DESIGNING OF 9 CELL REDUCED BETA ELLIPTICAL CAVITY FOR HIGH INTENSITY PROTON LINAC*

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Abstract

A superconducting rf cavity is designed for acceleration of particles travelling at 81% of the speed of light (beta=0.81). This 1.3 GHz cavity will be used in the SILC section of the proposed high intensity proton linac at Fermilab and will accelerate particles in the energy range of 466 MeV to 1.2 GeV. It will be shorter than 9 cells, beta =1 cavity but it will have nearly same ratio of the surface magnetic field to the surface electric field. The inter cell to cell coupling coefficient is also optimized to get good field flatness. Both longitudinal and transverse higher order modes are studied. The shapes of end cells are optimized to avoid dangerous modes while keeping same field flatness & same operating frequency as for ILC type cavity.

INTRODUCTION

Project X is the proposed high intensity proton driven linac to be built at Fermilab, USA. In the current scheme, the linac 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 466MeV- 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 was 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 but there are few concerns in this design, such as 1.) The cavity has 11 cells which makes cavity efficient only for narrow energy range. It can be easily seen from Fig. 1 that for larger no. of cells, cavity will be efficient for narrow energy range. 2.) The large no. of cell also increases possibility of chemical residual and processing difficulties that is why industrial production yield of cavity is expected to be low. 3.) The 11 cells cavity is more susceptible to trapped modes. The new alternative design of 9 cells β 0.81, 1.3 GHz cavity, is proposed for SILC section. Prior to designing a cavity by using electromagnetic and mechanical code one has to determine operational parameters of cavities. These are summarized below for inner cell and end cell:

Inner cell design;

- Keeping same peak surface magnetic field to peak surface electric field ratio as for ILC cavity.
- Achieving reasonable inter cell to cell coupling.

End cell and multi-cells design:

- Peak surface magnetic field to peak surface electric field ratio should be same or even less as for inner cell.
- Field flatness should be less than 5 %.

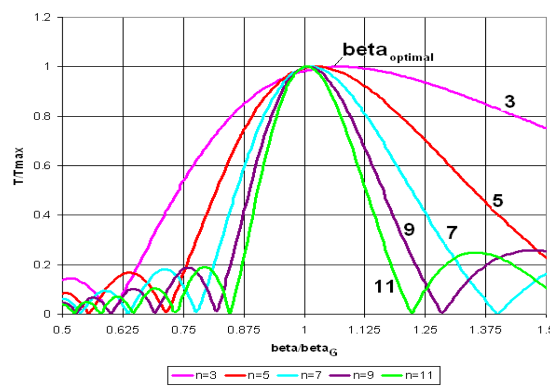


Figure 1: Dependence of Transit time factor on beta for different no. of cell.

CELL GEOMETRY

The shape which is utilized to make all calculation is shown in Fig. 2. The half cell is composed form two

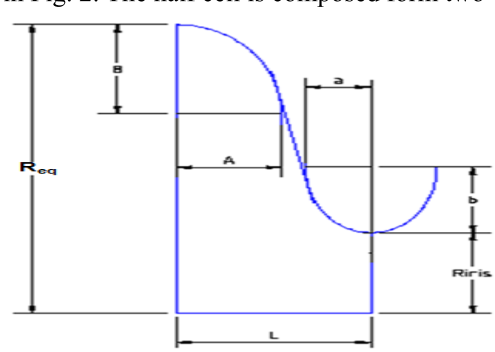


Figure **2:** Geometrical Parameters of the cavity.

elliptical arc i.e. equatorial elliptical arc and iris elliptical arc. The equatorial elliptical arc has the semi axis A & B while iris arc has a & b. The both segments are joined by the straight line which is common tangent on both arc. It decides the wall inclination angel which is important parameter from cleaning processing and mechanical stability point of view. The length of half inner cell is decided by geometrical beta and frequency of fundamental mode. It is given as

$$L = 1/4 * \beta * \lambda; \quad (1)$$

The equatorial radius (R_{eq}) is selected for frequency of fundamental mode. The iris radius (R_{iris}) is selected to get the required inter cell to cell coupling .

DESIGNING OF INNER CELL

The inner cell is designed for optimized shape. The optimization means to serach the shape which achieves operation requirements. The SuperLANS code [2] is used for all calculation. There is special program, called TunedCellAngle which tune the equatorial radius of cell for given frequency, length of cell, iris radius and sami axes for both elliptical arc. To compare the field enhancement factor of different shapes with Tesla we introduce the normalized field enhancement factors;

$$e = (Es/Eacc)_{beta0.81} / (Es/Eacc)_{Tesla};$$
$$h = (Hs/Eacc)_{beta0.81} / (Hs/Eacc)_{Tesla}; \quad (2)$$

The electric field enhancement factor (Es/Eacc) & Magnetic field enhancement factor (Hs/Eacc) for Tesla cavity are 2.0 & 4.2 mT/(MV/m) respectively, where Es , Hs & Eacc are peak surface electric field , peak surface magnetic field and accelerating electric field respectively. The choice of comparison with Tesla structure is made as this structure has been produced at large scale so correct optimization can give an economic effect. The different shapes are studied for different geometrical parameters. The optimization procedure is summarized in Fig 3. The black straight line has 45 degree slope it means h/e =1 for all the geometry which are laid on this line. The curve line shows the behaviour of inter cell coupling coefficient (k) with the variation in semi axes of elliptical arc for given iris radius. It can be seen that coupling coefficient increases with increasing iris radius. The larger iris radius implies larger cell to cell coupling (Fig 3.) and hence field flatness, reduction in beam losses & low possibility of trapping of higher order modes but we will have to pay for increment in field enhancement factor, reduction in transit time factor and effective impedance thus It is needed to optimize iris radius to achieve required coupling coefficient. The requirement of coupling coefficient comes from the field non uniformity in multi cell cavity. The field non uniformity in multi cell cavity[3] is proportional to no. of cell (N) and relative error of cell frequency(**Δf/f**)

$$\sim \Delta f/f * N^{3/2} / k; \quad (3)$$

This implies that for the designing of cavity with more than 9 cells, inter cell to cell coupling coefficient should be increase to maintain same field flatness as in ILC cavity. In term of frequency k can be expressed as

$$k(\%) = 2 * (f_{pi} - f_0) / (f_{pi} + f_0) * 100; \quad (4)$$

where f_{pi} is frequency of fundamental mode & f_0 is frequency of zero mode. It is 1.87% for the standard 9 cell, 1.3 GHz ILC cavity.

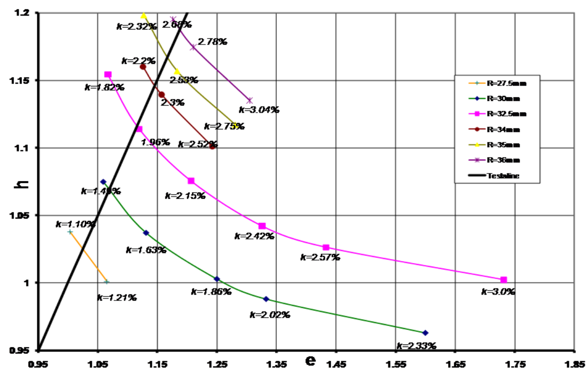


Figure 3: Optimization curve for inner cell

In our case, we optimized the iris radius to achieve both operational requirements i.e.

- h/e ~ 1;
- k ~ 1.87 %

The inner cell is designed for iris radius 33 mm for which inter cell to cell coupling coefficient is 2 % and h/e ~1;

DESIGNING OF END CELL

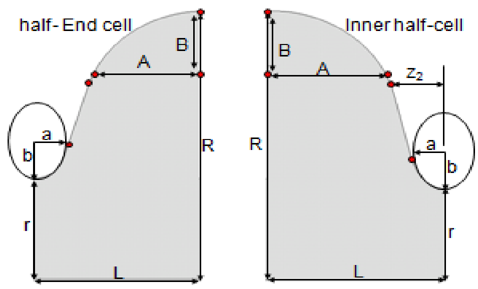
The end cell is used to connect the end of cavity with the beam pipe so to maintain the same operating frequency, shapes of half of end cell is needed to optimize. The optimization includes to design the end cell in such a way that natural frequency spectrum of the end cell is close to natural frequency spectrum of regular cell otherwise it may cause possibility of trapping of higher order modes. The shape of end-cells must lead to a reasonable axial electrical field flatness about ~2 %. Peak surface fields must be equal or lower than inner cells value. Many different end-cell shapes can satisfy these criteria.

STUDY OF 9 CELL CAVITY

The 9 cell 1.3 GHz cavity is designed by using optimized inner cell & end cell. The geometrical parameters are shown in Fig .4. The rf parameters are studied for fundamental mode and summarized in table 1.

Table 1: RF Parameters for Fundamental Mode.

Parameters	Units	Magnitude
Transit time factor	-	0.77
Coupling Coefficient	%	2
R/Q	Ohm	688
G	Ohm	226
Ep/Eacc	-	2.26
Hp/Eacc	mT/(MV/meter)	4.75
Wall angle	degree	5.8
Beam pipe dia	meter	78
Active Length	meter	0.84



r	39*
R	102.56
L	44.63
a	10
b	20
A	33.5
B	35

r	33
R	102.56
L	46.75
a	12
b	21
A	33.0
B	35.0

Figure 4: Geometrical Parameters for half inner cell (left) and half end cell (right).

The filed flatness [4] is also calculated for the multi cell cavity (Fig. 5) by using the equ. 5.

$$\text{Field Flatness (\%)} = 100 * \frac{(E_{cmax} - E_{cmin})}{\frac{1}{N} \cdot \sum_{i=1}^{N} E_c} \qquad \textbf{(5)}$$

Where E_{cmax} is maximum of peak fields in multi cell cavity. E_{cmin} is minimum of peak fields in cavity; Ec is peak field in ith cell. & N is total no. of cell in cavity. The electric field distribution along the axis of cavity is shown for fundamental mode (Fig. 5). The field flatness is found 2.24 % which is close to our requirement.

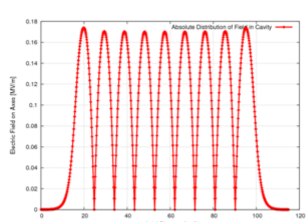


Figure 5

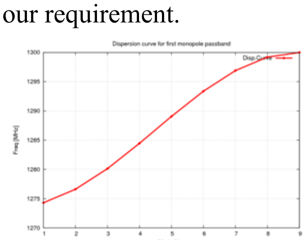


Figure 6

The dispersion curve is drawn for first monopole pass band which consists fundamental mode.(Fig 6). It can be seen that cell is coupled electrically. The relative separation of fundamental mode with its neighbor is 0.24 % which is larger than ILC cavity (0.064 %) and 11 cell cavity (0.054 %). This implies more tolerances on tuning of cavity.

STUDY OF HIGHER ORDER MODES FOR 9 CELL CAVITY

The Higher Order Modes (HOM) play an important roles in beam dynamics so it is necessary to investigate the structure for dangerous HOM and trapped modes. The cavity has been studied for longitudinal and transverse higher order mode. The distribution of effective impedance of longitudinal HOM & transverse HOM is shown in Fig. 7 & Fig 8 respectively..

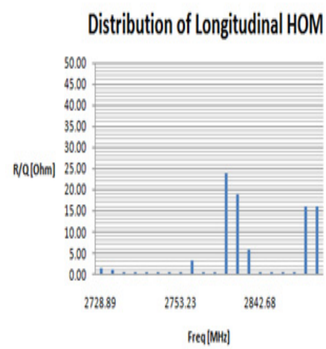


Figure 7

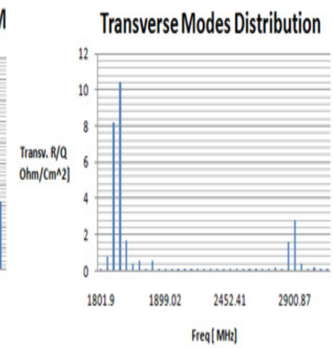


Figure 8

CONCLUSION

The 9 cells, 1.3 GHz cavity is proposed as an alternative for 11 cells, 1.3 GHz cavity for the acceleration of beam from ~450 MeV to ~1.2 GeV in the SILC section of proposed high intensity proton driven linac at Fermilab. The cavity has advantage over 11 cells cavity like 1) efficiently acceleration of beam for wider range of energy, 2) low possibility of trapped higher order modes, 3) low field enhancement factors which allow us to increase gradient of cavity, 4) the industrial yield of cavity is also expected high compare to 11 cell cavity.
The cavity has been studied for higher order modes and found free from any trapped modes.

AKONWLDGEMENT

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