DEVELOPMENT OF A PHOTOCATHODE RF GUN FOR AN L-BAND ELECTRON LINAC

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Abstract

We have begun development of the L-band photo-cathode RF gun for the L-band linac at ISIR, Osaka University to advance studies with the high-intensity and low emittance electron beam, in collaboration with KEK and Hiroshima University. As the fist step, we plan to develop and commission the L-band RF electron gun for the Superconducting RF Test Facility at the High Energy Accelerator Research Organization. While waiting for delivery of an RF cavity and an input coupler from the Fermi National Accelerator Laboratory, we are preparing for the low lever RF measurement. Some results of the preparatory works are reported, including computer simulation for tuning of RF characteristics of the cavity, design of an input coupler for low level RF measurement, and computer simulation to evaluate characteristics of the accelerated electron beam.

INTRODUCTION

We conduct experiments on radiation chemistry by means of pulse radiolysis and basic study on Self-Amplified Spontaneous Emission (SASE) in the far-infrared region using a high-intensity single-bunch electron beam from the 40 MeV, L-band electron linac at the Institute of Scientific and Industrial Research (ISIR), Osaka University. The linac is equipped with a DC 100 kV thermionic electron gun and can accelerate the single bunch electron beam with charge up to 91 nC.

A project to develop and use an L-band photo-cathode RF gun is being conducted at the Superconducting RF Test Facility (STF) at High Energy Accelerator Research Organization (KEK), which is a facility to develop accelerator technology necessary for construction of the main linac of the International Linear Collider (ILC). The aim of the project is to evaluate performance of superconducting accelerating structures using a multi-bunch electron beam that meets specifications given by ILC. A 1.5 cell L-band RF electron gun to produce such an electron beam is being fabricated currently at Fermi National Accelerator Laboratory (FNAL) in USA for the experiment.

In order to advance the studies at ISIR, Osaka University further in future, we joined the project in 2008 and began development of an L-band photo-cathode RF electron gun, which can produce a high-intensity and low emittance electron beam, in collaboration with KEK and Hiroshima University. We will evaluate RF performance of the cavity to be made at FNAL at a low RF level and then will conduct its high power test. In parallel with the activities, we plan to design an L-band RF electron gun optimized for the L-band linac at Osaka University based on results of the measurement and computer simulation for the FNAL gun.

We currently study how to tune the resonance frequency of the cavity, 1.3 GHz in the π mode, by calculating relations of the frequency and field balance between the half cell and the full cell with variations of the cavity shape and dimensions. We have also begun on design and fabrication of an RF coupler of the coaxial feed type to be used in the low level RF measurement. In this paper, we will report results of electric field calculation for the cavity of the electron gun being made at FNAL, progress of preparation for the low level RF measurement, and results of evaluation of electron beam characteristics calculated with PARMELA.

L-BAND RF GUN

Cavity for Electron Gun

We begin design study of a cavity for the L-band RF electron gun of the resonance frequency 1300 MHz, based on the design of the 1.5 cell RF cavity being fabricated at FNAL. The L-band RF cavity adopts the same design of the cavity used for the XFEL project in Europe, which has been designed by scaling the cavity for the S-band RF electron gun developed at BNL [1] up to the L-band. Cooling water channels of the cavity are reinforced to endure the high duty cycle RF power [2], and a coaxial RF coupler is adopted to make axial symmetry of the

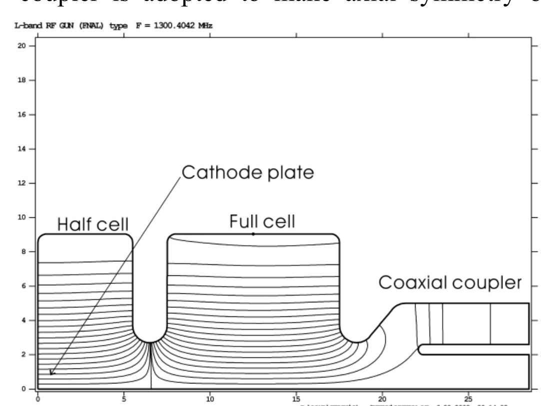

Figure 1: Electric field distribution of the π mode in the L-band RF electron gun.

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electric field higher in the cavity. In any way, the side wall of the cavity is occupied with water channels for cooling and there is no space to install an RF coupler on the wall like the BNL design. Figure 1 shows the shape of the cavity of the L-band RF electron gun and the distribution of the electric field in the π mode calculated with SuperFish [3]. The principal dimensions are as follows; lengths of the half and the full cells are 55 and 100 mm, respectively, the diameter of the cells (2b) is ~180 mm, and the radius of the disk (2a) and the downstream aperture of the full cell is ~54 mm.

Frequency Tuning

The final tuning of the FNAL cavity will be made at KEK. The resonance frequency will be adjusted by varying the temperature of the cooling water and the ratio of electric fields in the half cell and the full cell is adjusted by mechanically pressing the cathode wall and the downstream wall of the full cell.

We calculate the frequency variation as a function of the cavity diameter (2b) with SuperFish. The resonance frequency becomes lower by ~15.02 MHz for increase of the radius (b) by 1 mm. The resonance frequency is inversely proportional to the cavity size, provided that the shape is similar, and the cavity size varies with its temperature due to thermal expansion. By taking into account the linear thermal expansion coefficient of copper of $\alpha = 1.6\times10^{-5}$ (1/K), it follows that increasing cooling water temperature by 1°C results in lowering the resonance frequency by 24 kHz. This temperature dependence of the frequency agrees well with the value –22 kHz/°C measured experimentally at DESY. Similarly, we calculate how much the field balance can be changed by pressing the wall for the cathode. As can be seen in Fig. 2, the field ratio varies by 10 % when the length of the half cell is varied by 1 mm. Practically it is not possible to change the cell length more than a few 100 µm, so that the tunable range of the field balance is anticipated to be within a few %.

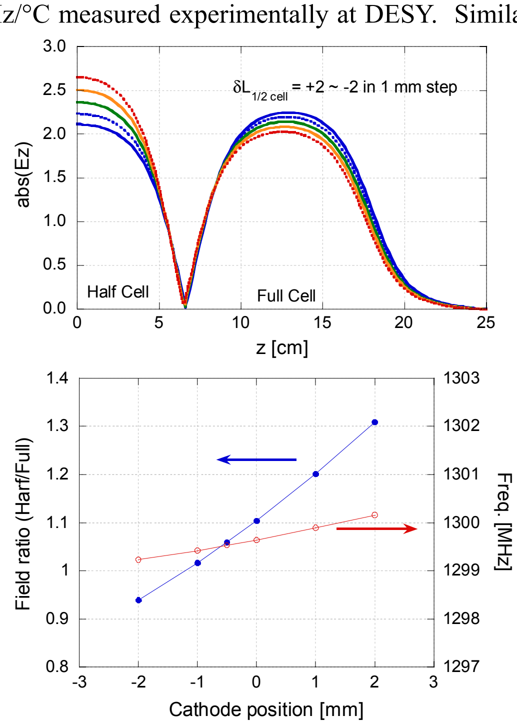

Figure 2: Electric fields on the beam axis for lengths of the half cell varied from –2 to +2 mm in a 1 mm step (top), and the field balance and the resonance frequency as a function of the cathode position (bottom).

Coaxial Waveguide Converter

As mentioned above, a coaxial type coupler is used to supply the RF power to the cavity of the RF electron gun. The RF power coming from a source through a rectangular waveguide in the TE01 mode is converted to the TEM mode in the coaxial waveguide using a doorknob type coaxial waveguide converter. The coaxial coupler including this converter will be made at FNAL, but delivery time will be later that that of the cavity, so that we have decided to make a coaxial waveguide converter for the low RF level measurement and the structure of the converter is studied with HFSS [2].

In the design of FNAL, he shorting plate of the waveguide is too close to the center of the coaxial line, so that a part of the doorknob is cut. To make machining of the coupler we will make for the low RF level measurement easier, we study another type of the converter, in which the shorting plate is set enough away

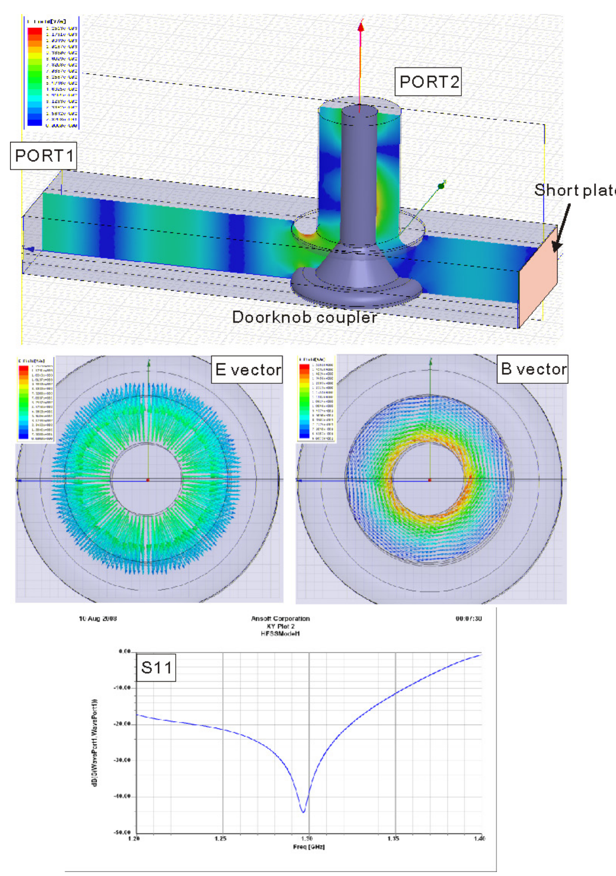

Figure 3: New design of the coupler (top), the electric and the magnetic field distributions at port 2 (middle), and the frequency dependence of S11 (bottom).

from the doorknob so that they do not interfere with each other. Figure 3 shows a three-dimensional drawing of the new type of the converter, the electric and the magnetic field distributions at port 2, and the frequency dependence of S11. In this calculation with HFSS, the shape and sizes of the doorknob are same as those of the FNAL design and the position of the shorting plate is determined to be 223 mm from the center of the coaxial waveguide so that reflection to the input is minimized or S11 becomes minimum. The function of the shorting plate as a capacitive stub is reduced because the plate is apart from the center of the coaxial waveguide, and it is conceivable that the plate works for reflection correction. Although the total length of the waveguide becomes slightly longer than that of the FNAL design, we will make the input coupler with the shorting plate apart from the coaxial waveguide as shown in Fig. 3.

BEAM SIMULATION

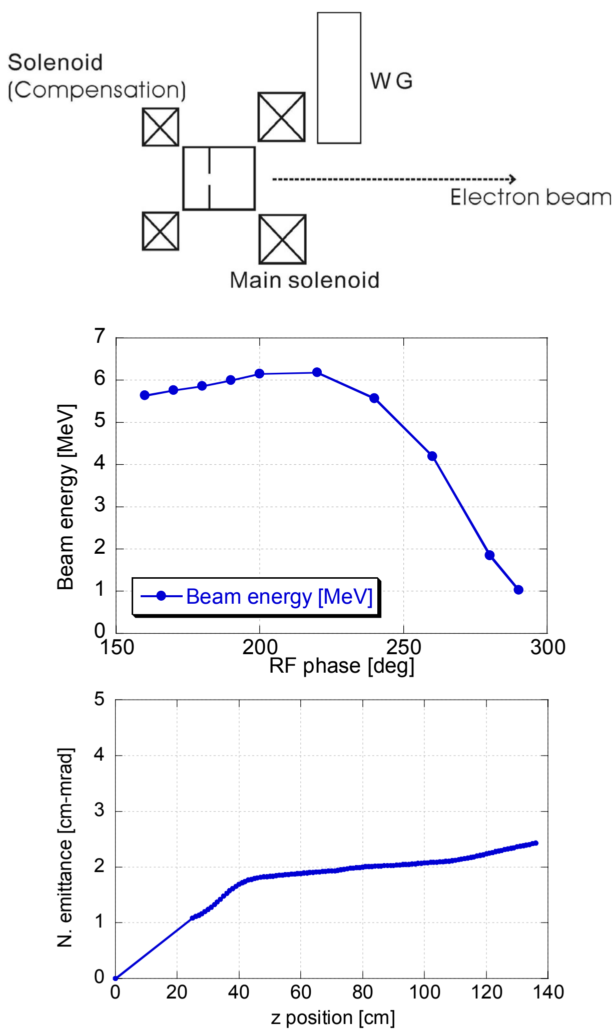

Figure 4: Schematic drawing of the beam line used for calculation with PARMELA (top), beam energy at the exit of the RF gun as a function of the injection phase of the laser (middle), and the normalized emittance in the horizontal direction along the beam line (bottom).

We conduct computer simulation of the beam acceleration with the designed L-band RF electron gun using the computer code, PARMELA. It is assumed that the beam line consists of the cavity for the RF gun, a solenoid coil for emittance correction, and a correction solenoid coil to cancel the magnetic field on the cathode, called as the backing coil, as shown at the top of Fig. 4.

When the electric field is assumed to be 60 MV/m at the cathode, the energy gain in the RF gun is calculated to be ~6.2 MeV at maximum. Figure 4 shows the relation between the injection phase of laser and the energy gain, and an example of the normalized emittance calculated along the beam axis, though parameters such as positions of the coils and strengths of their magnetic fields are not optimized. Values of the parameters used in the calculation are charge 1 nC, the radius of the laser beam 1 mm (σ), the pulse duration 10 ps (σ), the injection phase of the laser 220°, and the magnetic field in the solenoid coil 1400 G. It is reported that the normalized transverse emittance of 3 π mm·mrad is realized for the charge 1 nC at PITZ (Photo Injector Test Facility at DESY Zeuthen) in Germany [2]. We plan to continue the calculation to optimize the parameters such as the beam size at the cathode, the pulse duration, the injection phase of the laser, and magnetic fields of the solenoid coils.

Because the coaxial coupler is adopted in this L-band RF electron gun, the bore radius of the solenoid coil for emittance correction becomes larger and consequently the gradient of the longitudinal magnetic field dBz/dz is significantly enhanced at ends of the solenoid coil, which deteriorates the emittance of the accelerated beam. It is also impossible to completely diminish and cancel the gradient of the radial magnetic field dBr/dr at the cathode using the backing coil. It is, therefore, important to optimize design and arrangement of the solenoid coils, and dimensions of the coaxial waveguide, especially the radius of the outer conductor. We will conduct thermal calculation of the RF cavity and study new arrangement of cooling water channels, and we will, based on these studies, investigate possibility to install a frequency tuner on the sidewall of the RF cavity.

ACKNOWLEDGEMENTS

We thank Dr. Ken Watanabe of KEK for his advice on calculation with HFSS. This study is supported by the program of KEK in fiscal year 2008, "Comprehensive Support Program for the Promotion of Accelerator Science and Technology".

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