SUPERCONDUCTING CAVITIES FOR THE REDUCED-BETA SECTION OF A PROTON LINAC

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Abstract

A proton linear accelerator with energies beyond 1.0 GeV has been proposed in [1] where the LEP2 superconducting (SC) cavities are to be used after decommissioning of LEP, in the high energy part of the linac. Energies ranging from 100 MeV to 1.0 GeV will be covered by superconducting cavities designed to accelerate protons with reduced value of beta. The basic idea is to keep the shape of the spherical LEP cavities for $\beta = 1.0$ and to adjust their length, for $\beta < 1.0$ in order to get an optimal acceleration for low energy protons. Three different values of β allow to cover the required range with a reasonable acceleration efficiency. The design of superconducting cavities for $\beta = 0.50$, 0.625 and 0.80 is presented here. In particular the choice of an elliptic iris profile is discussed.

1 CAVITY DESIGN

All the LEP2 radiofrequency equipment, such as the RF plants and HOM couplers could be used in a lower energy range, i.e. 100 MeV up to 1 GeV, if new SC accelerating cavities with the same resonant frequency of 352 MHz can accelerate the beam with an acceptable efficiency. Three reduced-β SC cavities have to be designed with axial length $L_{cell}=\beta\lambda/2$.

A simple linear scaling [2] of the already existing LEP2 cavity [3] has shown a remarkable deterioration of the cavity electromagnetic (EM) parameters with respect to the LEP2 due to the smaller volume and the electric field density decrease along the cavity axis. For the cavity with $\beta = 0.5$ the ratio between the peak surface electric field and the accelerating electric field E_{sp}/E_a is doubled with respect to LEP2. This ratio is one of the most important parameter for the SC Nb/Cu cavity since it is related to the field emission limitation and to the maximum gradient that the cavity can substain. An improvement of the cavity shape is then required.

The cavity profile should be optimized according to fixed design constraints coming from the SC design technique and the manifacturing experience. The door-bell geometry of the LEP2 cavities should be maintained to minimize the multipacting risk. In order to utilize the CERN equipment the external cavity diameter should be close to that of LEP2 cavities. Flat cell side walls should be avoided for mechanical stability reasons, their inclination should be ≥ 8°- 10°.The cell to cell coupling factor K should be kept sufficiently high to achieve acceptable field flatness, so the iris beam tube radius can not be decreased too much. The Higher Order Modes should not be trapped in the cavity, and this also limits the size of the beam tube radius.

All the simulations have been performed with the computer code OSCAR2D [4] and the EM cavity parameters have been calculated for normal conducting copper at room temperature.

1.1 The reduced-beta cell with an Elliptic Iris Shape

The design of the lowest $\beta = 0.5$ cavity is the more troublesome to perform. This cavity is the smallest one with an axial length half of the LEP2 cavity.

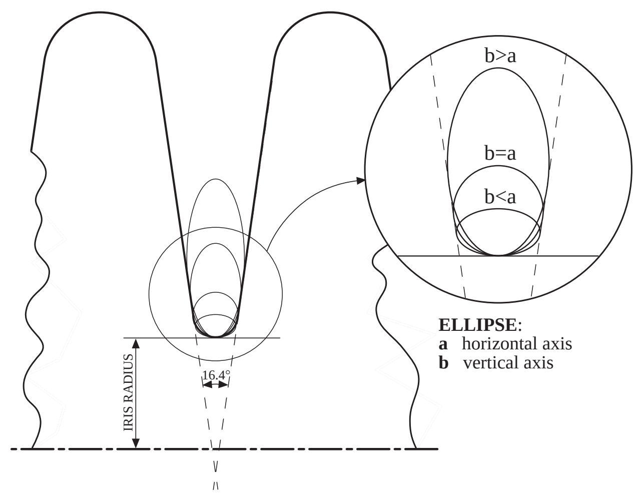

Figure 1: Sketch showing the elliptical iris shape. When the eccentricity is changed, the tangency condition to the side wall should be matched. The inclination of the side walls is kept constant.

A cavity with circular iris shape tailored for particles with $\beta = 0.48$ has been presented in [5] and [6]. Starting from these shapes and taking into account the design specifications, the optimization of two cavity size parameters, the beam tube radius and the iris shape have been done to improve the EM cavity parameters. This optimization should take into account that these two parameters are strongly correlated. In fact, once the cavity side wall inclination has been fixed, the decreasing of the iris beam tube radius leads to the decreasing of the circular iris radius tangent to the side wall, as shown in figure 1. The basic idea is to replace the circular iris radius with an elliptic shape and to investigate the behavior of main EM cavity parameters

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as a function of the elliptic sizes. It should be noted that the design guidelines do not allow to modify other cavity dimensions. In addition, when the beam iris radius is changed some adjustments of the cell diameter are required to tune the resonant frequency.

The variation of the E_{sp} as a function of the ellipse eccentricity b/a is shown in figure 2 for different beam tube radii.

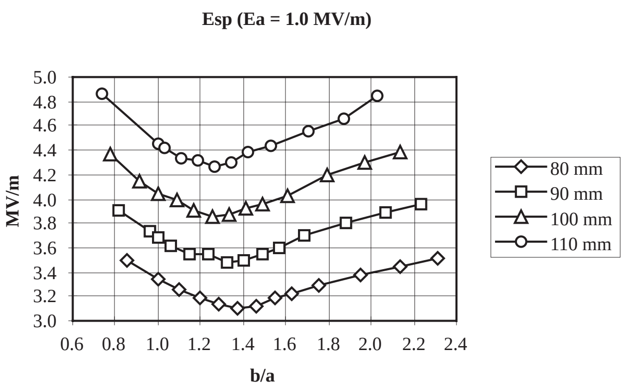

Figure 2: The E_{sp} as a function of b/a.

The results show that the minimum values occur far from the circular profile. Lessening the beam tube radius the E_{sp} becomes smaller.

The E_{sp} value as a function of the ellipse's vertical axis b is skctched in figure 3 for different beam tube radii.

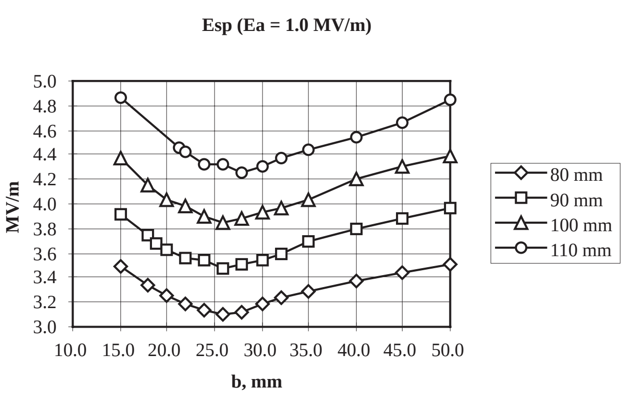

Figure 3: The E_{sp} as a function of b.

The requested reduction of the E_{sp} with respect to the circular iris profile ranges from -4.6% (r = 100 mm) to -7.2% (r = 80 mm). The other EM cavity parameters are not influenced by this elliptic profile. The elliptical shape of the iris seems to be a good alternative that matches the SC design specifications.

1.2 The EA-1 cell design for β = 0.5

The present choice of β = 0.5 for the first accelerating structure allows a more comfortable design, since the cavity axial length is increased. All the previous results on the elliptical iris profile still hold. Due to the increased sizes, another cavity shape parameter can be further optimized, the hat radius R. Preliminary studies suggest to keep R ≥ 50 mm. Once the elliptical iris profile is optimized the E_{sp} value for both hat radius R = 55 mm and R = 50 mm does not change. But a big difference is found in the shunt impedance value, which is 30 % greater for R = 55 mm. The choice of which profile is better depends on the possibility to use the existing CERN manifacturing tools or on the possibility to save the 30% of the refrigerator power. Figure 4 shows one of the optimized profile and table 1 the TM_{010} π-mode for both the shapes.

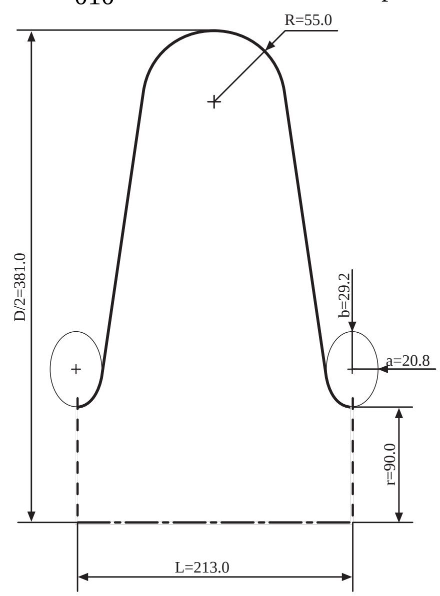

Figure 4: The EA-1 cell final shape.

	R=55mm	R=50mm	LEP2
Fr, MHz	352.2	352.2	352.0
K, %	1.55	1.92	1.76
E_{sp}/E_a	3.29	3.33	2.35
H_{sp}/E_a Gauss/MV/m	62.4	71.2	39.1
Z, MΩ	0.47	0.37	3.51
Q	29400	27800	57600

Table 1: Parameters of the TM_{010} π-mode for both the two EA-1 cells and the LEP2 cell, as a reference values.

1.3 The EA2 cell design for β = 0.625

The increase of the axial cell length also enlarge the hat radius.

It has been shown that the E_{sp} does not change once the elliptical profile has been chosen. This result allows to start the design with a cell shape that matches the requested specifications and then to optimize the elliptical iris profile.

To keep the K value greater than 1.5%, the hat radius for the EA-2 cell should be greater than 70 mm. Better values of the peak surface magnetic field and shunt impedance are found for R = 80 mm and beam tube radius r = 100 mm. Starting with these dimensions the elliptic iris shape is optimized. The minimum value of E_{sp} is reached for an ellipsis axis b = 48 mm and b/a=1.59. Table 2 shows the cavity EM parameters.

1.4 The EA3 cell design for β = 0.80

This is the last and less difficult cavity to design, since, due to its axial length, the hat radius R ranges from 51.0 mm to 65.0 mm.

Trying to increase the shunt impedance with a larger value of R and smaller value of r leads to an increase of the peak surface electric field. A good compromise is reached with R = 120 mm and r = 110 mm. The miminum value of E_{sp} is found as before, for an elliptic axis b = 58 - 60 mm and an eccentricity b/a=1.6.

	EA-2	EA-3	LEP2
Fr MHz	352.2	352.2	352.0
K %	1.57	1.58	1.76
E_{sp} /E_a	2.65	2.27	2.35
H_{sp}/E_a Gauss/MV/m	54.1	45.2	39.1
Z, MΩ	0.94	1.95	3.51
Q	36900	47000	57600

Table 2: EA-2 and EA-3 optimized cavity parameters.

2 MULTICELL DESIGN

The full cavity is made up of four cell structure. This number seems to be a good compromise between a cavity with a larger number of cells, which has more fabrication drawbacks and a smaller acceptance range in β, and a cavity with fewer cells, which has lower accelerating voltage for similar costs.

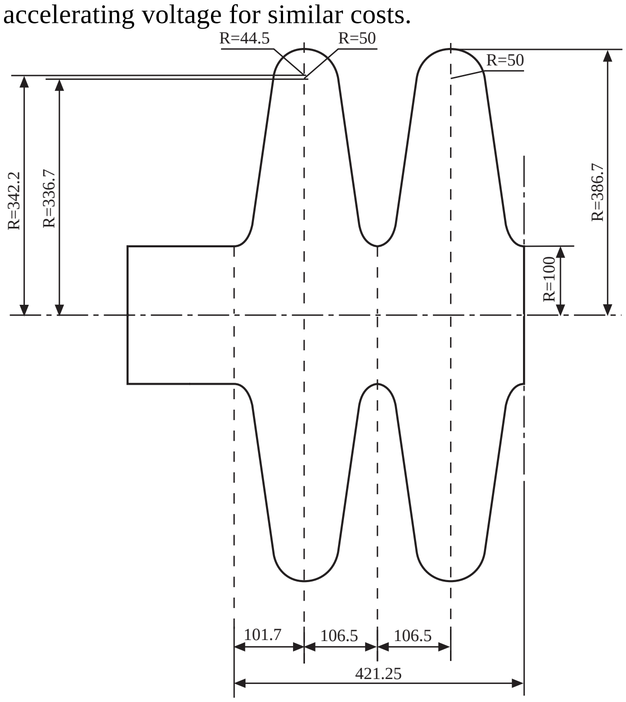

Figure 5: Half of theEA-1 cavity.

In all cavities the external cell has been adjusted to get an acceptable field flatness for the operating TM_{010} π-mode. To compensate this mode the cell hat radius of the external half-cell has been changed. The side wall inclination and the length of the axes of the ellipse have been kept constant by adjusting correspondingly the axial length of the external half-cell. In this way the peak electric field behaviour in the external cell iris region is similar to the one found for the single cell. The beam tube radius has been left untouched as well. Figure 5 shows the final result for the EA-1 cavity. Similar considerations hold for the EA-2 and EA-3 multicell design.

The acceleration efficiency η of each cavity for all proton energies in consideration has been evaluated. Due to the tail behavior of the end cell electric field the η reaches the peak value for a particle speed that is slightly higher than the $\beta = \beta_0$ value.

Cavity	EA-1	EA-2	EA-3
Input Energy, MeV	100	209	411
η at Input Energy	0.64	0.86	0.83
Output Energy, MeV	209	411	997
η at Output Energy	1.09	1.04	1.03
Number of cavity	32	36	80

Table 3: Energy range, efficiency and number of cavities of the Linac sections. The η normalization has been done for $\beta = \beta_0$.

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