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# RF design, optimization and multiphysics study of a β = 1, 1.3 GHz single cell accelerating cavity for High-Intensity Compact Superconducting Electron Accelerator (HICSEA)


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## Abstract

High-energy electron accelerators have been used in water purification for several years. They are very effective for the removal of complex impurities. This study aims to design a superconducting electron beam accelerator with an output energy of 1 MeV and beam power of 40 kW for wastewater treatment. A 1.3 GHz single cell elliptic cavity with β = 1 was designed and optimized for $TM_{010}$ mode and an accelerating gradient of 15 MV/m. For the optimized cavity, the RF parameters, namely, R/Q, transit time factor and geometry factor (G) were found to be 174.93 Ω, 0.67 and 276 Ω, respectively. Multiphysics studies showed that the value of R/Q for fundamental accelerating mode was 174.93 Ω. It was much higher than that of other modes, thus, HOM coupler is not required for the system. The Lorentz force detuning coefficient after stiffening the cavity iris, and the temperature rise due to the RF surface losses were found to be 0.20 Hz/(MV/m)$^2$ and 0.085 K, respectively. It is also observed that there is no occurrence of multipacting for the designed accelerating gradient.


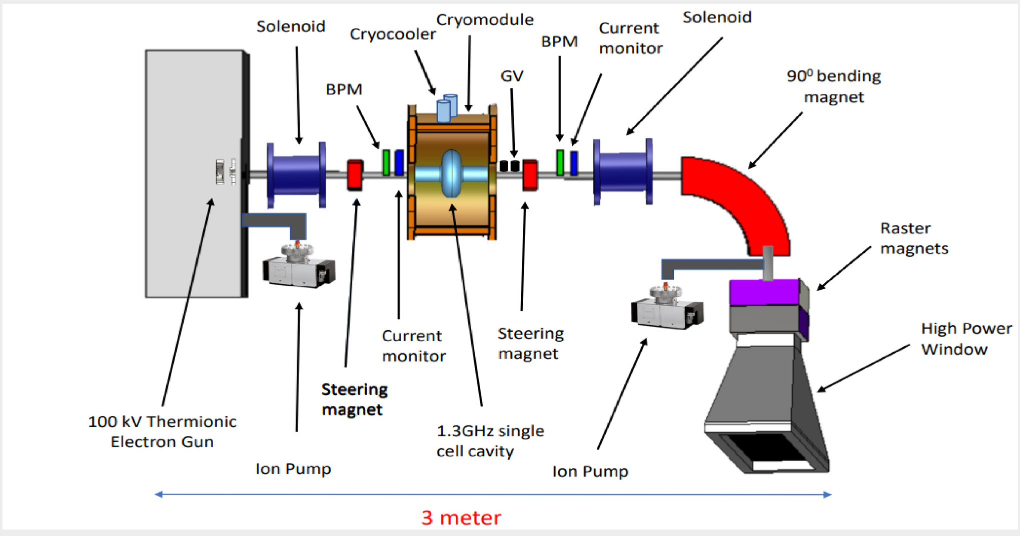


Fig.: Schematic of proposed system

## RF cavity design and optimization

- System with an output energy of 1 MeV and 40 kW beam power

**RF requirement**

- Accelerating gradient ($E_{acc}$) = 15 MV/m
- Low power loss, $B_{pk}/E_{acc}$, and $E_{pk}/E_{acc}$ , high R/Q and G

**Approach**

- Minimize the value of $B_{pk}/E_{acc}$ for a small fixed value of $E_{pk}/E_{acc}$ (~1.6)

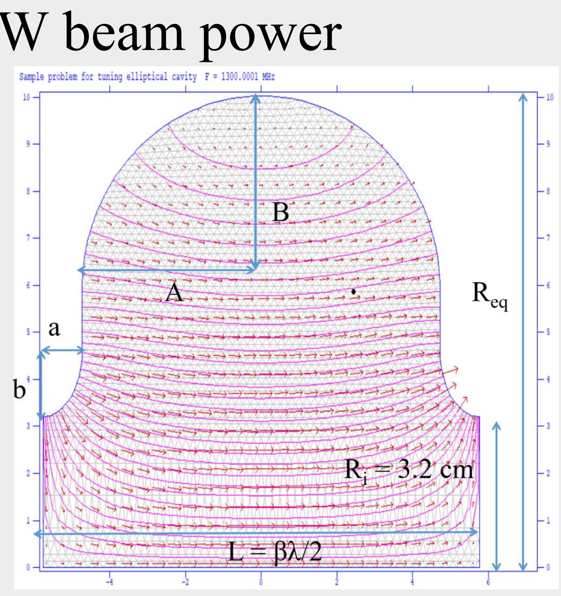


Fig.: Cavity design in 2D and geometry parameters

- Initially, a/b = A/B = 1, and B = L/4
- Following the constraint $E_{pk}/E_{acc}$(~1.6): B = 4.1 cm

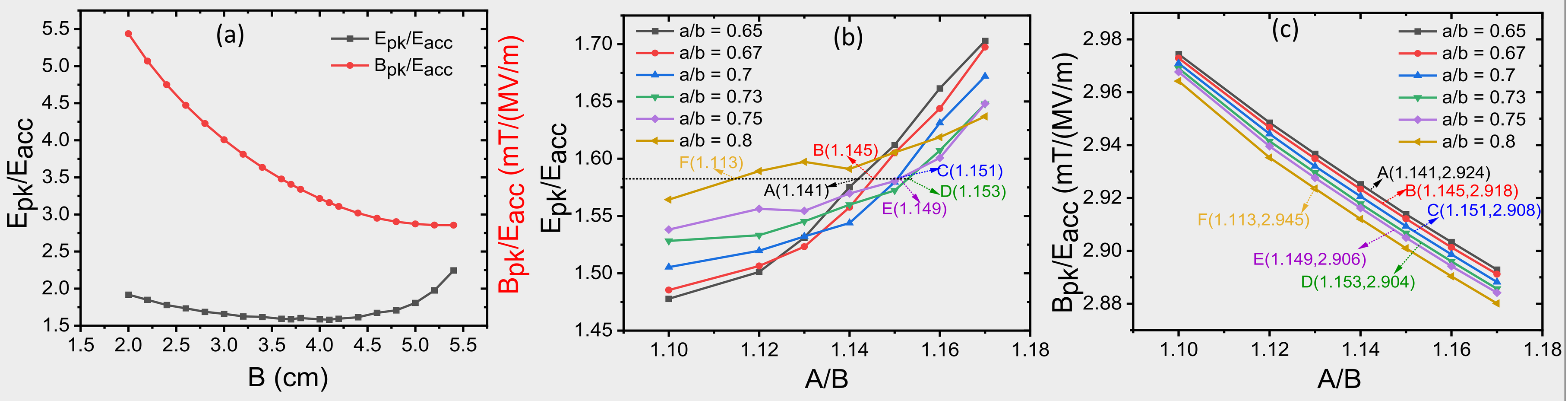


Fig.: (a) $E_{pk}/E_{acc}$ and $B_{pk}/E_{acc}$ versus geometry parameter B, (b) $E_{pk}/E_{acc}$ versus A/B, and (c) $B_{pk}/E_{acc}$ versus A/B for different a/b ratio

- Final value of A = 4.73 cm and a/b = 0.73

| RF parameter | Value | Unit |
|---|---|---|
| $E_{acc}$ | 15 | MV/m |
| Quality factor ($Q_0$) | $5.17\times10^{10}$ | - |
| R/Q | 174.93 | Ω |
| Geometry factor (G) | 275.98 | Ω |
| $B_{pk}/E_{acc}$ | 2.90 | mT/(MV/m) |
| $E_{pk}/E_{acc}$ | 1.59 | - |

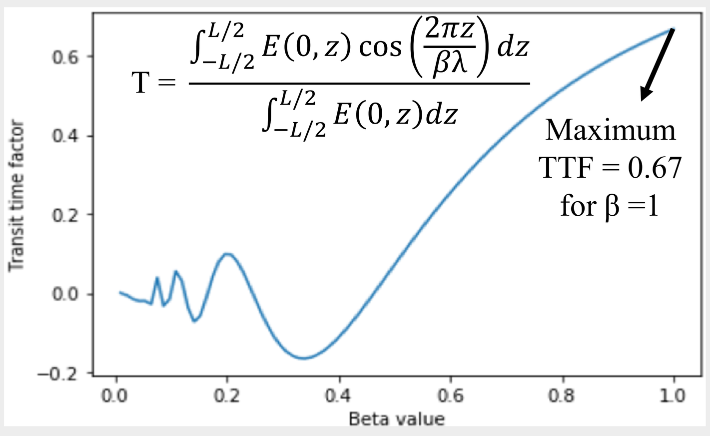


Fig.: Transit Time Factor (TTF) as a function of beta

## Multiphysics Study

### 1. Higher Order Modes (HOMs) Analysis

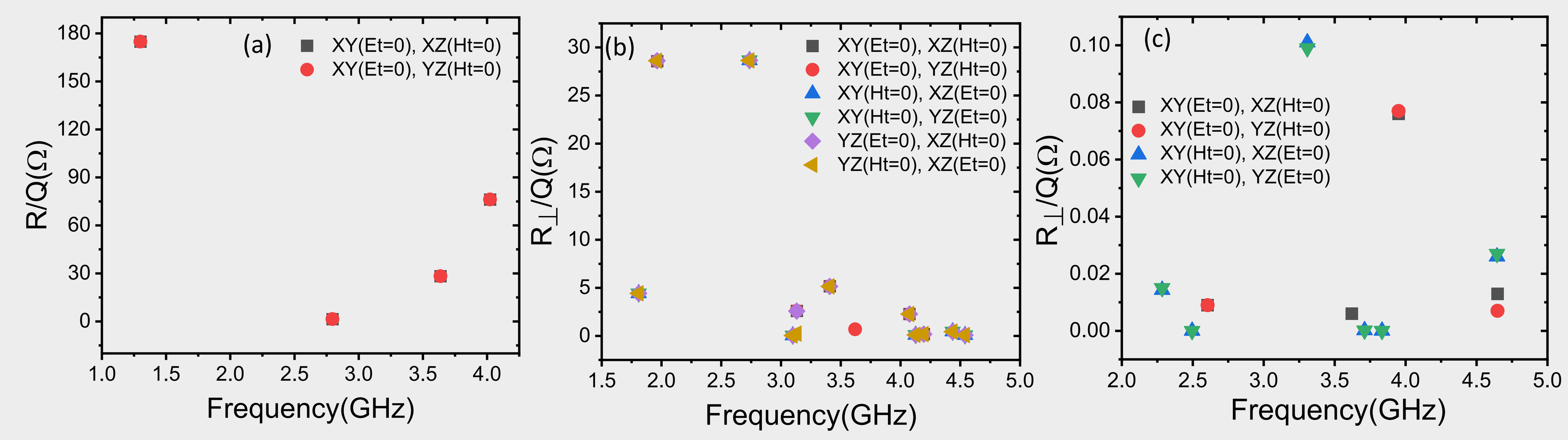


Fig.: (a) R/Q value for monopoles (b) $R_\perp/Q$ for dipoles (c) $R_\perp/Q$ for quadrupoles for different symmetry conditions in XY, YZ, and XZ planes

- Maximum value of R/Q for dipoles: 26.87 Ω
- Maximum value of R/Q for quadrupoles: 0.10 Ω
- R/Q of accelerating mode = 174.93 Ω


## Acknowledgements

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### 2. Lorentz force detuning (LFD)

- Cavity wall thickness = 3 mm
- Displacement before stiffening the beam tube = 0.0129 cm
- Displacement after stiffening the beam tube = $5.62\times10^{-7}$ cm

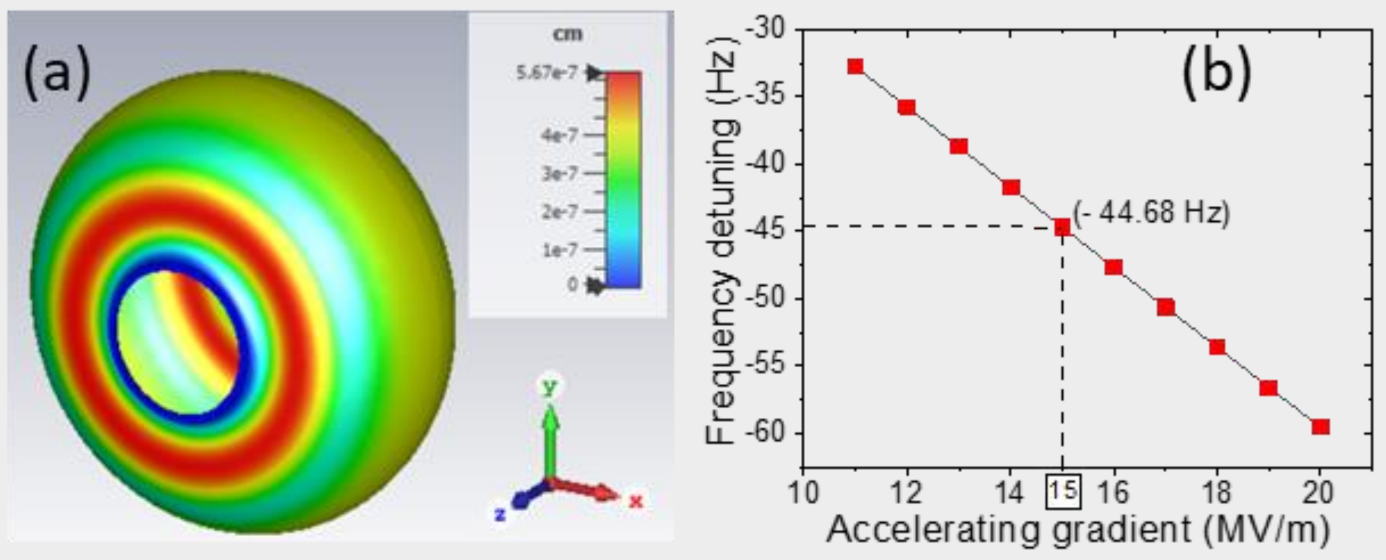


Fig.: (a) Displacement of the cavity after fixing the iris for $E_{acc}$ = 15 MV/m, (b) Resonant frequency detuning for different $E_{acc}$

### 3. Multipacting

- Multipacting yield (MY):

$$MY = \frac{\int_{T1}^{T2} I_{emission} dt}{\int_{T1}^{T2} I_{collision} dt}$$

- No multipacting was observed within 13.33 % deviation from 15 MV/m accelerating gradient

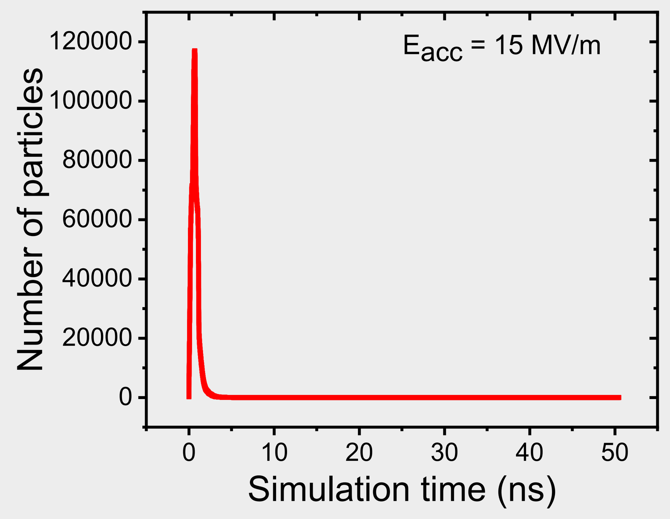


Fig.: Number of particles versus time plot for 15 MV/m $E_{acc}$

### 4. Thermal analysis

- RF surface losses = 0.1569365 W
- Temperature rise = 0.085 K

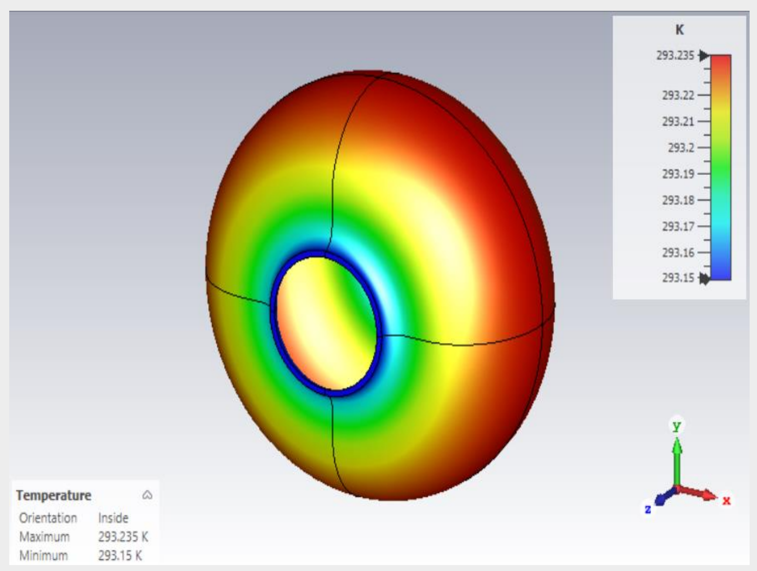

Fig.: Temperature rise profile of the cavity

## Beam Dynamics Results

- RF fields for cavity with 10 cm beam tube are considered.
- Maximum energy gain of particle with β = 0.9: 2.26 MeV

## Conclusion

The surface peak fields for the optimized single cell SC cavity are $E_{pk}$ ~ 23.85 MV/m and $B_{pk}$ ~ 48.45 mT, which are less than the permissible limit of 93 MV/m and 180 mT for niobium respectively. The multiphysics analysis of the single cell elliptical cavity shows:

- Negligible transverse R/Q (28.67 Ω for dipoles and 0.1 Ω for quadrupoles).
- LFD coefficient and temperature rise due to RF surface losses are small.
- Multipacting is not observed.

## References


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