United States Patent [19]
Tran
[11] 3,906,300
[45] Sept. 16, 1975

[54] MULTIPERIODIC ACCELERATOR STRUCTURES FOR LINEAR PARTICLE ACCELERATORS

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[22] Filed: **July 5, 1973**
[21] Appl. No.: **376,584**

[30] **Foreign Application Priority Data**
July 7, 1972 France 72.24746

[52] **U.S. Cl.** **315/5.42;** 315/3.5; 315/5.41; 328/233
[51] **Int. Cl.** **H01j 25/10**
[58] **Field of Search** .... 315/5.41, 5.42, 3.5 X, 315/3.5; 328/233

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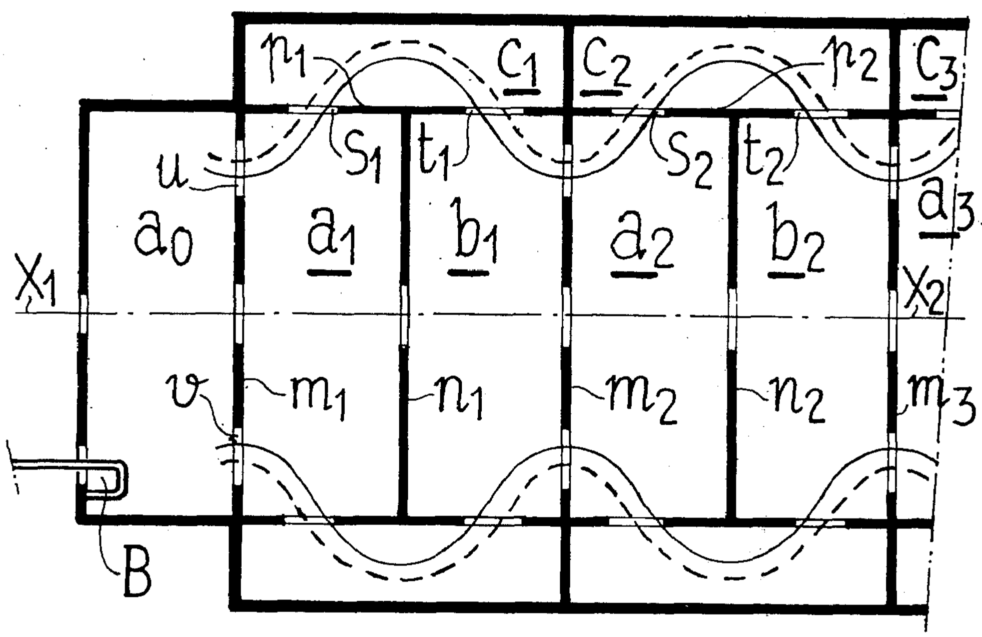
Attorney, Agent, or Firm—Oblon, Fisher, Spivak, McClelland & Maier

[57] **ABSTRACT**

High efficiency linear accelerator structures comprising a succession of cylindrical resonant cavities which are accelerating cavities, and coupling annular cavities which are located at the periphery thereof, each of these annular cavities being coupled to two adjacent cylindrical cavities.

8 Claims, 16 Drawing Figures



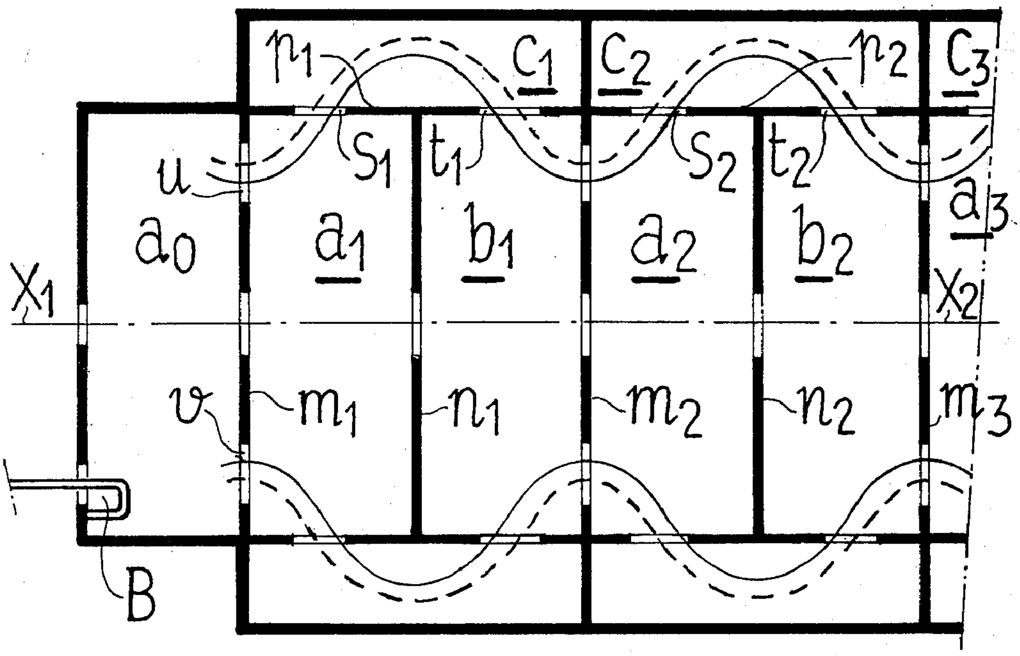

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Fig. 1

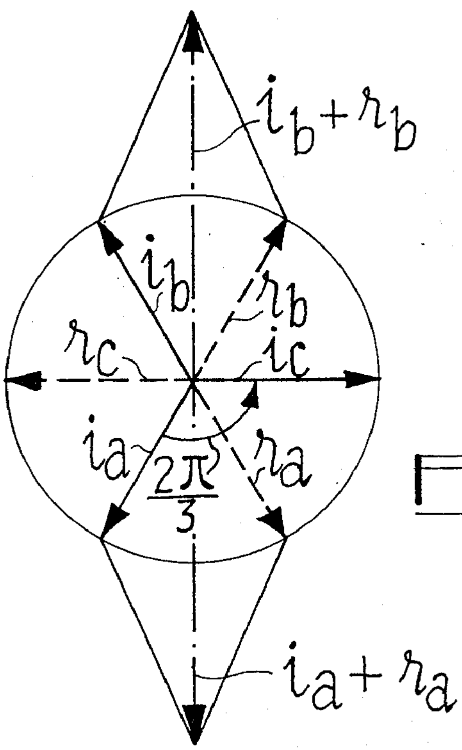
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Fig. 2

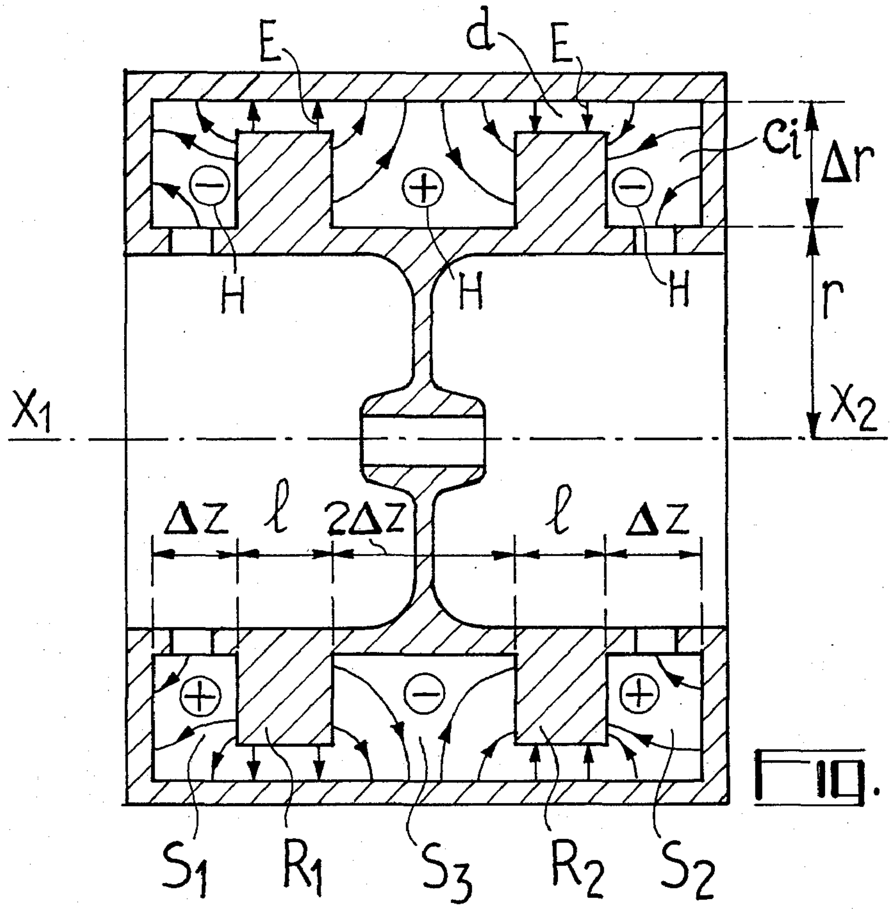

Fig. 3

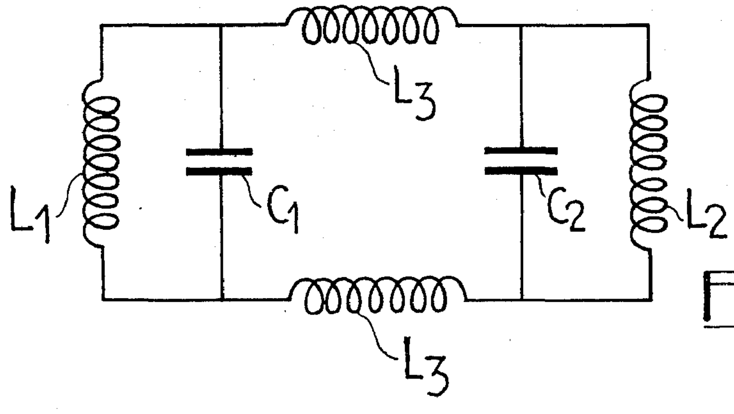

Fig. 4

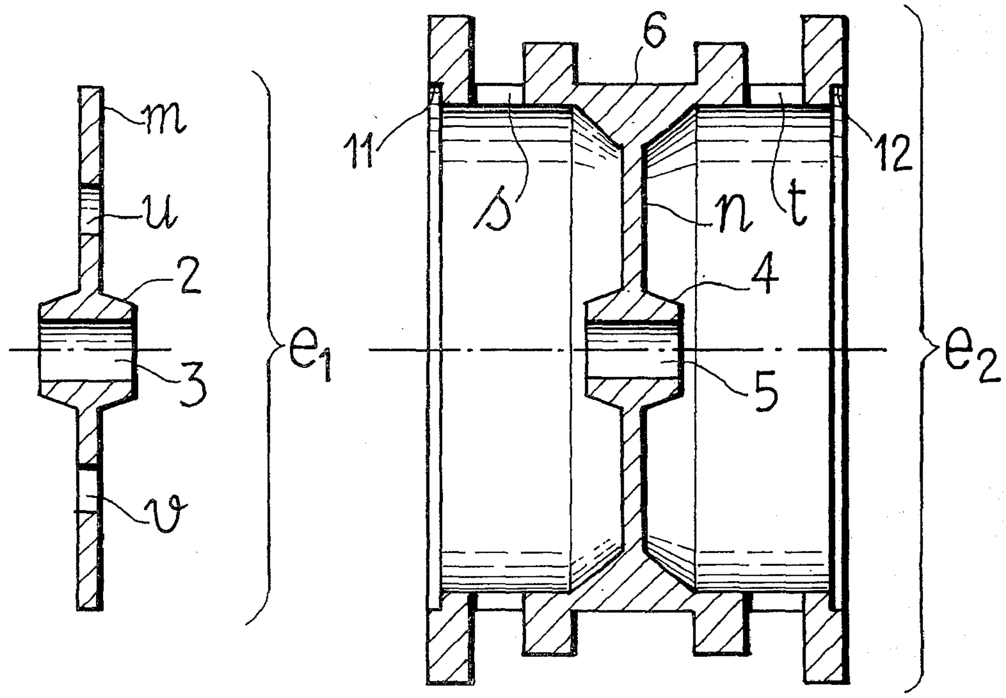

Fig. 5

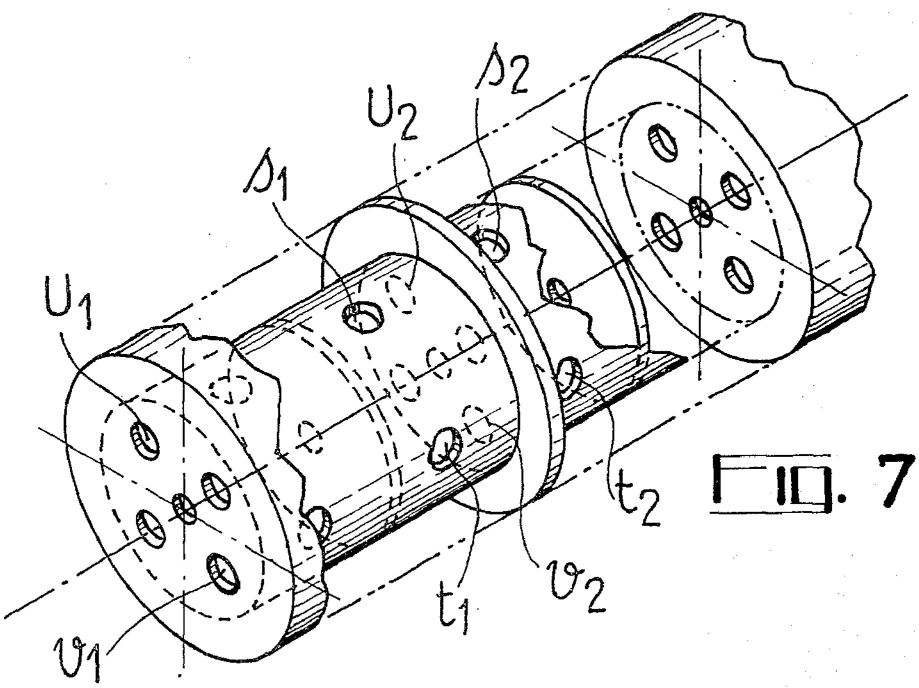

Fig. 7

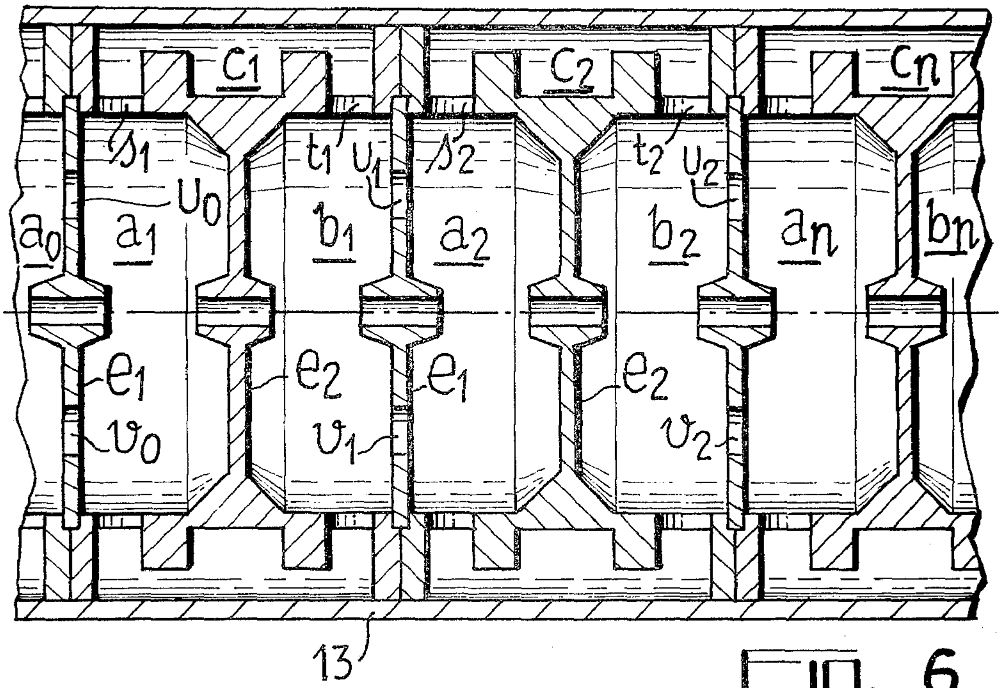
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FIG. 6

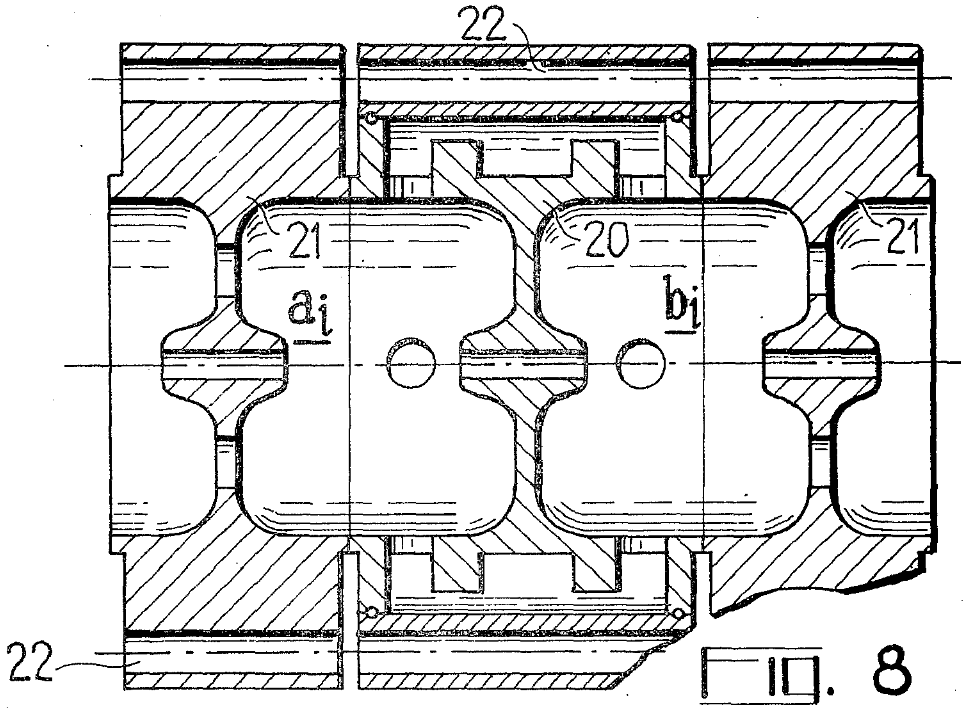
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FIG. 8

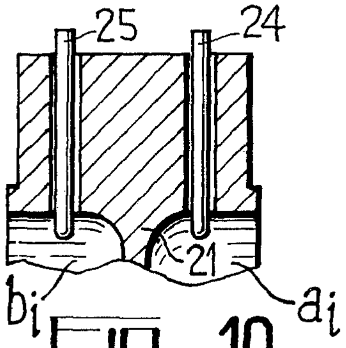

Fig. 10

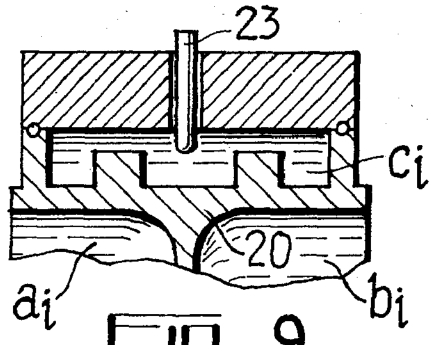

Fig. 9

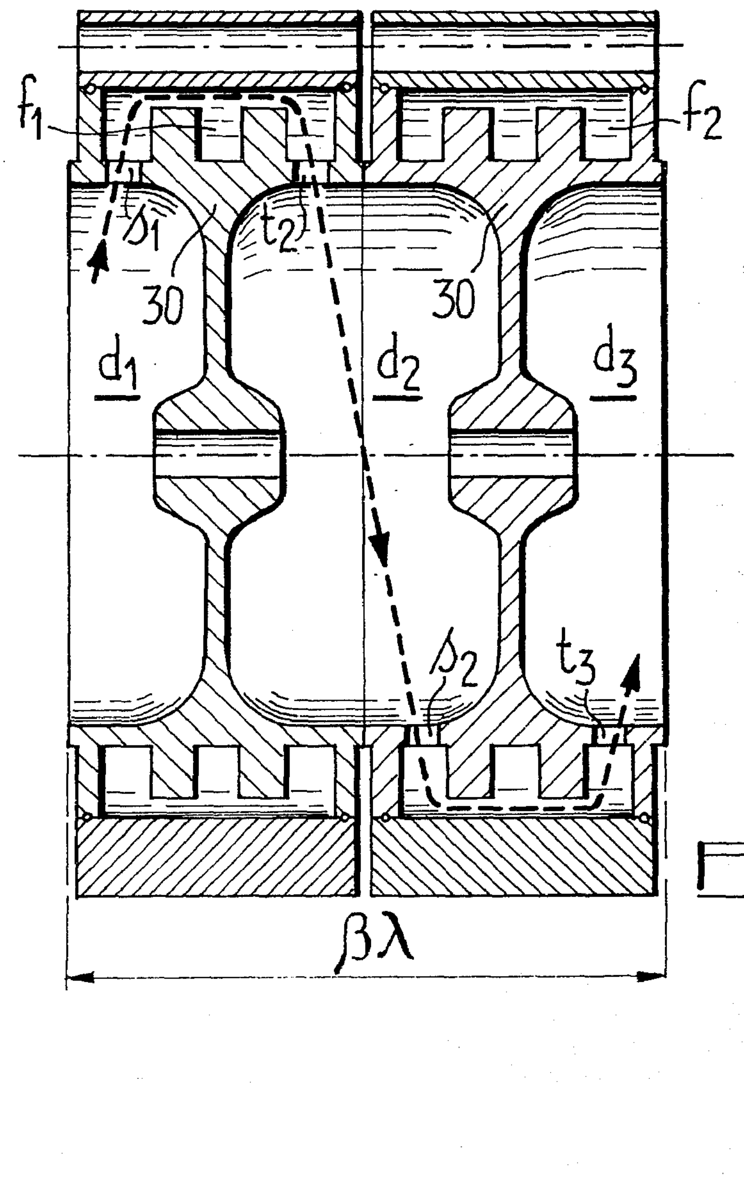

Fig. 11

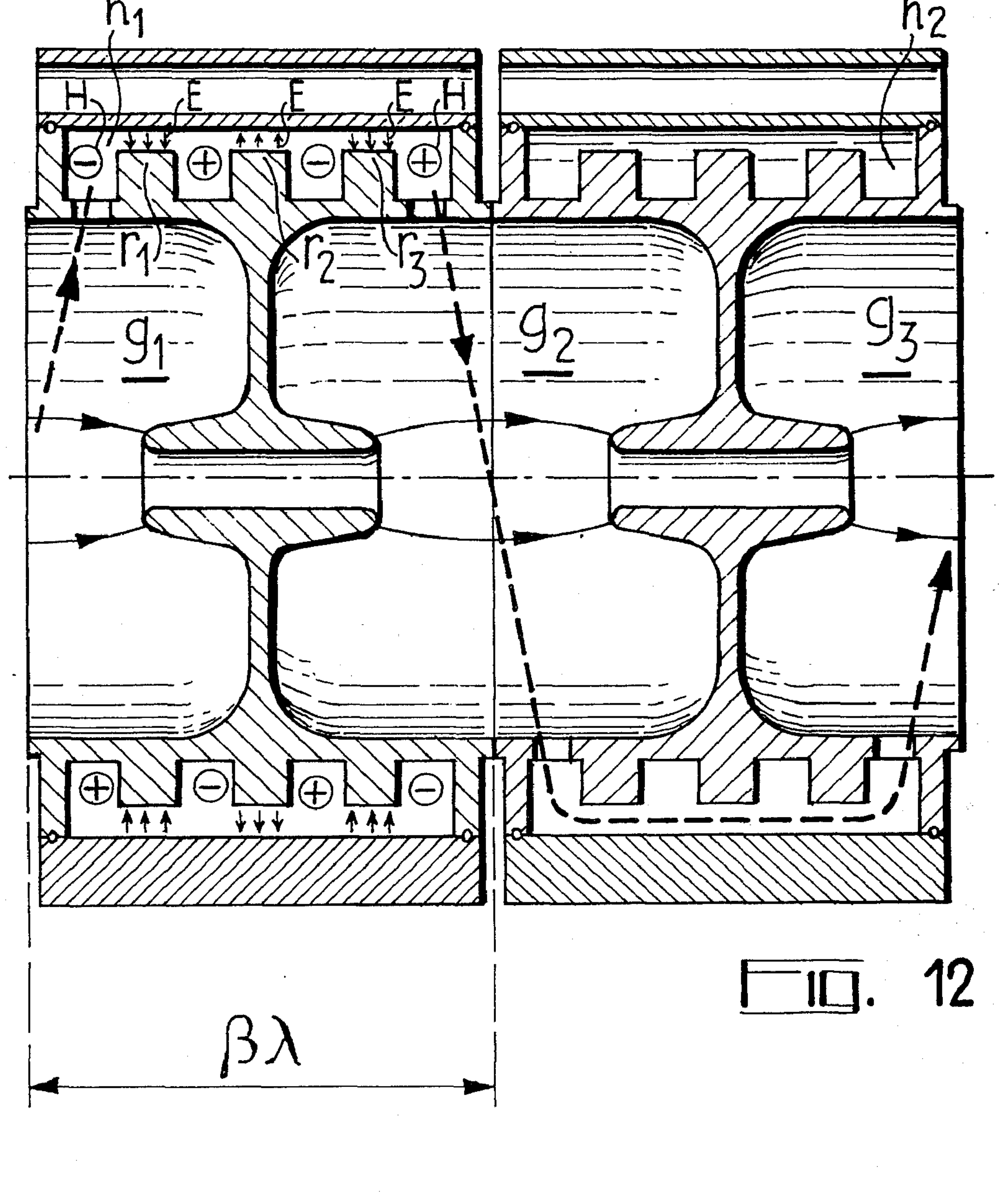

FIG. 12

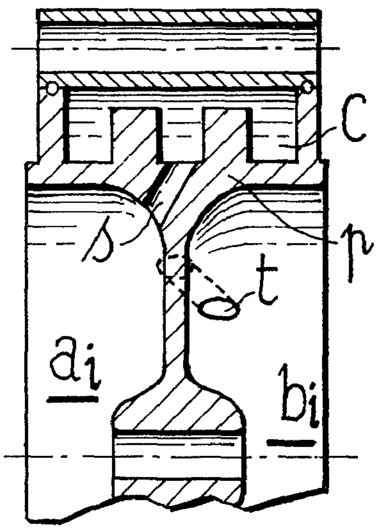

Fig. 13

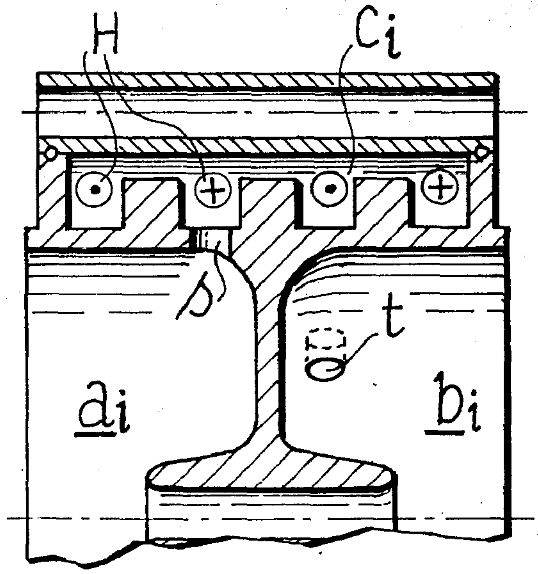

Fig. 14

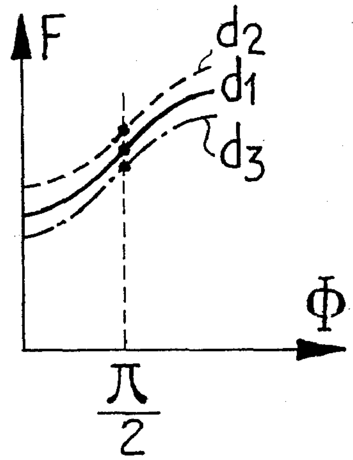

Fig. 15

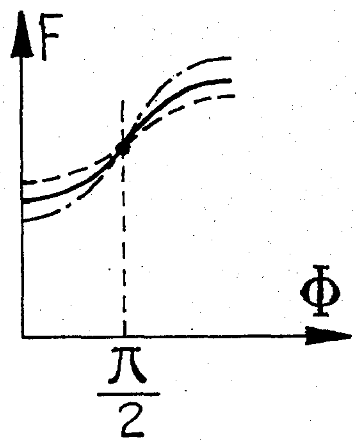

Fig. 16

MULTIPERIODIC ACCELERATOR STRUCTURES FOR LINEAR PARTICLE ACCELERATORS

Multiperiodic structures in linear accelerators are generally constituted by groups of two or three resonant cavities which are accelerating cavities; these accelerating cavities are coupled with one another by a coupling cavity, each of such groups(two accelerating cavities and one coupling cavity) corresponding to one period of the electromagnetic wave which is created within this accelerating structure.

It is important that, in such structures, the energy stored in the accelerating cavities should be maximum and that the energy stored in the coupling cavities should be as low as possible.

It is an object of this invention to achieve this aim in a particularly effective manner, while, in the same time, providing a structure which is simple to manufacture, is readily adjustable and has an operating frequency which is not sensitive to minor machining or adjustment inaccuracies.

In accordance with the invention, there is provided a linear structure for a linear particle accelerator comprising an input cavity and a plurality of successive accelerating cylindrical resonant cavities, means for coupling said cylindrical resonant cavities to each other and means for feeding, said electromagnetic energy into said input cavity, said coupling means comprising a plurality of annular cavities coaxial with said cylindrical resonant cavities and located at the peripheries thereof, each of said annular cavities being coupled to two adjacent cylindrical resonant cavities.

For the better understanding of the invention and to show how the same way be carried into effect, reference will be made to the drawings accompanying the ensuing description in which:

FIG. **1** schematically illustrates a linear structure in accordance with the invention,

FIG. **2** illustrates a vector diagram indicating the phase shift in the incident wave and reflected wave in one set of three associated cavities (two accelerating cavities and one coupling cavity),

FIGS. **3** and **4** schematically illustrate an example of a coupling cavity in accordance with the invention, and the equivalent circuit diagram of said cavity,

FIG. **5** illustrates in detail the elements of a structure according to the invention,

FIGS. **6** and **7** respectively illustrate a triperiodic structure according to the invention and in a somewhat simplified manner, the arrangement of the coupling apertures between the different cavities of this structure,

FIGS. **8**, **9** and **10** respectively illustrate another embodiment of an accelerator structure according to the invention, and two tuning systems therefor,

FIGS. **11** to **14** illustrate still other embodiments of a structure according to the invention and,

FIGS. **15** and **16** respectively show resonance frequency curves of two biperiodic structures in accordance with the invention.

The accelerator structure in accordance with the invention, schematically illustrated in FIG. **1**, comprises a succession of cylindrical cavities a_1, b_1, a_2, b_2, a_3, b_3 having a common axis X_1X_2 substantially coincidental with the mean trajectory of the accelerated particle beam.

The pairs of adjacent cavities a_1 and b_1, b_1 and a_2, a_2 and b_2, b_2 and a_3, a_3 and b_3, are preceded by an input cavity a_0.

Two adjacent cavities have a common walls m_1, n_1, m_2, n_2, m_3, n_3, *perpendicular to the axis* X_1X_2. In the embodiment shown by way of example, every wall m_i is provided with two holes u and v for coupling purposes, whilst the other walls n_i have no coupling apertures at all. The cylindrical cavities a_1, b_1, a_2, b_2, a_3, b_3, are respectively coupled, in pairs to annular cavities c_1, c_2, c_3, disposed coaxially at the periphery of the cylindrical cavities a_1, b_1, a_2, b_2a_3, b_3, with which they are associated by means of coupling holes s_1, t_1, s_2, t_2, s_3, t_3 formed in the walls p_1, p_2, p_3, respectively common to an annular cavity and to the pair of associated cylindrical cavities. In FIG. **1**, the path followed by the electromagnetic which has been fed into the first cavity, that is to say into the input cavity a_o, for example, by means of a coupling loop B, is illustrated by a full line and the reflected electromagnetic wave by a broken line.

The shape and dimensions given to the first and last cylindrical cavities a_o and b_n of the structure, and the shape and dimensions given to the annular cavities of coupling cavities $c_i$are so selected that, as known, in the standing wave operation the components of incident and reflected waves add to each other in the cylindrical cavities and cancel one another out in the annular cavities. The vectoral diagram of FIG. **2** illustrates the phase shift $2\pi/3$ which exists between the cavities a_1, c_1, b_1, of a "2πmode" triperiodic structure.

FIG. **3** schematically illustrates an example of an annular cavity and FIG. **4** shows its equivalent circuit diagram.

Designating by r and $r+\Delta r$ the outer radius of the annular cavity Ci, by Δz the length of the terminal inductive portions S_1 and S_2 of the annular cavities C_i, by 2 Δz of central inductive portions S_3, by **1** the length of the re-entrant portions R_1 and R_2, these portions S_1, S_2, S_3, R_1, R_2 being respectively illustrated in the equivalent circuit diagram of FIG. **4** as inducators L_1, L_2 and L_3 and the capacitors C_1 and C_2, the value of the inductions L_1 and L_2 is given by:

$$L_1 = L_2 = \frac{\mu_o \Delta r \Delta z}{2\pi\left(r + \frac{\Delta r}{2}\right)}$$

whilst that of the capacitances C_1 and C_2 is given by:

$$C_1 = C_2 = \frac{2\pi\varepsilon_o . 1}{\mathrm{Log}\,\frac{1}{1 - \frac{d}{r+\Delta r}}} \# \frac{2\pi\varepsilon_o \ell (r+\Delta r)}{d}$$

where d is the width of the capactivie space formed by the re-entrant portions.

If the inductance of the intermediate inductive portion L_3 is equal to 2 L_1, the resonance frequency of the annular cavity is given by:

$$f \# \frac{3.10^8}{\sqrt{2\pi}} \left[\frac{d\,(r + \frac{\Delta r}{2}}{r + \Delta r) \cdot \Delta r \cdot \Delta z \cdot l} \right]^{1/2}$$

In the example chosen, $f = 3$ Ghz and

$l = 7.5$ mm
$\Delta r = 15$ mm
$d = 2.5$ mm
$r = 40$ mm
$\Delta z = 10$ mm

FIG. **6** illustrates, in longitudinal section, an example of a triperiodic structure in accordance with the invention. In this example, the accelerator structure is produced by stacking, into a cylindrical sleeve **13**, elements e_1 and e_2 which are solids of revolution, such as shown in FIG. **5**. Each element e_1 has substantially the shape of a circular plate m exhibiting a central portion **2** having an increase thickness through which a hole **3** extends. Each element e_2 is in the form of a cylindar the lateral wall of which is constituted with an embattle ring **6**. This cylinder is provided with a circular wall n comprising a central portion **4** having an increased thickness and through which a hole **5** extends. The elements e_1 are furthermore provided with apertures u and v formed in their circular plate m and the rings **6** constituting the lateral walls of the elements e_2 contain two apertures s and t disposed symmetrically at either side of the circular plate n. The rings **6** of the elements e_2 exhibit two shoulders **11** and **12** between which accomodate the plates m of the elements e_1.

The elements e_1 and e_2 are assembled together in the manner shown in FIG. **6**, within a cylindrical sleeve **13** thus forming cylindrical cavities a_1, b_1, a_2b_2, a_3, b_3, and annular cavities c_1, c_2, c_3 . . . . The coupling between the cavities b_1 and a_2; b_2 and a_3 . . . . is effected through apertures u_1, v_1; u_2, v_2, ... formed in the circular plates m. To avoid direct coupling between the cavities c_1 and a_2, c_2 and a_3 . . . . , the coupling apertures u_1, v_1, u_2, v_2, ... are arranged in such a fashion that they are staggered in relation to the apertures s_1, t_1, s_2, t_2, as shown in the cut-away perspective view of FIG. **7**.

The cavities a_o and b_n at the ends of the structure are identical to one another but differ slightly from the cavities a_1, a_2, a_3 . . . b_1, b_2 . . . Their dimensions are such that at the resonance frequency of the accelerating cavities a_1, a_2, . . . b_1, b_2, when the latter are operating in the 2π mode for example, they subject the reflected wave to a phase shift of $\pi/2$ in relation to the input wave so that within the accelerating structure a standing wave situation is created in which the electromagnetic field is cancelled in all the annular coupling cavities so that optimum efficiency on the part of the structure is ensured.

FIG. **8** illustrates embodiment of a triperiodic structure in accordance with the invention. The elements **20** and **21** are assembled by means of rods which are, for example, four and are 90° angularly spaced. These rods extend through tubular passages **22** longitudinally disposed at the periphery of the elements **20** and **21**. At least one adjustable tuning plunger **23** is associated with each annular coupling cavity c_i (FIG. **9**), and at least two adjustable tuning plungers **24** and **25** are respectively associated with each two adjacent cavities a_i and b_i to tune these cavities c_i, a_i and b_i.

The structures described hereinbefore are of the triperiodic type but biperiodic structures can be produced in a similar way. FIG. **11** illustrates in longitudinal section a biperiodic structure operating in the π mode. The length of the cylindrical accelerator cavity is in this case equal to $\beta\lambda/2$, being the reduced velocity of the particles propagating through the cylindrical cavities and λ the operating wavelength of the structure. Such a structure is particularly suitable because it is constituted by identical elements **30**, which build up cylindrical cavities d_1, d_2, d_3 . . . The coupling between two adjacent cylindrical cavities d_1, d_2; d_2, d_3; . . . is effected solely through the medium of the annular cavities f_1, f_2 . . . by means of coupling apertures s_1, t_2; s_2, t_3; . . .

FIG. **12** illustrates another embodiment of a biperiodic structure in which the phase shift between two successive cylindrical accelerator cavities is 2, the electrical length of each of these cavities being $\beta\lambda$. The structure comprises cylindrical cavities g_1, g_2, g_3 . . . coupled in pairs through annular cavities h_1, h_2 . . . having a profile with three re-entrant portions r_1, r_2, r_3, the components of the electric field H of the electromagnetic wave being distributed within the structure in the manner indicated in FIG. **12**.

This "2πmode" biperiodic structure is better suited to accelerators of relatively low energy whereas "πmode" biperiodic structures and "2πmode" triperiodic structures are better suited to high energy accelerators. In other words, the efficiency of a structure is better if the length of the accelerator cavity is substantially equal to their radius; however this radius depends essentially upon the operating wavelength λ. Thus, the fact that the length of a cell of a "π mode" biperiodic structure is $\beta\lambda$ (instead of $\beta\lambda/2$ as in the case of "π mode" biperiodic structures or "2π mode" triperiodic structures), favours the acceleration of particles of relatively low velocity.

The structures in accordance with the invention have been described by way of non-limitative examples and their characteristics generally depend on the selected dimensions of the coupling apertures, on their location and number. By a suitable selection of the parameters it is possible to obtain the desired predetermined operating pass band.

It is also possible to improve the operation of a "$\pi/2$ mode" biperiodic structure having annular coupling cavities c_1, c_2 . . . c_n with two re-entrant portions such as illustrated in FIG. **6**, by arranging the coupling apertures s and t not at the ends of the annular cavity c_1, c_2 . . . c_n as in FIG. **6** but in the central part of said annular cavity as shown in FIG. **13**.

As a matter of fact, the resonance frequency of the system formed by the accelerating cavities a_i, b_i and coupling cavities; c_i highly depends upon the coupling factor, and therefore upon the dimension of the coupling apertures s, t when said apertures s, t are arranged at the ends of the re-entrant section of the annular cavity c_i. It is possible to remedy this drawback by arranging the coupling apertures s, t at the centre of the annular cavity c_i (FIG. **13**), as mentioned before.

Apertures s and t are therefore formed obliquely in the central zone of the wall p (FIG. **13**) common to the accelerating cavities a_i, b_i and to the coupling cavity c_i associated therewith, these apertures s and t, which respectively couple the annular cavity c_i with the accelerating cavities a_i and b_i, being arranged on different radii making an angle with one another in order to avoid direct coupling between the two apertures s, t. The dimensions of these apertures s and t arranged in the central zone of the annular cavity c_i are not critical in so far as the resonance frequency of the accelerating structure is concerned. This makes it possible to adjust separately the frequency of the structure and the coupling between the cavities.

FIGS. **15** and **16** respectively illustrate, in the case of a biperiodic structure operating in the $\pi/2$ mode, the variation of the resonance frequency of the structure as a function of the dimensions d_1, d_2, d_3, of the coupling apertures s, t when these apertures are arranged at the ends of the annular cavity c_i (FIG. **15**) and in the case where the apertures are arranged at the centre of said annular cavity c_i(FIG. **16**).

FIG. **14** illustrates a biperiodic "2π mode" structure, the annular cavity c_i of which has three re-entrant portions. The coupling apertures s and t are in this case arranged at either side of the central re-entrant portion and in different planes, in order to avoid direct coupling between the apertures s and t.

The particle accelerator structures in accordance with the invention can advantageously be utilised in linear electron or proton accelerators.

What we claim is:

1. A linear structure for a linear accelerator comprising an input cavity and a plurality of successive pairs of accelerating cylindrical resonant cavities, means including coupling apertures for coupling said pairs of cavities, means for coupling said cavities forming each said pair to each other comprising a plurality of annular cavities each coupled through apertures to one of said pairs of cavities, said annular coupling cavities arranged coaxially with said cylindrical resonant cavities and located at the periphery thereof; and means for feeding electromagnetic energy into said input cavity.

2. A linear structure as claimed in claim **1**, wherein said annular cavities have a section of re-entrant profile type.

3. A linear structure as claimed in claim **2**, wherein said structure is biperiodic.

4. A linear structure as claimed in claim **3**, wherein every two adjacent cylindrical cavities are coupled to each other by means one of said annular cavities, said annular cavities having a re-entrant section, and being provided with coupling apertures (s, t).

5. A linear structure as claimed in claim **4**, wherein said apertures (s, t) are arranged at the ends of said re-entrant section, said section having two re-entrant portions.

6. A linear structure as claimed in claim **4**, wherein said apertures (s, t) are located in the central portion of said re-entrant section, said section having two re-entrant portions.

7. A structure as claimed in claim **2**, wherein said structure is triperiodic.

8. A linear structure as claimed in claim **7**, wherein adjacent pairs of cylindrical cavities are coupled through apertures formed in a transverse common wall of said adjacent pairs of cylindrical cavities.

* * * * *