THE CUT DISK ACCELERATING STRUCTURE FOR HIGH ENERGY LINACS

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Abstract

New accelerating structure for particles velocities $0.4 \leq \beta_p \leq 1.0$ is proposed. The Cut Disk Structure (CDS) is the compensated one, has coupling coefficient to 30% without distortions in the dispersion curve and 3D calculated effective shunt impedance not less than for another Coupled Cells Structures (CCS). There are no parasitic modes in the operating passband. The outer diameter is small enough ($\approx 0.6\lambda$). Accelerating cells in CDS are open for effective cooling. The design of the structure provides simple manufacturing and tuning procedures.
The philosophy of the structure, design, criteria of optimization and results are presented.

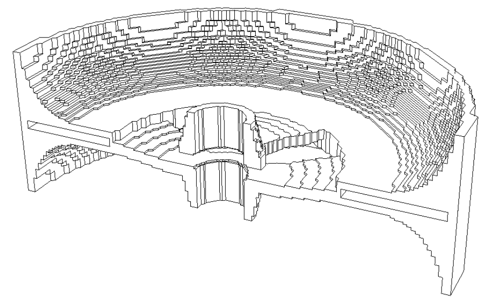

Figure 1: One half of the Cut Disk Accelerating Structure (CDS) period, two windows option.

1 INTRODUCTION

Several compensated accelerating structures are now widely used for acceleration of charged particles for relative velocities $\beta_p > 0.4$. 'Compensated' are named the structures in which at operating frequency coincide frequencies of two modes with differing parity of field distribution (accelerating and coupling modes). Examples of compensated structures are well known Side-Coupled Structure (SCS) [1], On-axis Coupled Structure (OCS) [2], Annular-Coupled Structure (ACS) [3], Disk And Washer structure (DAW) [3], and so on. These structures combine high efficiency with high stability of the accelerating field distribution to deviations in cells parameters and beam loading. The value of the coupling coefficient k_c defines this stability.
Comparison and present state of art in the structures development are given in [4]. The structures, mentioned above, may be distinguished into two groups - structures with coupling slots - $k_c \approx 3\% \div 5\%$ (SCS, ACS, OCS) and $k_c \approx 40\%$ (DAW). In this paper new structure (CDS) [5], which combines the features of CCS with high coupling of DAW, is described.

2 THEORETICAL BASIS

From electrodinamic consideration of compensated structures follows [6], that group velocity β_g (or coupling coefficient $k_c = \frac{4\beta_g}{\pi\beta_p}$) are:

$$\frac{\beta_g}{\beta_p} = \mid \frac{\pi \int_V (\epsilon_0 \vec{E}_a \vec{E}_c - \mu_0 \vec{H}_a \vec{H}_c) dv}{\sqrt{2 W_a W_c}} \mid, \quad W_{a,c} = \frac{\mu_0}{2} \int_V \mid \vec{H}_{a,c} \mid^2 dv, \qquad (1)$$

where V - the volume of one half of the structure period, $\vec{E}_a, \vec{H}_a, \vec{E}_c, \vec{H}_c$ - distributions of electric and magnetic field of the accelerating mode and coupling one. Taking into account TM_{011}-like field distributions and different parities, one can show $\epsilon_0 \mid \int_V (\vec{E}_a \vec{E}_c) dv \mid \ll \mu_0 \mid \int_V (\vec{H}_a \vec{H}_c) dv \mid$.
For structures with coupling slots, considering the slot as the part of transmission line, one can derive [7] estimation for k_c:

$$k_c \sim \frac{l_s^3 \Delta H_{as} H_{cs}}{t\sqrt{W_a W_c}}, \qquad (2)$$

where Δ and l_s - are the width and the length of coupling slot, t - is the thickens of the web between cells, H_{as}, H_{cs} - magnetic fields of accelerating mode and coupling one at the slot.
For CCS there are no big reserve in k_c increasing due to l_s increasing, because all time it assists with reduction in effective shunt impedance Z_e. The coupling slots provide perturbation for rf current distribution in accelerating cell. The maximum value of rf current density j_{max} takes place at the ends of slots, the minimum one j_{min} - in the middle. Strong dependence of k_c and rf current redistribution from the l_s increasing takes place due to resonant-like character of coupling with slots.

Our investigations show [5] that SCS and ACS are limited in k_c increasing due to the design particularities. Better result ($k_c \approx 12\% \div 15\%$, [8]) is for OCS with reduced thickens of the web between cells and optimization of coupling cells.
Anyhow, if the structure has clearly distinguished cells, overlapping of $\vec{H}_a, \vec{H}_c$ will be in restricted region near the slots and k_c will be not big (1). For big coupling overlapping of $\vec{H}_a, \vec{H}_c$ should be in total volume of the structure (like DAW).

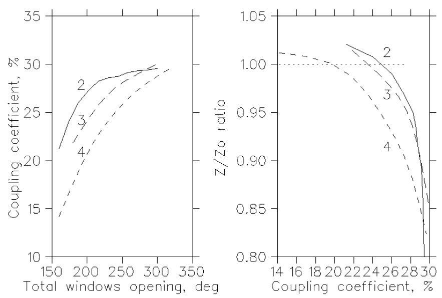

Figure 2: The coupling coefficient vrs total opening and reduction in Z_e for 2, 3 and 4 - windows options.

3 THE STRUCTURE FORMATION

Let suppose one has the set of half of drift tubes, placed in couples along the axis of the cylinder. The distance between couples is l_a (accelerating gap in future), between half tubes in the couple - l_c (coupling gap), $l_c \ll l_a$. There are also the disks in the middle of coupling gap perpendicularly to the axis and in radial direction from the radius of tubes r_t to the radius of the cylinder R_c. Suppose, we excite TM_{011}-like coupling mode, which must satisfy to 'magnetic' boundary conditions in the middles of accelerating gaps. Electric field of such mode will be strongly concentrated in the coupling gap, because $l_c \ll l_a$, but magnetic one will be distributed outside tubes. The disks do not perturb these fields distributions. Then, we will Cut the Disks along radius from r_t to $r_c, r_t < r_c < R_c$ in m petals, ($m = 4, 6, 8...$), and connect in turn petals to half of drift tubes. First petal connects to left half-tube, second to right one, third to left and so on. If at an angular position given at left side from coupling gap the petal is connected to left half-tube, at right side there is no connection, there is the window from coupling gap to right accelerating cell. Such alternating connection of petals to left and to right is essential to have big coupling. Finally, we decrease the thickness of petals (approximately to one half from the disk width) from the side of coupling gap.

After this transformation of the disks we do not disturb strongly fields distributions of coupling mode, but the half of drift tubes are attached to the cylindrical wall and cells of the CDS structure (Fig. 1) are formed as follows:

- accelerating cells of usual Ω-shape with distributed electric and magnetic fields;
- coupling cells, with electric field concentrated in the short space between half tubes, but **main part of magnetic field is distributed in the volume of accelerating cell.**

For CDS radius of the windows is the radius of coupling cell. Extension of coupling cell beyond windows is not nesessary and may be only from technological or decorative purposes. The description of the CDS formation has only one purpose - to show this structure realizes another idea than OCS with coupling slots. The main principle and the difference of the CDS from structures with slots is **non-resonant character of coupling.** Instead of CDS is very similar to OCS outwardly (and formally speaking, CDS is the structure with On-axis Coupling, but with another realization of coupling), some time conclusions, based on experience with coupling slots, are not correct for CDS.

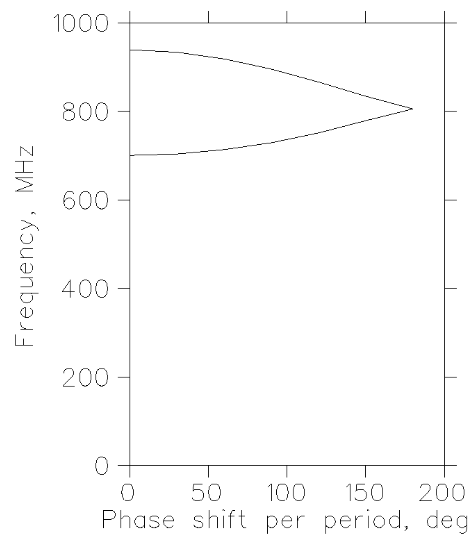

Figure 3: The operating part of the Brillouin diagram for CDS. $\beta_p = 0.6, f_0 = 805 MHz$.

4 THE CDS PROPERTIES

Below are results of 3D numerical simulations (using MAFIA) of CDS parameters.

Main particularity of the CDS is big k_c, because overlapping of magnetic fields $\vec{H}_a$ and $\vec{H}_c$ takes place in main part of accelerating cell and in the region (near drift tube), where $\mid \vec{H}_a \mid$ and $\mid \vec{H}_c \mid$ have maximal values. The plots of dependencies $k_c(\Phi_w)$ are shown in Fig. 2(a) for two - (Fig. 1) three - and four windows options. The total opening Φ_w means the sum of opening of all windows at one side of the disk. One can see from Fig. 2(a), that dependence $k_c(\Phi_w)$ do not satisfies to relation (2) and saturation take place. There are no, also, strong dependence of k_c from the petal thickness.

To tune coupling mode to operating frequency, one should match the window opening ϕ and cut radius r_c. Critical point in the choice of dimensions for coupling gap is the value of maximum electric field of coupling mode at the surface of the structure E_{csm}, which is related to W_c. One should control E_{csm} (by the choice of l_c and r_t) to avoid:

- sparking in coupling cells during transient;
- sparking in coupling cells in steady state regime;
- multipactoring in coupling cells in steady state regime;

Relations between requirements depend on regime of the accelerator and for different regimes one of these requirements widd come in front.

The shunt impedance Z_e decreases with increasing of Φ_w (Fig. 2b). For small ϕ values $Z_e > Z_0$, where Z_0 is effective shunt impedance of solid accelerating cell without any windows, because we remove a part of metal surface in the region of strong magnetic field $\vec{H}_a$. With Φ_w) increasing total angle opening of petals Φ_p appropriately decreases and the density of rf currents along petals rises, leading to Z_e reduction. For the accelerating mode magnetic field turns around petal. From this reason we consider preferable two windows option with $\Phi_w \approx (200^0 \div 220^0)$. It provides very good coupling ($k_c \approx 26\%$) and $Z_e \approx Z_0$. This particularity of the CDS provides higher Z_e in comparison with another structures. Really, the accelerating cell has the same shape as for another structures. It is known, that Z_e of the CCS decreases with increasing of the web thickness between accelerating cells, but this decreasing is smooth and with reasonably thick web we have reduction in Z_e not more than $5\% \div 10\%$. This reduction is the price for thick web, but **there is no reduction in Z_e due to coupling slots** and finally 3D calculated Z_e for CDS with $k_c \approx 25\%$ is at $5\% \div 15\%$ higher than for SCS with $k_c \approx 5\%$. The thick web allows to place cooling chanel (Fig.1, Fig. 4) not so far from drift tubes, providing (together with thick petals) good conditions for the structure cooling.

Mutual orientation of windows at opposite sides of accelerating cell is important not for k_c value, but for perturbation of axial symmetry of accelerating field. Like slots, windows provide quadruple ($m = 4$), sextuple ($m = 6$) and so on, components in accelerating field. Because all CCS have π-type operating mode, perturbations from windows (slots) at opposite sides add if windows are rotated at the angle $2\pi/m$ and subtract if windows are placed face to face.

As one can see (Fig. 1, Fig. 4), the design of the structure is very simple. Instead of high precision of mashinering must be done for windows and petals (to reduce frequency spread for coupling mode), it is no problem for modern Numerically Controlled equipment. To reduce E_{csm} all sharp edges at petals, windows and coupling gap should be rounded.

The structure is open from cylindrical wall for vacuum and cooling equipment. The outer diameter (for accelerating cell) $2R_c \approx 0.6\lambda$ and the structure has the smallest transverse dimensions in comparison with another CCS. This case we can consider 'low frequency' applications for CDS, because even for $f_0 \approx 400MHz$ dimensions remain technologically reasonable ($2R_c \approx 45cm$).

For $\Phi_w \approx 210^0 \Phi_w > \Phi_p$ and one can look through the structure (it provides some improvement in the vacuum conductivity of the CDS). Nevertheless, CDS has 'ideal' spectral properties. The passbands of the Brillouin diagram for operating mode (calculated in 3D approximation by using MAFIA with Floquet boundary conditions) are shown in Fig. 3. Fitting with the standart five parameters lumped circuit model shows neighbor coupling coefficients k_1 and k_2 being practically zero. Nearest high order modes TM_{11n}-type are placed at frequencies $\approx 1.5 f_0$.

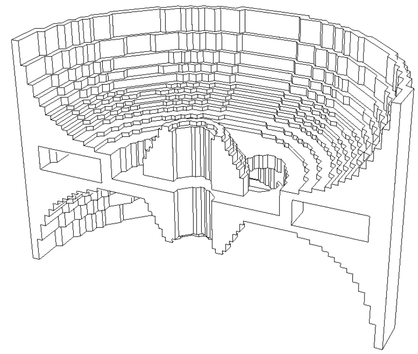

Figure 4: The CDS for electron linac with heavy heat loading. $\beta_p = 1.0, f_0 = 2450MHz, k_c = 25\%, Z_e = 89M\Omega/m$.

5 CONCLUSION

New accelerating structure for high energy linacs is described. Differing from known CCS, CDS realize idea of nonrezonant coupling. As the result, CDS combines:
high coupling ($k_c \approx 25\%$);
high effective shunt impedance;
simple, mechanically strong design;
small transverse dimensions.
With the combinations of these parameters, CDS looks as very attractive candidate for proton and electron linacs both for fundamental investigations and for industrial applications.
Theoretical study of the structure continues and experimental investigations are now under way.

6 ACKNOWLEDGMENTS

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