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DEVELOPMENT OF A 1.3-GHZ BUNCHER CAVITY FOR THE COMPACT ERL

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Abstract

In a high-brightness injector of the Compact ERL, a 1.3-GHz buncher cavity is used to compress the electron bunches from a photocathode DC electron gun. To produce required rf voltage of about 130 kV under extremely-low pressures, we have developed a normal-conducting cavity. In its design, we included several measures to reduce the outgas from the cavity, together with careful rf designs to avoid any rf problems. Under high-power tests, we successfully tested the buncher cavity up to an rf voltage of about 190 kV without any problem. We also achieved extremely-low pressure of about (2-3)×10^{-9} Pa when the rf voltage is less than about 130 kV.

INTRODUCTION

The Compact ERL (cERL) [1,2] is a superconducting test accelerator for the future 3-GeV energy-recovery linac project [3] at KEK. The cERL consists of a 5-MeV injector, a 30-MeV main linac, and a recirculation loop. In a 500-kV photocathode DC gun of the injector, low-emittance and high-current electron beams are produced at a bunch repetition of 1.3 GHz in CW mode. The beams pass through a buncher cavity, and then, they are accelerated up to a kinetic energy of about 5 MeV using superconducting injector cavities.

The buncher cavity is used to compress initial bunch lengths of 3-10 ps (rms) down to 1-3 ps, or shorter. The maximum rf voltage required is about 130 kV, where each bunch passes the cavity at an rf phase of 90° off crest. We define the rf voltage (V_c) as the maximum energy gain (ΔE=eV_c) of the particle having the velocity of light (v=c). Because the buncher cavity is installed adjacent to the photocathode DC gun, it should work under extremely-low pressure of about 10^{-9} Pa. To preserve the low beam emittance, the field distribution in the buncher cavity should be kept as symmetric as possible [4]. Available longitudinal space for the buncher cavity is 180 mm. We have developed a normal-conducting cavity which meets these requirements.

DESIGN OF THE CAVITY

We designed an inner shape of the buncher cavity by scaling that of an old 500-MHz accelerating cavity [5] for the PF storage ring. The geometry of the cavity is shown in Fig. 1. A resonant frequency of the cavity was calculated using simulation codes superfish [6] and CST Microwave Studio® [7]. We also estimated the frequency shifts due to several ports and to the other effects, and fed them back to the resonant frequency of bare cavity. The principal parameters of the cavity are shown in Table 1. The resonant frequency and an external-Q of an input coupler were also checked using a model cavity.

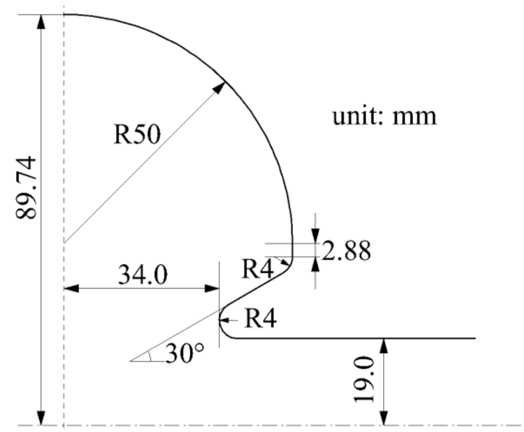

Figure 1: Inner shape of the buncher cavity.

Table 1: The Principal Parameters of the Buncher Cavity (Shunt impedance is defined by $R_{sh}=(V_c)^2/P_c$)

Resonant frequency	1.300 GHz
R_{sh}/Q (for $\beta=v/c=1$)	232.8 Ω (calc.)
R_{sh}/Q (for $\beta=v/c=0.863$)	194.7 Ω (calc.)
R_{sh}/Q (for $\beta=v/c=0.824$)	181.3 Ω (calc.)
Shunt impedance R_{sh} (for $\beta=v/c=1$)	5.33 MΩ
Unloaded-Q Q_0	22900 (meas.)
External-Q of input coupler Q_{ex}	21100 (meas.)
Coupling of input coupler	1.08 (meas.)
Maximum cavity voltage (V_c) for usual operation	130 kV
Dissipated power in cavity P_c (at V_c=130 kV)	3.17 kW
Maximum cavity voltage during conditioning (at P_c=7 kW)	193 kV

We also calculated the frequencies of higher-order modes (HOMs). We confirmed that all frequencies of the monopole and dipoles modes below the cutoff frequencies of the beam port are apart from the harmonics of 1.3 GHz by at least 74 MHz. This ensures that no resonant excitation happens under CW operation.

At the maximum rf voltage of 130 kV, the maximum power density on the inner wall is 6.9 W/cm², while the maximum electric field is 4.8 MV/m. These values are well within our experience of the PF accelerating cavity.

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Taking a margin, we decided the maximum dissipated power in the cavity during conditioning to be 7 kW, and designed cooling-water channels.

A mechanical design of the buncher cavity is shown in Fig. 2. The cavity body is made of oxygen-free high-conductivity copper (OFHC), and vacuum flanges and parts of the ports are made of stainless steel.

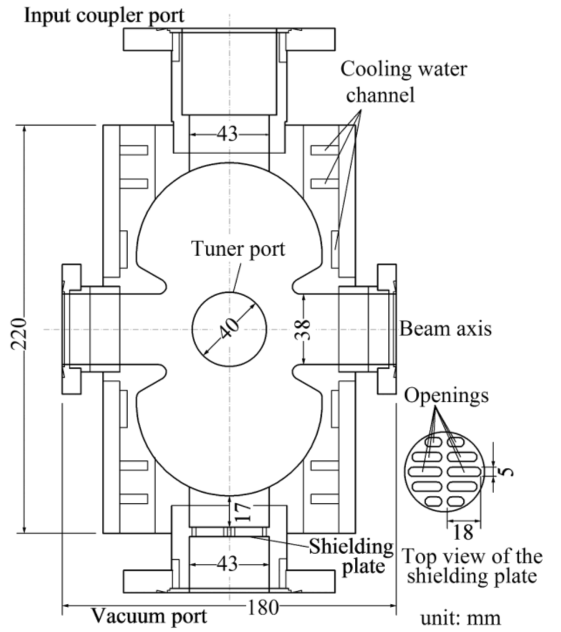

Figure 2: Cross section of the buncher cavity.

Two ports (inner diameter: 43 mm) for an input coupler and for a vacuum pump are located at the top and the bottom of the cavity, respectively. An rf-shielding plate with pumping slots is built into the vacuum port. We optimized the location of the rf-shielding plate using a simulation code CST Microwave Studio® [7] so that asymmetry of the rf field due to the input coupler can be compensated by the vacuum port [4].

Ports (inner diameter: 40 mm) for a movable tuner and for a fixed tuner are located in the right and left sides of the cavity. After the fabrication, we adjusted the dimension of the fixed tuner so that it has approximately the same protrusion (4.17 mm from the inner surface) as that of the movable tuner under high-power operations. This compensates asymmetry of the rf field due to the tuner [4]. We have chosen a gap of 0.7 mm between the tuning plunger and the tuner port, by which we can avoid multipacting. These tuners are made of OFHC, and cooled by water. The movable tuner has a stroke of 15 mm that corresponds to a tuning range of 4.6 MHz. The movable tuner was designed so that it has as low outgas as possible. The cavity has also two small ports (inner diameter: 11.4 mm) for field probes.

DESIGN OF THE INPUT COUPLER

We chose a loop-type coupler with a cylindrical ceramic window and a coaxial-to-waveguide transformer, as shown in Fig. 3. Basic dimensions were roughly determined by scaling those of a proven 500-MHz coupler for the PF storage ring except for the thickness (5 mm) of the ceramic window, and they were optimized using a simulation code HFSS [8]. To match the waveguide to the coaxial line, we considered three designs, and chose the design in Fig. 3 because it showed relatively uniform electric fields around the ceramic window.

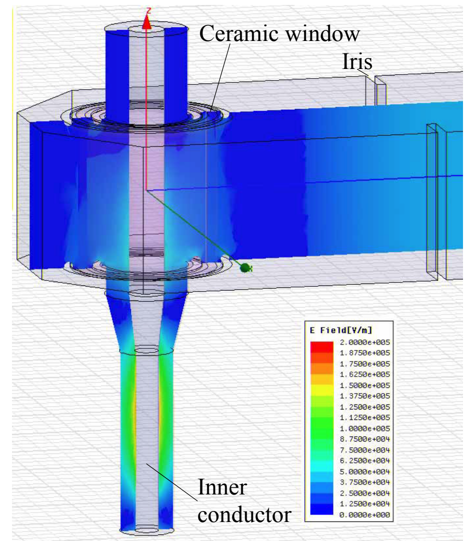

Figure 3: Design of the input coupler with its electric field distribution that is calculated by the HFSS code.

With the designed dimensions, we checked that we can avoid multipacting of 1/2-cycle under operating conditions. To evacuate possible gas pockets at the junction of an outer conductor, we put some holes having a diameter of 2 mm.

Because the beam loading is zero in the buncher cavity, an external-Q of the input coupler was adjusted nearly equal to the unloaded-Q of the cavity. To adjust the external-Q, the loop of the input coupler was mounted at an angle of about 45 degrees to the beam axis. We determined by simulations that the top of the loop is apart from the inner surface of the cavity by 11.4 mm (cave).

INSTALLATION OF THE CAVITY

Prior to the assembly, each component of the cavity was separately baked at 150°C for one week. Then, we assembled the buncher cavity together with the neighboring two chambers in a clean room, and baked the assembled unit for one week. We then installed it into the injector using a local clean hut. After a low-power measurement, we baked the buncher section of the injector at 150°C. Figure 4 shows the buncher cavity after the installation; the gun and the injector module are located at the left and right sides in Fig. 4, respectively.

HIGH POWER TEST

After the assembly and bake-out of the buncher section, we carried out high-power test in February, 2013. Figure 5 shows the progress in the first high-power test. An interlock level of the cavity vacuum was set to 6.5×10^{-6}

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Pa during the test. After three hours, we could input the maximum rf power of about 7 kW into the cavity. After the conditioning for a few days, we could keep base pressure of 3×10^{-9} Pa (measured at a neighboring mirror chamber) when the rf voltage was less than 130 kV.

Figure 6 shows calculated temperature distribution (color map) of the cavity at a dissipated power of 7 kW; measured and calculated temperature rises (ΔT) are also shown. The measured temperature rises during the high-power test agreed well with those calculated.

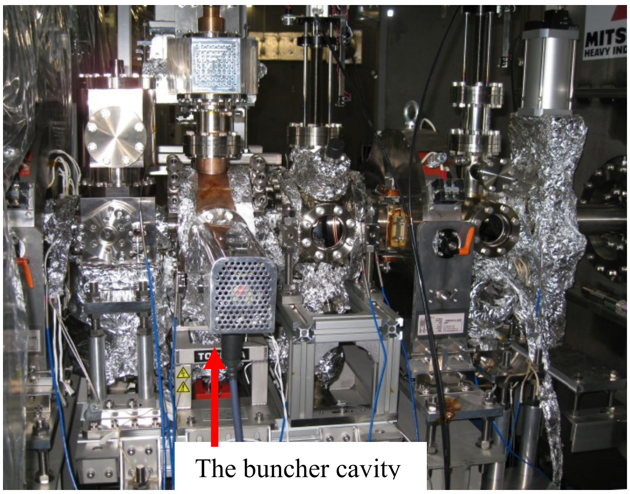

Figure 4: The buncher cavity as installed in the injector.

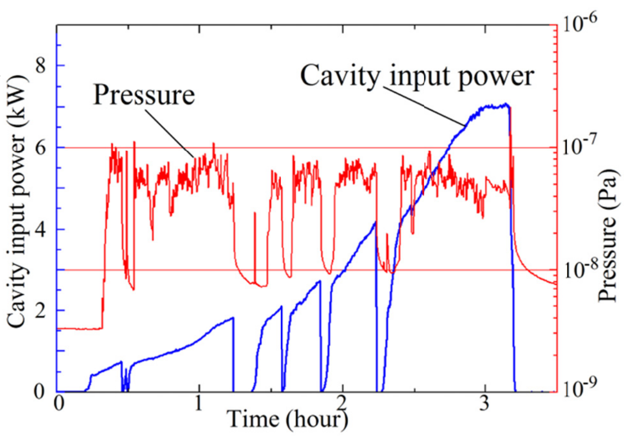

Figure 5: Input power to the cavity (kW) and pressure in the cavity (Pa) during the first high-power test.

BEAM OPERATION

The cERL injector was commissioned in April, 2013 [9]. During the commissioning, we demonstrated that an initial bunch length of approximately 10 ps (FWHM) could be compressed down to 0.5 ps (rms) at an exit of the injector; an applied buncher voltage was 30 kV with 90° off-crest phase under low bunch charges. Under the present cERL operations from May to June, 2014, the buncher cavity is routinely used very stably; typical rf voltage is 30 kV (for low charges below 0.1 pC/bunch) with a typical pressure of about $(2\text{-}3)\times10^{-9}$ Pa.

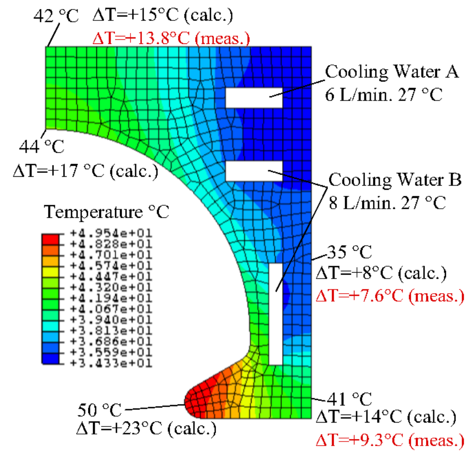

Figure 6: Calculated and measured temperatures of the cavity at the dissipated power of 7 kW.

CONCLUSION

We developed a buncher cavity for the cERL injector. The buncher cavity can produce the maximum rf voltage of 190 kV with an input power of 7 kW. The base pressure of the cavity is about $(2\text{-}3)\times10^{-9}$ Pa, and we can keep this pressure when an rf voltage is less than about 130 kV. The buncher cavity is routinely used under the present operations [1,2] of the cERL.

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