

DEVELOPMENT OF A PHOTOCATHODE RF GUN FOR THE L-BAND LINAC AT ISIR, OSAKA UNIVERSITY

S. Kashiwagi[#], K. Furuhashi, G. Isoyama, R. Kato, Y. Morio, N. Sugimoto, Y. Terasawa,
 ISIR, Osaka University, Ibaraki, 8-1 Osaka 567-0047, Japan
 H. Hayano, H. Sugiyama, Y. Takahashi, T. Takatomi, J. Urakawa,
 KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
 H. Iijima and M. Kuriki
 AdSM, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8511, Japan

Abstract

The L-band photo-cathode RF gun is being developed for the L-band electron linac at Osaka University, which also meets the specifications for the International Linear Collider Project. The critical issue of the RF gun is the high average power input. The cooling-water system of the RF gun cavity is designed and its performance is studied with simulation for thermal analysis. It is shown that the cooling system works well as designed. The DESY-type L-band RF gun is being commissioned at KEK. Reported are the present status of the commissioning of the RF gun and the construction of the injection beam line of the Superconducting RF Test Facility at KEK.

INTRODUCTION

We are developing the L-band photo-cathode RF gun in collaboration between the Institute of Scientific and Industrial Research (ISIR), Osaka University, High Energy Accelerator Organization (KEK), Hiroshima University. The 40 MeV, 1.3 GHz L-band electron linac at ISIR, Osaka University can accelerate a high-intensity single-bunch electron beam with charge 30 nC/bunch using the thermionic electron gun and the 3-stage sub-harmonic buncher system for SASE experiment [1] and pulse radiolysis experiment [2], but its normalized emittance is high. In order to advance these studies, we plan to replace the present injector system with a photo-cathode RF gun. The RF gun will be also used for the Superconducting RF Test Facility of KEK (KEK-STF) [3], so that it has to meet the specifications required for the International Linear Collider (ILC) Project. The RF gun must be stably operated for the input RF power of 5 MW with the 1 ms duration at the repetition rate of 5 Hz, resulting in the average input power of 25 kW, to produce a long multi-bunch electron beam. The critical issue is the heat load due to the high power input. The heat produced on the cavity wall has to be efficiently removed to suppress the expansion and the deformation of cavity. We are developing the water-cooling system for the L-band RF gun.

In parallel to the study to develop the new RF gun, we are commission the DESY-type L-band RF gun [4] at

KEK-STF, which was fabricated at the Fermi National Accelerator Laboratory (FNAL). The resonant frequency and the field balance of the RF gun cavity were adjusted at KEK-STF. We will conduct a beam acceleration experiment with the RF gun at KEK-STF for ILC.

In this paper, we will report the basic design of the L-band RF gun cavity and its thermal analysis and the present status of the commissioning of the DESY-type RF gun and construction of the injection beam line for KEK-STF.

L-BAND RF GUN DEVELOPMENT

Conceptual Design

The L-band RF gun under development is a 1.5 cell normal conducting RF gun, design of which is based on the RF gun for the European XFEL [5] developed at DESY. The cooling performance of the RF cavity is enhanced with many water channels in the cavity wall so that it can be stably operated at a high duty factor. Figure 1 shows a half cutaway view of the RF gun cavity. The RF power is fed using a coaxial coupler to be attached at the exit of the RF gun.

We consider tolerances for temperature rises of the gun cavity and cooling water in the steady state. The frequency shift produced by the temperature change of the cavity is approximately $-24 \text{ kHz}/^\circ\text{C}$ estimated with the RF wavelength and the coefficient of linear thermal expansion of copper, while the value experimentally measured at DESY is $-22 \text{ kHz}/^\circ\text{C}$ [6]. The frequency shift due to the temperature rise of the cavity must be smaller than the resonant bandwidth of the cavity (Δf). The bandwidth is obtained from the loaded Q value ($Q_L = \sim 11,500$) and the resonant frequency of the cavity ($f_0 = 1.3 \text{ GHz}$). This bandwidth corresponds to an approximately $4.7 \text{ }^\circ\text{C}$ change in temperature of the cavity body, so that the temperature increase of the cavity body due to the RF power input must be less than approximately $5 \text{ }^\circ\text{C}$ ($\Delta T_{\text{cav}} < 5 \text{ }^\circ\text{C}$). The expansion of the cylindrical wall of the cavity has an especially large impact on the frequency shift.

If the temperature of cooling water increases by a value comparable to the temperature rise of the cavity body owing to its cooling, the temperature of the cavity may not be uniform, resulting in non-uniform deformation of the cavity due to thermal expansion. The temperature rise

[#]Present address: Research Center for Electron Photon Science, Tohoku University, 1-2-1 Mikamine, Taihaku-ku, Sendai, Miyagi 982-0826, Japan, kashiwagi@lns.tohoku.ac.jp

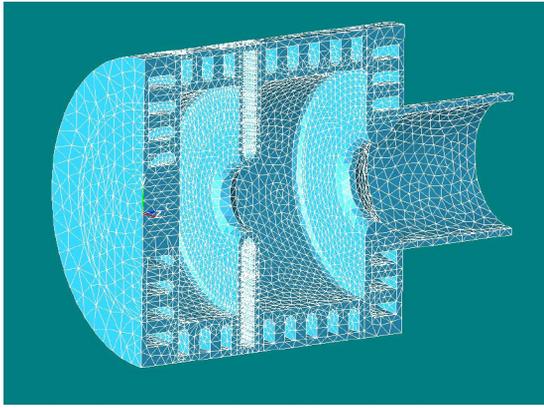


Figure 1: Half cutaway view of the L-band RF gun cavity.

of the cooling water at the exit of the cooling channel in the cavity should be sufficiently less than ΔT_{cav} .

Water Cooling System

The distributions of the cooling water channels and their cross sectional shapes and sizes have to be optimized to make the temperature rise in the cavity body uniform. We divided the cavity body into five parts; the end plate for the cathode, the cylindrical part of the half cell, the disk or iris wall part, the cylindrical part of the full cell, and the other end plate. The distribution of the power dissipation on the cavity wall is calculated as shown in Fig. 2(b) using SUPERFISH code. The average temperature rise at each part can be estimated by $\Delta T = P / (h \times S_{surf})$, where P is the dissipated power, h the heat conductivity from copper to water, and S_{surf} the inner surface area of water channel (S_{surf}). The heat conductivity (h) is calculated by $h = k_{water} \cdot (N_u / d_c)$ [$W/m^2 \cdot K$], where $k_{water} = 0.6245$ [$W/(m \cdot K)$] is the heat conductivity of water, N_u is the Nusselt number ($143.7 = 0.023 \times Re^{0.8} \times Pr^{0.4}$ with $Re = 2.578 \times 10^4$ being the Reynolds number and $Pr = 4.642$ the Prandtl number), and the d_c is the effective diameter of the water channel. In the calculation, the flow rate of cooling water is assumed to be 2 m/s. The number of parallel cooling channels was finally determined to be 16 for the whole cavity, as shown in Figure 1, and the total flow rate of

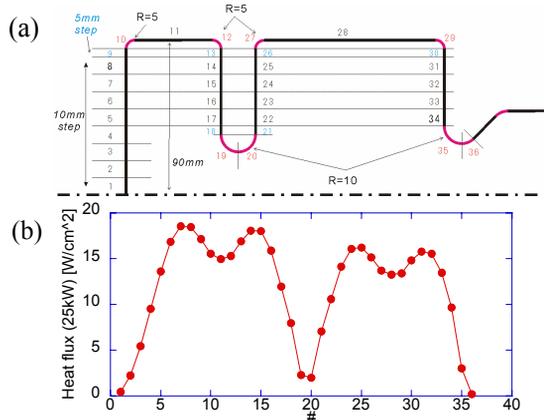


Figure 2: (a) Divided areas of the cavity inner wall with numbers. (b) Distribution of the heat flux density for the input power of 25 kW.

02 Synchrotron Light Sources and FELs

T02 Lepton Sources

cooling water is required to be about 490 liter/minute. In particular, the wall of the water channel in the disk part is serrated to enhance the heat conductivity from copper to water for making the temperature rise in the part as low as in the other parts.

Numerical Simulation

To confirm performance of the designed cooling system quantitatively, the temperature distribution and deformation of the cavity with the RF input are calculated using the AMPS code for the steady state thermal conductivity analysis. In calculation, the inner-wall of the cavity is divided to 36 areas as shown in Fig. 2(a) and the constant input power density is assumed for each area, as shown in Fig. 2(b) with the red circle.

Figure 3 shows the calculated temperature distribution of the L-band RF gun cavity. The initial temperature (T_i) of the cavity and the cooling water is assumed to be 25 °C, and the average input power (P_{ave}) is 25 kW. Figure 4 shows the displacement of the cavity in radial direction (Y direction in AMPS) and the deformation model at a magnification of 1000. The temperature on the cylindrical wall of the half and full cells rises by about 4 °C as shown in Fig. 3. The displacement of expansion in radial direction of the wall is 4~4.5 μm , which produces the frequency shift of -58~65 kHz. This frequency shift caused by expansion of cavity body is smaller than the limit set by Q_L , ~113 kHz. The maximum temperature rise is approximately 6.8 °C in the end plates on the cathode side and the beam exit side. The displacement of the end plates also produces the frequency shift. The displacement of each plate is calculated to be approximately 5 μm and the frequency shift due to the deformation of the end plates is estimated to be -14 kHz by using SUPERFISH. The balance of the electric field between the half and the full cells will vary little, because deformations of the two end plates are nearly symmetric. The disk part is also slightly distorted as can be seen in Figure 4 (b). The disk with one large water channel inside becomes symmetrically thinner near its root to the cylinder part by ~10 μm , producing a frequency shift of ~10 kHz. It is shown from this simulation that the present designed of the cooling water system meets the

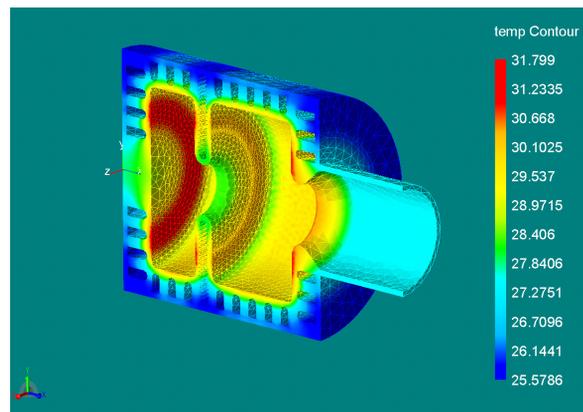


Figure 3: Temperature distribution of the L-band RF gun cavity calculated for $P_{ave} = 25kW$ at $T_i = 25^\circ C$.

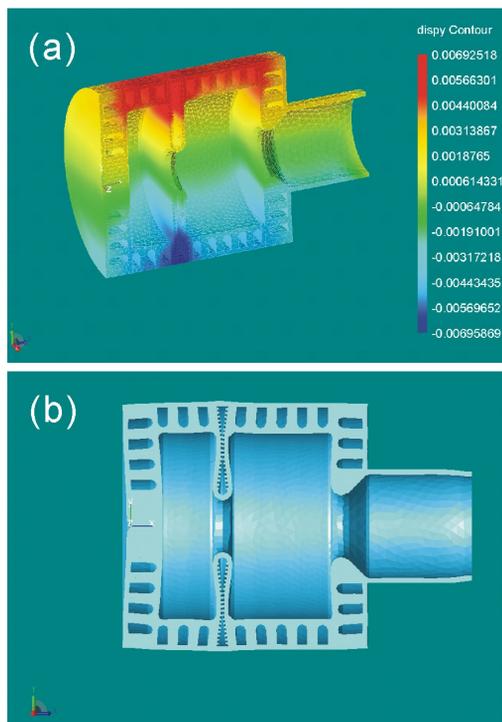


Figure 4: (a) Displacements in the radial direction. (b) Deformation model ($\times 1000$).

specifications that the average temperature rise of the cavity should be less than $\sim 5^\circ\text{C}$ for the input RF power of 25kW and local deformations of the cavity should be sufficiently small not to generate a frequency shift comparable to that produced by the average temperature rise. The frequency shift produced by the small temperature rise in the steady state can be compensated for by slightly changing the temperature of cooling water.

RF GUN FOR STF

The main body of the L-band RF cavity for STF-KEK was fabricated at FNAL. The resonant frequency of the RF gun was tuned to be 1300.00MHz at the operation temperature of 51.5°C at KEK. The temperature dependence of the resonant frequency for the cooling water was experimentally measured to be $-21.9\text{ kHz}/^\circ\text{C}$. The Q_0 value is 23,000 and the coupling (β) was adjusted to 1.0 by inserting a 5 mm thick spacer flange between the gun cavity and the waveguide coupler. The L-band RF gun was installed on the STF beam line in March 2010. Figure 5 shows the STF injector, in which the RF gun cavity with the solenoid magnet and the load-lock system for the Cs_2Te cathode are installed on the accelerator table. The L-band RF gun system will be used in the upcoming Quantum Beam experiment and in STF Phase-2 to follow the S1-Global experiment, which is currently under preparation. Now RF processing of the gun cavity is going on for the beam acceleration experiment of STF.

The injector part of the STF beam line consists of the L-band photocathode RF gun, the emittance compensation solenoid, a chicane section, a quadrupole magnet, the second solenoid, and two 9-cells



Figure 5: The L-band rf gun system at KEK-STF injector.

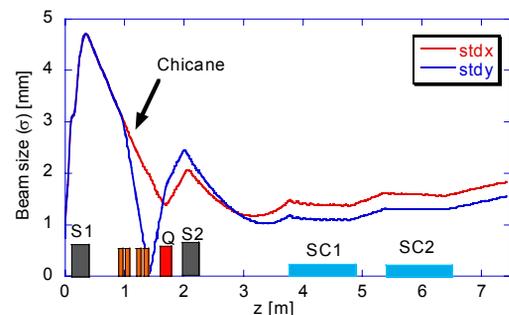


Figure 6: Transverse beam size along the beam line of the STF injector section.

superconducting accelerating structure. The chicane section, which consists of four rectangular dipole magnets, beam slits, beam profile and beam position monitors, is installed to cut a dark current from the RF gun cavity and to measure the beam properties. Figure 6 shows the beam envelope calculated using GPT. The quadrupole is installed downstream of the chicane to control the focusing balance in transverse directions and the second solenoid make the waist at the entrance of first superconducting structure. The production of beam line components completed and they will be installed this year for the beam experiment.

ACKNOWLEDGMENTS

The authors would like to thank Messrs T. Nishidono and K. Watanabe, Miss K. Horiuchi of Komiyama Electron Co., Ltd. for their help in the fabrication and the simulation. This study is partly supported by the Supporting Program for Universities in the General Supporting Program on Accelerator Sciences of KEK.

REFERENCES

- [1] R. Kato, et al., Nucl. Instr. and Meth. A 483 (2002) 46.
- [2] T. Kozawa, et al., Nucl. Instr. and Meth. A 440 (2000) 251.
- [3] <http://lcdev.kek.jp/STF/>
- [4] K. Flöttmann, et al., Nucl. Instr. and Meth. A 393 (1997) 93.
- [5] <http://www.xfel.eu/>
- [6] K. Flöttmann, private communication.