NEW ALVAREZ TYPE LINAC STRUCTURE WITH CHAIN-LIKE ELECTRODES

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ABSTRACT

Characteristics of an Alvarez type linac structure with a chain-like electrode configuration is being studied. Aim of design of the structure is to use the high frequency field for focusing of ions as well as for acceleration. However, the chain-like structure differs from the ordinary RFQ linacs in that the two focusing and acceleration functions are separated in space, unlike to the latter. Our intention is to realize a new linac structure having a moderate effective shunt impedance in the region of velocity where the ordinary RFQ linac fails because of lack of power efficiency

As a basis of the resonator type, the TM-010 mode of a cylindrical cavity has been chosen. A few electrode configurations were devised and compared. Though the field pattern in the most part of the cavity is similar to that of the Alvarez linacs, the field on the acceleration axis is quite different and shows behavior which suggests a moderate effective shunt impedance for the structure.

INTRODUCTION

Recent success of the RFQ linacs which use high frequency electric field not only for acceleration but also for focusing has solved most problems associated with acceleration of intense low velocity ions.[1] There are many plans to apply this technology for acceleration of light and heavy ions.[2]

On the other hand, the idea of spatially uniform acceleration and focusing scheme of Kapchinsky and Teplyakov[3] which forms basis of the RFQ linacs is known to be applicable only to a low energy region, 2 MeV/n or less, because of its low effective shunt impedance. Acceleration to the higher energy is usually done by the ordinary Alvarez linacs. If the scheme of focusing by RF field can be applied at the region of the Alvarez energies without sacrificing the effective shunt impedance too much, a linac system relieved of trouble of tuning of focusing elements becomes reality. Boussard tried focusing by the high frequency accelerating field by attaching circular fingers to the face of drift tubes.[4] Similar configuration was proposed by R. W. Muller for his split coaxial structure.[5] Realization of acceleration of intense beam of heavy ions with a small charge to mass ratio by the Muller's linac, though still at a very low velocity region, proved feasibility of an RFQ linac other than the vane type developed by LANL.

We have begun to study another structure. Its electrode arrangement looks like a chain. It is formed by interlacing horizontal and vertical members which have four sides.

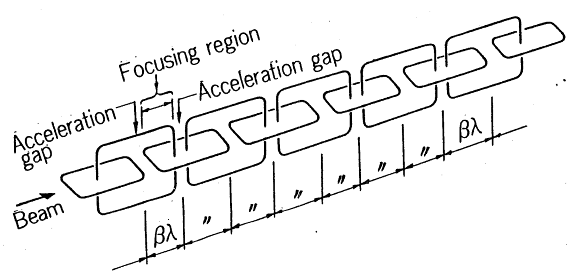

Fig. 1. Scheme to combine electrodes to form a chain-like accelerating structure.

Characteristics of the interlaced structure is different from that of the Boussard's configuration developed from the drift tube array of the usual linacs. Direction of axial component of the electric field in the Boussard's configuration is always same everywhere with that of the TM-010 field, whereas in our structure, local inversion of field direction exists along the acceleration axis. Though our study still remains in a preliminary stage and its geometry is not optimized yet, relatively good acceleration efficiency has been found for geometries used for the models studied. Some preliminary results have been reported at the Linac'84 Conference at Seeheim.[6]

PRINCIPLE OF OPERATION

Figure 1 shows a schematic construction of the chain structure and Fig.2, two photographs of a model showing the stems supporting the electrodes. (a) sees the model sideways and (b) in the axial direction. Installed in a cylindrical envelope, it looks like a multi-stem Alvarez linac. However, the distribution of the electric field along the beam axis is very different from the Alvarez types. Acceleration field exists between the two parallel race-tack shaped plates. The plates are supported by the radial stems via longitudinal bars in the same azimuthal angles around the accelerator axis. The next acceleration gap is formed by another plate pair of which stems are in the azimuthal position rotated by 90 degree. Thus the orientation of the plate pair alternates for each next gap. In the acceleration gaps, the axial component of the field has the same sign with that of the TM-010 mode of the cylindrical cavity. Distance between the gaps must be integer multiple of βλ in order that acceleration condition be satisfied. If the integer

(a)

(b)

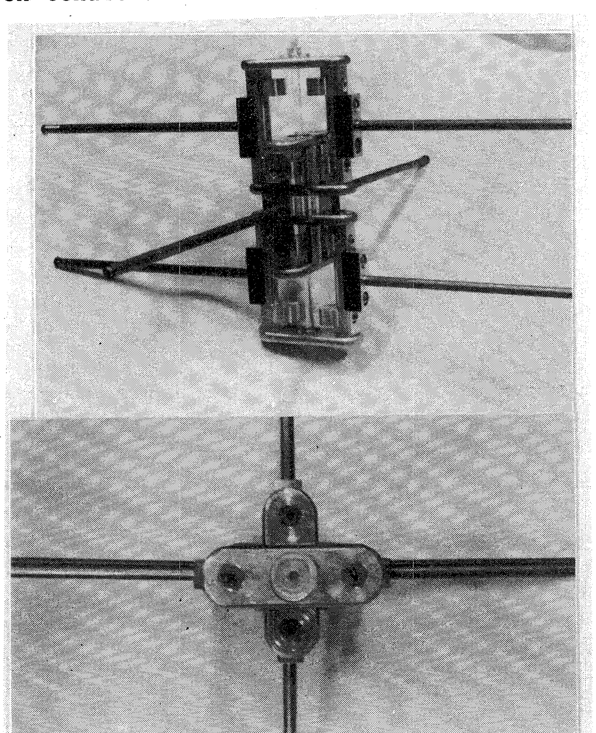

Fig. 2. Photographs of the electrode assembly. (a) Side view. (b) Front view.

is chosen as one, the distance between stems in a group of the same azimuthal position becomes $2\beta\lambda$. The voltage across the acceleration gaps corresponds to this distance instead of length of $\beta\lambda$ as in the Alvarez linacs.

On the other hand, in the region between the plates belonging to the different groups, the sign of field is reversed and is contrary to that of the main field. The potential difference between the pair of plates here corresponds to length of $\beta\lambda$, half of that for the acceleration gaps. This part is named focusing region since we propose to establish a high frequency electric quadrupolar focusing field here, by attaching semi-circular cylindrical poles to the four longitudinal bars connecting the plates and the radial stems.

This pattern of the field distribution, that the acceleration field having the same sign with the main field of cavity is separated by the field of reverse sign in the focusing region is quite different from that of the Alvarez linac in spite of seeming similarity.

The π mode-like pattern gives rise improvement of acceleration efficiency on one hand and decrease of effective voltage felt by the particles under acceleration from the value specified by the distance between radial stems $2\beta\lambda$ or $\beta\lambda$ on the other hand. In the π-mode, where the equi-potential surfaces at the same level exist on the both sides of the relatively thin electrode with a large aperture as our race-track like plate, the maximum or minimum potential along the beam trajectory through the aperture may be considerably different from that of the electrode. The amount of difference depends on the ratio of aperture to plate thickness and on distance of the neighboring electrodes. Nevertheless, by choosing a suitable electrode geometry, the effective voltage gain per cell can be made much larger than the gain for the case of Alvarez resonator with the same axial gradient of the TM-010 mode.

SOME RESULTS OF MODEL STUDY

Magnetic analogue as well as high frequency models were used for study of the characteristics of the chain structure. Figure 3 shows a high frequency model. In our structure, the field configuration is expected to be complex, especially in the region of focusing. Detailed study of the behavior of the field components as a function of the radial, azimuthal and longitudinal coordinates is necessary. But it is difficult with high frequency models to separate field into the components and the magnetic analogue models can do better. Fig. 4 is the one to study central region. Figure 5 shows distribution of the axial field component in one cell along the central beam axis. The beam hole in the center of the plates is 14 mm and the plate thickness is only 8 mm. Field integrated across the acceleration gap is only 70 % of the voltage difference between the plates in this case. The hole was made large so that off-axis field distribution may be measured. Fig. 6 gives such an example of axial field distribution along lines 3 mm off axis. Figure 7 shows radial focusing field. (a) is the distribution at the center of the focusing region. Longitudinal length of the pole which generates the quadrupolar field is 13 mm and distance between the pole tips in the opposite azimuthal angles is 20 mm. The radial fields for the two azimuthal angles at the longitudinal center of poles almost coincides with each other. (b) is the measurements at the longitudinal position 4mm displaced from the center. (c) is for the position 10.2 mm from the center or 3.7 mm outward from the edge of the pole.

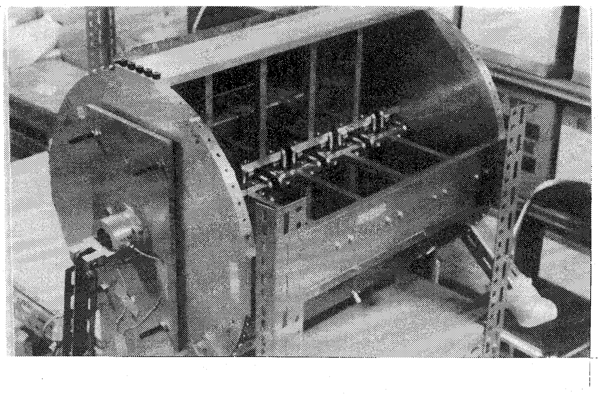

Fig.3. High frequency model on the testing stand.

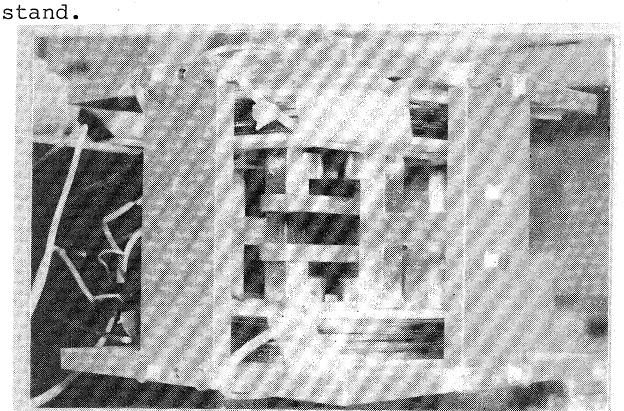

Fig. 4. A magnetic analogue model to study the field distribution in the central region.

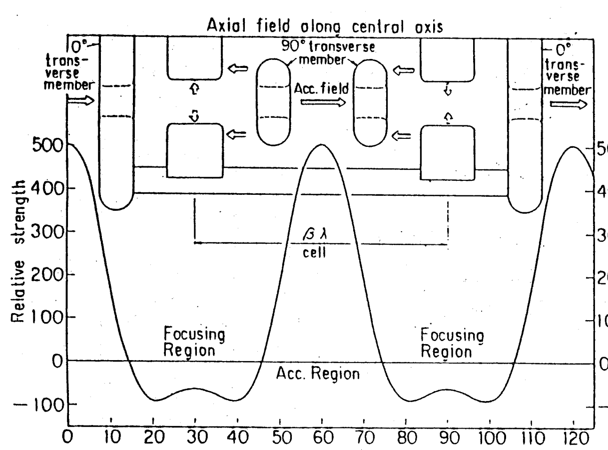

Fig. 5. Distribution of axial component of field along the central axis

Dependence of focusing strength on the azimuthal and axial positions is seen. Orbit calculation by use of these distributions of axial and radial field is being made.

Only constant velocity high frequency models have been constructed. Number of cell of the model shown in Fig.3 is ten. Its resonant frequency spectrum is relatively simple. For a diameter 50 cm of the cylinder, resonances have been observed at 264.12, 724.25, 767.75, 768.59, 824.78 and 827.72 MHz below 900 MHz.

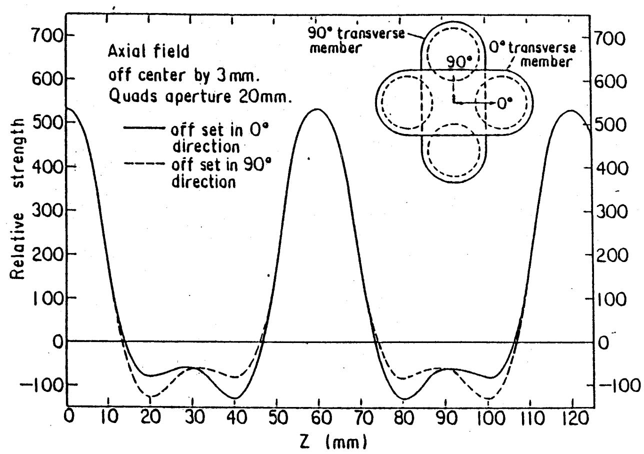

Fig. 6. Axial field components along lines 3 mm off-axis. In the focusing region, the distribution changes according to the azimuthal positions of the lines.

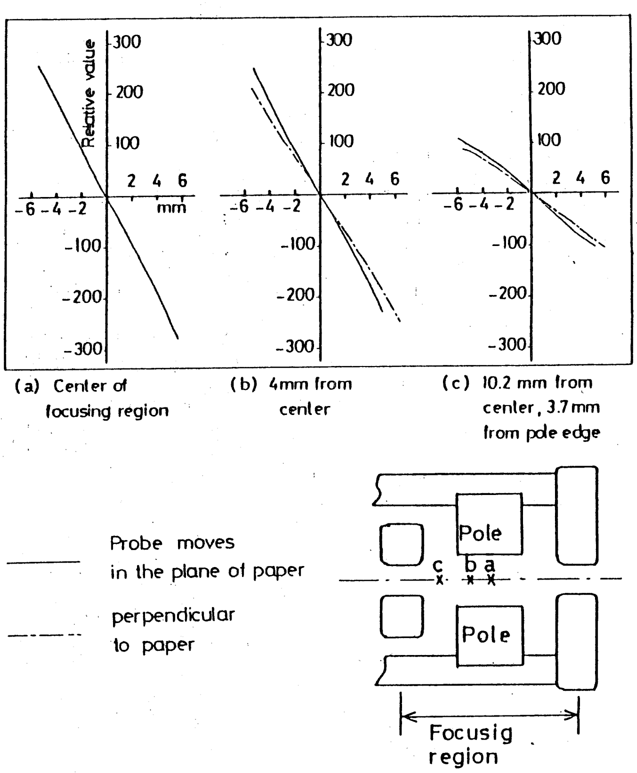

Fig. 7. Focusing radial field. (a) Center of the focusing region. (b) 4 mm from the center. (c) 10.2 mm from the center. Longitudinal length of the focusing electrode is 13 mm and distance between the electrode chips is 20 mm. Dependence of the focusing field on the azimuthal position can be seen.

DISCUSSIONS AND CONCLUSIONS

From the measured axial and radial field distributions, energy gain per cell and focusing strength can be calculated. For instance, for an accelerating gradient of 1 MV/m of the TM-010 mode, we found 84 keV times phase factor of the synchronous particle as the gain of energy per cell for a singly charged projectile for the distribution of Fig.5. The gain corresponds to 1.4 MeV/m for the projectile with stable phase at the crest of the RF. The calculated energy gain is larger than that expected for an Alvarez linac having the same field gradient and cell length, in this case 60mm and gap to cell ratio of 1/4. Reason of the large energy gain is as follows: First, the potential difference which appears across the accelerating gap is larger than that corresponding to length of a unit cell, because distance between the stems supporting the electrodes is two cell instead of one cell for the Alvarez case ; Second, as seen in Fig. 5 and 6, there exists axial field with reversed sign in the focusing region. Though it is not strong as in the accelerating gaps, still gives π-mode acceleration effect. In the present geometry, the focusing field gradient is 18 kV/cm. The quadrupole strength is adjustable by replacing pole chips.

On the other hand, we have found considerable dependence of the energy gain on the various geometrical parameters of the cell like beam aperture in the accelerating electrode, thickness of electrode and so on. Correlation and weight of the parameters on the field distribution and energy gain must be studied in detail.

There is a periodicity of $\pi/2$ for deviation from a circular symmetry in the off-axis longitudinal and transversal fields around the beam axis in the focusing region as noted above. Its effect on beam trajectory must be studied numerically and its code is being prepared. Since the azimuthal dependence is not very pronounced and the off axis characteristics is common to all the RFQs, probably no serious difficulty will be met.

This structure looks like a multistem structure of Alvarez type. But its acceleration mode is 2π-mode between neighbouring acceleration regions with additional small π mode effect in the focusing region. It is interesting to know which tendency of Alvarez's or of Wideroe's is followed for change of the effective shunt impedance as a function of the particle velocity. Models for this study are being prepared.

ACKNOWLEDGEMENT

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