ROOM TEMPERATURE ACCELERATING STRUCTURE FOR HEAVY ION LINACS

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Abstract

In this report we consider room temperature DTL structure for heavy ions acceleration from $150\frac{keV}{u}$ to $400\frac{keV}{u}$. The structure design is based on known and proven solutions. The structure has no end wall problem. It allows flexible segmentation in RF cavities to place transverse focusing elements between cavities. As compared to well known IH DTL, considered structure has smaller transverse dimensions and is designated for lower operating frequency. The structure promises high RF efficiency: calculated effective shunt impedance value is higher than $1.0\frac{GOm}{m}$ for operating frequency $\sim 70MHz$ and particle energy $E \sim 150\frac{keV}{u}$.

INTRODUCTION

Interdigital H-type Drift Tube (IH DT) structure, see, for example [1], [2] and related references, is now well developed and widely used for heavy ion acceleration. Idea of Interigital Structure (IS) is in two steps. First one is to generate RF voltage between two conductors, placed along the beam line, providing a transverse electric field. At the second step with drift tubes, connected in turn to opposite conductors, transverse field transforms into longitudinal accelerating one. Efficiency of such structure depends on number of drift tubes per unit length and a zero order estimation for effective shunt impedance Z_e is $Z_e \sim \frac{1}{\beta^2}$, where β is the relative particle velocity.
Similarly we can consider another classical device - Radio Frequency Quadrupole (RFQ). With some RF geometry one should provide RF voltage between four conductors, placed along the beam line. Every RF circuit for quadruple RF voltage distribution can be adopted for dipole one to be the IS basement. Basing on this approach, several RF circuit, used for RFQ, were considered in [3] for IS at operating frequency $f = 105MHz$. The Split Ring (SR) RF circuit, applied in TRIUMF RFQ [4] at $f = 35MHz$ and adopted in [3] for IDS with $f = 105MHz$, Fig. 1, have shown attractive properties - the small cavity outer diameter and calculated $Z_e \sim 1.0\frac{GOm}{m}$ for $\beta = 0.015$.
The lower operating frequency for DTL part of the heavy ion linac [5] results in the higher linac acceptance. In this report we consider the parameters of Split Ring Drift Tube (SR DT) structure for operating frequency $f = 70MHz$.

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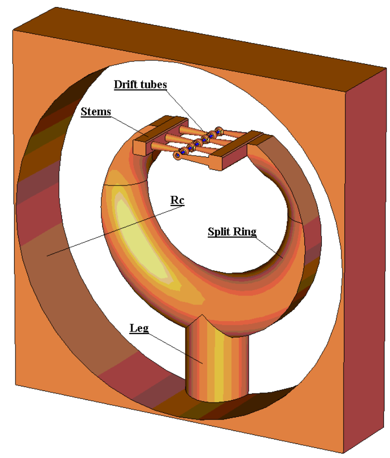

Figure 1: Proposed structure with Split Ring RF circuit and Drift Tubes. Half of the structure period.

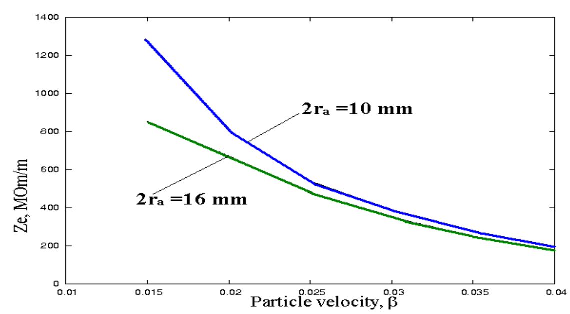

Figure 2: Z_e dependence on β for aperture diameters $2r_a = 10mm$ and $2r_a = 16mm$, $\alpha = 0.5$.

PERIODICAL STRUCTURE

RF parameters of the proposed structure at operating frequency $70MHz$ can be estimated in consideration of one half of ideal periodical structure shown in Fig. 1. For $Z_e(\beta)$ dependence estimation the gap ratio $\alpha = \frac{l_g}{L_p} = \frac{2l_g}{\beta\lambda}$, where l_g is the accelerating gap length, L_p is the period length, λ is the operating wavelength, was fixed to $\alpha = 0.5$. Effective shunt impedance Z_e is defined as:

$$Z_e = \frac{(E_0T)^2 N_p L_p}{P_s}, \quad \text{MOm/m} \qquad (1)$$

where E_0 is the average electric field along the structure axis, T is the transit time factor, $N_p = 6$ is the number of accelerating periods in the half structure, P_s is the RF loss power in the half structure.

Calculated $Z_e(\beta)$ dependence is plotted in Fig. 2 for two values of the beam aperture radius, $r_a = 5mm$ and $r_a = 8mm$. At low $\beta = 0.015$ SR DT shows very high Z_e value, $Z_e \approx 1300\frac{MOm}{m}, 2r_a = 10mm$, but drops as $Z_e(\beta) \sim \frac{1}{\beta^2}$. In our consideration the structure has been optimized in Z_e for $\beta = 0.015, 2r_a = 10mm$ and dimensions obtained were applied for another β, except ring radius, changed for operating frequency adjustment. The dependence $Z_e(\beta) \sim \frac{1}{\beta^2}$ is not a low and can be weakened by dimensions optimization for another β. As one can see from Fig. 2, for $2r_a = 16mm$ this dependence is not valid and structure Z_e value for $\beta > 0.015$ can be improved by optimization distance between stems, gap ratio α and drift tube radius r_t. To improve Z_e value we have to reduce capacitative load in the structure. A typical $Z_e(\alpha)$ and $T(\alpha)$ dependences are shown in Fig. 3 for $\beta = 0.015, 2r_a = 10mm$. The optimal number of drift tubes, supported by one ring, should be defined for each cavity. If we suppose the same number of periods $N_p \sim 12$, supported by one ring, at high $\beta > 0.25$ one will see the tilt in E_0T distribution. The length of stems becomes large and there is a natural cosine filed tilt as at open end of line, formed by two conductors (stems). To avoid this tilt, stems should be shorter and one ring should support less number of drift tubes at higher β.

At the frequency $f = 70MHz$ Kilpatrick limit is $E_k = 10\frac{MV}{m}$. In modern linacs operation with electric field $1.5E_k$ is usual. For SR DT the ratio $\frac{E_{smax}}{E_0T} \sim (4.6 \div 5.3)$, depending on the drift tube shape, is for $\beta = 0.015$ and decreases with β increasing. Assuming the maximal electric field at the surface $E_{smax} = 15\frac{MV}{m}$, accelerating rate tolerable is $E_0T \sim (2.8 \div 5.3)\frac{MV}{m}$. To define the operating accelerating gradient, one has to take into account the cooling conditions of the structure.

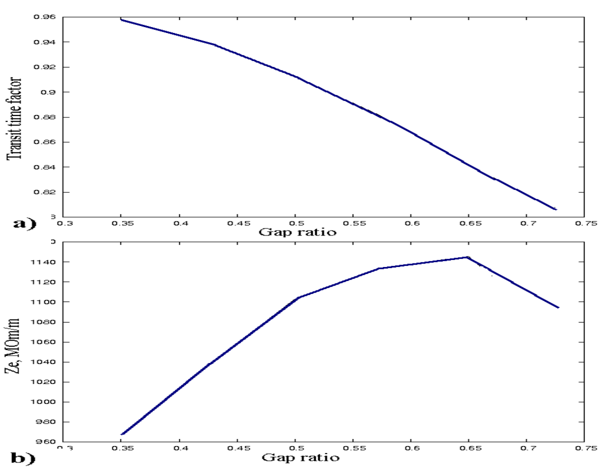

Figure 3: $T(\alpha)$ and $Z_e(\alpha)$ dependences for $\beta = 0.015, 2r_a = 10mm$.

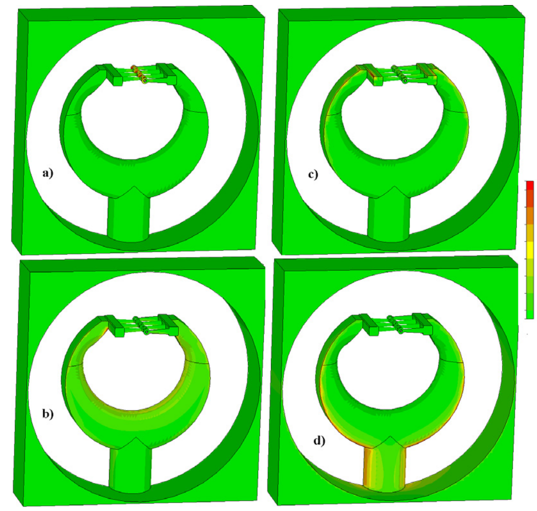

Figure 4: Electric $\epsilon_0 E^2$ (a),(c) and magnetic $\mu_0 H^2$ (b),(d) energy density distribution at the structure surface for operating (a),(b) and parasitic (c),(d) modes.

Parasitic Mode

In the vicinity of operating mode SR DT has the parasitic mode. Operating mode has zero RF potential in the bottom of the ring and there is no RF current at the leg, Fig. 4a. Stems have $\pm V$ RF potential with respect to cavity wall and voltage difference between neighbor drift tubes is $2V$. The parasitic mode has the same potential at the stems and strong RF current at the leg. Distributions of the energy density for electric $W_e = \epsilon_0 E^2$ and magnetic $W_m = \mu_0 H^2$ for operating and parasitic modes are shown in Fig. 4. With different choice of structure dimension, we can have parasitic mode both lower and higher than operating one. As one can see from Fig. 4, operating and parasitic modes have quite different E^2 and H^2 distributions and required reasonable frequency difference between these modes can be obtained by appropriate dimensions correction without strong deterioration of operating parameters.

SR DT CAVITY

Due to design idea, the structure has no end wall problem and can be easy segmented into cavities. To have more equalized capacitative load for both stems, it is preferable to have the same number of drift tubes at both stems and odd total number of accelerating gaps in the cavity. The cavity can be short, with one supporting ring, for lower β range and with number of periods $N_p \sim 13$ or less. In Fig. 5 such short cavity is shown just for illustration, with variable period length ($\beta \sim 0.01797 \div 0.02017, \alpha = 0.5, N_p = 13$), corresponding to ion acceleration with $E_0T = 2.4\frac{MV}{m}$. Electric field distribution for operating mode is shown in Fig. 6. Because potential difference between cavity wall and end tubes is a half from potential difference between regular tubes, electric field amplitude

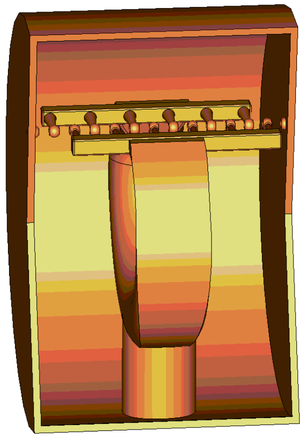

Figure 5: Short SR DT cavity with one supporting ring.

in end gaps is reduced. If required, the field in end gaps can be enlarged by appropriate gap length decreasing, as it is realized for the triple gap bunchers [6].

Also one can see a regular field reduction from lower β

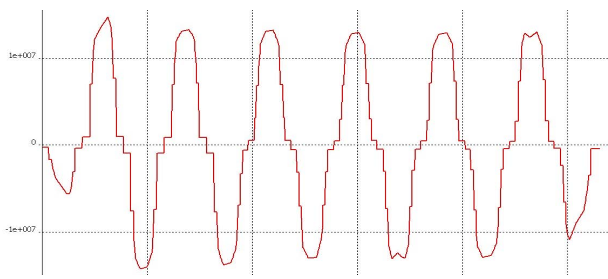

Figure 6: Electric field distribution along the beam axis in the short SR DT cavity.

periods to higher β ones. The potential difference between stems is constant, and with growing period length $L_p = \frac{\beta\lambda}{2}$ the average electric field decreases. Without any correction the field tilt is $\frac{\Delta E}{E} = \frac{\Delta\beta}{\beta}$. This tilt can be corrected either by easy gap ratio decreasing, or, more complicated, by drift tubes radii change. The short SR DT cavity, shown in Fig. 5, has the inner diameter of $853mm$ and length of $531mm$. Calculated Z_e value is of $619\frac{MOm}{m}$. RF power losses in both end walls are of 4.7% from the total dissipated power. To provide flat electric field distribution, SR DT cavities with a larger number of accelerating gaps should have several supporting rings. The long SR DT cavity with two supporting rings and variable period length, ($\beta \sim 0.02383 \div 0.02748, \alpha = 0.5, N_p = 13$), is shown in Fig. 7. The cavity has the inner diameter of $860mm$ and length of $1153mm$. Calculated Z_e value is of $420\frac{MOm}{m}$. RF power losses in both end walls are of 1.6% from the total dissipated power.

For parasitic mode frequency, both in short, and in long SR DT cavities, the stem terminations near ens walls are important. At the stem ends parasitic mode has the largest W_e value. With easy cavity segmentation, magnetic ele-

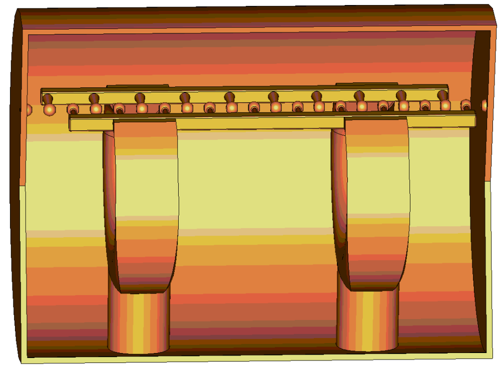

Figure 7: Long SR DT cavity with two supporting rings, $N_p = 21$.

ments for transverse beam foqucing can be placed outside cavities for easy mantainance. Such elements of the real cavity as fixed tuners, movable tuners and so on, can be easyly adopted from the same elements, developed, tested [2] and proven in operation. The structure is designated for CW operation and cooling problem is very important. For SR DT we can naturaly adopt the concept and parts of design of split ring RFQ [4], which are well tested in operation.

SUMMARY

Considerations shows for the proposed SR DT structure also attractive properties at the operating frequency $f = 70MHz$ - expected Z_e value higher than for IH DTL and definitely smaller cavity diameter. SR DT parameters at frequency $70MHz$ are comparable with IH DTL ones at frequency $105MHz$, but lower frequency results in the higher linac acceptance. In case of RFQ at frequency $70MHz$ [7], assuming Split Ring RFQ, SR DT application will also provide technological unity in the the line Split Ring RFQ - Split Ring DTL, opening possibility for linac cost reduction.

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