OPTIMIZATION OF END CELLS OF LOW BETA CAVITY OF HIGHER ENERGY PART OF PROJECT X *

A.Saini, K.Ranjan. University of Delhi, Delhi, India
A. Lunin, N. Solyak, S. Mishra, Y. Yakovlev, Fermilab, Batavia, IL 60510, U.S.A.

Abstract
11 cell elliptical cavity is designed for acceleration of particles travelling at 81 % of the speed of light. It will operate at 1.3 GHz & will be served to accelerate the particles from 0.450 GeV to 1.2 GeV in high energy section of Project-X. The cavity is studied for higher order mode (HOM) & trapped modes. The shapes of end cells of cavity is optimized to increase the field amplitude in end cells so that coupling of trapped modes may increase with HOM coupler & they can be extracted easily but keeping the field flatness & operating frequency undisturbed.

INTRODUCTION

Project X is the proposed high intensity proton driven linac to be built at Fermilab, USA. In the current scheme,the linac (Fig 1.) is segmented into two parts on the basis of energy; low energy section & high energy section. The high energy section, which is used for the acceleration of the beam from 0.45 GeV- 2GeV, includes squeezed ILC (SILC) sub-section which uses squeezed ILC type beta 0.81, 1.3 GHz cavity and ILC sub-section which uses ILC type beta=1, 1.3 GHz cavity. The initial design of SILC type rf cavity is optimized for 11 cells [1]. Its length is kept almost same as that of the ILC type cavity to utilize existing design of the cryomodule and other auxiliary components like couplers, tuners etc. It was done to reduce the cost and time. The Fig. 2 shows the 11 cell cavity with the HOM coupler and power coupler.

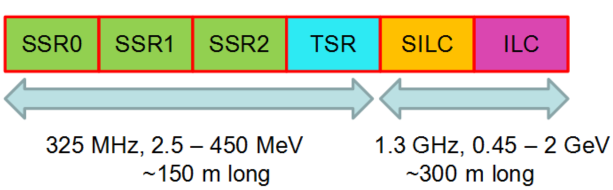

Figure 1: Baseline of initial part of linac.

The initial design of the symmetrical 11-cells cavity (the same end cell at both ends) has been studied for higher order modes using the 2D code SuperLANS [2]. There are few modes of concern whose electric field amplitude are concentrated within the inner cells. They have very low amplitude within the end cells so the EM-field decays in beam pipe before reaching to the HOM coupler. Hence these modes are usually weakly coupled with the HOM coupler and remain localized within the cavity. These modes are known as Trapped Modes. As a consequence the energy corresponding to trapped modes is accumulated within the cavity and it reaches a considerable value after passing of several bunches. It increases unnecessary cryogenic losses and also causes beam instability. The presence of additional 2 cells makes the cavity more sensitive to trapped modes comparing to the standard ILC structure.

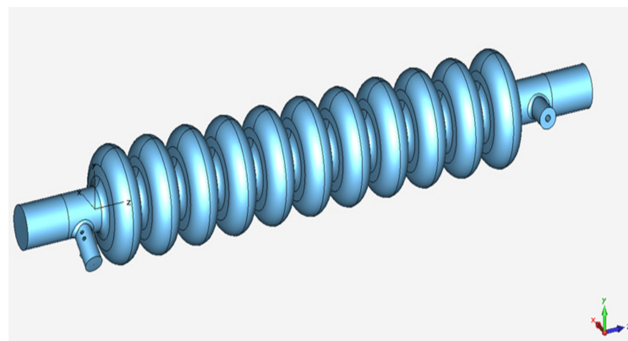

Figure 2: Configuration of 11 cell cavity with couplers.

Avoiding from trapped modes (even with low effective impedance) is an important part of the cavity design. The possible solution is to make a cavity asymmetrical . One of the end cells is detuned so that any mode is trapped from one side only, The study of trapped modes and optimizing the end cells of the structure leaving the field flatness of fundamental mode undisturbed are the main scope of this work.

INVESTIGATION FOR TRAPPED HIGHER ORDER MODES

In a proton linac, beam velocities β (v/c) changes significantly after passing each accelerating cavity unlike the electron accelerator where $\beta \sim 1$ remains constant. As a result, the interaction between the proton beam and the accelerating cavity depends on the speed of protons . The preliminary design of symmetrical 11-cells squeezed ILC type cavity is studied for the complete range of β (0.75 to 0.90) in order to investigate dangerous Higher Order Modes (HOM) . The monopole modes and dipole modes are taken into account only. The monopoles third pass band is found to be most sensitive toward trapped modes. The distribution of the HOMs effective impedances (R/Q) is plotted for the 3rd pass band for complete range of β (Fig.3) The mode #2 (2847.79MHz) has highest effective impedance (80 Ohm) for β =0.90 while mode #3 (2847.90MHz) has highest effective impedance (24 Ohm) for geometrical β = 0.81. The electric field distribution for mode #2 is plotted along the axis of the cavity (see Fig.4).

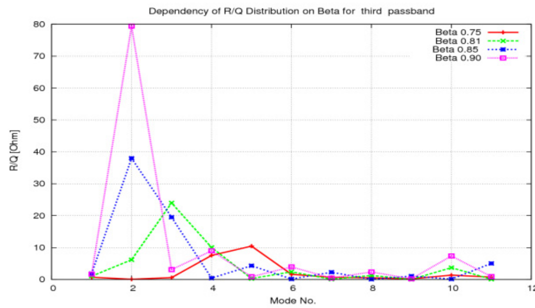

Figure 3: R/Q distribution of modes for third branch of monopoles.

The electric field is largely concentrated within inner cells while the amplitude at end cells is relatively small. The results were also verified by using 3D code HFSS. The HFSS result for field map of mode #2 in 11-cells cavity is shown in Fig. 5

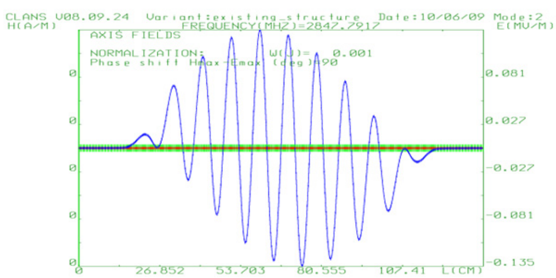

Figure 4: Electric field distribution along the axis of cavity for mode 2.

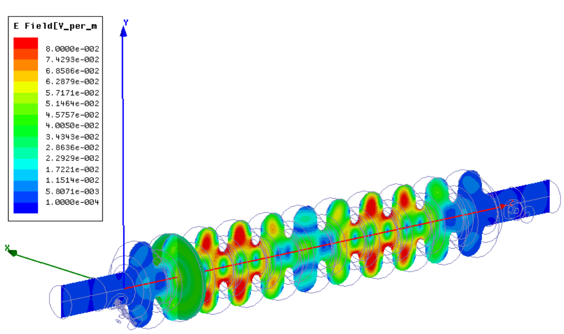

Figure 5: Electric field distribution within cavity for mode 2 of third pass band.

The electric field of mode #3 is also localized within inner cells (see Fig. 6). Thus the symmetric cavity is found to be sensitive for trapped modes at monopole third pass band. It is necessary to detune one of end cells & optimizing it for avoiding the trapping of higher order modes.

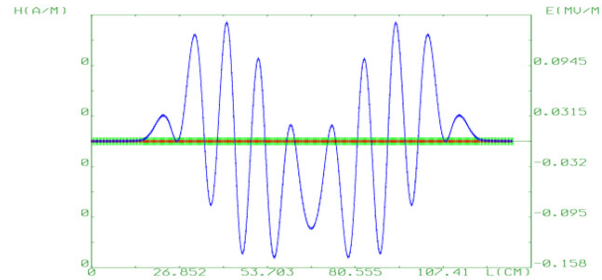

Figure. 6: Electric field distribution along the axis of cavity for mode 3.

PROCEDURE FOR END CELL OPTIMIZATION TO AVOID TRAPPED MODES

The end cell is used to connect the end of the cavity with the beam pipe. In order to maintain the same operating frequency, shapes of half end cell is optimized thus the coupling between end cell and regular cell is different than coupling between inner-inner cells. That is a reason why some modes are reflected back and get trapped within inner cells only. One of end cell of the cavity is detuned a little by changing cell parameters. To do this we used a special optimization module of SuperLANS code named TunendCellEnd. It optimizes length & wall inclination angle for given cell parameters i.e semi axes for equatorial elliptical arc (A, B), semi axes for iris elliptical arc (a, b) , iris radius (Riris) & equatorial radius R_{eq} . (Fig 7).

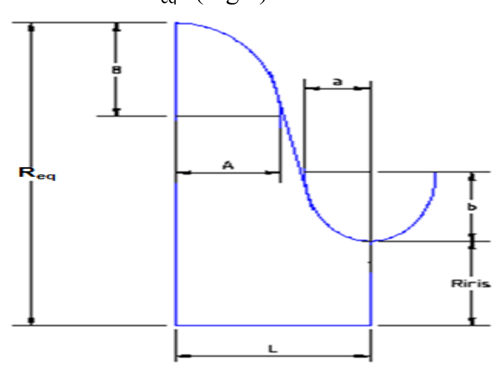

Figure. 7: Cavity parameterization.

The shape of the end cell is optimized in such a way that the cell eigen frequency comes closer to the frequency of most dangerous mode (i.e. 2847.79 MHz). It helps to increase field amplitude at the end cell and, thus, easily couples with the HOM coupler. At the same time the field enhancement factor of the end cell should be equal or less than the field enhancement factor of inner cell. The eigen frequency spectrum of each kind of cells is shown in the Table 1.

Table 1: Eigen Frequency Spectrum after end Cell Optimization

Pass band	Inner cell	End cell 1	End cell 2
1	1300 MHz	1300 MHz	1300 MHz
2	2734.3 MHz	2732.4 MHz	2726.6 MHz
3	2850.1 MHz	2851.6 MHz	2847.6 MHz

Finally the asymmetrical 11-cells cavity with different end cells has been studied for most dangerous modes. The distribution of HOMs effective impedances (R/Q) for 3rd monopole pass band for complete range of β is plotted in Fig 8..

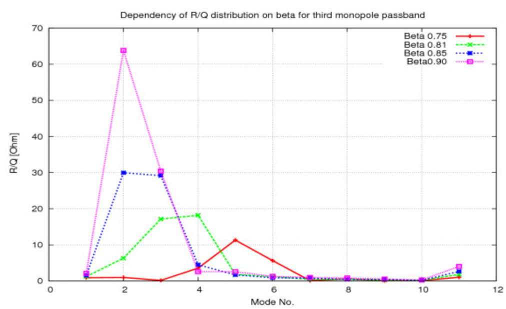

Figure 8: R/Q distribution of modes for third pass band of monopoles of Asymmetrical cavity.

The mode #2 (2847.74 MHz) & mode #3 (2847.82 MHz)_are most concerned modes. The mode #2 has highest effective impedance 64 Ohm for β=0.9 and mode #3 has 30 Ohm for the same β. The fields distributions of both modes are illustrated in Fig.9 & Fig 10. One can see that these modes are not trapped anymore because they have sufficient amplitude within at least one a the the end cell to make them coupled with HOM coupler.

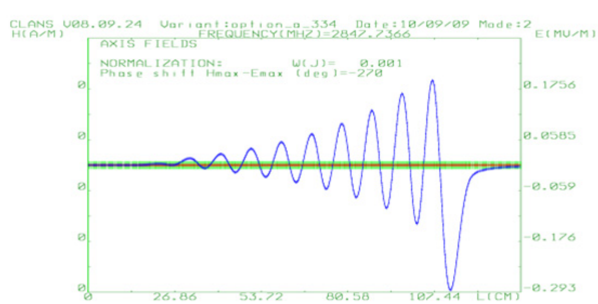

Figure 9: Electric field distribution along the axis of cavity for mode 2.

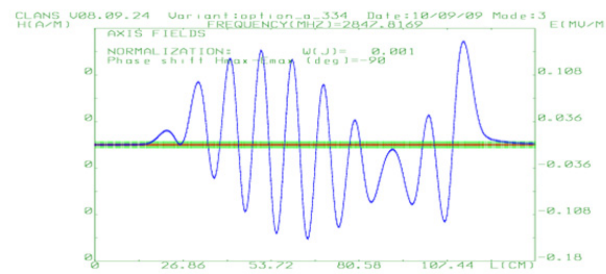

Figure 10: Electric field distribution along the axis of cavity for mode 3.

The 11-cells cavity has been studied for the same configuration of couplers as the ILC type cavity i.e two HOM couplers & one input coupler (Fig. 1) by using 3D code HFSS. The $Q_{external}$ of most dangerous modes were calculated & compared for both symmetrical and asymmetrical cavity. The results are summarized below.

Table2: $Q_{external}$ for the Dangerous Monopole Modes of 3rd Passband

Mode No.	$Q_{external}$ (Symmetrical cavity)	$Q_{external}$ (Asymmetrical cavity)
1	6.34e+08	6.43e+06
2	1.89e+08	1.75e+07
3	4.57e+08	1.98e+07
4	3.61e+08	2.02e+07
5	2.68e+08	1.63e+07

It can be noticed that $Q_{external}$ decreases significantly for asymmetrical cavity.

CONCLUSION

The asymmetrical 11 cell, β= 0.81, 1.3 GHz cavity is designed by optimizing one of end cells to get rid on dangerous trapped modes & keeping resonant frequency hence field flatness unperturbed.

AKNOWLEDGEMENT

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[1] J.-P. Carneiro & N.Solyak et al, Multicell reduced beta elliptical cavities for a proton linac.
[2] D. Myakishev & V. Yakovlev, "The new possibilities of SuperLANS code," PAC 1995.