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A LOW-COST RF-STRUCTURE FOR ELECTRON AND PROTON LINAC

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Summary

The side-coupled accelerating structure developed at LAMPF is known as the most efficient for electron and proton linacs. The mechanical design is, however, not very simple and the structure fabrication needs several sophisticated machining and brazing processes. As a result the cost of the structure is high. Attempts have been made in our laboratory to simplify this geometry and we are proposing a new ring-coupled structure which, besides the advantage of a low-cost fabrication, would give the possibility of increasing the coupling coefficient in order to provide a low sensitivity to errors and beam loading.

Introduction

The side-coupled accelerating structure developed at LAMPF, Los Alamos, is known as the most efficient for proton and electron linac. The mechanical design is however not very simple and the structure fabrication needs several machining and brazing processes. The presence of side cavities makes also progressive focussing unpracical and so could be an non-negligible drawback when long section is needed. Attempts have been made by some laboratories to simplify this geometry in using "on-line" coupled biperiodic[1] or triperiodic[2] structure, where the coupling as well as the accelerating cells are on the beam line, accepting some losses on shunt impedance and allowing beam excitation in the coupling cells. The loss of efficiency in the beperiodic scheme can be minimized however by using the triperiodic one where the number of coupling cells is halved, unhappily at the expense of an increased sensitivity of the structure to mechanical errors. In the course of fabrication, the structure tuning represents also a non-negligible process. A first tuning, cavity by cavity, is usually followed by a second one on the assembled structure. It would be very attractive if this second tuning can be made unnecessary by increasing the band-width.

The prupose of this paper is to propose a ring-coupled structure which might ensure the following requirements : accelerating efficiency equivalent to the side-coupled structure, simple fabrication processes, overall size small enough to allow progressive focussing by solenoid and large band-width.

Structure description

Choice of parameters

In the proposed structure, the side-cavity is substituted by an annular ridged cavity shown in fig.1 with coupling holes placed in alternate sectors, in such a way that direct coupling between accelerating cells can be completely suppressed. The Ω form of the main cell is favourable to high shunt impedance requirement and together with the ring form of the coupling cell, provides large surface for coupling apertures. The coupling cell is composed by three hollow regions where magnetic field is predominant and two re-entrant regions where electric field is predominant. There are two possible oscillating regimes. The first one, electrically asymetric, i. e. corresponding to resonance with opposite electric fields in two re-entrant regions, has maximum magnetic field in the coupling region, while the second regime, electrically symetric, has null field in this region. Of course, only the first regime is of interest. The two corresponding résonant frequencies can be approximately determined from the lumped circuit represention shown in fig.2. If L_1 represents the inductance of the two opposite magnetic regions, $2L_2$, the inductance of the central, i. e. coupling region and C_1, the capacitance of the two identical electric regions, these parameters can be related to the different dimensions shown in fig.1 by :

$$(1)\quad \begin{cases} L_1 = \dfrac{\mu o r l_1}{2\pi R} \\[2ex] L_2 = \dfrac{\mu o l_3\,(r + 1/2\ l_3\ tg\alpha)}{2\pi R} \\[2ex] C_1 = \dfrac{\varepsilon o 2\pi R l_2}{d} \end{cases}$$

Then, the two resonant frequencies are given by :

$$(2)\quad \begin{cases} f_1^2 = \dfrac{1}{4\pi^2}\left(1 + \dfrac{L1}{L2}\right)\dfrac{1}{L_1\ C_1} \\[2ex] f_2^2 = \dfrac{1}{4\pi^2}\ \dfrac{1}{L_1\ C_1} \end{cases}$$

By studying the current distribution without losses in the equivalent circuit, one can verify that f_1 and f_2 correspond respectively to maximum and null current in L_2. Thus, the only difference between the classical biperiodic structure and the proposed structure lies on the existence of a second resonance in the coupling cell. In order to see the effect of this resonance, let us examine the dispersion relation of the structure, by using a lumped circuit model. It can be shown[3,4] that :

$$(3)\qquad \text{Cos } \emptyset = -1 + \frac{1}{K^2}\left(1 - \frac{fo^2}{f^2}\right)\left(1 - \frac{f_1^{\,2}}{f^2}\right)\left(1 - \frac{f_2^{\,2}}{f^2}\right)^{-1}$$

Where Ø is the phase shift of a period, fo, the resonant frequency of the accelerating cell and K, the coupling coefficient to which the relative band-width can be related by :

$$(4)\qquad BW = \frac{4\ K\ (4\ (1-k) + k^2\ K^2)^{1/2}}{2 - kK^2 + (8\ (1-K^2))^{1/2}}$$

Where k is defined as $(1 + \frac{L1}{L2})^{-1}$ and then smaller than 1, or :

$$(5)\qquad BW \simeq \frac{4K}{1 + \sqrt{2}}\left(\frac{L_1}{L_1 + L_2}\right)^{1/2}$$

provided K^2 is small compared to 1.

As K is defined as $m/(2\ L_o\ L_2)^{1/2}$, m representing the mutual inductance between coupling and accelerating cells and L_o, the equivalent inductance of this latter relation (5) shows that, in order to obtain a wide band-width, L_2 must be chosen small enough compared to L_1, but large enough however to provide sufficient space for coupling apertures.

By the same analysis, it can be shown that the ratio between the frequency of the lowest mode of the pass-band and the second resonant frequency of the coupling cell is approximately equal to $k^{-1/2}$ and so, the existence of this resonance has no influence on the pass-band as long as L_2 is not too large compared to L_1. This condition is furthermore consistent with a large band-width requirement. In the practical case of fig.1 where k is chosen equal to 0,59, this ratio is 1.3 and the BW very close to K. These above considerations can help for the optimal choice of the structure geometry.

Triperiodic arrangement

The design shown in fig.1 corresponds to a biperiodic cell of $\beta \simeq 1$. When small overall diameter is desired and especially in case of low-β structure, the triperiodic arrangement may be used. The structure is then made from elements of two kinds as shown in fig. 3. Elements with coupling cell will have identical geometry and length while elements without coupling cell will have lengths variable according to the β-value. In this arrangement indeed the length of the element of the first kind can be chosen longer than a half wave length, leading to a small r-value figured in relation (1) and hence to an overall reduced diameter.

Practical design

According to size and weight, two fabrication technics can be used. For S-band or X-band structure, the whole structure or sections can be assembled by piling elements inside a cylindrical envelop and brazing at one time. As the envelop is vaccuum tight, only low temperature brazing will be needed. Each element will need only a lathe machining.
An alternative technic consists in realizing the envelop by electroforming, the ridged geometry of the coupling cell having been filled up previously with wax. For L-band structure, because of large dimension and weight, the best way would be to achieve tooling, assembling, brazing and tuning cavity by cavity and to assemble the whole structure by a second brazing. In the first case, cooling circuits can be realized by tubings welded at low temperature along the envelop and, in the second case, by hollow rings welded around the structure in grooves housed between elements.

A typical device for rf-power input is shown in fig.4.

Model test results

After the principle had been well verified on a simple shaped model[3] with two periods, a second three period model with actual shape, as shown in fig.1, was realized recently in view of testing the rf-behavior of structure and also the fabrication technics described above. For commodity of measurement equipments available, the model has been designed in S-band. Fig.5 shows a picture of a disassembled cavity and an assembled one.

RF-Test

On of the most interesting feature of the proposed structure is its capacity of wide band-width. Fig.6 shows the dispersion curve. A typical band-width of 13 % is obtained with two diametrally opposite coupling apertures of 10 mm wide and 70° long. This figure might be increased by chosing larger aperture, but possibility of direct coupling between accelerating cells and mechanical stiffness of the elements must be kept present in mind.

Fabrication technics

The model has been made following the first technic described above for S-band structure. Some precautions have to be taken to prevent machanical deformation during tooling and assembling. The coupling apertures, for instance, must be cut only at the last moment. In order to take into account the envelop roundness defects, sufficient clearance has to be provided between elements and envelop, unless these elements had been frozen before introduction.

Conclusion

These first tests show that this type of structure can answer to the requirements stated above. The overall diameter does not exceed 12 cm at 3 GHz, the bandwidth is large and the fabrication processes are proving easy. In order to test the actual behavior of this kind of structure against mechanical errors, a long section is being designed. As the mechanical tolerance is getting tight at high frequency, the frequency will be chosen in X-band.

References

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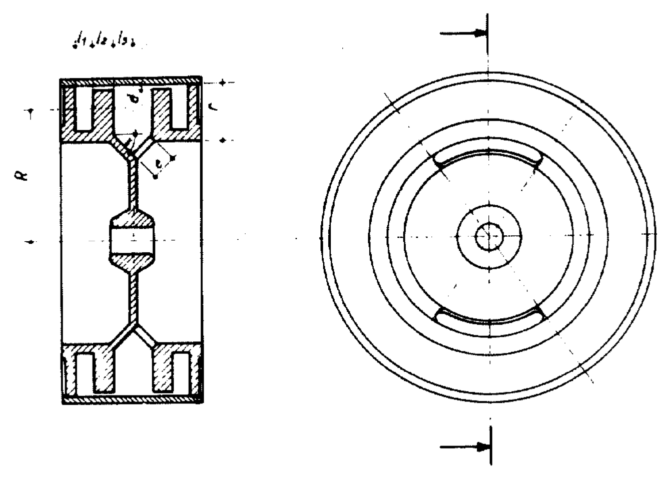

Fig.1 Cross section and plan view of the ring-coupled structure. Dimensions (in mm) : R =47 , r = 16, l_1 = 6, l_2 = 7, l_3 = 7, d = 3.8, α = 45°.

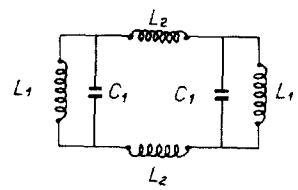

Fig.2 Lumped-circuit representation of the coupling cavity.

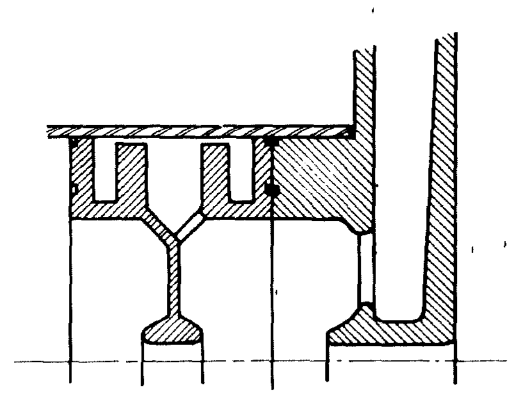

Fig.4 Power-input port.

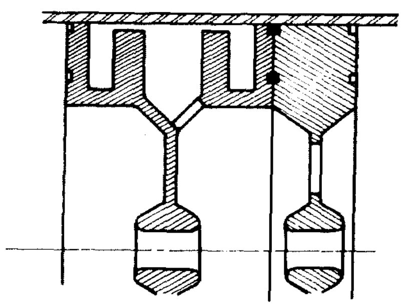

Fig.3 Triperiodic arrangement : $\beta \simeq 0.7$.

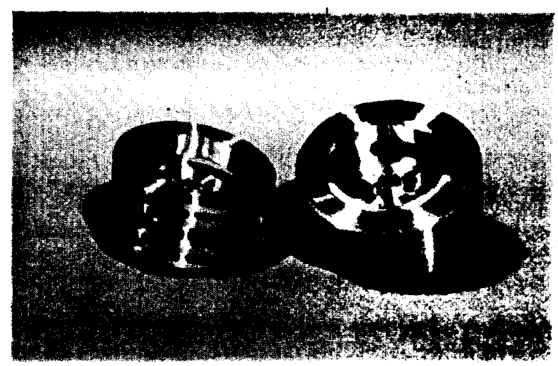

Fig.5 Photograph of a disassembled and an assembled cavity.

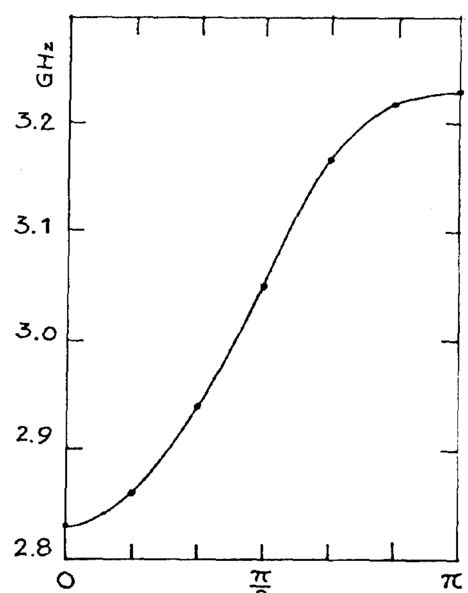

Fig.6 Dispersion curve.