Experimental Study for the Model of the Accelerating Structure with Increased Coupling Coefficient

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The Cut Disk Structure (CDS) was proposed as the compensated accelerating structure for high energy linacs. Cold rf model was manufactured to examine CDS parameters, partially for S-band electron linacs. In agreement with design parameters, coupling coefficient near 22% was obtained together with high shunt impedance. Results of experiments are presented.

Introduction

The Cut Disk Structure (Fig. 1) was proposed [1] as the result of investigations for coupling coefficient k_c increasing in compensated accelerating structures. Results of numerical simulations [1] have shown attractive features of the structure - high k_c value together with high effective shunt impedance Z_e. Nine cell $\beta = 1$ cold model with operating frequency $f_0 = 2450$ MHz was produced to proof CDS design parameters for high β region. This paper describes design parameters, rf model, tuning procedure and results of experiments.

1. The CDS particularities

Instead of CDS is very similar outwardly (Fig. 1) to On-axis Coupled Structure with coupling slots, it realise another idea. In CDS accelerating mode is distributed in accelerating cell of usual Ω-shape with distributed electric and magnetic fields. For coupling mode electric field is concentrated in the short space between half tubes (in "coupling cell", Fig. 1), but main part of magnetic field is distributed in the volume of accelerating cell. It results in strong overlapping for magnetic fields of coupling and accelerating modes and high k_c value.

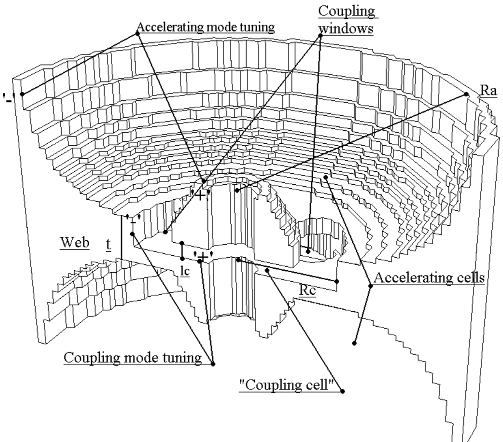

Figure 1: The sketch of the CDS structure.

In CDS coupling windows serve as real 'window' trough which main part of magnetic field for coupling mode penetrates in the volume of accelerating cells and some conclusions, based on extensive experience with coupling slots, are not correct for CDS. For example, k_c is practically not sensitive to the thickness of window. (For $\beta = 1, f_0 = 2450$ MHz two times increasing of the window thickness reduces k_c only from 22% to 19%. The frequency shift for accelerating mode due to coupling windows is also smaller than for slot coupled structures.

For small k_c values $Z_e > Z_0$ [1] and for every β there exists such k_c^0 value when calculated $Z_e = Z_0$ where Z_0 is the effective shunt impedance of solid accelerating cell without any windows. Due to increasing of the volume for accelerating cell with β increasing, k_c^0 decreases from $\approx 30\%$ at $\beta = 0.4$ to $\approx 22\%$ at $\beta = 1$.

2. CDS model

In the CDS design we allow Z_e reduction due to increased web thickness hoping this reduction be compensated with CDS particularities and resulting Z_e value will be not less than for another CCL structures, which loose Z_e with k_c increasing. The shape of accelerating cells was 2D optimised for accelerating gradient $E_0T = 10.0$ MV/m to have $Z_{e2D} = 89.7$ MOhm/m, $Q_{2D} = 17900$. The web thickness $t = 10$ mm.

2.1. The model description

The cold CDS model was manufactured from aluminum alloy to simplify the manufacturing procedure. The units of the model have been manufactured in INR with using usual equipment. Soft tolerances (not stronger than $\pm 50\mu$) were accepted for essential dimensions of the structure - dimensions of "coupling cell", coupling windows and accelerating cell. The radius of accelerating cell R_a and the length of "coupling cell" l_c (see Fig. 1) were reduced with respect to design values to have ≈ 50 MHz reserve for rf tuning.

The model contains nine periods of the structure. The termination of the model is with two plates in the middle of end accelerating cells. In each period of the structure there are two caps. Joint between caps (the place of rf contact) are in middle-planes of accelerating and "coupling cells". To reduce quadruple perturbation of accelerating field by coupling windows, at opposite sides of accelerating cell windows are placed face-to-face. Because rf properties of material are not known well, to have information about quality factor Q, special reference cylindrical cavity was manufactured from the same material, at the same equipment, with the same requirements, with the same length $\beta\lambda/2$, with the same typ end number of rf joints.

The usual equipment was used to provide rf and bead-pull measurements.

2.2. Tuning procedure

As usual, tuning of compensated accelerating structure should have three procedures:

- tuning of the accelerating mode frequency f_a to f_0 one;
- tuning of the coupling mode frequency f_c to confine with f_a (closing of the stop-band);
- tuning of the accelerating field distribution (if needed).

During the mode frequencies tuning there were no tuning of individual cells. Both for accelerating mode tuning and coupling one the change in dimensions was the same for all cell in the section. But after each step of the frequencies tuning the frequencies of accelerating mode and coupling one were determined by measuring frequencies of two 0 type and one π type modes in the assembly from two caps terminated with end plates. It was done just for purpose of investigation.

The accelerating mode frequency tuning in CDS do not differs from the same procedure in another CCL and may be performed by R_a increasing (decreasing of f_a) or drift tube shortening (increasing of f_a) (Fig. 1). Starting f_a value was 2598 MHz and f_a tuning has been performed in three steps. Two steps (draft) were done by increasing of R_a value to achieve $f_a = 2451$ MHz. Because this kind of f_a tuning is soft enough ($df_a/dR_a \approx 45$ MHz/mm), there were no problems. Last step of f_a tuning was done after f_c tuning by providing narrow circular ditch at the spherical surface of accelerating cavity.

Due to big k_c value, direct determination of the coupling mode frequency both for each cell and for total section, which is reasonable in usual CCL structures, provides big error $\Delta f_c \approx f_c k_c^2/2$. The coupling mode frequency f_c tuning is based on our experience in the tuning of Disk and Washer accelerating structure [2]. The coupling mode frequency tuning in CDS may be performed by R_c increasing (decreasing of $f_c, df_c/dR_c \sim$ 30MHz/mm) or by increasing the gap between half drift tubes l_c (increasing of $f_c, df_c/dl_c \approx$ 285 MHz/mm) (Fig. 1). Starting f_c value was 2413 MHz and f_c tuning has been performed in two steps.

The first step (draft) to achieve f_c = 2447 MHz was done by increasing of l_c value at total area of "coupling cell". Because this kind of f_c tuning is not soft, the second step has been performed by providing washer-type ditch in the space between half drift tubes. For coupling mode in CDS the tuning procedure should be under special attention.
In this study no efforts have been performed to tune accelerating field distribution, because coupling windows in this model should be identical. The mutual orientation of caps, to fix mutual orientation of windows, has been controlled with maximum deviation not more 0.25^o.

3. Results of experiments

After the model tuning, operating frequency f_0 = 2450.1 MHz, the stop-band width δf = 400 kHz (relative value $\delta f/f_0 = 1.9 * 10^{-4}$) were obtained. The relative values for standard deviation for frequencies of accelerating cells σ_{fa}/f_0 and "coupling cells" σ_{fc}/f_0 are $1.63 * 10^{-4}$ and $1.42 * 10^{-3}$ respectively. This σ_{fc} value is due to only soft tolerances for "coupling cell" dimensions.

The measured dispersion curve is shown at Fig. 2 and calculated with this curve the coupling coefficient value k_c = 22% confirmed the designed one. In spite of one can look through the structure (there is overlapping of windows), the CDS has practically "ideal" shape of the dispersion curve. The fitting with the standard five parameters lumped circuit model shows neighbour coupling coefficients k_1 and k_2 being practically zero. Nearest high order modes of TE_{11n}-like type are placed at frequencies $\approx$ 3670 MHz with the passband width $\approx$ 160 MHz. The experimental results for spectral parameters of the CDS model confirm fine the design values.

The electric field distribution as the result of bead-pull measurements is shown at Fig. 3 and exhibits the standard deviation value σ_E = 1.05%. The main part in σ_E contribute deviations of k_c, because contribution due to deviations in frequencies of cells σ_{ef} is estimated as $\sigma_{ef} \approx 0.12\%$ for k_c, σ_{fa}, σ_{fc} and δ_f given.

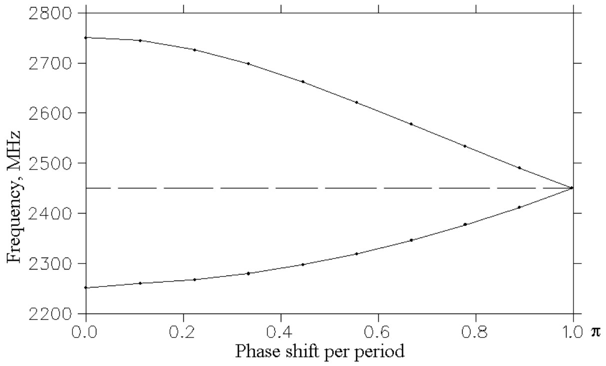

Figure 4: Dispersion curves for operating passband (experiment).

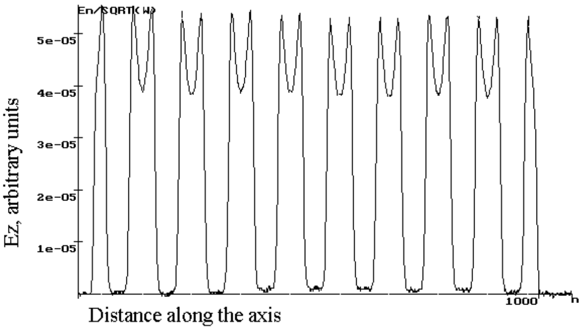

Figure 3: Electric field distribution along the axis of the model.

The measured value of the quality factor for aluminium model Q_{eCDS} = 7880, and for cylindrical reference cavity Q_{eref} = 9850. Taking into account additional rf losses in two end walls (42% from rf losses in one CDS period) and assuming 2D calculated Q factor for the solid copper reference cavity $Q_{cref} = 19400$, we are expecting Q for solid regular copper CDS structure as $Q_{CDS} \approx 16240$. The calculated from bead-pull measurements R/Q value is $(R/Q)_e = (3.6 \pm 0.07)$ kOm/m, in good agreement with calculated by using 3D MAFIA $(R/Q)_c = 3.625$ kOm/m. Together with transit time factor $T = 0.861$ for solid regular copper CDS we obtain $Z_e \approx$ 85.5 MOm/m, 95% from 2D calculated one. This value do not takes into account the surface imperfectness and possible rf contacts, but is not less in comparison with another CCL structures (with low coupling) and confirm that CDS practically do not lose in shunt impedance due to strong coupling.

Conclusion

The results of experiments with 9-period $\beta = 1$ cold model of the CDS structure confirm parameters as high coupling ($k_c \approx 22\%$) and high effective shunt impedance. Another attractive CDS features are in simple design, manufacturing and tuning procedures, small transverse dimensions. As the results of experiments, recommendation for CDS design and manufacturing procedure improvements are developed. The treatment of "coupling cells" and windows regions should be careful. With the combinations of these parameters, CDS looks as very attractive structure for electron and high energy proton linacs.

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