DESIGN STUDY ON 650MHZ, HIGH-β MULTI-CELL ELLIPTICAL SHAPE SUPERCONDUCTING RF LINAC CAVITY

Sudeshna Seth, Sumit Som, Aditya Mandal, S. Saha, R.K. Bhandari
Variable Energy Cyclotron Centre, Kolkata

Abstract:

Design, Analysis and Development of high-β multi-cell elliptical shape Superconducting RF linac cavity has been taken up by VECC, Kolkata as a part of IIFC collaboration. The project aims to provide state-of-the-art technology achieving very high electric field gradient in superconducting linac cavity, which can be used in high energy high current proton linear accelerator to be built for ADSS programme in India and in Project-X at Fermilab, USA. The shape of an elliptical cavity is determined by geometric parameters like cell length, equator radius, iris radius, iris ellipse ratio, equator ellipse ratio, slope of the side wall and the distance measured from the iris plane. RF characterization of superconducting cavity is mainly described by the resonant frequency, accelerating gradient, Q-value, Rsh/Q, field flatness, peak surface electric field and peak surface magnetic field etc. Influence of geometric parameters of elliptical cavity on different RF parameters of the cavity has been studied and the cavity shape optimization studies have been done using 3D CST Microwave studio and 3D HFSS codes for a 5-cell, 650 MHz, β=.61 cavity. Higher order modes have also been studied for the cavity. Based on these study and analysis, preliminary design parameters for the multi-cell cavity have been determined.

INTRODUCTION

In view of vast thorium resources in India, the concept of Accelerator Driven Sub-critical System (ADSS) gained momentum, especially, when nuclear power generation is expected to reach the target of 20000 MW or more. In ADSS, when high energy (~1 GeV), high current (~ 10 mA or more) proton beam hits the target of heavy element (such as Th, Pu or U etc.), spallation neutron is produced. Spallation target is surrounded by a blanket assembly of nuclear fuel (such as ${}_{90}Th^{232}$, a fertile isotope) which breeds to ${}_{92}U^{233}$ and sustaining fission chain reaction takes place. So, a high energy (~ 1 GeV), high current (~ 10 mA or more) proton accelerator is required to build for ADSS.[1]For high energy high intensity proton beam, linear accelerator (Linac) with superconducting rf linac cavity is one of the best choices. In a high energy high current proton accelerator, multi-cell elliptical shaped superconducting rf linac is used in medium-β to high-β $(= v/c$, where 'v' is the speed of the particle and 'c' is the speed of light) stages. The simulation study of a 5-cell elliptical cavity for β=0.61, at 650MHz has been done and discussed in detail in the following sections.

CAVITY DESIGN

For designing a multi-cell cavity using electromagnetic codes, one has to determine the operational parameters for the cavities and study the influences of geometry on those parameters.

Choice of shape

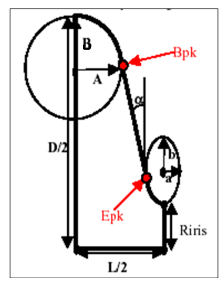

Figure 1: Reference geometry for the cavity shape

The elliptical shaped cell of the cavity consists of two elliptic arcs and, possibly, a straight line between them. Elliptical shape equatorial area eliminates multipacting which limits performance of cylindrical pillbox cavity and reduces peak surface magnetic field (Bpk) by making magnetic field along surface more uniform. Elliptic arc in iris reduces peak electric field (Epk). The length of the accelerating gap of the cavity is usually L =βλ/2, where λ is the wavelength for the accelerating mode (π-mode) in multi-cell cavities.[2][3]

Choice of frequency

In case of superconducting cavity at a operating temperature 2K, the losses grow linearly with frequency above 3 GHz, whereas for frequencies below 300 MHz the losses grow with 1/*f*. To minimize the dissipation in the cavity wall, *f* should be selected in the range 300 MHz to 3 GHz. Though at the higher frequency, niobium and cryostat cost will be smaller due to small size of cavity, we have chosen a relatively low frequency 650MHz, to reduce wake field losses, beam induced cryogenic losses and beam emittance growth. Also cavity wall losses are smaller due to f^2 dependence of the BCS resistance of superconducting material. Large transverse aperture and cleaning facilities are also the factors in choosing the frequency. [3]

Number of Cells

5-cell structure is adopted since it can keep good acceleration efficiency while making coupling of modes easier and field flatness in the cells better compared to 7~9 cell structures. β=.61cavity should accelerate a beam whose velocity changes with position. The choice of 5 cells is a reasonable compromise between a long structure to provide higher accelerating voltage and a small number of cells for higher velocity acceptance.[3][4]

Criteria for Cavity Design

Table1: Dependence of RF parameters on Geometric parameters [2] [3] [5]

Criteria	RF parameters	Dependence on Geometry
Operation at High accelerating gradient, lower losses and field emission	Lower Epeak/Eacc	improves when R_{iris} decreases, depends on iris shape
	Lower Bpeak/Eacc	improves when R_{iris} decreases, depends on equator shape
High accelerating gradient with lower stored enegy and low cryogenic losses	Higher R/Q (ohm) Higher G (ohm)	improves when R_{iris} decreases, depends on equator shape
High Beam current	low HOM impedance	Improves when R_{iris} decreases
Coupling of modes between cells	K_{cc}	Improves when R_{iris}decreases,no of cells decreases
Field flatness		Improves when R_{iris}decreases, K_{cc} & β increases, no. of cell decreases

CAVITY SIMULATION RESULTS

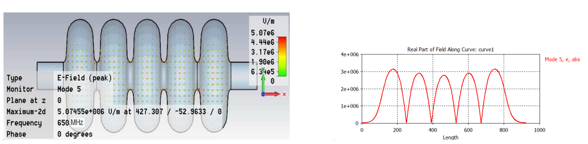

Figure 2&3: π-mode E-field lines & field along cavity axis

Table2: Electromagnetic characteristics of cavity

β	0.61
E_p/E_{acc}	3.11
B_p/E_{acc}	4.9
R/Q	310
G	196
K_{cc}	1.27%

CAVITY HIGHER MODES

5-cell cavity structure has been analysed for transverse and longitudinal higher order modes and their impedances has been studied. Table3 shows transverse and longitudinal higher order modes at lowest frequencies.

Table3: Higher order modes

Transverse HOM (MHz)	946.1,951.4,959.5,967.5,972 1220,1262.9,1297,1300, 1310.6,1350, 1630.85, 1645.37,1668.49
Longitudinal HOM (MHz)	1423.23,1429.37,1439.23, 1450.19,1458.82, 1613.49,1621.44

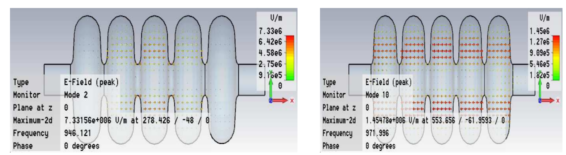

Figure 4&5: Electric field of some transverse HOMs

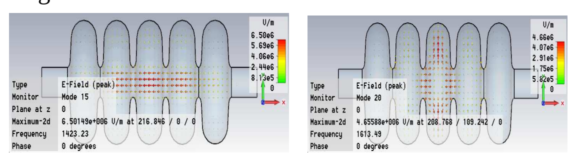

Figure 5&6: Electric field of some longitudinal HOMs

CONCLUSION

Electromagnetic analysis has been carried out mainly using 3D CST Microwave Studio-2009.We have also used 2D SUPERFISH Code and 3D HFSS Code to determine some of the electromagnetic characteristics. Based on above analysis, a list of preliminary design parameters have been shown in Table2.

REFERENCES

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