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HORIZONTAL TEST RESULTS OF 1.3 GHz SUPERCONDUCTING RF GUN #2 AT KEK

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Abstract

Superconducting radio-frequency (SRF) electron guns are attractive for delivery of beams at a high bunch repetition rate with a high accelerating field. The SRF gun with 1.5 cell has been developing at KEK to demonstrate fundamental performance. The SRF gun consists of 1.3 GHz SRF gun cavity and multi-alkali photocathode coated on 2 K cathode plug. In the vertical test of the gun cavity, the surface peak electric field and the surface peak magnetic field reached to 75 MV/m and 170 mT, respectively. The SRF gun was installed into the horizontal multipurpose cryostat equipped with a superconducting solenoid, photocathode preparation chamber and beam diagnostic line. The peak surface gradient dropped to 42 MV/m. This was probably due to particulate issued that entered the cavity during assembly. The results in the horizontal test are presented in this paper.

INTRODUCTION

The design of a superconducting RF gun has been started at KEK for demonstration of fundamental performance based on the beam parameters of the KEK ERL project [1]. The gun consists of a 1.3 GHz, 1.5-cell niobium SRF cavity and a niobium cathode plug cooled down to 2 K. A prototype cavity (gun #1) was developed for demonstrate high gradient performance in vertical test. Optimized surface treatment methods for gun cavity shape were developed. a maximum surface electric field of 75 MV/m and a maximum surface magnetic field of 170 mT were achieved [2]. The KEK SRF gun #2 is designed to demonstrate high gradient performance with small current beam operation. RF design of gun #2 is same as gun #1. A helium jacket with frequency tuner, a superconducting magnet, and a 90-degree bending magnet were designed and fabricated. A beam line was designed to measure beam emittance and beam energy.

DESIGN OF KEK SRF GUN #2

Figure 1 shows the structure of the superconducting RF electron gun, which consists of a 1.3 GHz, 1.5-cell niobium superconducting RF accelerating cavity, a niobium cathode plug, and a choke cell to stop RF leakage from the cathode plug side. The cathode plug is removable and cooled by conduction cooling from the holder in 2 K helium bath of the cavity. The helium jacket covers the cavity and the cathode plug holder. The jacket has a bellows to tune the cavity frequency and inside double bellows to adjust the position of the cathode plug. The frequency tuner is attached to the helium jacket.

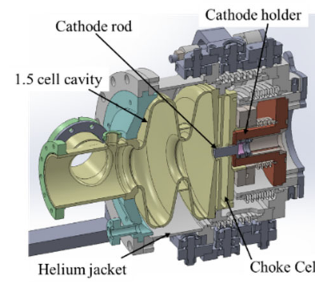

Figure 1: Structure of the KEK SRF gun #2.

Figure 2 shows the electromagnetic field distribution on the axis and surface of the superconducting RF electron gun. Because static magnetic field cannot penetrate superconducting wall, the beam is focused by the accelerating electric field distribution. In addition, the cell length of the second cell is shortened to prevent deceleration due to the RF leakage electric field. The acceleration voltage of the second cell is set low to achieve an acceleration voltage of 2 MV.

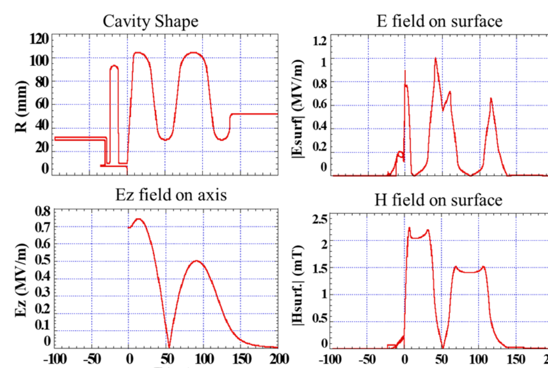

Figure 2: RF field distribution of the KEK SRF gun #2.

Table1: RF Parameters of KEK SRF Gun #2

Parameter	Value
RF frequency	1.3 GHz
Accelerating Voltage (Vc)	2 MV
Geometrical Factor	133.1 W
Surface Peak Electric Field (E_{sp}) @Vc=2MV	41.9 MV/m
Surface Peak Magnetic Field (H_{sp}) @Vc=2MV	92.4 mT
H_{sp}/E_{sp}	2.2 mT/(MV/m)
Z_{ESP} *	241.3

$*E_{sp} = Z_{ESP}\sqrt{Q_0 P_{loss}}$

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Table 1 shows RF parameters of the gun #2. The target acceleration voltage is 2 MV, at which the maximum surface electric field is 41.9 MV/m and the maximum surface magnetic field is 92.4 mT. This is approximately half of RF critical field. Figure 3 shows the results of vertical tests with and without cathode plugs. The maximum surface electric field reached to 75 MV/m without the cathode plug. However, both the maximum acceleration field and Q-value were lower with the cathode plug. This was due to insufficient tuning of the choke frequency and field emission (FE). Since the onset of FE was higher than the target value, test shifted to the horizontal test.

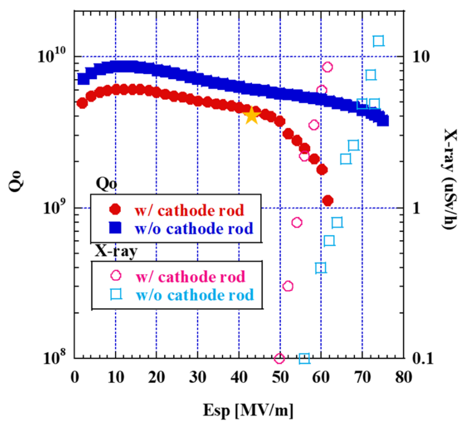

Figure 3: Vertical test results of KEK SRF gun #2.

FREQUENCY TUNER

The frequency tuner has two stages: a mechanical coarse tuner that moves in the 450 kHz range and a fine tuner with a piezoelectric element that moves in the 200 Hz range. A mechanics diagram of the mechanical tuner is shown in Fig. 4. Figure 5 shows a photograph of the frequency tuner. The points shown in the Fig. 5 correspond to the points of Fig. 4. Point O is fixed to the fixed end side of the cavity and point C is the free end side. The line OC is the length of the cavity. Point A, which is located halfway between points O and C, is placed slightly off the line OC. Since point D moves parallel to line CO and the length of line AD is fixed, the length of line CO changes as point D moves. Point D can be driven from outside the cryomodule. Since this structure can be placed along the helium jacket, it saves space and is suitable for the horizontal test cryostat with restrictions on overall length and outer diameter.

Figure 6 shows the results of the operation test at room temperature. The horizontal axis is the number of revolutions of the trapezoidal screw at point D. Between the point O and the cavity of the coarse tuner, a piezo motor is mounted. The other side of the Fig. 5 has same structure and a total of two piezo motors are mounted.

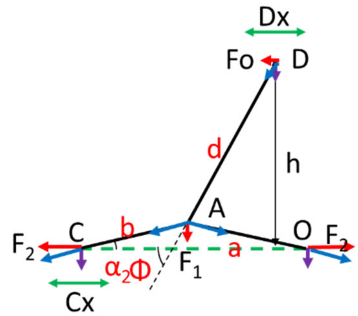

Figure 4: Mechanics diagram and picture of mechanical tuner.

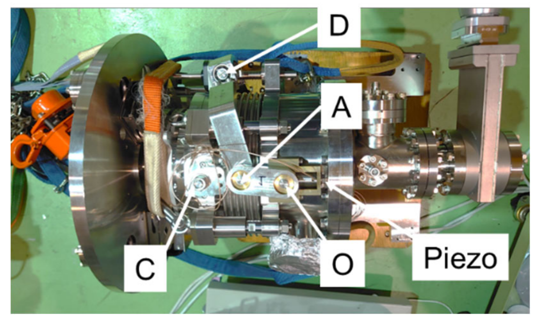

Figure 5: Frequency tuner.

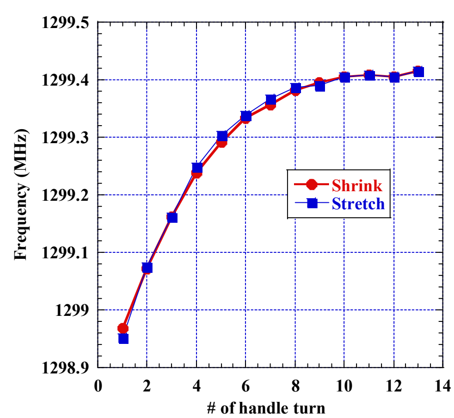

Figure 6: Tuning range of mechanical tuner at room temperature.

MAGNETIC SHIELD

Magnetic shields (Ota's Permalloy PC) are inserted inside and outside of the helium jacket (Fig. 7). The residual magnetic field at the niobium plate in the cavity is less than 10 mG in any orientation with an external magnetic field of 0.4 Gauss. The performance of the magnetic shield was measured by using a one-dimensional magnetic probe along the beam axis to measure the magnetic field along the cavity axis (Fig. 8). The magnetic field distribution is in good agreement with the simulation.

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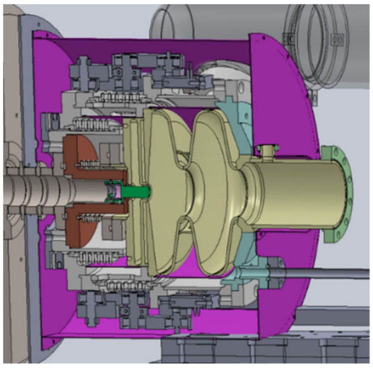

Figure 7: Arrangement of magnetic shield. The pink parts indicate the magnetic shield.

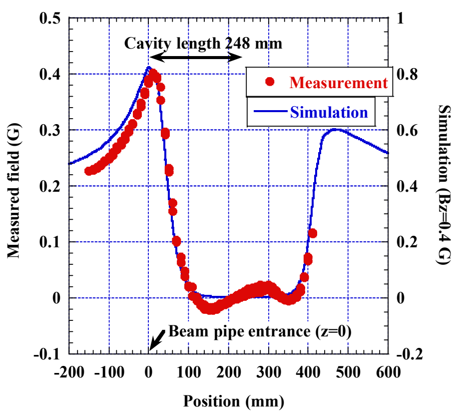

Figure 8: Magnetic field distribution on beam axis.

PHOTOCATHODE COATING CHAMBER

The photocathode coating chamber functions to introduce the niobium cathode plug from the atmosphere, coat K_2CsSb photocathode and transfer the photocathode to the SRF gun cavity. The photocathode was grown after heat cleaning, 530 ºC for 1 hour. Figure 9 shows an example of photocathode growth. Sb was deposited to 10 nm. The growth rate of Sb was calibrated by thin film deposition monitor before coating. K and Cs was deposited until the QE was maximized. Although a maximum quantum efficiency of about 4 % was obtained and the dark lifetime was very short 8.7 hours. Further study is needed.

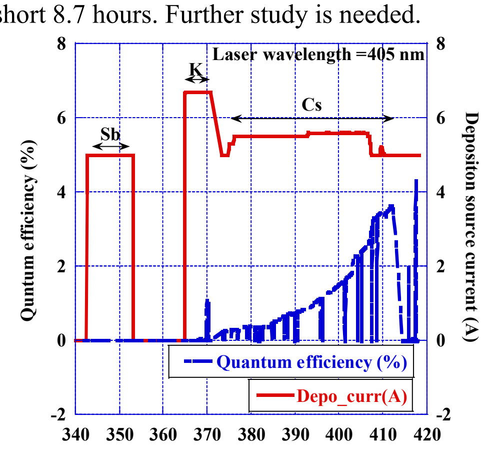

Figure 9: Example of photocathode growth operation.

SUPERCONDUCTING SOLENOID

The solenoid was placed close to the electron gun to focus beam just after gun exit. The solenoid consists of NbTi/Cu wire coil and iron yoke. Both coil and yoke is conduction cooled from 2 K 2-phase pipe with high purity aluminum. The maximum magnetic field was set the focal length of 2 MeV beam was 100mm. Performance of the solenoid was measured in vertical test cryostat with 4 K LHe. Figure 10 compares the measurement result of the magnetic field on beam axis with simulations using CST and Opera2D. The magnetic field distribution was confirmed to perform as designed and installed in a horizontal cryostat. It was cooled enough and no loss up to maximum current.

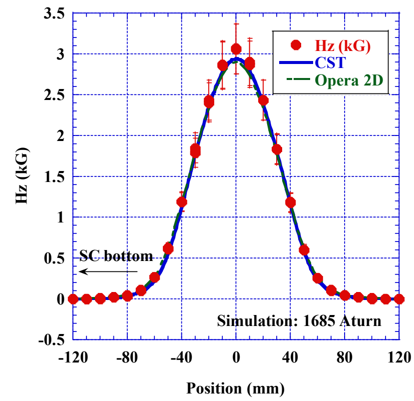

Figure 10: Magnetic field on beam axis of superconducting solenoid.

90 DEGREE BEANDING MAGNET

A 90-degree bending magnet was designed to measure beam energy of 2 MeV and to make a laser path (Figure 11). It will be able to measure an energy spread of about 0.1 % by measuring the beam size at a beam monitor located 500 mm downstream from the magnet.

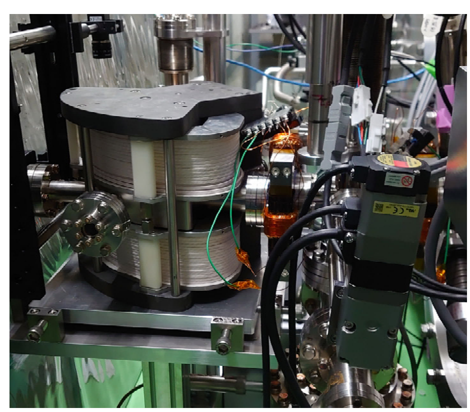

Figure 11: Photograph of 90 degree bending magnet.

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LASER

The green laser path was design to inject from front of the photocathode. A 162.5 MHz Nd:YLF source was installed above the cryomodule due to space constraints in the bunker. The laser position was adjusted by monitoring the laser position by CCD using a laser sampler after the photocathode position was aligned with the axis using double slits. Figure 12 shows the laser system layout.

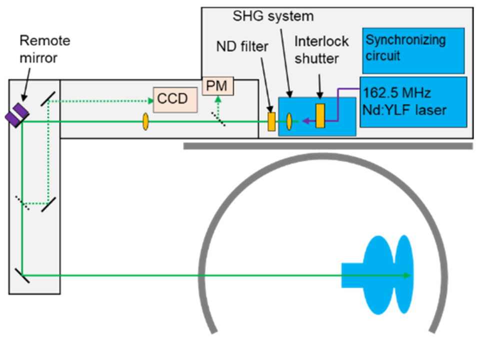

Figure 12: Layout of the laser system.

LLRF AND DATA TAKING SYSTEM

Figure 13 shows the LLRF and data taking system. The LLRF was used existing system for horizontal test cryostat [3]. For electron gun operation, a line for laser synchronization system was added. The repetition frequency of the laser is synchronized to the RF frequency of the gun. An EPICS server was added for data taking, and CS-Studio was installed for control.

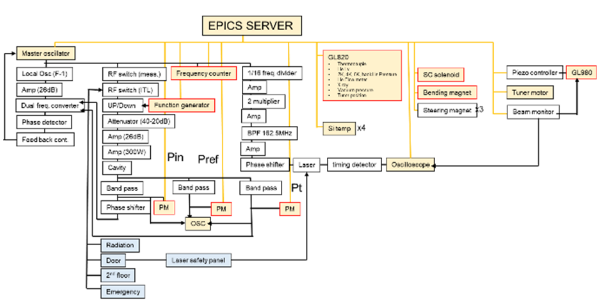

Figure 13: LLRF and data taking system.

HORIZONTAL TEST CRYOSTAT

A multi-purpose horizontal test cryostat, shown in Fig. 14, was used to perform high gradient test [3]. The cryostat consists of 2 K liquid helium 2-phase piping, 5 K thermal anchor and slide table to hold cavity, and 80 K radiation shielding with liquid nitrogen. It is also equipped with a 1.3 GHz, 300 W RF amplifier and LLRF. The SRF gun cavity was installed with the superconducting solenoid. The photocathode coating chamber, the 90-degree bending magnet, the beam monitor, and the laser were connected to the cryostat.

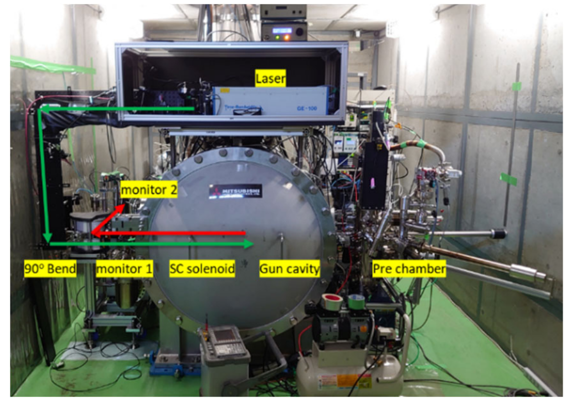

Figure 14: Horizontal test cryostat for SRF gun.

HORIZONTAL TEST

The SRF gun #2 was assembled into a horizontal cryomodule and a total of six cooling experiments were performed. A local clean booth and slow pumping were used for assembly. The first and fifth horizontal test were used to confirm the cavity assembly and cooling procedures, and no high gradient tests were performed. High gradient test results are shown in Fig. 15. The RF coupling of input port was set at 4×10^9 for the second through fourth high-field tests. In the sixth high field test, the antenna of the RF input port was shortened and the coupling of the input port was changed to 7×10^7 for stable cavity operation in consideration of beam operation.

To achieve high gradient, the cavity was disassembled before the second, third, and sixth horizontal tests, and appried HPR. However, multipacting at low gradient of about several kV/m range was observed in all high gradient tests. This low gradient multipacting could be processed by RF process of about 2 hours. The maximum surface peak gradient was limited aroud 20 to 40 MV/m by field emission or quench. The cavity was appried HPR to improved gradient, but field emission and quench could not be overcome. Since local clean booth was used for installation into the

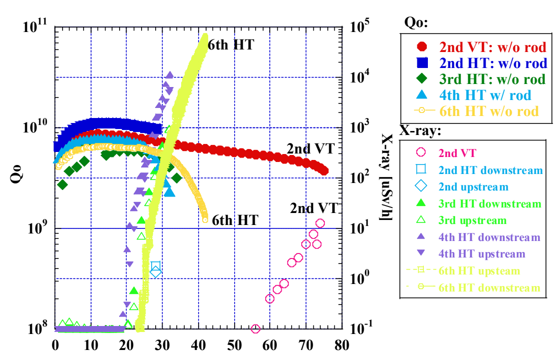

Figure 15: High gradient performance in horizontal test cryostat.

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horizontal test cryostat, the clean booth had to be moved several times to complete assembly. We suspect particulates enterd into the cavity during assembly. It is necessayr to simplefy the assembly to achieve high gradient.

CONCLUSION

The KEK SRF gun #2 was built to evaluate the fundamental performance. Suppression of FE is important to achieve high gradient operation. Cavity itself can be achieved high gradient performance with EP and HPR. However, the assembly for the horizontal test was complicated and degraded the cavity performance. It is important to establish appropriate assembly procedures. In addition, we are preparing equipment to evaluate SRF gun performance with beam tests. Although the short life of the photocathode remains an issue, individual performance evaluation of the superconducting solenoid, 90-degree bending magnet, and other equipment has been completed.

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