CDS STRUCTURE FOR THE NORMAL CONDUCTING ACCELERATING CAVITIES IN TESLA LINEAR COLLIDER

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Abstract

Due to some beam dynamic requirement, accelerating cavities for TESLA injector linacs should be embedded into solenoid magnetic field and TESLA superconducting cavities can not be applied. Consideration shows the Cut Disk Structure (CDS) as a good option for TESLA Normal Conducting (NC) accelerating cavities. The structure cells shape has been optimised at operating frequency 1300 MHz for different accelerating gradients and beam bore hole diameters. Results of the thermal stress analysis show the ability to operate with high accelerating gradient (up to 14 MV/m) and long ($\sim 800\mu s$) rf pulse. Different options for the structure segmentation, both single cavities and cavities with coupling bridges, are considered. Design parameters for CDS cavities are presented.

1 INTRODUCTION

Due to large emittance of the positron beam after conversion target the focusing with solenoidal field should be applied in the beginning of the TESLA Positron Pre-Accelerator (PPA) [1] and a normal conducting accelerating shtructure with a small outer diameter should be used. Comparison between travelling wave and standing wave structures shows for the TESLA operating frequency 1300 MHz (L-band) more effective and flexible solutions with the Standing Wave (SW) operating mode. Comparing different SW structures and taking into account the enlarged coupling coefficient k_c for CDS structure, the higher (several percent) shunt impedance Z_e in CDS and basing on results of numerical simulations [2],[1], results of the cold model measurements [3], and the fact that CDS and the On-axis Coupled Structure (OCS) are similar in parameters of the accelerating cells (operating mode), the CDS structure for PPA is recommended.

This structure is also proposed for another NC cavities of the TESLA project, for example the pre-accelerator of the polarised electrons source.

2 CDS DESIGN PARAMETERS

CDS looks similar to the well known OCS but realize a different idea in the design of the coupling mode [2], resulting in an increased value $k_c \approx 20\%$ for $\beta = 1.0$ without drop of an Z_e. CDS rf properties were tested in S-band cold model (Fig. 1) measurements, confirming the idea and design parameters of this structure [3].

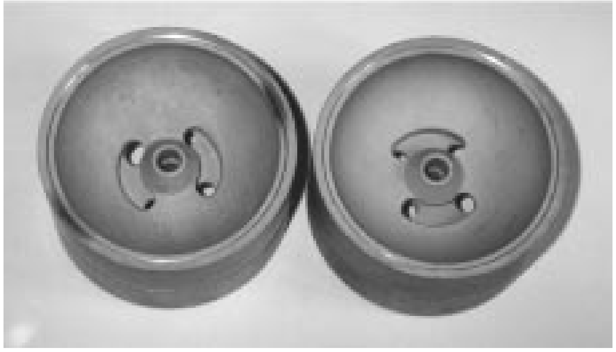

Figure 1. A general view of the S-band CDS $\beta = 1.0$ cold model, $k_c = 22\%$.

The same way as for another coupled cells structures, the CDS shunt impedance Z_e decreases with the web (between accelerating cells) thickness increasing But this decreasing is smallest for $\beta = 1.0$ - the case for application in TESLA. Taking into account the CDS operating parameters for the TESLA project - duty factor 0.04 and enough high accelerating gradient, the total web width is chosen to be equal $T_w = 32mm$, consisting of two walls ($14mm$ thick) and $4mm$ for the coupling cell length. The wall thickness of $14mm$ is sufficient for the mechanical strength and for the cooling channel placement. Between drift tube the coupling cell has a conic shape to supress a multipactor discharge [4].

Extensive cell dimensions optimization has been performed at the operating frequency $1300MHz$ [1]. The maximum surface electric field E_{smax} is limited for CDS design to $E_{smax} = 40MV/m = 1.29E_k$ - a rather conservative value, taking into account long TESLA pulse ($800\mu s$), a multi-gap cavity design and the fact that the possible improvement in the Z_e rises slow with increasing E_{smax}. For the optimized cell shape the plots of the Z_e dependencies are shown in Fig. 2 assuming $T_w = 32mm, E_{smax} = 40MV/m$.

The plots on Fig. 2 show the well known behaviour - Z_e decreases with a and E_0T increasing. But due to the extensive optimization these Z_e are maximized. From the PPA beam dynamics study [1],[7] a relatively large aperture radius $\sim 23mm$ and two E_0T values $14.8MV/m$ and $8.5MV/m$ are required. The first one is mostly limited by the structure. The moderate $8.5MV/m$ value is also related to the available rf power and the section length in the second PPA part (restricted by the focusing period length). Even though the Z_e value difference for $E_0T = 14.8MV/m$ and $E_0T = 8.5MV/m$ is not drastic $\approx 14\%$, it is reasonable to chose for the PPA two CDS cell geometry options.

The CDS design parameters for the TESLA PPA are listed

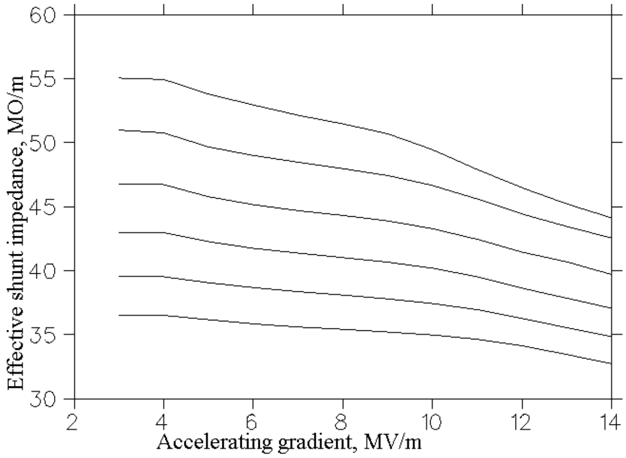

Figure 2. Z_e dependencies on E_0T for a CDS cell with different aperture radii. Up to down - $a = 12mm, 15mm, 18mm, 21mm, 24mm, 27mm$.

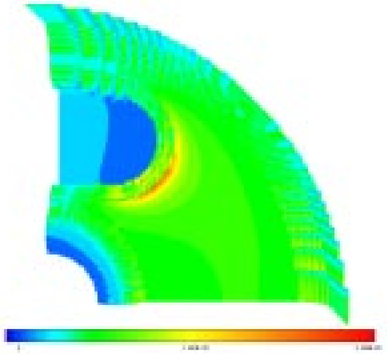

Figure 3. RF losses distribution along the CDS-PPA surface.

Table 1: CDS design parameters for the TESLA PPA.

Parameter	**Unit**	**14.5**	**8.5**
Operating frequency	MHz	1300.0	1300.0
Phase velocity		1.0	1.0
Aperture diameter $2a$	mm	47.0	46.0
Total web thickness	mm	32.0	32.0
Gap length g	mm	73.46	66.16
Drift tube cone angle	deg.	20.0	20.0
Lower DT radius r_1	mm	8.87	2.25
Upper DT radius r_2	mm	8.87	2.42
Upper cell radius r_3	mm	8.50	8.50
Outer cell radius R_c	mm	85.45	82.52
Effective impedance Z_e	$M\Omega/m$	33.15	37.76
Coupling coefficient k_c	$\%$	9.1	11.4
Quality factor Q_0		21100	20700
Transit time factor T		0.783	0.801

i Table 1.

If an enlarged aperture radius is not nesessary for another CDS applications, it looks reasonable to choose the third CDS cell option for Z_e improvement, remaining the main ideas and technological solutions in the CDS cavity design. The coupling windows, following the CDS idea, are chosen shorter and wider in comparison to standard OCS slots and a coupling window shape is optimized to reduce as mutch possible the rf current redistribution. The typical rf losses distribution at the CDS surface is shown in Fig. 3. With a correct choice of the coupling window shape and dimensions there are no regions with high rf current density at the ends of the coupling windows (as compared to another slot-coupled structures). This CDS property ensures an enlarged k_c value without Z_e reduction. Due to the relatively large aperture radius $a/\lambda_0 \approx 0.1$ in the CDS-PPA options, there is no space to realise the maximum coupling coefficient $k_c \approx 20\%$ for CDS at $\beta = 1$. For this purpose the lower window radius should be smaller. But the values obtained (see Table 1) are higher than usual for OCS structure and are sufficient to construct an accelerating cavity with $40 \div 60$ accelerating cells.

An important point for the stable structure operation is a cooling capability. Real 3D thermal stress analysis has been performed by coupled simulations with MAFIA and ANSYS codes [5]. About 50% of a total rf losses at $\beta = 1$ take place in the web (including drift tube), below the upper window radius. With a significant heat load value P_h the heat conductivity of copper is not sufficient to transfer a large heat flow from the drift tube region to outer circumferential channels. For a moderate heat loading $P_h \leq (10 \div 15)kW/m$ the usual cooling scheme with two web channels and a set of poter circumferential channels, similar to usual OCS cooling sheme [6], ensures reliable CDS operation. For the PPA $5Hz$ repetition rate and $\approx 800\mu s$ pulse the $P_h \approx 12kW/m$ corresponds to possi-

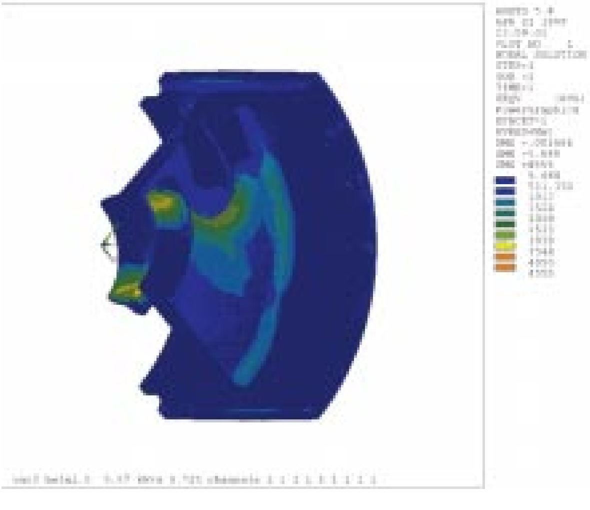

Figure 4. Von Miss thermal stress distribution for the PPA CDS moderate gradient option.

ble accelerating gradient $E_0T \approx 12MV/m$. The operating frequency shifts due to the surface deformation are within tolerable limits to be removed by the frequency control system. The internal stress values S_{st} are below the yield strength $S_{stlim} \approx 530kg/cm^2$ of OFHC copper and the total reduction of the shunt impedance $\approx (2 \div 6)\%$ due to surface heating is not dangerous. Typical von Miss thermal stress distribution is shown on Fig. 4 for the PPA CDS moderate gradient option.

For high heat load $P_h \geq 15kW/m$ with the usual web channel scheme the limitation come from the internal stress value - S_{st} may exceed the yield strength of OFHC copper. Two parallel web channels should be replaced by four radial ones, from outer circumferential channels to the circular channel in the drift tube. Such cooling scheme is foreseen for high accelerating gradient $E_0T \sim 14.5MV/m$ PPA accelerating cavities.

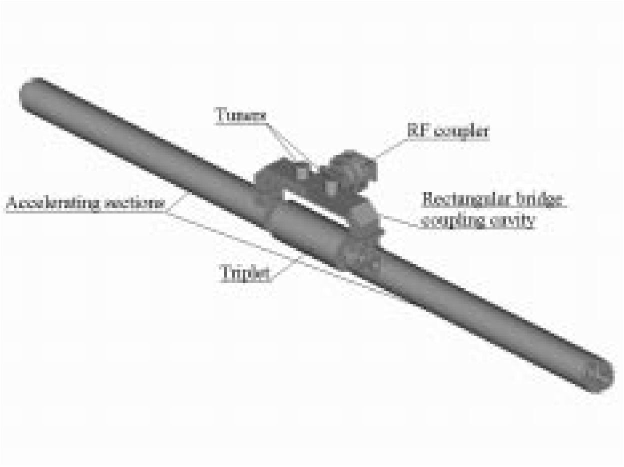

Figure 5. The CDS cavity with the Rectangular Directly Coupled Bridge cavity.

3 CDS CAVITIES

Two types of the CDS cavities are considered now for the TESLA PPA. The firsh one is a single cavity with a rf drive in the midle (to be driven from 10 MW TESLA klystron). Such cavities are in a short (11 cells, $E_0T \approx 14.5MV/m$) and a longer (37 cells, $E_)T \approx 8.5MV/m$) options.

If, due to the focusing scheme, we cannot use long cavities, the cavity should be broken in two accelerating sections and a focusing element should be placed between sections. To combine sections into a joint resonant system and drive them from a single rf source, a coupling bridge cavity may be used.

Comparing the well known cylindrical bridge cavities and Rectangular Directly Coupled Bridges (RDCB) and taking into account that RDCBs have a better mode separation with smaller rf losses, a smaller transverse dimensions, a flexible tuning of the rf field between CDS sections, a simpler manufacturing and tuning procedure, the RDCBs look more preferable to maintain features of the CDS structure as easy-to-do low-cost ones.

To combine the requirements to the distance between the sections and the total length of the bridge coupler, the RDCB should be formed in Π-shape (Fig. 5). The correct value of the RDCBs vertical part length H_l should be chosen so that the dependence $f_0(H_l)$ has a small slope and neighbour modes are placed symmetrically at the frequency scale (see [7] for details).

As a coupling cavity, RDCB doesn't increases rf losses essentially (low field in RDCB) but can be matched with the driving waveguide (field in RDCB is low, but nonzero). To tune fine the CDS cavity parameters, the RDCB is equipped with two plug tuners (Fig. 5). With simultaneous motion of the RDCB tuners we can change the own frequency of the RDCB, thus tuning the position of the nearest modes practically with small changes of the operating frequency for the total cavity. With opposite motion of the RDCB tuners one can change the rf field level between CDS sections by several percent. The driving waveguide is attached to the narrow wall in the RDCB middle point, matching the H_x component of the TE_{10} wave in the WR650 waveguide with the H_z component of the TE_{10N} RDCB mode.

Due to the enlarged coupling k_c in CDS, tolerances for all accelerating cell dimension are relaxed in comparison to OCS structures and values of $\pm(50 \div 80)\mu m$ are reasonable. For the length of the coupling cell the deviations should be smaller $\pm(15 \div 25)\mu m$. The fabrication of the CDS structure is cheaper, in comparison to other SW structures, due to the CDS simplicity and the relaxed tolerances. The tuning procedure for the CDS structure was developed and described in [3].

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