DESIGN OF LOW-BETA SUPERCONDUCTING RESONATOR FOR PELLETRON-LINAC FACILITY AT TIFR

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Abstract

The Pelletron accelerator facility at TIFR serves as both a stand-alone accelerator and as an injector to the Superconducting LINAC booster. At present, ion beams from the Pelletron, heavier than nickel, are below the velocity acceptance of the accelerating superconducting cavities and hence cannot be boosted by the LINAC. It has been proposed to develop low-beta (β~0.05) halfwave and medium-beta (β~0.07) quarterwave Niobium superconducting resonators for the facility, so that a wide range of ion beams across the periodic table can be accelerated. The halfwave cavities have been optimized to operate at a resonant frequency of 93.75 MHz. This paper presents details of the 2D and 3D design of halfwave superconducting resonator.

INTRODUCTION

The split-ring and quarterwave resonators for the existing LINAC booster at TIFR operate at a resonant frequency of 150 MHz for $\beta = 0.1$ [1], where $\beta c = v$ is the beam velocity. In the cavities, the centre-gap to centre-gap distance (d) is of order $\beta\lambda/2$, where λ is the RF wavelength. For $\beta = 0.05$ and frequency of 150 MHz, the distance ‘d’ becomes too small and is impractical. Hence it was decided to choose the operating frequency for these low-beta cavities as 93.75 MHz, which corresponds to (10/16) of the main linac frequency of 150 MHz.

The halfwave resonator (HWR) is more favourable, since it combines the advantages of the split-ring resonator [2,3] and the quarterwave resonator [4]. The halfwave resonator consists of two vertical inner conductors shorted to an outer cylinder at one end and with drift tubes at the other end. The halfwave resonator is thus, a 3-gap structure and therefore provides a much higher voltage gain than a 2-gap quarterwave structure at the same frequency, β and transverse dimension. This allows the possibility of building accelerating structures for very low velocity ions. In view of the above considerations, it has been decided to optimize a halfwave resonator for velocity of 0.05c. The resonator will be built from bulk Nb since it has a higher T_c, higher critical magnetic field and lower surface resistance as compared to Pb and consequently a higher achievable Q value. The inner conductors will be made hollow for filling with liquid helium, while the outer cylinder will be cooled by a liquid helium jacket surrounding the cavity.

DESIGN SPECIFICATION

As the longitudinal direction (along the beam axis) is much smaller than the RF wavelength, the design can be separated into two parts:

- The inductor treated as pure electromagnetic transmission line problem,
- The drift tube as a purely electrostatic problem.

From symmetry, the inductor problem is reduced to that of a cylindrical inner conductor inside an outer half-cylinder and the problem was solved in 2D for one quadrant in POISSON SUPERFISH [5]. For a fixed outer cylinder radius ‘b’, the radius of the inner conductor ‘a’ and the distance ‘L’ of the centre of inner conductor from the symmetry axis (axis on which voltage = 0) was varied and the peak surface electric field and the net force on the inner conductor was determined. Fig. 1 shows the peak surface electric field on the inner conductor (on both sides - one facing symmetry axis and the other facing outer cylinder) at the optimized location as a function of the radius ‘a’ of the inner conductor. Fig. 2 shows the dependence of the net force on the inner conductor as a function of the distance ‘L’. It should also be noted that the surface magnetic fields are trivially related to the surface electric fields. Hence, the optimum choice for the radius and location of the inner conductors are chosen to achieve minimum surface electric fields and zero net force to ensure least coupling of the mechanical vibrational modes to the RF excitations in the cavity.

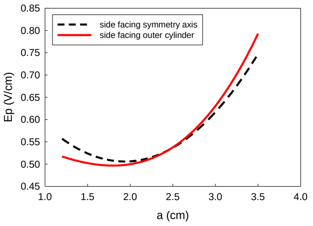

Fig. 1: Variation of peak surface electric field on inner conductor with its radius ‘a’.

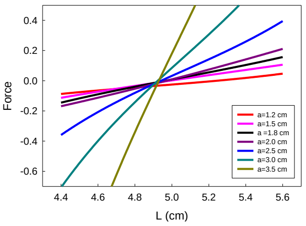

Fig. 2: Dependence of net force on inner conductor on distance ‘L’.

Superconducting accelerating structures are limited mostly in their achievable gradient by field emission. Field emission is dominant at the location of the drift tubes. Therefore, considerable effort was put into the design of the drift tubes. For optimizing the radius and location of drift tubes at the place where electric fields are dominant, the drift tubes were treated as spheres within an outer conductor. The outer surface was treated as both a sphere and a cylinder to approximate the geometry of the cavity. Again from symmetry, both the geometries (spherical inner drift tube inside an outer cylindrical surface and a spherical inner drift tube inside an outer spherical surface) were solved in 2D for one quadrant in POISSON SUPERFISH. The dependence of peak surface electric field on the radius ‘a_1’ of the drift tube for both

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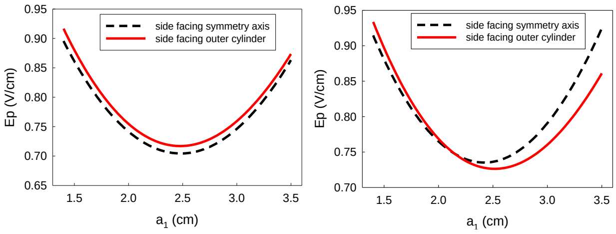
the geometries is shown in Fig. 3. The curves correspond to zero net force on the drift tubes. Fig. 4 shows the dependence of the distance ‘L_1’ of the centre of the drift tube from the symmetry axis on its radius ‘a_1’ for both geometries. For each of these geometries, the radius ‘a_1’ and distance ‘L_1’ were optimized to maximize the ratio of voltage gain to peak surface electric field. However, this was balanced against the fact that the drift tube capacitance is small in order to avoid any substantial decrease of the shunt impedance with loading capacitance. The calculated transit time factor for the halfwave resonator at the optimized parameters is shown in Fig. 5. Such optimized geometry would result in very small radiation pressure frequency shift and very small frequency sensitivity to external vibration.



(a) (b)

Fig. 3: Variation of peak surface electric field with radius ‘a_1’ of the two drift tubes for two geometries (a) sphere within cylindrical outer cylinder and (b) sphere within spherical outer cylinder.

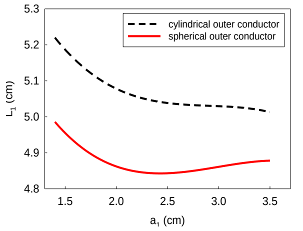


Fig. 4: Dependence of distance ‘L_1’ on radius ‘a_1’ of drift tubes.

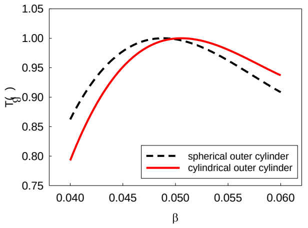


Fig. 5: Transit time factor for $\beta = 0.05$ halfwave resonator.

The optimized radii of cylindrical inner conductor ‘a’ and drift tubes ‘a_1’ are not same. Similarly, the optimized location of inner conductor ‘L’ is different from that of drift tubes ‘L_1’. Hence detailed 3D simulations of the resonator were performed using the optimized 2D data for the cavity at the desired resonance frequency of 93.75 MHz. The HWRs RF design was carried out using Vector Fields OPERA v11.006 [6]. The optimized parameters are listed in Table 1.

Table 1: Optimized parameters for design of HWR.

Parameter	**Value**
Diameter of outer conductor	20.0 cm
Diameter of inner conductor	4.0 cm
Length of inner conductor	74.98 cm
Diameter of drift tube	5.0 cm
Distance between centres of two drift tubes	4.9 cm

The electric and magnetic field profiles obtained at the location of drift tubes and the shorting plate respectively in HWR are shown in Figs. 6 and 7.

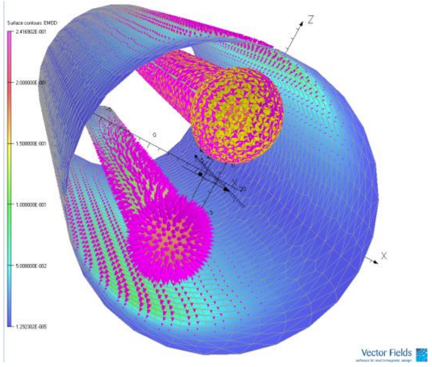


Fig. 6: Electric field profile at the location of drift tubes.

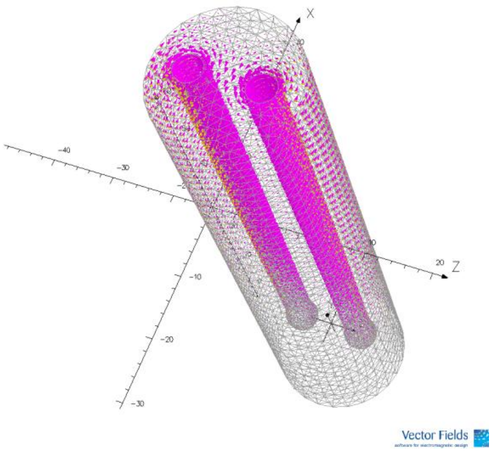


Fig. 7: Magnetic field profile on the shorting plate.

The resonant frequency obtained was 93.74 MHz. The next lower order frequency supported by the cavity was 93.03 MHz. At present, tuners are being designed to increase the spacing between the two modes. Design of RF power feed is also in progress.

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