Poster ID: THPOGE03

Design & Multiphysics Analysis of Three-cell, 1.3 GHz Superconducting RF Cavity for Electron Beam Accelerator to Treat Wastewater

Pankaj Kumar*[1], Abhishek Pathak[1], Raghava Varma[1]

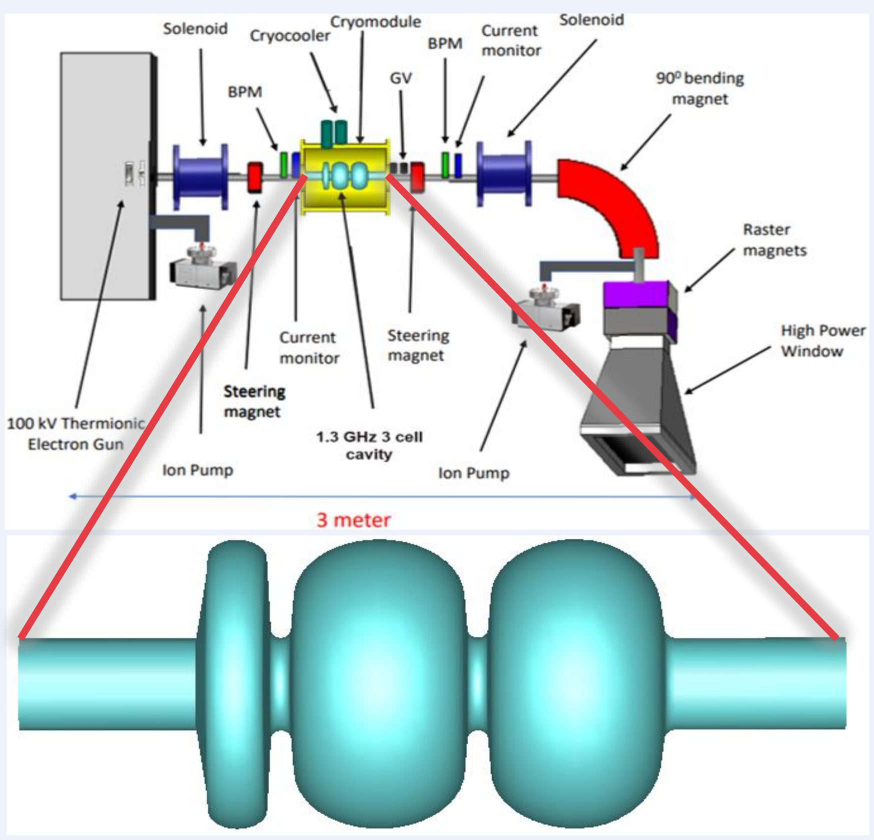
[1]Department of Physics,
Indian Institute of Technology Bombay (IIT-B),
Mumbai 400076, India
*Email: Panku.r.k@gmail.com

Abstract

To treat industrial effluents including contaminants of emerging concern (CECs), Irradiation treatment by electron beam accelerator has shown promising results. Our aim is to design and develop a superconducting linear electron accelerator. A 1.3 GHz, three cell conduction cooled, TM class superconducting cavity has been proposed to accelerate a 100 mA electron beam from 100 keV to 4.5 MeV. The main aim of the design is to optimize the cavity for low heat loss and high accelerating gradient. The optimized ratio of peak surface electric and magnetic field to accelerating field for cavity are Epk/Eacc= 2.72 and Hpk/Eacc= 4.11 mT/(MV/m). The optimized Geometry factor (G) and R/Q values for this cavity are 246.7 and 306.4 ohms respectively. Here we also addressed other multiphysics issues such as Lorentz force detuning (LFD), Higher order modes (HOMs) and Multipacting. The multiphysics analysis helps to estimate the degree of these challenges. The final Lorentz detuning factor of the cavity has been reduced to 0.12 Hz/(MV/m)^2, HOMs of 2.18 and 2.9 GHz modes are dominating except the main mode and Multipacting phenomena is not found at 15 MV/m of accelerating gradient.

Motivation

Schematic Diagram of HICSEA System



- Conventional water treatment plants are unable to treat toxic and complex compounds.
- Irradiation by electron beams is an effective method to do so.
- This SC cavity must be capable of operating at cryogenic temperatures using two or more cryocoolers.
- Design a 3 cell Niobium cavity for low power loss and high accelerating gradient.

1. RF Cavity Designing and Optimization

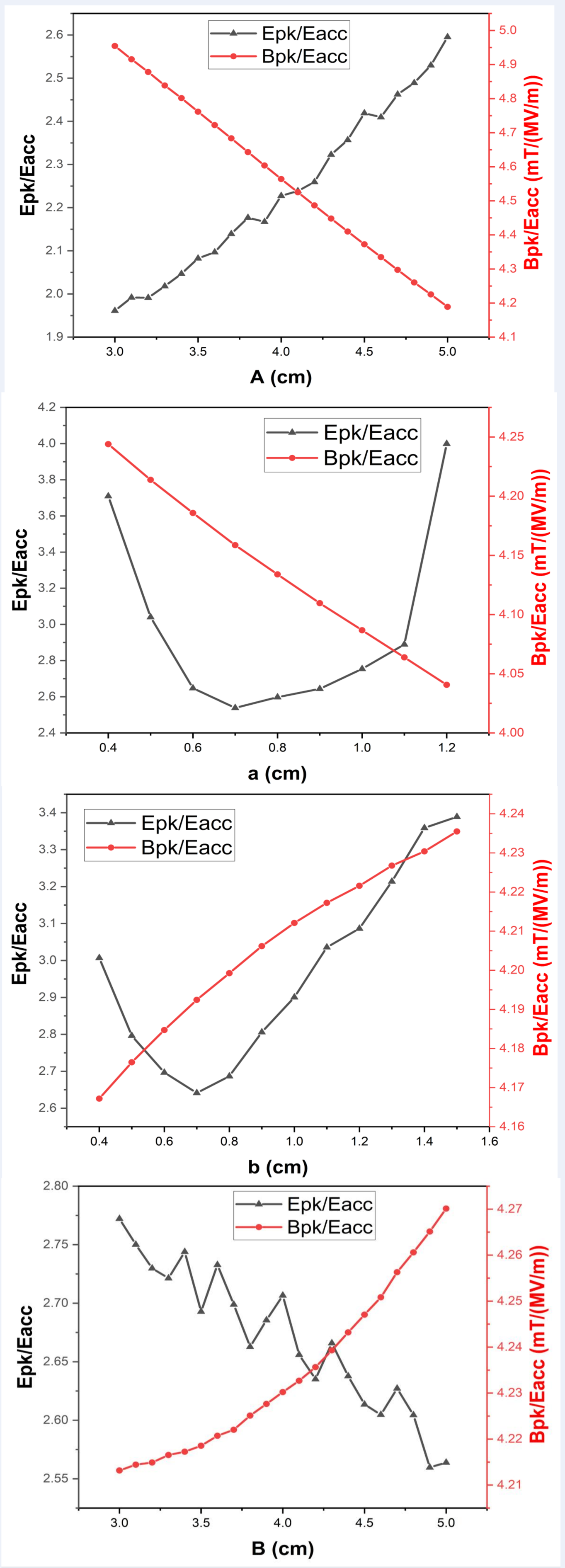
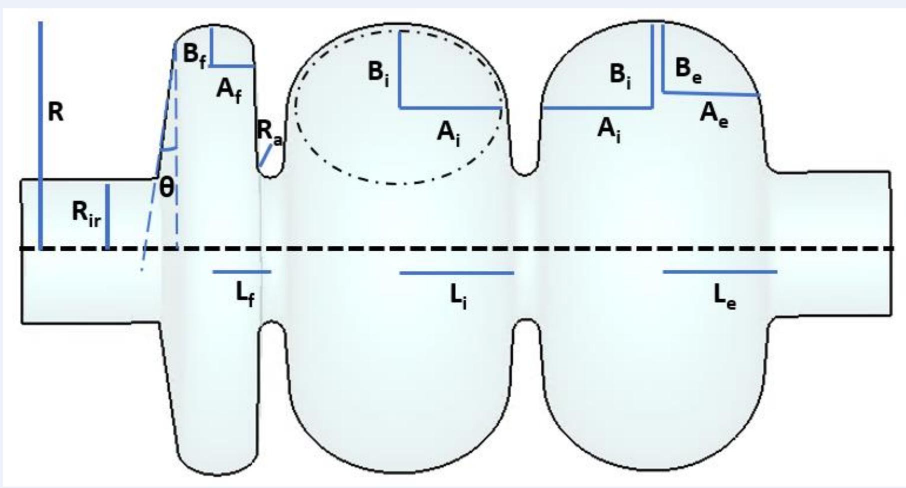


Fig: E_{pk}/E_{acc} and B_{pk}/E_{acc} variation on varying a,b, A and B.



- The tunable parameters are optimized to get the best RF results.
- The first cell of cavity is designed to match the phase of the incoming electron with the RF field.
- Second and third cells are tuned for minimum heat loss and a strong accelerating gradient

RF Parameters	Value
Frequency (GHz)	1.3
Accelerating gradient (MV/m)	15
E_{pk}/E_{acc}	2.72
B_{pk}/E_{acc} (mT/(MV/m))	4.11
Q	4.6 x 10^{10}
G (Ω)	246.7
R/Q (Ω)	306.4
G x R/Q (Ω-Ω)	75619
K_{cc} (%)	1.86

Table: Final optimized RF parameters of the cavity

2. Multi-Physics Analysis

a) LFD Analysis

- Initial LFD factor (K_L) =-Δf/Eacc^2 = 3421 Hz/(Mv/m)^2
- Final LFD (K_L) = 0.12 Hz/(MV/m)^2
- Initial frequency change = 769.7 kHz
- Final frequency change = 27 Hz

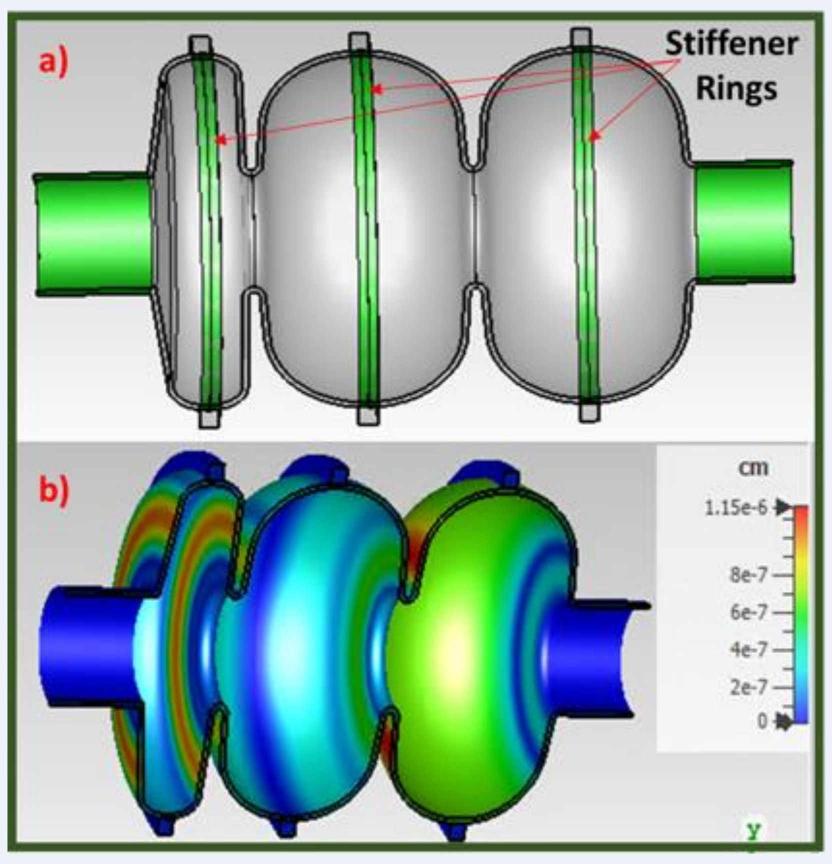
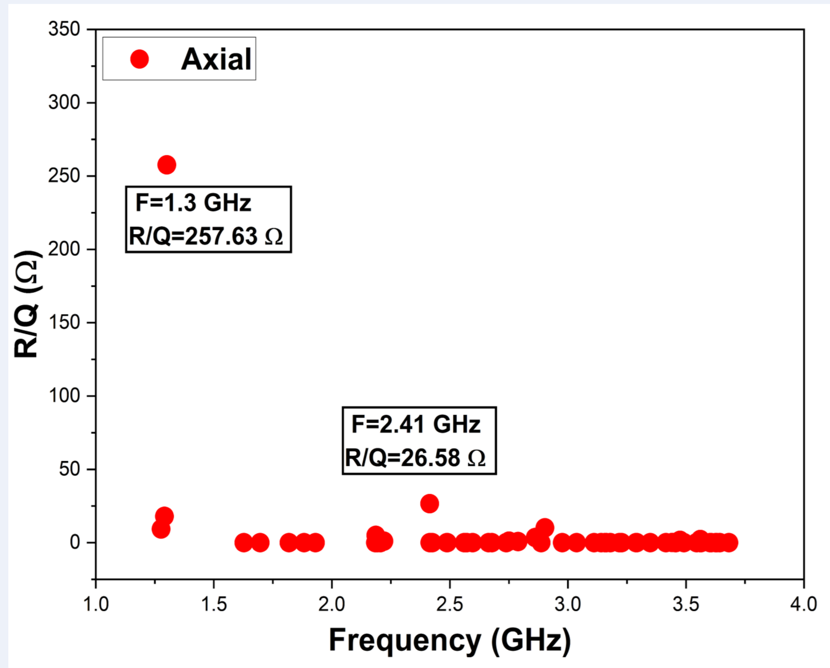


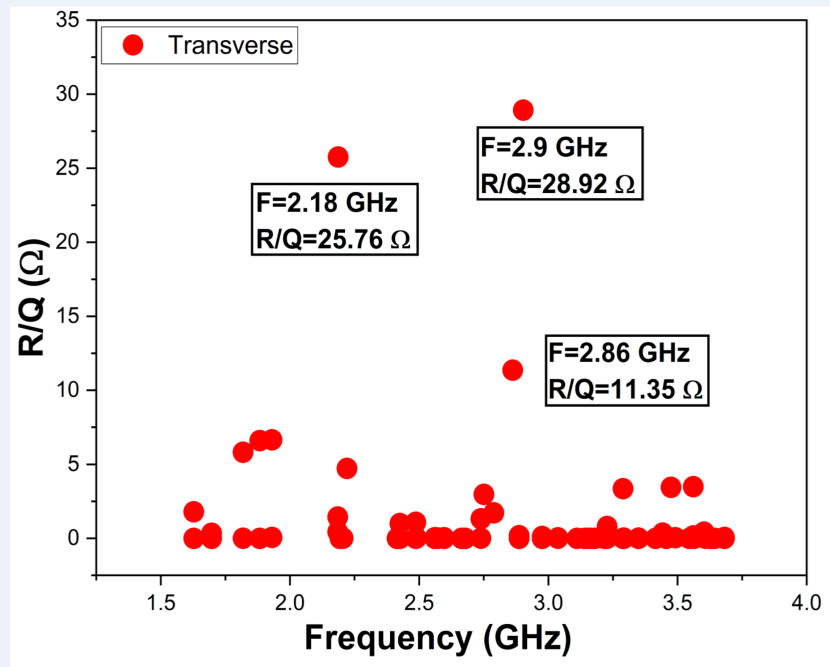
Fig (a): Stiffener rings with boundary conditions of $\Delta X = \Delta Y = \Delta Z = 0$ cm (green color)

Fig (b): Cavity deformation (in cm)

b) Higher Order Modes (HOMs) Analysis

$$(R/Q)_{\parallel,n} = \frac{\left|\int_{-\infty}^{+\infty} E_{n z}(r=0,z)e^{i\omega_n z/c}dZ\right|^2}{\omega_n U_n} \qquad (R/Q)_{\perp,n} = \frac{\left|i\frac{c}{\omega_n a}\int_{-\infty}^{+\infty} E_{n z}(r=0,z)e^{i\omega_n z/c}dZ\right|^2}{\omega_n U_n}$$

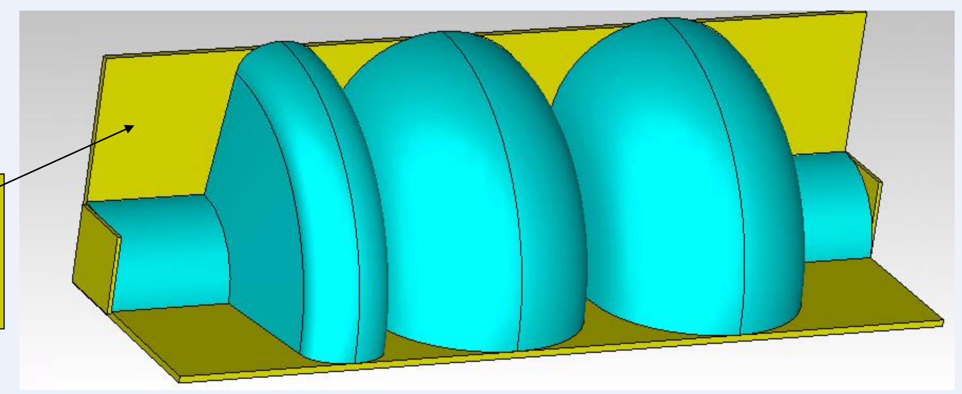




c) Multipacting Analysis

- ¼ of the SC cavity

1. True Secondary electron yield =0
2. Diffusion Secondary electron yield=0
3. Reflectivity = 100%



- No multipacting found for E_{acc}= 15 MV/m

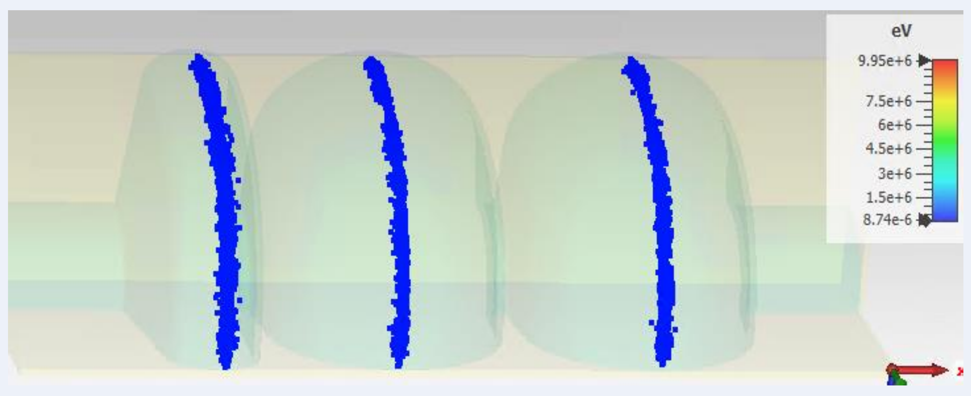


Fig (a): Multipacting region found for E_{acc}= 20 MV/m

Conclusion

- The peak surface electric and magnetic field for 15 MV/m of E_{acc} would be 40.8 MV/m (<93 MV/m) and 61.65 mT (<180 mT) respectively,
- At E_{acc}=15 MV/m, the electron may be accelerated from 100 keV to 4.5 MeV in a cavity.
- The findings of multiphysics analysis aid in the improvement of cavities with reduced faults.

References

1. Janssen, D at.el, Status of the 3 ½ Cell Rossendorf Superconducting RF Gun, Jan. 2004
2. Li Zhaodong et al, Optimization of the low loss SRF cavity forthe ILC, 2007
3. M.H. Awida et al, Multiphysics Analysis of Frequency Detuning in Superconducting RF Cavities for Proton Particle Accelerators Fermi National Accelerator Laboratory, Batavia, IL 60510, USA
4. Hasan Padmsee, RF Superconductivity for Accelerators Wile

Acknowledgement

The authors would like to thank Manisha Meena, Anjali Bhagwan Kavar, and Pragya Nama for their assistance, support, and insightful discussion.