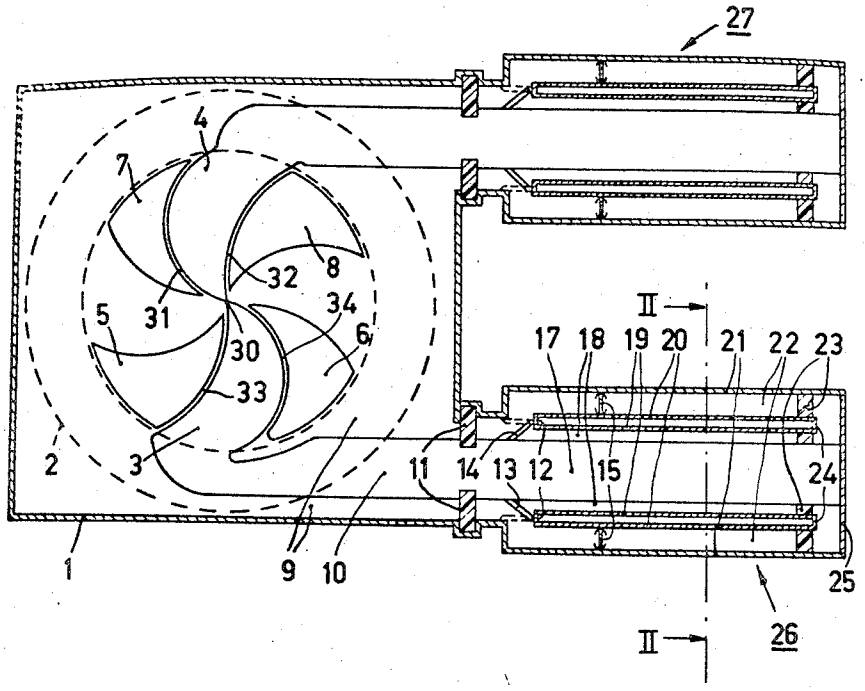
2,763,842	9/1956	Olive	333/82 B X
3,452,293	6/1969	DeLong et al.	333/82 B
3,634,790	1/1972	Turteltaub	333/82 B
2,553,312	5/1951	Gurewitsch	333/82 B X
2,542,974	2/1951	Abbot et al.	333/82 B
2,525,452	10/1950	Gurewitsch	333/82 B X

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[57] **ABSTRACT**

An electric high-frequency resonator for accelerating charged atomic particles, comprising a first hollow conductor, a second hollow conductor extending within the first hollow conductor, a third hollow conductor extending within the second hollow conductor and a fourth hollow conductor extending within the third hollow conductor. The second and third hollow conductors and the first and fourth hollow conductors are connected respectively to form first and second waveguides for the propagation of high-frequency waves. Input coupling means are employed to connect the interposed first and second waveguides in series thereby providing increased electrical length characteristics for the propagation of high-frequency electric waves without increasing the structural length of the resonator.

5 Claims, 3 Drawing Figures



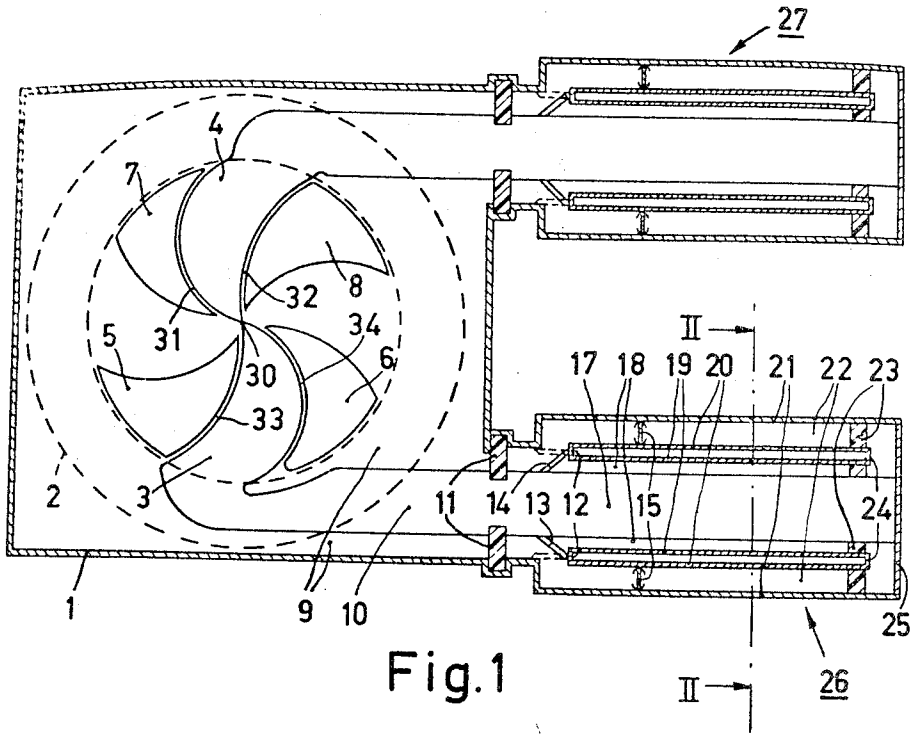

27
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II
17 18 19 20 21 22 23
2
3
11 14 13 12 15
24
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9 10
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II
26

Fig.1

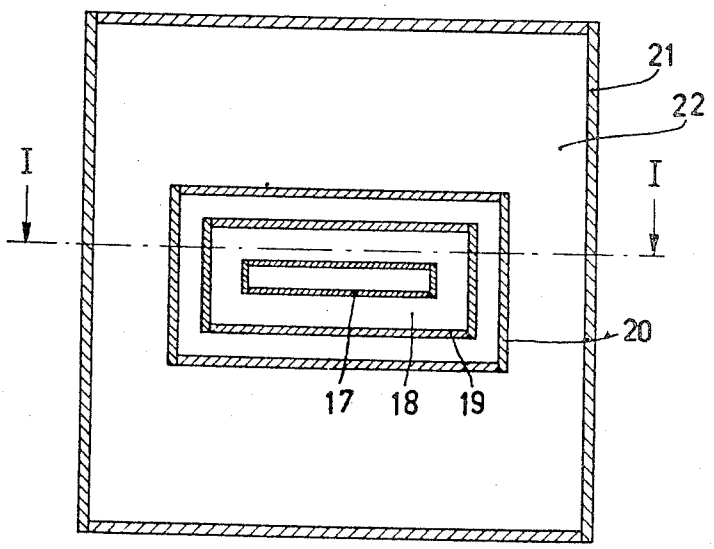

21
22
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I
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17 18 19

Fig.2

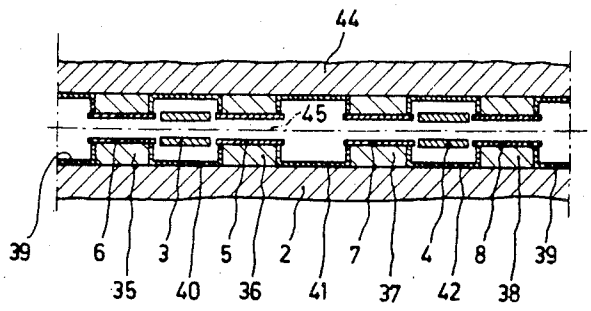


Fig. 3

SHORT HIGH-FREQUENCY RESONATOR HAVING A LARGE FREQUENCY RANGE FOR CYCLOTRONS

This is a division of application Ser. No. 132,326, filed Apr. 8, 1971.

The invention relates to an electric high-frequency resonator for a device for accelerating charged atomic particles, comprising a wave-guide having an inner conductor and an outer conductor, two accelerating electrodes and a short-circuit plate which is arranged in the wave-guide so as to be slidable. The invention also relates to a device for accelerating charged atomic particles, in particular a cyclotron, comprising such a high-frequency resonator.

High-frequency resonators of the type mentioned in the first paragraph are known. By means of such a high-frequency resonator, charged atomic particles are accelerated, for example, in an isochronous cyclotron, a high-frequency voltage having a constant amplitude of, for example, 10 to 70 kV and a constant frequency of, for example, 1 to 50 MHz being set up between the accelerating electrodes. The required frequency depends, inter alia, on the type of the atomic particle to be accelerated and on the magnetic field used in the cyclotron. For accelerating so-called heavy ions and also for accelerating particles to a comparatively low energy compared with the energy maximally achievable in the cyclotron, an accelerating voltage is necessary having a frequency which must be considerably lower than the highest desirable frequency which occurs during the acceleration of protons to the highest energy possible in the cyclotron. Such a low frequency is associated with large dimensions of the resonator. Actually, a resonator of the type mentioned in the first paragraph may be considered analogous to an electric oscillatory circuit having a capacity and an inductance, the capacity being formed by the capacity between the accelerating electrodes (the usually earthed surrounding which is connected to one of the accelerating electrodes is considered to belong to said electrode) and the inductance being formed by the inductance at one end of the wave-guide which is shortcircuited at the other end by the shortcircuit plate. If the capacity between the accelerating electrodes is small relative to the capacity per unit of length of the wave-guide, the effective length of the wave-guide is approximately one fourth of the wavelength which is associated with the desirable frequency. From this it appears, and by calculations it can be proved, that the resonator for low frequencies is very long relative to the other dimensions of the cyclotron. It is to be noted that a wave-guide is to be understood to mean herein a piece of high-frequency line of the type which is sometimes termed coaxial, although neither an exact coaxial state nor a circular cross-section of the wave-guide is implied here.

In a known high-frequency resonator of the type mentioned in the first paragraph, which is described in Dutch Patent application No. 6,815,876, the length of the wave-guide which is necessary for the lowest resonant frequency is reduced by providing a fixed capacitor parallel to the wave-guide and in the region of the shortcircuit plate at the highest resonant frequency. In this resonator the highest possible frequency is not influenced because at that frequency the capacitor is short-circuited by the shortcircuit plate. However, such a capacitor is difficult to provide because the available space for doing this is very restricted. A further drawback is that at low frequencies, the voltage across said capacitor substantially is the voltage between the accelerating electrodes; this voltage is so large that breakdown can easily occur.

It is the object of the invention to provide a high-frequency resonator which has a length which is much smaller than the length of the wave-guide active for wave propagation and does not exhibit the above-mentioned drawbacks.

According to the invention, in an electric high-frequency resonator for a device for accelerating charged atomic particles, comprising a wave-guide having an inner conductor and an outer conductor, two accelerating electrodes and a shortcircuit plate which is arranged in the wave-guide so as to be slidable, the wave-guide consists of two parts in such manner that the outer conductor of the inner part is present within the inner conductor of the outer part, the outer conductor of the inner part being connected for high-frequency currents to the inner conductor of the outer part and the inner conductor of the inner part being connected for high-frequency currents to the outer conductor of the outer part of the wave-guide on the side of the two parts of the wave-guide remote from the accelerating electrodes, the accelerating electrodes being connected for high-frequency currents to arbitrarily one of the two parts of the wave-guide. By dividing the wave-guide into two parts, providing one part within the other, and connecting both parts in series, a structural length is obtained which is approximately half of the length of the wave-guide which is active for the wave propagation at the lowest possible resonant frequency. Since the resulting advantages may not be associaed with a decrease of the highest possible frequency of the resonator which occurs if the active length of the wave-guide is as small as possible, the invention provides for a switching possibility as a result of which the accelerating electrodes can also be connected directly to the part of the wave-guide in which the shortcircuit plate is present. By moving the shortcircuit plate as close to the accelerating electrodes as possible, a very short active length of the wave tube is obtained and consequently a high resonent frequency.

A high-frequency resonator according to the invention can advantageously be constructed so that the inner conductor and the outer conductor of both parts of the wave-guide each have a substantially rectangular cross-section, the sides of the rectangular cross-sections being mutually substantially parallel. This construction has advantages with respect to the way in which the accelerating electrodes are connected for high-frequency currents to arbitrarily one of the two parts of the wave-guide. This connection may be carried out, for example, by means of flat plates which are mounted in the resonator in such manner that the correct manner of connection is obtained.

Another advantageous construction of the high-frequency resonator according to the invention is such that the outer conductor of the outer part and the inner conductor of the inner part of the wave-guide each have a substantially rectangular cross-section, the sides of the rectangular cross-sections being mutually substantially parallel, and the outer conductor of the inner part and the inner conductor of the outer part of the wave tube each consisting of two parallel conductors

extending in the longitudinal direction of the two parts of the wave tube and having cross-sections which are constituted by four whole parallel sides of two rectangles and at most parts of the four other sides, the sides of said rectangles being substantially parallel to those of the rectangle which constitutes the cross-section of the outer conductor of the outer part of the wave tube. This presents advantages in particular if the short-circuit plate is provided in the inner part of the wave-guide. In that case the shortcircuit plate actually can be moved by a mechanism which is connected to the shortcircuit plate through a slot in the outer conductor of the inner part and the inner conductor of the outer part of the wave-guide.

A particularly advantageous construction for the way in which the accelerating electrodes for high-frequency currents are connected to arbitrarily one of the two parts of the wave-guide is such that one of the two accelerating electrodes is permanently connected to the outer conductor of the outer part of the wave-guide and the other of the two accelerating electrodes is permanently connected to the inner conductor of the inner part of the wave-guide and arbitrarily the outer conductor of the inner part on the side of the accelerating electrodes is connected to the outer conductor of the outer part of the wave-guide or the inner conductor of the inner part on the side of the accelerating electrodes is connected to the inner conductor of the outer part of the wave-guide. This construction which is possible because one of the two parts of the wave-guide is present within the other part gives a considerable saving of the necessary number of connection members.

If the construction of the high-frequency resonator is such that the inner conductor and the outer conductor of the two parts of the wave-guide each have a substantially rectangular cross-section in which the sides of the rectan-gular cross-sections are mutually substantially parallel and that one of the two accelerating electrodes is permanently connected to the outer conductor of the outer part of the wave-guide and the other of the two accelerating electrodes is permanently connected to the inner conductor of the inner part of the wave-guide and arbitrarily the outer conductor of the inner part on the side of the accelerating electrodes is connected to the outer conductor of the outer part of the wave-guide or the inner conductor of the inner part on the side of the accelerating electrodes is connected to the inner conductor of the outer part of the wave-guide, a very simple construction is possible for the way in which the accelerating electrodes are connected for high-frequency currents to arbitrarily one of the two parts of the wave-guide. The configuration of the two parts of the wave-guide can then advantageously be chosen to be so that the electromagnetic field in the case of resonance of the resonator in each of the two parts of the wave-guide is present mainly in two spaces, the cross-section of which is substantially rectangular, and which are located diametrically opposite to each other. This can be realized for both parts of the wave-guide by making the quotient, which is found by dividing the length of one side of the rectangular cross-section of an inner conductor by the distance from said side to an outer conductor associated with the said inner conductor, relatively large for the parts of the cross-section in which the electromagnetic field must mainly be present with respect to the quotient for the two other parts of the cross-section found in the same manner. This configuration enables a construction such that a device, with which arbitrarily the outer conductor of the inner part on the side of the accelerating electrodes is connected to the outer conductor of the outer part of the wave-guide or the inner conductor of the inner part on the side of the accelerating electrodes is connected to the inner conductor of the outer part of the wave-guide, consists of two connection members which arbitrarily connect two parallel sides of the outer conductor of the inner part to two sides of the outer conductor of the outer part of the wave-guide likewise extending parallel to said parallel sides, or connect two sides of the inner conductor of the inner part extending parallel to the first-mentioned sides to two sides of the inner conductor of the outer part of the wave-guide likewise extending parallel to said parallel sides. The parallel sides which are connected by the connection members must then adjoin the spaces which mainly contain the electromagnetic field.

The same simple construction is possible if the construction of the high-frequency resonator is such that the outer conductor of the outer part and the inner conductor of the inner part of the wave-guide each have a substantially rectangular cross-section, in which the sides of the rectan-gular cross-sections are mutually substantially parallel, and the outer conductor of the inner part and the inner conductor of the outer part of the wave-guide each consist of two parallel conductors which extend in the longitudinal direction of the two parts of the wave-guide and have cross-sections which are constituted by four whole parallel sides of two rectangles and at most parts of the four other sides, in which the sides of said rectangles are substantially parallel to those of the rectangle which forms the cross-section of the outer conductor of the outer part of the wave-guide, and that one of the two accelerating electrodes is permanently connected to the outer conductor of the outer part of the wave-guide, and the other of the two accelerating electrodes is permanently connected to the inner conductor of the inner part of the wave tube and arbitrarily the outer conductor of the inner part on the side of the accelerating electrodes is connected to the outer conductor of the outer part of the wave tube or the inner conductor of the inner part on the side of the accelerating electrodes is connected to the inner conductor of the outer part of the wave-guide. If the configuration of both parts of the wave-guide is then chosen to be so that the electromagnetic field in the case of resonance mainly adjoins those sides of the conductors which in the cross-section are formed by a whole side of a rectangle, then it is possible to construct the high-frequency resonator in such manner that a device, with which arbitrarily the outer conductor of the inner part on the side of the accelerating electrodes is connected to the outer conductor of the outer part of the wave-guide, or the inner conductor of the inner part on the side of the accelerating electrodes is connected to the inner conductor of the outer part of the wave-guide, consists of two connection members which arbitrarily connect two parallel sides of the outer conductor of the inner part of the wave tube which in the cross-section are formed by two whole sides of a rectangle to two sides of the outer conductor of the outer parts extending parallel to said parallel sides or connect two sides of the inner conductor of the inner part extending parallel to the first-mentioned sides to two sides of the inner conductor of the outer part of the

wave-guide, likewise extending parallel to said parallel sides. In this case also the parallel sides which are connected by the connection members should adjoin the spaces which mainly contain the electromagnetic field.

The above-described construction of the connection of the accelerating electrodes to the wave-guide, which is very simple as it is since it consists only of two connection members which are each used for both connection possibilities, is carried out particularly elegantly if the outer conductor of the inner part and the inner conductor of the outer part of the wave tube on the side of the accelerating electrodes are provided with a connection and the two connection members each pivot substantially about an axis which coincides sub-stantially with said connection.

For working with a device for accelerating charged atomic particles, comprising a high-frequency resonator according to the invention, it is furthermore particularly handy if the two frequency ranges which are obtained by moving the shortcircuit plate if the accelerating electrodes are connected to the inner part of the wave-guide respectively by moving the shortcircuit plate if the accelerating electrodes are connected to the outer part of the wave-guide, overlap each other. This can be obtained by a suitable choice of the characteristic impedances of the two parts of the wave tube.

It is to be noted that the invention can be used with the short-circuit plate in the outer part of the wave tube or with the shortcircuit plate in the inner part of the wave tube.

Furthermore it is to be noted that the inner conductor of the outer part and the outer conductor of the inner part of the wave tube may form one assembly mechanically. A construction is possible consisting of two conductors with the interposition of any material, preferably a light-weight material, which conductors are connected at the ends, and also a construction is possible consisting of one conductor on which as a result of the known skin effect two conductors for high-frequency currents are formed on the inner surface and the outer surface.

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

FIG. 1 is a diagrammatic cross-sectional view of a cyclotron having two high-frequency resonators according to the invention, in which the plane of the cross-section substantially coincides with the path of the particles to be accelerated.

FIG. 2 is a cross-sectional view of one of the wave tubes taken on the line II—II of FIG. 1;

FIG. 3 is a cross-sectional view taken unrolled along the line III in FIG. 1.

Reference numeral 1 in FIG. 1 denotes a vacuum chamber of the cyclotron which has a circular pole 2. One of two high-frequency resonators is constituted by a wave-guide 26 and three electrodes 3, 5 and 6. The electrodes 5 and 6 together form one electrode which is often termed "dummy-D" and which is connected to an outer conductor 21 of the outer part 22 of the wave-guide 26 via a conductive coating (39, 40, 41 and 42 in FIG. 3) of the pole (44 in FIG. 3) 2 and a second pole of the cyclotron located on the other side of the plane of the drawing, as well as via a conductive coating 9 in the vacuum chamber 1. The electrode 3 which is often termed "D" is connected to an inner conductor 17 of the inner part 18 of the wave-guide 26 via a stem 10. In the same manner, three electrodes 4, 7 and 8 are connected to a wave-guide 27 and constitute a second high-frequency resonator. Charged particles which are injected by an ion source (not shown) in the proximity of a center 30 in the cyclotron are accelerated by an electric field in four accelerating gaps 31, 32, 33 and 34 between the electrodes 3, 4, 5, 6, 7 and 8.

In the embodiment chosen of the cyclotron the electrodes 3 and 4 are interconnected in the center 30 of the cyclotron. The electrodes 5, 6, 7 and 8 are also connected together via the conductive coating of the poles. This is related to the fact that the voltages of the electrodes 3 and 4 must be in phase in this cyclotron and is in no relation to the invention.

The stem 10 is connected to the inner conductor 17 via a lead-in insulator 11 which forms an air-tight wall between the vacuum chamber 1 and the wave-guide 26 which is in atmospheric air.

The wave-guide 26 comprises the inner part 18 with the inner conductor 17 and an outer conductor 19 and the outer part 22 with an inner conductor 20 and the outer conductor 21. The wave-guide 27 is constructed in the same manner. A diagrammatically shown short-circuit plate 15 is present in the outer part 22 of the wave-guide 26 and connects the outer conductor 21 to the inner conductor 20, by which the active length of the wave-guide 26 is determined. In a corresponding place in the wave-guide 27 there is also a short-circuit plate. The two short-circuit plates are movable by a driving mechanism (not shown).

The inner part 18 and the outer part 22 of the wave-guide 26 are connected in series with two connections 24 and 25.

In two diagrammatically shown connection members 13 and 14 the inner conductor 20 and the outer conductor 19 are interconnected by means of a connection 12.

In the position shown of the connection members 13 and 14, which in the Figure only diagrammatically show the way of connection, the electrodes 3, 5 and 6 are connected to the outer part 22 of the wave-guide 26. In the broken-line position of the connection members 13 and 14 the electrodes 3, 5 and 6 are connected to the inner part 18 of the wave-guide 26. An insulator 23 supports the inner conductor 20 and the outer conductor 19 which mechanically form one assembly. A connection of the resonators to an oscillatory circuit which supplies the two high-frequency resonators with electric energy as a result of which the electric field is formed across the accelerating gaps 31, 32, 33 and 34, is not shown in the drawing.

FIG. 2 is a cross-sectional view of the inner part 18 with the inner conductor 17 and the outer conductor 19 of the wave-guide 26 as well as the outer part 22 with an inner conductor 20 and the outer conductor 21.

FIG. 3 is a cross-sectional view taken unrolled along the line III in FIG. 1 to more clearly point out the interconnecting conductive coatings on the poles. The figure shows pole 2 of a cyclotron with pole-pieces 35, 36, 37 and 38 which are often called hills and which serve for the magnetic focussing of the particle beam. The unrolled particle beam almost coincides with the line 45. The electrodes 5, 6, 7, and 8, which are also shown in FIG. 1, form the "dummy Dees" and are intercon-

nected via the conductive coating on pole **2** designated by the reference numerals **39, 40, 41,** and **42** of which **39** and **41** are also visible in FIG. **1.** The accelerating electrodes **3** and **4,** the so-called "Dees," are situated in two of the four valleys between the hills or pole-pieces **35, 36, 37,** and **38.** The other pole **44** of the cyclotron has a symmetrical construction with respect to pole **2.** The conductive coating **39, 40, 41** and **42** on pole **2** and the corresponding conductive coating on pole **44** are connected with the conductive coating **9** in the vacuum chamber **1** and through this to the waveguide, as shown in FIG. **1.**

The diameter of the poles **2** of the cyclotron shown in FIG. **1** is 850 mm. This cyclotron can inter alia accelerate protons to an energy of approximately 18 meV which are extracted from the cyclotron by means of an extractor not shown. The length of the wave-guides **26** and **27** from the connection members **13** and **14** to the connection **25,** is 1,645 mm. The dimensions of the cross-sections of the conductors are:

outer conductor **21**; 420 mm × 420 mm
inner conductor **20**: 224 mm × 117 mm
inner conductor **17**: 180 mm × 27 mm
outer conductor **19**: 220 mm with a height at right angles to the plane of the drawing of FIG. **1** which varies from 57 mm at the connection 24 to 77 mm at the connection **12.** As a result of this two overlapping frequency ranges are obtained, namely from 11.4 to 25.8 MHz in the broken-line position of the connection members **13** and **14** and from 17.8 to 56.5. MHz in the solid-line position. The voltage across the accelerating gaps **31, 32, 33** and **34** can be adjusted to a maximum amplitude of 30 kV.

What is claimed is:

1. An electric high-frequency resonator comprising an outer tubular conductor extending a predetermined length and having an open end and a closed end, an inner conductor extending coaxially within said outer conductor for said predetermined length and having one end thereof connected to said closed end of said outer conductor and an open other end, a tubular conducting member extending coaxially in the intermediate space between said conductors for a length shorter than said predetermined length to provide two concentric waveguide parts communicating with each other at respective end portions of said conductors, first short-circuit means disposed in one waveguide part to form adjacent resonating cavities therein, and second short-circuit means connected to the end of said conducting member near the open ends of said conductors and being tiltable between a first position in contact with said inner conductor and, respectively, a second position in contact with said outer conductor to couple selectively one of said cavities to the open end portions of said conductors while short-circuiting the other cavity.

2. A resonator as claimed in claim **1** for use in connection with a cyclotron, said open ends of said conductors being connectable to acceleration electrodes of said cyclotron.

3. A resonator as claimed in claim **1,** wherein said first short-circuit means includes sliding plates positioned between said outer and inner conductors to tune said resonator.

4. A resonator as claimed in claim **3** wherein said sliding plates tune over two frequency ranges, said frequency ranges overlapping each other.

5. A resonator as claimed in claim **1** wherein said outer and inner conductors and said conducting member are substantially rectangular in cross-section having confronting sides substantially parallel to each other.

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