THE CDS PARAMETERS FOR PROTON LINAC WITH MODERATE HEAT LOADING

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Abstract

The Cut Disk Structure (CDS) was originally proposed for high energy linac in L-band or S-band frequency range. CDS combines simultaneously high coupling coefficient, high efficiency and small transverse dimensions. For lower particle velocity ($\beta < 1$) the structure loses in the effective shunt impedance Z_e value due to relatively thick partition with internal cooling channels. For moderate heat loading internal cooling is not necessary and partition thickness is limited only by mechanical rigidity. The structure equalizes in Z_e value with another bi-periodical structures and original CDS advantages come in front. Calculated CDS parameters for proton linac are presented.

INTRODUCTION

For high energy part ($\beta \geq 0.4$) of proton linac such well known normal conducting accelerating structures as Side Coupled Stricture (SCS) [1], Disk and Washer Structure (DAW), Annular Coupled Structure (ACS) [2] are realized. Topologically these structures can be considered as External Coupling Cell (ECC) structures, Fig. 1a with coupling cells removed from the beam axis. The septum thickness t_1 between adjacent accelerating cells is defined by structure rigidity and placement of cooling channels.
The Cut Disk Structure (CDS) has been proposed [3] ini-

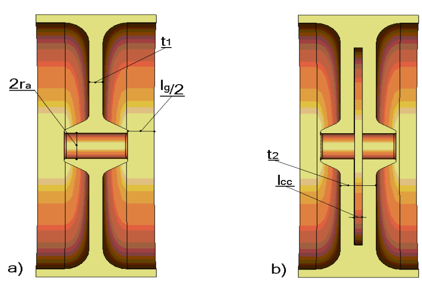

Figure 1: Accelerating cells in structures with External (a) and Internal (b) Coupling Cells - ECC and ICC.

tially for electron $\beta \approx 1$ linac with S-band and L-band operating frequency to join both high Z_e and coupling coefficient k_c values. Topologically initial CDS is the structure with Internal Coupling Cells (ICC), Fig. 1b. The coupling cell with the length l_{cc} is placed in the septum between accelerating cells. Cooling of the drift tube region is required for intense linacs with high heat loading at the structure. If internal cooling channels are required, the effective septum thickness $\frac{2t_2}{\beta\lambda}$ is still high for ($\beta \sim 0.4 \div 0.5$) and CDS loses in Z_e value with respect to another structures.
Further CDS development [4] has shown preference of the four windows CDS option (CDS4W, Fig. 2c), as compared to two (CDS2W, Fig. 2b) or three windows - sufficient $k_c \approx (10 \div 15)\%$ value, a higher vacuum conductivity, a simpler cooling scheme, slightly higher Z_e value, absence of transversal field for coupling mode, strongly reduced possibility of multipactor discharge in coupling cells. For lower operating frequency $f_0 \geq 700MHz$ the

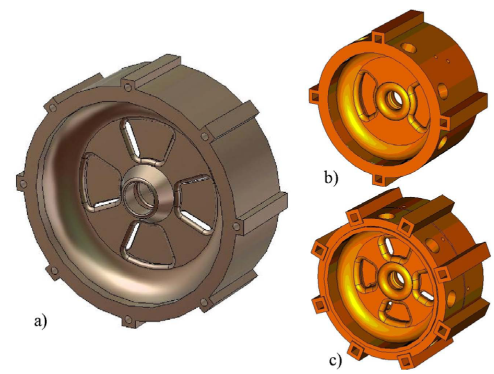

Figure 2: CDS structure for proton linac (a) and for electron intense linac, (b) - CDS2W, (c) -CDS4W.

relative septum thickness becomes smaller and CDS with internal cooling is competitive with another structures [5] in Z_e value and has big advantage of small transverse dimensions.
With the moderate average heat loading to the structure $\sim 3kW/m$ internal cooling is not strongly necessary. The septum thickness in CDS can be reduced.

CDS RF PARAMETERS FOR THIN SEPTUM

The CDS RF parameters were calculated for operating frequency $f_0 = 991MHz$ with aperture radius $r_a = 17mm$ and septum thickness $t_2 = 14mm$ for particle velocity range $0.4 \leq \beta \leq 0.8$. Results are plotted in Fig. 3. The CDS coupling value $k_c \approx (14 \div 17)\%$ appears naturally, due to original concept [3] and is well balanced with respect DAW coupling $k_c \approx 50\%$ and SCS-ACS one, $k_c \approx 5\%$.
Comparison with another structures in Z_e value is presented in Fig. 4. Coupling windows in CDS4W are placed in the region of the maximal magnetic field for accelerating mode, resulting in th surface decreasing and related

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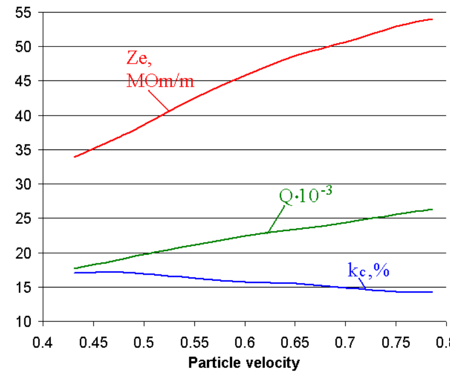

Figure 3: CDS RF parameters Z_e, k_c and Q for $0.4 \leq \beta \leq 0.8$ and thin septum $t_2 = 14mm$.

RF loss reduction. The calculated and the measured Z_e value for CDS4W is higher, than for ECC, Fig. 1a, without windows $k_c = 0$ (zero coupling) even for more thick CDS4W septum (Ze value for ESS, Fig. 1a, is calculated for $t_1 = 10mm$). The magnetic field enhancement at windows ends is not so strong, as compared to field enhancement at coupling slots in ACS, SCS, and higher coupling k_c is not connected with Z_e reduction, which normally takes place in SCS, ACS with the rate $\frac{\partial Z_e}{Z_e} \sim -2\%$ for $\delta k_c = 0.01$. In Fig. 4 Z_e valus for SCS and ACS are estimated with respect directly calculated Z_e for ECC (Fig. 1a) assuming this rate for Z_e reduction.

The calculated Z_e value for DAW in INR linac is from [6].

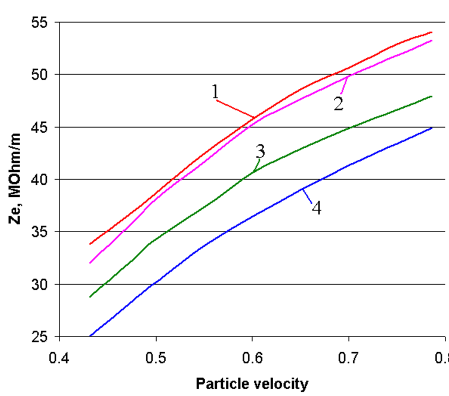

Figure 4: Z_e value for CDS (1), ECC $k_c = 0, t_1 = 10mm$ (2), SCS and ACS assuming $k_c = 5\%, t_1 = 10mm$ (3) and DAW (4).

The lower Z_e value, as compared to Z_e in SCS, is due to L-stems for washer support. Three L-stems in each DAW period do not disturb the electric field distribution for accelerating mode, but are placed in the region with a high magnetic field value and provide additional RF losses.

As comparison shows, see Fig. 4, the CDS4W with relatively thin septum exceeds equivalent structures in efficiency together with very good k_c value.

Calculated dispersion curves for operating and High Order Modes (HOM) are shown for CDS4W in frequency range $f < 2f_0$ in Fig. 5. Due to small transverse dimensions $r_c \sim 0.33\lambda_0 \approx 110mm$ the nearest curve for HE_{11a} modes is well separated from the pass band of operating TM_{01} modes. Due to original CDS coupling concept, only operating TM_{01} modes are coupled significantly. The nearest HOMs are twice degenerated in frequency, due to CDS4W symmetry, and have field distributions concentrated either in accelerating cells (HE_{11a}, EH_{11a}) or in coupling cells, (EH_{11c}). In comparison with another structures, mentioned in this report, CDS has no HOM problem.

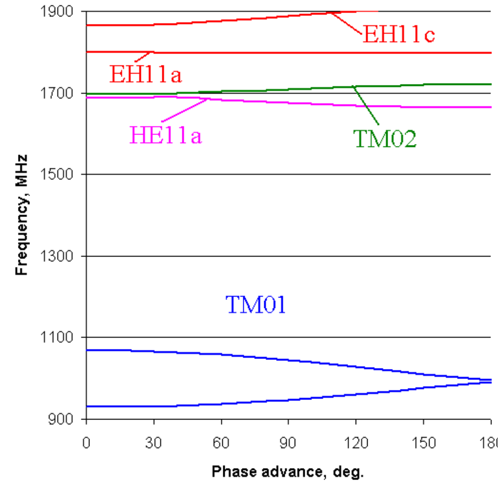

Figure 5: Calculated dispersion curves in CDS4W for operating and high order modes in frequency range $2f_0$.

CDS4W EXTERNAL COOLING

The complete thermal-structural analysis for CDS4W with the thin septum has been performed according [7]. The moderate for modern intense proton linac value of average heat dissipation in the structure $3kW/m$ is assumed with $+10\%$ safety margins. In the consideration, the cooling circuit consists from 8 cylindrical cooling channels at outer cylindrical wall, Fig. 2a. The water flow velocity is $V = 1.5\frac{m}{sec}$, corresponding to the value of heat exchange coefficient $h = 9200\frac{W}{K^o m^2}$ and input water temperature $T_i = 27C^o$. The results of thermal-stress analysis are summarized in the Table 1.

The example of RF loss power distribution at the surface of the CDS cell is presented in Fig. 6a and shows not so essential heat flux enhancement at the ends of coupling windows. Corresponding temperature distribution is shown in Fig. 6b. The maximal surface temperature T_m is at drift tubes and exceeds the input water temperature at $\delta T_m = T_m - T_i \approx 10C^o$. Coupling windows in CDS reduce the own septum heat conductivity and δT_m value is approximately two times higher, as compared to ideal ECC cell, Fig. 1a, for the same cooling conditions. But the value $\delta T_m \approx 10C^o$ is well tolerable for stable structure operation.

The example of internal stress distribution, induced by

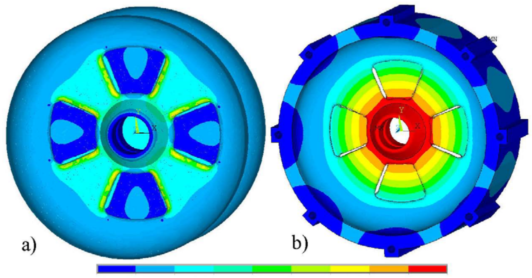

Figure 6: RF loss density (a) and temperature (b) distributions in CDS4W, $\beta = 0.6$.

Table 1: Summary for CDS thermal-stress analysis.

β	$\delta T_m, C^o$	σ_m, MPa	$\delta z_m, \mu m$	$\delta f_0, kHz$
0.43	8.5	0.21	9.8	-193.6
0.60	10.8	0.28	12.5	-199.4
0.78	12.6	0.36	14.9	-189.5

the temperature distribution in Fig. 6b, is shown in Fig. 7a. The maximal stress value σ_m, as one can see from the Table 1, is well below the yield stress σ_y for the annealed Oxygen Free Copper (OFC), $\sigma_y \approx 34MPa$ [8]. The thermal induced distribution of longitudinal displacements with respect the cell center is shown in Fig. 8b. The maximal δz_m value is at the drift tube nose tip and $\delta z_m \approx 10\mu m$, as one can see form the Table 1. This value consists from two parts. The first part is the own thermal expansion of the half drift tube and is of $\approx (3 \div 5)\mu m$. The second part is the displacement of the half drift tube as a whole due to thermal web deformation, see Fig. 8b. The second part dominates in the total drift tube displacement. As the result, the shift of operating frequency due to thermal structure expansion is rather significant, $\delta f_0 \approx -190kHz$, see Table 1. It is not drastic value, but lower δf_0 is more convenient, because initial artificial structure heating for the first RF pulse input will be lower. The CDS cell shape can be changed slightly to provide such drift tube displacement, when two parts of displacement will compensate each other.

The thermal - stress analysis for CDS without internal

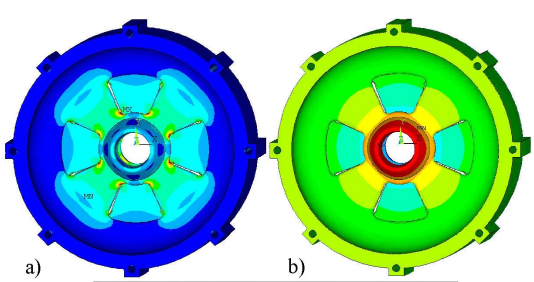

Figure 7: Internal stress (a) and longitudinal displacements (b) distributions in CDS4W, $\beta = 0.6$

cooling shows acceptable results for reliable operation with moderate average heat dissipation in the structure.

SUMMARY

Consideration shows, that CDS structure with the thin septum overlaps the equivalent structures for the same destination in all essential RF properties. In application with moderate average heat loading the thermal condition inside CDS cell are tolerable even without internal cooling. Internal stress values are well below the yield stress limit for OFC copper. The thermal induced shift of operating frequency is acceptable and can be reduced by further CDS shape optimization.

CDS transverse dimensions in comparison with another

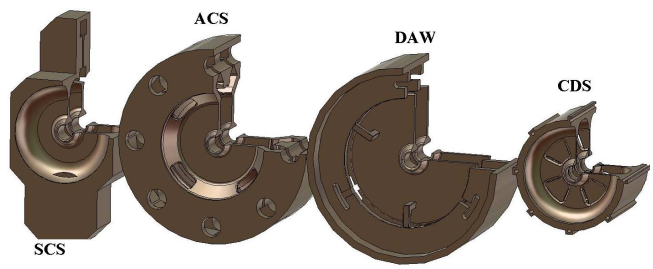

Figure 8: Comparison for transverse dimensions of SCS, ACS, DAW and CDS structures, $f_0 = 991MHz, \beta = 0.6$

structures one can estimate from Fig. 8.

At present time consideration of RF superconductivity for the high energy part of the hadron linacs is usual. But may be the possibility of normal conducting structure application due to 'special purpose'. This case CDS structure is the promising candidate for further consideration.

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