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BUNCHER CAVITY FOR ERL

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Abstract

Design of the buncher cavity for Cornell / JLab ERL project is presented. This is a reentrant spherical copper cavity at a frequency of 1300 MHz. It will be installed between a 500 keV electron gun and superconducting accelerating sections in the injector part of ERL. The cavity has Q of 20,000 and a shunt impedance of 2.1 MOhm. For a design cavity voltage of 200 kV, power dissipated in cavity is as much as 9.6 kW. The cavity has a coaxial loop coupler and will be driven by a 17.5 kW klystron. The estimates of cavity influence on beam dynamics are also discussed.

1 INTRODUCTION

The project of a 100 MeV, 100 mA Energy Recovery Linac (ERL) is in the R&D stage at Cornell University and Jefferson Laboratory [1], [2], [3]. To obtain the required beam properties, bunching of the beam produced by the gun is necessary. Therefore a buncher cavity will be built and installed between the electron gun and the first accelerating section of ERL injector. It will produce an energy spread of about 10 keV in a σ = 12 ps, 500 keV bunch coming from the gun so that the bunch will be shortened to σ = 2.3 ps in the drift space between the buncher cavity and the first injector cavity.

2 CAVITY DESIGN

The frequency of the buncher cavity is equal to the frequency of injector and main ERL linacs (1300 MHz). The maximum RF voltage that the buncher cavity should provide is 200 kV. This voltage is relatively small. Therefore there is no reason to build a superconducting cavity despite the fact that other accelerating structures of the ERL are superconducting. The buncher cavity is a copper cavity that has a spherical reentrant shape, which was optimized using the SLANS computer code [4]. Its geometry is shown in Figure 1. Table 1 summarizes main cavity and cavity-related parameters.

Table 1

Energy of electrons, E	500 keV
Velocity of electrons, v/c	0.863
Beam current, I_0	100 mA
Resonance frequency, f	1300 MHz
Q	20,000
Shunt impedance, $R = V^2/2P$	2.1 MOhm
Nominal operating voltage, V	120 kV
Maximum accelerating voltage, V_m	200 kV
Maximum dissipating power, P_m	9.6 kW
Peak surface electric field, E_p	8.8 MV/m
Cavity detuning by beam current, ψ	73°

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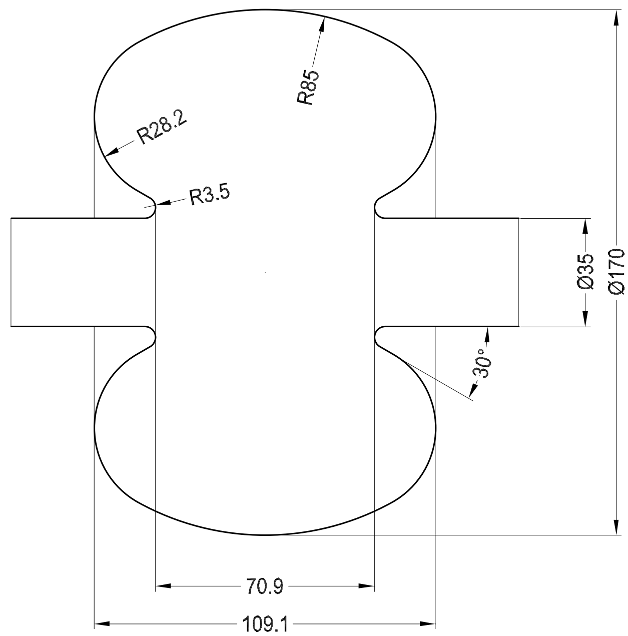

Figure 1: Geometry of the ERL buncher cavity.

The cavity has four 40 mm diameter ports: a port for input coupler on the cavity top, a pump-out port on the cavity bottom, and two ports in the horizontal plane for tuners. There is also a small 15 mm port for the field probe.

3 INPUT COUPLER

The cavity has a water-cooled coaxial loop type coupler (see Fig. 3). However, the coaxial part is short and ends with a coax-to-waveguide transition with a ceramic window similar to the warm window of the TTF III coupler for TESLA cryomodule [5]. The coupling can be

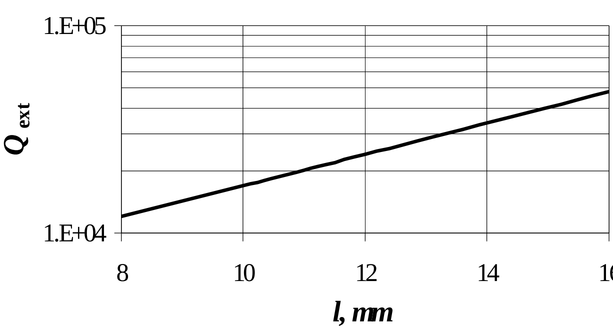

Figure 2: Dependence of Q_{ext} of the cavity on the distance between the coupling loop and the port opening.

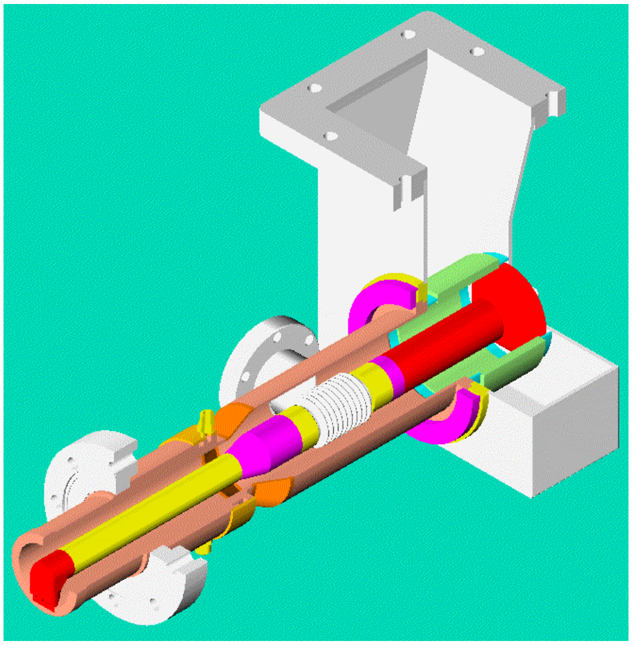

Figure 3: Design of the input coupler.

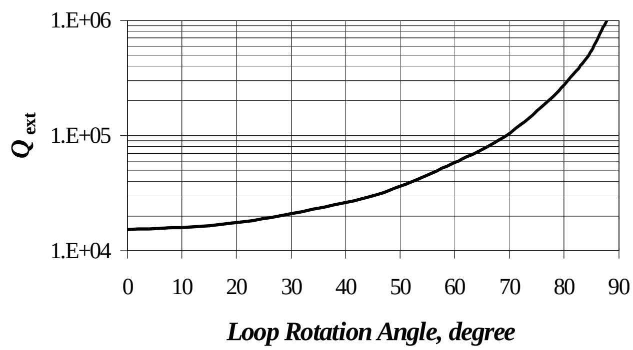

Figure 4: Dependence of Q_{ext} of the cavity on the coupling loop rotation.

adjusted by rotation of the coupling loop. Figure 2 shows the dependence of Q_{ext} of the cavity on the distance l between the loop and the port opening; Figure 4 shows the dependence of Q_{ext} on the loop rotation for $l = 10$ mm.

The average RF power delivered by buncher cavity to the beam is zero. Therefore no overcoupling is necessary and the Q_{ext} of the input coupler should be equal to $Q_0 = 2.0\times10^4$.

The RF power that goes trough the coupler to the cavity during routine operation is 3.4 kW and is 9.6 kW during operation at highest voltage (see Table 1). However, for the fast beam turn-on an operation with pre-detuned cavity (73° off resonance) will be necessary that requires a higher RF power of 12 kW at high reflection. Similar power requirements are valid for operation with a discontinuous electron beam. For operation at the highest voltage with a discontinuous beam the RF power goes up to 23 kW that is higher than the klystron power (17.5 kW). In this case the cavity will be operated halfway detuned.

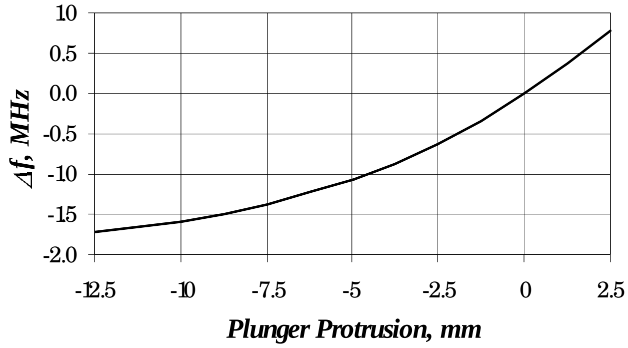

Figure 5: Tuning the cavity frequency by a plunger tuner.

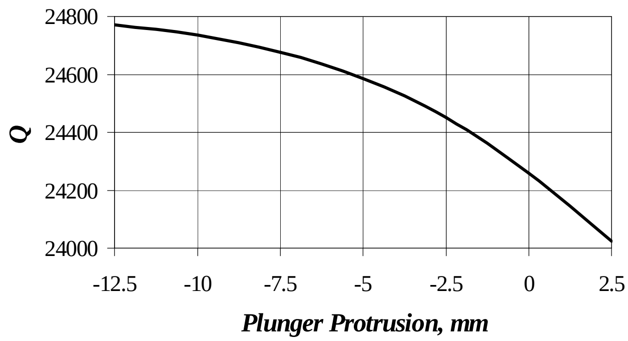

Figure 6: Cavity Q as a function of tuner position.

4 TUNERS

The cavity has two plunger type water-cooled tuners. Two tuners provide a better field symmetry on the beam axis. Only one tuner is used for routine operation, the other one is used for preliminary frequency adjustment. Figures 5 and 6 show how the cavity frequency and Q depend on tuner position. These results were calculated by the 3D computer code CST Microwave Studio® [6].

During operation, the tuner has to compensate thermal effects (roughly 400 kHz from cold cavity to maximum voltage) and beam detuning (108 kHz). That corresponds to plunger travel of 2.5 mm. The full stroke of one tuner is 10 mm that gives a tuning range of 1.6 MHz.

5 FIELDS ON BEAM AXIS

The cavity has to have very low transverse fields on the beam axis. Therefore we try to symmetrize perturbations of an ideal cavity shape: there are two tuners symmetrically placed in the horizontal plane and in the vertical plane the input coupler is balanced by a pumping port optimized to minimize the vertical kick on the electron beam.

Figure 7 presents transverse fields on the beam axis calculated by CST Microwave Studio®. Using these data, transverse kicks were calculated:

$$\frac{V_x}{V_{acc}} = \frac{\int_{-l}^{l} (E_x \sin kz + vB_y \cos kz)dz}{\int_{-l}^{l} E_z \cos(kz)dz} = 2.3\times10^{-4}\ / \ mm ,$$

$$\frac{V_y}{V_{acc}} = \frac{\int_{-l}^{l} (E_y \sin kz - vB_x \cos kz)dz}{\int_{-l}^{l} E_z \cos(kz)dz} = 3.5\times10^{-4}.$$

(The horizontal kick was calculated for the difference of positions of two tuners of 1 mm).

The values of kicks are small, they are an order of magnitude smaller than the ERL requirement (1.6×10^{-3}) [7].

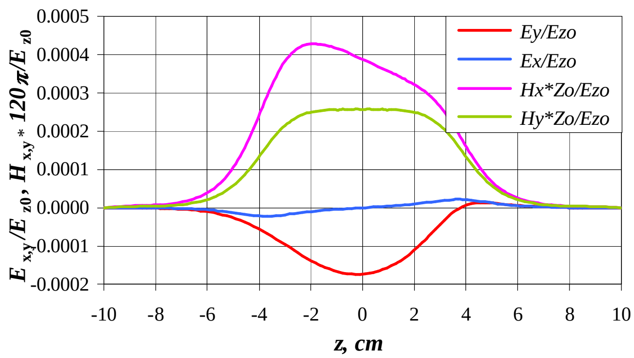

Figure 7: Transverse fields on the cavity axis for 1 mm difference of positions of two tuners.

6 HIGHER ORDER MODES

Higher order modes of the cavity were calculated and the results are presented in Figure 8 (the modes having frequencies above cut-off frequencies of the beam pipe and being able to propagate along the beam pipe are not shown). In the ERL machine electron bunches will pass the cavity at the rate of 1300 MHz. Accordingly, only modes with resonance frequencies multiple of 1300 MHz can be dangerous for the beam stability. The dashed lines in Figure 8 correspond to harmonics of 1300 MHz. As one can see, there are a few modes that seem to be close to these frequencies but they are at least 20 MHz away from dangerous harmonics. Therefore no dedicated HOM dampers are provided in the buncher cavity.

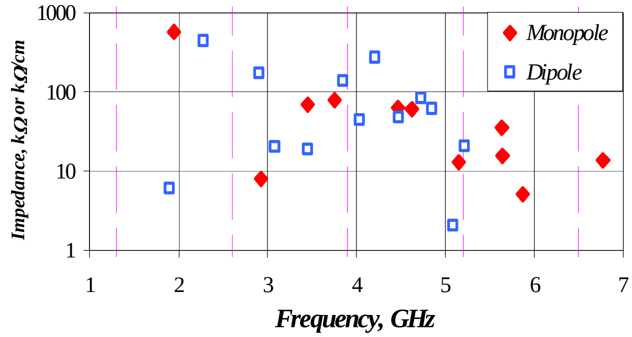

Figure 8: Calculated impedances of higher order modes.

7 CONCLUSION

A preliminary design of the buncher cavity for Cornell / JLab ERL project has been done. The cavity was optimized for getting a minimal wall loss and low transverse kick.

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