A High Current, High Gradient Electron Double Accelerating Structure

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Abstract

LAL is in charge of the study and the construction of a pair of electron accelerating sections, so-called High Current Structure (HCS), intended for the CLIC Test Facility (CTF-II) at CERN. This structure must accelerate a train of high charge electron bunches (1μC). It consists of two 0.6 meter long constant gradient S-band sections operating on the $11\pi/12$ mode with an accelerating field of 50 MV/m . The sections are designed to exhibit a low beam loading and minimized wakefield effects. A frequency shift between the two short electron-linacs allows one to reduce the effects of beam energy spread. Here we present the choice of HCS section parameters, simulations and final design.

1 INTRODUCTION

The drive beam of CTF-II [**?**] requires an accelerating system capable of increasing the energy of a train of 44 bunches with a total maximum electrique charge σ of 1μC, from the energy of the RF gun (2 MeV) to $T_0 = 2 \times 30$ MeV (unloaded), with a small energy spread and a low emittance growth.

The beam loading compensation is obtained by splitting the accelerating system into two elements of length $L \sim 0.5$ m, shifted by $\pm\Delta$f from the central frequency ($f_0 = 2998.550$ MHz) and by injecting the beam with an appropriate phase advance.

The two accelerating structures are separately fed by two LIPS systems provinding an input power of $P = 120$ MW during $\tau = 0.7\mu$s.

2 ACCELERATING STRUCTURE DESIGN

All things considered, we have decided to build two identical (except frequency) constant impedance structures running in TW mode. These elements, so-called HCS-1 and HCS-2 (High Charge Section), are tuned at $f_0 + 7.8$ MHz and $f_0 - 7.8$ MHz respectively.

To achieve beam loading compensation, the energy spead $\Delta T/T_0$ shoud not exceed 30%. If k_1 is the fundamental mode loss factor, neglecting the input energy gain of the RF gun and the structure attenuation, we can use a set of inequations to obtain the main structure parameters.

$$\frac{2k_1}{E_0} < \frac{\Delta T}{T_0}\frac{1}{\sigma} \quad (1)$$

$$(2k_1\tau LP)^{1/2} > T_0 \quad (2)$$

$$E_0 < E_{lim} \quad (3)$$

where E_{lim} is the maximum accelerating field strength for reliable operation.

To determine the dominant cell geometrical dimensions, given the right value of k_1, the following analytical formula [**?**] is usefull:

$$k_1 = \frac{\eta_\theta J_0^2(u_{01}(a/R))}{2\epsilon_0\pi(h/D)R^2J_1(u_{01})} \quad (4)$$

where

$$\eta_\theta = \frac{2}{\theta}sin(\frac{\theta}{2}(h/D)) \quad (5)$$

$u_{01} = 2.405$, D, a, h, R are shown in Fig.1, θ is the fundamental mode phase advance per cell.

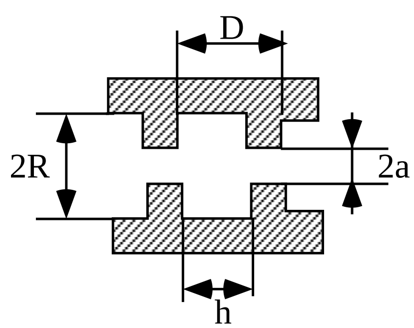

Figure 1:

2.1 Choice of mode

The required group velocity and the acceptable peak surface electric field restrict the choice of inner cell dimensions. Under these constraints, the (a/R) and (h/D) parameters of formula (4) vary in a narrow range. The main lever to act k_1 is η_θ. It is clear from (5) that to obtain a small value of η_θ, θ must be close to π. To escape mode degeneration and an excessive number of cells per wavelengh, we have chosen:

$$\theta = 11\pi/12$$

2.2 *Choice of parameters*

In introducing the values of θ in the formula (4), the optimum parameters are found for:

$h/D \sim 0.5$ and $a/R \sim 0.35$

With these values the HCS cells exhibit an unusual shape:

a very thick iris wall t and a large iris radius:

$t \geq 22$ mm and $2a \geq 30$ mm)

2.3 *Choice of section parameters*

With typical S-band parameters and a large iris aperture value, the formula (4) shows that it is impossible to achieve the required value of k_1 satisfying the set of previous inequations with the initial parameters. We have found a compromise for:

$k_1 \sim 10^{12}$ V/m/C and $L \sim 0.6$ m

For these values one finds an accelerating field : $E_0 = 53$ MV/m. The possibility to accelerate a stable beam with an electric field strength of 60 MV/m has been demonstrated previously at LAL [**?**]. The ratio of surface field to accelerating field for this type of cell is ~ 2.4, so that the maximum surface field is ~ 130 MV/m. This level is 2.5 times lower than the theoretical limit[**?**].

3 CELL FINAL PARAMETERS

The final values of cell parameters have been obtained by an extensive use of simulation codes (URMEL and ABCI).The cell shape is given in Fig.2 and mechanical parameters by table 1, where the dimensions are in mm.

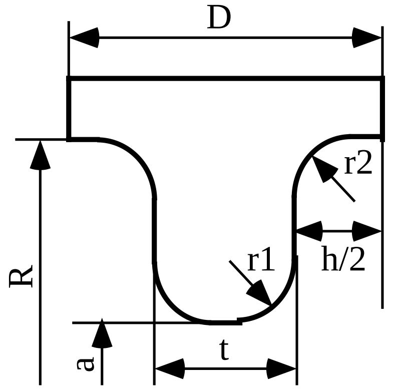

Figure 2: HCS cell

Table 1:

Sect.	2R	2a	D	h/2	t
HCS-1	88.52	30.29	45.70	11.50	22.70
HCS-2	89.29	31.30	45.94	11.50	22.94

HCS-1 and HCS-2 radius r_1 and r_2 are identical with:

$r_1 = 10.90$ mm and $r_2 = 10.99$ mm

The RF parameters are given for TM_{01} and TM_{11} modes in table 2 and 3, respectively. k_0 is the coupling coefficient between two consecutive cells and R_{PE} the ratio of peak surface field to effective electric field strength.

Table 2:

Sect.	Q_0 x10^3	R/Q_0 x10^3	k_0 x10^{-3}	v_g/c x10^{-3}	R_{PE}
HCS-1	13.06	1.03	8.35	3.10	2.36
HCS-2	13.11	1.02	8.72	3.24	2.38

The values of this table are given for a phase velocity equal to the velocity of light

Table 3:

Sect.	Q_0 x10^3	k_0 x10^{-3}	v_g/c x10^{-3}	$mode$ xπ	f_c GHz
HCS-1	14.08	-28	19.38	1.3	4.12
HCS-2	14.03	-30	20.75	1.3	4.11

4 COUPLERS

We have decided to use two symmetrical input and output couplers, to keep the field symmetric and reduce the electric field strength on the iris surface. The iris apertures are circular. For simplification, the height of the coupling volumes are identical and equal to the height of the standard waveguide (RG 48/U).

Two waveguides, connected through a hybrid coupler, feed the section couplers. The length of RF net-work arms are calculated to give a phase difference of π at the entrance of the two input coupler ports.

The iris radius a_c of coupler can be calculated (in a right angle approximation) by the following analytical formula [**?**]

$$\beta = \frac{16 \times N \times Z_0 k k_{01} a_c^6 exp(-2\alpha_c t_c)}{9\pi A B R_c R_s (R_c + H_c)(1 + \frac{Z_0 R_c}{2R_s(R_c+H_c)}\frac{v_g}{c})} \quad (6)$$

$$\alpha_c = \frac{2\pi}{\lambda}\left((\lambda/3.14a_c)^2 - 1\right)^{1/2} \quad (7)$$

Where :

Z_0 is the free space impedance, $k = 2\pi/\lambda_0$, $k_{01} = k\left(1 - (\lambda/2A)^2\right)^{1/2}$, $R_s = 0.00143\ \Omega\mathrm{m}^{-2}$ for copper at 3 GHz,

A and B are the width and the height of the waveguide, R_c and H_c are the raduis and the height of coupler volume, t_c is the iris wall thickness. N is the number of input RF ports

With these conditions and $< t_c > = 5$ mm :

$a_c = 13.33$ mm

The coupling factor β is very sensitive to t_c thickness and radius corners, so we have kept a safety margin on design dimension:

$a_{c,d} = 12$ mm (before adjustment)

The Fig.3 gives the principle sketch of coupler (symmetrical half view)

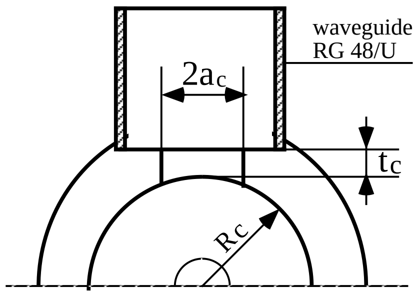

Figure 3: 1/2 view of coupler

5 SECTION

The accelerating sections are composed of 13 cells and 2 couplers. Tables 4 and 5 give the main structure characteristics without couplers.

Table 4:

Sect.	Δf MHz	k_1 x10^{12} V/m/C	τ μs	L m
HCS-1	+ 7.8	9.72	0.56	0.60
HCS-2	- 7.8	9.52	0.54	0.60

Table 5:

Sect.	E_0 MV	X Np	$< E >$ MV	T_0 MeV	$\Delta T/T_0$
HCS-1	46.70	0.46	37.43	27.97	0.42
HCS-2	45.46	0.44	36.77	27.14	0.42

The input power is assumed equal to 120 MW

6 TUNNING

The couplers will be adjusted on a special measurement bench by an extended Kyhl method [**?**]

The cells will be tuned only after the high temperature brazing process. Tunig is obtained by wall deformation with respect to the cell phase advance law. (We have checked that this method is efficient with a large iris aperture).

7 ACTUAL STATUS

Prototype cells and couplers are currently being fabricated by a private firm (Philips Eindhoven).

8 ACKNOWLEDGMENTS

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