THE CUT DISK STRUCTURE PARAMETERS FOR MEDIUM PROTON ENERGY RANGE

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Abstract

For intense proton beam acceleration the structure aperture diameter should be $\approx 30mm$. With such aperture room temperature coupled cell accelerating structures have the maximal effective shunt impedance Z_e value at operating frequency $\approx 650MHz$. For this frequency well known Side Coupled Stricture (SCS), Disk and Washer Structure (DAW), Annular Coupled Structure (ACS) have large transversal dimensions, leading to essential technological problems. The Cut Disk Structure (CDS) has been proposed to join both high Z_e and coupling coefficient k_c values, but preferably for high energy linacs. In this report parameters of the four windows CDS option are considered at operating frequency $\approx 700MHz$ for proton energy range $80MeV \div 200MeV$. The outer diameter $\approx 30cm$ and $kc \approx 0.12$ result naturally, but Z_e value is of $(0.7 \div 0.9)$ from Z_e value for SCS ($k_c = 0.03$). Small cells diameter opens possibility of CDS applications for twice lower frequency and structure parameters at operating frequency $\approx 350MHz$ are estimated too. Cooling conditions for heavy duty cycle operation are considered.

INTRODUCTION

The scaling relation for effective shunt impedance of a structure $Z_e \sim \sqrt{f}$, where f is an operating frequency, is widely known and is frequently used for fast Z_e estimations at different f values. It means, that we simultaneously scale all dimensions of the structure. It is not perfectly correct for practical case.

Let us consider typical Ω-shaped accelerating cell geome-

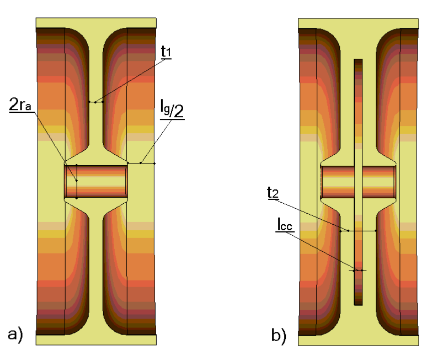

Figure 1: Typical cells geometries for structures with ECC (a) and ICC (b).

tries, shown in Fig. 1 for structures with External Coupling Cells (ESS), such as SCS, ACS, Fig. 1a, and for Internal Coupling Cells (ISS), for example, On-Axis Coupled Structure (OSC), Fig. 1b. The aperture diameter of the structure $2r_a$, Fig. 1a, is defined by a transverse beam size and safety margins. These parameters are not related directly with operating frequency. We can not reduce $2r_a$ for high operating frequency, but there are no reasons for $2r_a$ increasing for lower f. As it is known well, Z_e value increases with r_a decreasing. A septum thickness t_1, Fig. 1a, for ESS, is defined by cooling channels placing and rigidity requirements. From these requirements a reasonable t_1 value is $(10 \div 15mm)$. We also can not reduce t_1 at higher f values and there are no reasons for t_1 increasing for lower operating frequency. And Z_e increases with relative $\frac{t_1}{L_p}$ increasing, where $L_p = \frac{\beta\lambda}{2}$ is the period length, β, λ are the relative particle velocity and the operating wavelength, respectively. For the ICC case we should have two septa with the thickness t_1 and coupling cell with the length l_{cc} in between with effective septum thickness $t_2 \approx 2 \cdot t_1 + l_{cc}$. To find a frequency for the maximal Z_e value we have the contradiction - for higher frequencies skin effect leads to RF losses reduction, but we have to increase ratio $\frac{r_a}{\lambda}$ and $\frac{t_1}{\lambda}$. For lower frequencies it are conversely.

CDS ADVANTAGES

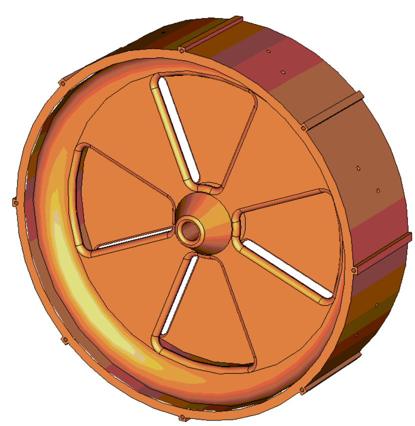

Figure 2: Four windows CDS option.

The CDS was proposed for high energy linacs $\beta \approx 1$ and L-band operating frequency [1]. CDS is topologically similar to OCS, but realizes quite different coupling concept - coupling mode has no own space for magnetic field, which should penetrate strongly through coupling windows (slots) in an accelerating cell, resulting in the high coupling coefficient value $k_c \sim 0.12 \div 0.25$. Coupling windows in CDS have not so strong magnetic field enhancement at windows ends, as compared to coupling slots in OCS, ACS, SCS and a high coupling coefficient is not connected with Z_e

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reduction. Windows are placed in the region of the maximal magnetic field for accelerating mode, resulting in RF loss reduction. Calculated and measured Z_e value for CDS is even higher, than for similar structure without windows (zero coupling). High order modes problem for CDS is absent. Further CDS development [2] has shown preference of the four windows CDS option, Fig. 2, as compared to two or three windows - sufficient value $k_c \approx 0.1 \div 0.15$, a higher vacuum conductivity, a simpler cooling scheme, slightly higher Z_e value, absence of transversal field for coupling mode, strongly reduced multipactoring possibility in coupling cells. But for L-band operating frequency the relative septum thickness $\frac{t_2}{L_p}$ is still high for $(\beta \sim 0.4 \div 0.5)$ and CDS loses in Z_e value to another structures. With the operating frequency reduction the ratio $\frac{t_2}{L_p}$ decreases, providing CDS competitiveness for medium proton energies.

Medium Operating Frequency

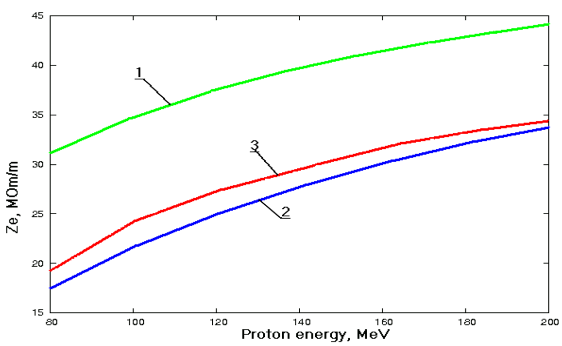

Figure 3: Effective shunt impedance at operating frequency $f = 704MHz$ for structures: 1 - with ECC ($k_c = 0$), 2 - ICC ($k_c = 0$) and 3 - CDS.

CDS parameters were estimated for operating frequency of $f = 704MHz$ with aperture diameter of $2r_a = 32mm$ and proton energy range $W_p = (80 \div 200)MeV$. Reference cell geometries, both for ICC and for ECC, Fig. 1, were optimized in 2D approximation following procedure, described in [3]. The septum thickness is fixed at $t_1 = 14mm$ for ECC, and at $t_2 = 36mm$ for ICC. Effective shunt impedance is defined as:

$$Z_e = \frac{(E_0 T)^2 L_p}{P_s}, \quad \text{MOm/m} \tag{1}$$

where E_0 is the average electric field along the structure axis, T is the transit time factor, P_s is the RF loss power at the period.

For each proton energy the optimal gap ratio $\alpha = \frac{l_g}{L_p}$, where l_g is the gap length, has been defined for the maximal Z_e value. An optimal α essentially depends on septum thickness and to have the maximal Z_e value structures with ECC and ICC have a different gap length for the same β. The optimal cell geometry with ICC were modified in CDS and simulated in 3D approximation with MWS [4]. Results of simulations are plotted in Fig. 3.

Comparing curve 1 and curve 2 in Fig. 3, one can see, that the effectively thick septum directly leads to lower Z_e value for the structures with ICC. The CDS utilizes the same reference geometry with the same thick septum but, due to design idea, partially regains initial Z_e defeat. But calculated Z_e value is still $\sim 75\%$ from similar value for structures with ECC ($k_c = 0$). The coupling coefficient $k_c \approx (0.14 \div 0.12)$ obtains for CDS naturally, together with the shown Z_e value. Such k_c values are not reachable for SCS and ACS - for that structures k_c increasing at 1% is coupled with Z_e reduction at $\approx 2.5\%$. For CDS we have to take into account only Z_e reduction due to surface roughness. Low RF level measurements show for [2] quality factor Q_0 and Z_e values are of 95% from calculated in 3D approximation. Outer CDS cell diameter is $\approx 305mm$ and CDS transverse dimensions do not provide problems for brazing technology.

For medium proton energy range CDS at operating frequency $704MHz$ has in times higher coupling coefficient and smaller transverse dimension, as compared to structures with ESS. But CDS effective shunt impedance is of $\approx 10\% \div 15\%$ lower, as compared to SCS or ACS with $k_c \sim 0.03 \div 0.05$.

Low Operating Frequency

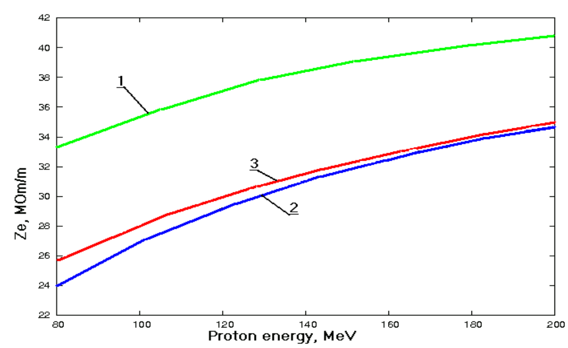

Figure 4: Effective shunt impedance at operating frequency $f = 352MHz$ for structures: 1 - with ESS ($k_c = 0$),2 - ICC ($k_c = 0$), and 3 - CDS.

Small transverse dimensions make it attractive to consider CDS parameters for twice lower operating frequency of $352MHz$. Similar simulations were performed with the same aperture diameter of $2r_a = 32mm$. The septum thickness is fixed at $t_1 = 16mm$ for ECC, and at $t_2 = 46mm$ for ICC. Results are plotted in Fig. 4.

For operating frequency of $352MHz$ a relative difference in Z_e value between ECC and ICC structures decreases, but remains essential. CDS remains in Z_e value higher than ICC structures, but $\approx 15\%$ lower than structures with ECC ($k_c = 0$). We can not consider ECC structures, which became not practical due to large ($> 1200mm$) transverse dimensions. At this frequency we can consider only ICC structures with outer diameter of $\approx 590mm$, defined by

TM_{010} mode frequency, definitely have lower, than CDS, Z_e value.
Another possible competitor is a simple chain directly coupled accelerating cells in π-mode. Sufficient k_c value can be provided only by coupling slots in the septum between cells. In π-mode a low Q element - the coupling slot, is excited with a twice higher amplitude, as compared $\frac{\pi}{2}$ mode. This case the magnetic field enhancement and related RF loss density increasing at the ends of coupling slot is larger. It leads to a larger rate of Z_e decreasing with k_c increasing, as compared to $\frac{\pi}{2}$ structures. Even with careful coupling slot shape definition (k_c increasing with the slot height increasing entails with a smaller Z_e decreasing, [5]) and slots rounding such $k_c \approx (0.15 \div 0.13)$ for directly coupled π-mode structure will be connected with very large Z_e reduction. For lower $k_c \approx 0.05$ values in π-mode structure the careful comparison should be performed - Z_e for CDS can be higher.

COOLING CONDITIONS

Cooling problem for CDS is not difficult. Differing from structures with ECC, heat dissipates from one one side of each web. A typical RF loss density distribution at the CDS cell surface is shown in Fig. 5. With the appropriate choice of shape and rounding of windows end magnetic field enhancement at the window ends is smaller, than at the ends of usual coupling slots.
Assuming CDS operation with E_0 of $4\frac{MV}{m}$ and duty fac-

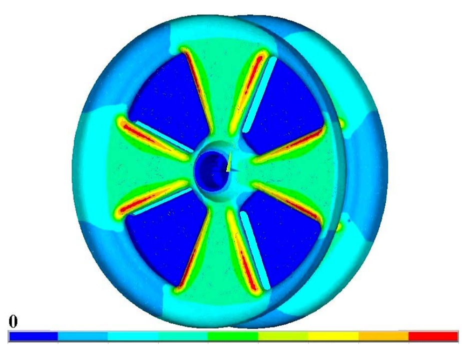

Figure 5: RF loss density distribution at the CDS cell surface, relative units.

tor of 4%, average RF power, dissipated in CDS period ($\beta = 0.4282$) is of $\approx 2.4kW$ for $f = 704MHz$ and of $\approx 4.75kW$ for $f = 352MHz$. The temperature distributions at the surface of CDS cells ($f = 704MHz$), calculated according [6] with ANSYS, [7], are shown in Fig .6 for cooling water velocity of $\approx 2\frac{m}{sec}$ and two options of internal cooling channels. A simple V-like internal channels in the septum are better adjusted with RF loss density profile and the maximal temperature difference at the surface, with respect incoming cooling water temperature of 27^oC, is of $\approx 8.8^oC$. With V-like channels the drift tube region has a maximal temperature, Fig. 6a. Intersecting internal cooling channels are realized in [2] for effective drift tube cooling at the expense of some temperature increase at outer CDS part. For small CDS radius at frequency $704MHz$ intersecting internal channels are realistic and lead to maximal temperature difference $\approx 10.3^oC$.
For operating frequency of $352MHz$ and outer CDS ra-

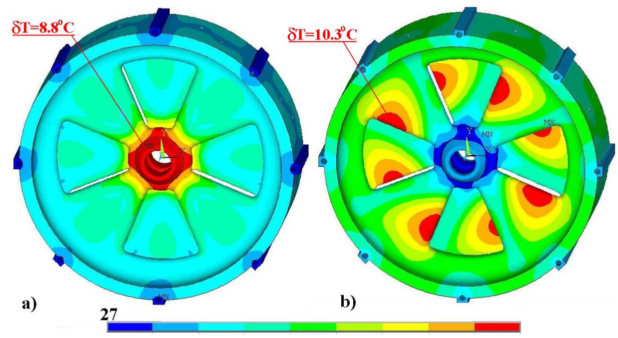

Figure 6: Temperature distribution at the surface of CDS cells ($f = 704MHz$) for V-like (a) and intersecting (b) internal channels.

dius of $\approx 300mm$ intersecting internal channels may be difficult in manufacturing and V-like channels look preferable. The calculated maximal temperature difference is estimated as of $\approx 11.9^oC$.

SUMMARY

Application at operating frequencies of $\sim 700MHz$ and lower smoothes the CDS disadvantage in medium $\beta \sim 0.4$ region - the effective shunt impedance decreasing due to necessity of thick septum. CDS advantages - the high coupling coefficient value, small transverse dimensions come in front in escort of competitive Z_e value. This case CDS is a reasonable candidate for proton accelerations in the medium energy range of $(80 \div 200MeV)$.
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