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DEVELOPMENT OF HIGH INTENSITY, HIGH BRIGHTNESS, CW SRF GUN WITH Bi-ALKALI PHOTOCATHODE

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Abstract

Superconducting RF gun can realize high acceleration voltage and high beam repetition. KEK has been developing the 1.3 GHz elliptical type 1.5 cell superconducting RF gun to investigate fundamental performance. A surface cleaning method and tools are developed by using KEK SRF GUN #1 and high surface peak gradient 75 MV/m was achieved without field emission. SRF GUN #2 equipped with the helium jacket and operable with electron beam was designed based on the SRF GUN #1. It can be operated with transmit type photocathode which include superconducting transparent material. The cathode rod is cooled by thermal conducting from the 2 K helium jacket and photocathode will be kept around 2K to maintain superconductivity. Bulk niobium photocathode rod, and substrate will used for the fundamental performance test.

CAVITY DESIGN

The SRF gun #2 cavity is 1.5 cell and 1.3 GHz shape designed based on SRF GUN #1. The feature of the cavity design is parallel shape choke filter. This design is important for HPR. High gradient performance has demonstrated using SRF GUN #1. The maximum surface peak electric field (Esp) reached 75 MV/m [1]. The difference from #1 is that #2 has the helium jacket and the cathode rod size was changed for improving the cathode rod cooling. Figure 1 shows the #2 design. Table 1 shows the RF parameters of KEK SRF GUN#2. Yellow parts are made of niobium and green and blue parts are made of titanium and gray parts are made of stainless steel. Helium jacket can be connected by flanges with indium seal. The choke filter is connected as close to the accelerating cell as possible to minimize the cathode rod length.

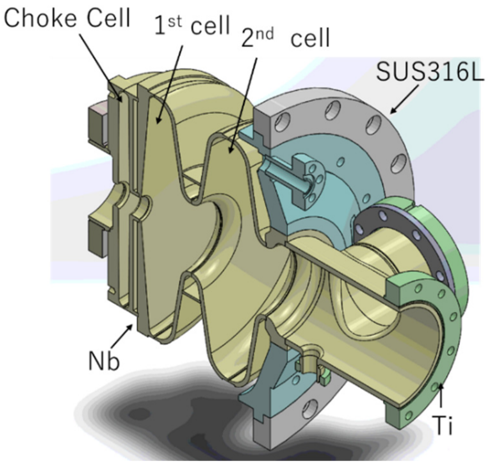

Figure 1: Design of KEK SRF GUN#2.

Table 1: RF Parameters of KEK SRF GUN#2

Parameter	Value
Frequency	1300 MHz
Geometrical factor	133.7 Ohm
Hsp/Esp	2.237 mT/(MV/m)
Z factor $(E_{sp} = Z\sqrt{Q_o P_{loss}})$	234.04

RF leakage from the choke filter is simulated using SUPERFISH. Figure 2 shows the simulation condition. Rod head is made of niobium, niobium surface resistance is set to 10×10-9 Ω. Other cathode holder parts are made of oxide free copper (OFC). Electrical resistivity of OFC is set to 1.68×10-8 Ω·m. Figure 3 shows the Q value dependence on the choke diameter. The maximum Qo is 1.36× 1010 at 186.6mm. If 1% degradation is allowed, the diameter fabrication tolerance is set to ±0.2 mm.

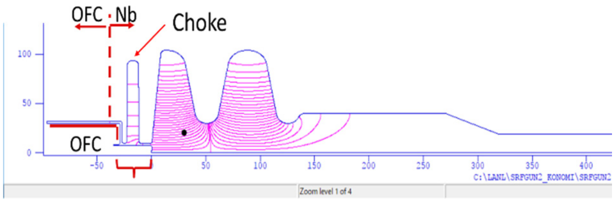

Figure 2: SUPERFISH simulation set up.

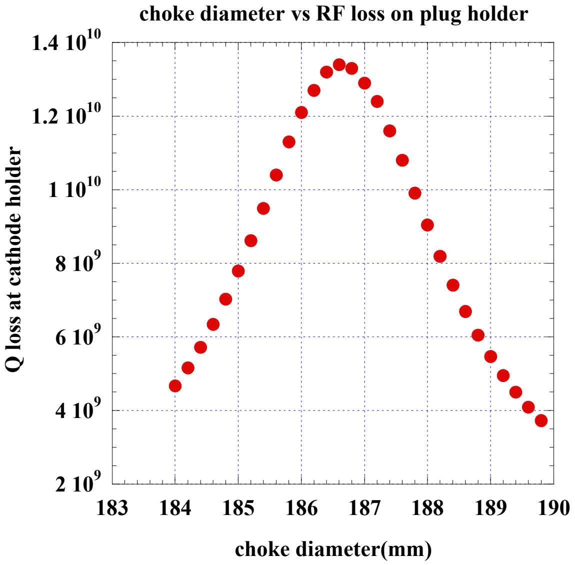

Figure 3: Q value dependence on choke diameter.

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VERTICAL TEST RESULT

The cavity fabrication was successfully completed (Fig. 4). The three half cells of accelerating cell were press formed with the same die as used for SRF gun #1. The choke cell and half-cell of 1st cell on cathode rod side were machined from niobium block. All parts were connected by the electron beam welding.

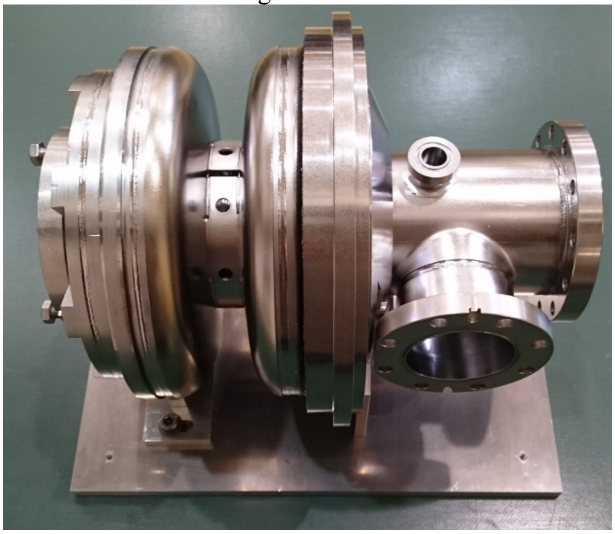

Figure 4: KEK SRF gun #2 cavity.

The surface treatment was followed with the experience in the gun cavity # 1. Procedure is as follows, 100 µm horizontal electrical polishing, 800 °C×3 hours annealing, field distribution and frequency tuning, 20 µm horizontal electrical polishing, ultra-sonic rinsing, high pressure rinsing, assembly in clean room, 120 °C×48 hours baking. We tried choke filter tuning in addition to field distribution tuning. Choke design is same as #1 cavity. However, choke tuning is more difficult because the cathode holder was made of copper and stainless steel. Loss Q at cathode holder is estimated $5\mathrm{x}10^9$. Target attenuation of the choke filter is required 30 dB or more to supress the RF loss less than 1 %. The setup for the choke tuning is shown in Fig 5. The input antenna is inserted from the beam pipe of the accelerating cell side and pickup antenna is same shape of the cathode rod and inserted to choke cell. Figure 6 shows the RF transmittance before and after choke tuning. The target transmittance is -70 dB to satisfy 30 dB attenuation. The choke attenuation is 10 dB higher than the target after choke tuning. 10% (0.8W) RF loss is acceptable for cooling ability of cathode holder. We suspect that cathode rod lean to one side. This dummy antenna is fixed. It is necessary to use the real holder which has bellows to tune the rod position.

Figure 7 shows the vertical test result without cathode rod. The peak surface electric field (Esp) reached 75 MV/m. Although X-ray can be observed, the onset is 58 MV/m and higher than target gradient 42 MV/m. There is good prospect of the cavity itself. We will shift target to the cathode rod development. There are two challenges for the cathode. One is effective cooling structure to keep the cathode rod around 2K. The other one is particle free cathode transport method. We will test with the cathode rod in horizontal test cryostat because it is difficult to adjust the cathode rod position in the vertical cryostat.

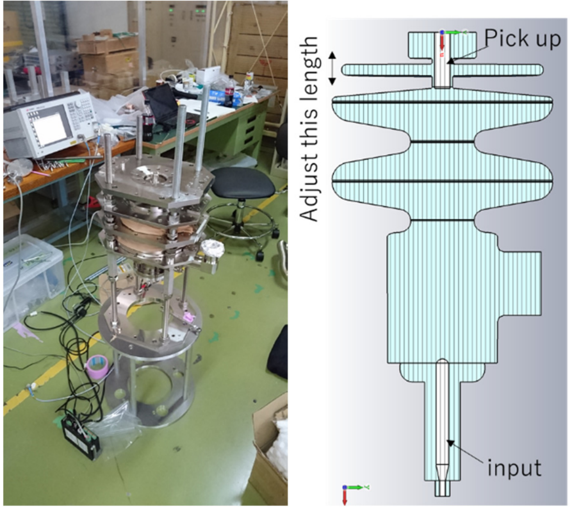

Figure 5: Set up for choke tuning.

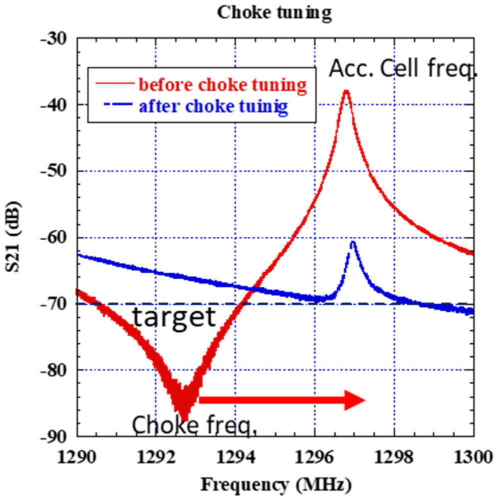

Figure 6: Choke tuning result.

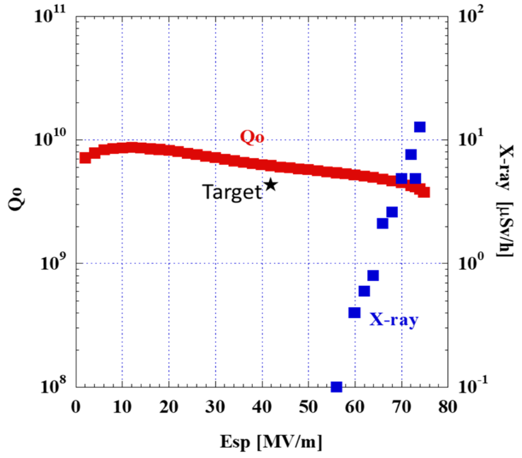

Figure 7: Vertical test result without cathode rod.

CATHODE ROD DESIGN

We plan to use a transparent superconductor for the substrate ($LiTi_2O_4$) of the photocathode. The transition temperature is 13 K. The cathode rod and holder were designed to cool down to around 2K. However, in this study, we use the dummy cathode rod made of Nb. The cathode holder was designed as a part of the helium vessel (Fig. 8). The cathode holder is made of copper block for high thermal conductivity. The cathode rod is touched to the holder with flat and smooth surface for easily machining. Spring constant in the cathode rod is 71.21 N/mm. Maximum load is 71.21 N. contact area is about 450 mm^2. Contact pressure is about 158 kN/m^2. According to the solid works database, the thermal resistance is estimated to 1×10^{-4} ~ 10×10^{-4} m^2K/W [2]. Figure 9 shows the cooling simulation model for CST. Heat source is on the cathode rod head. The ideal heat load of 2K cathode rod made of Nb is 240 mW. Cathode holder flange is kept at 2K because the flange touches to 2K liquid helium bath. Thermal conductivity of the rod and holder is enough smaller than the thermal contact resistance between holder and rod. Figure10 shows the relation of cathode head temperature and thermal contact resistance. It can be cooled down to around 3 K when the thermal contact resistance is lower than 1×10^4 m^2K/W. However, the thermal contact resistance is difficult to simulate, it is necessary to test using real structure. The fabrication of the cathode rod holder was completed. The contact surfaces of the cathode rod and the holder were applied electrical polishing and machining with diamond bit respectively. Figure 11 shows the measurement set up. Heater is on the cathode rod head and thermocouples are monitored the temperature difference between rod and holder. These are in the vacuum. Figure 12 shows the temperature difference at room temperature (RT) and liquid nitrogen temperature (LN2). The thermal contact resistance is 21.7×10^{-4} m^2K/W and 63.2×10^{-4} m^2K/W at RT and LN2 respectively. These are tens of times higher than the target. We will apply the mirror polishing (Ra ~1nm) to both cathode and holder to achieve smoother surface.

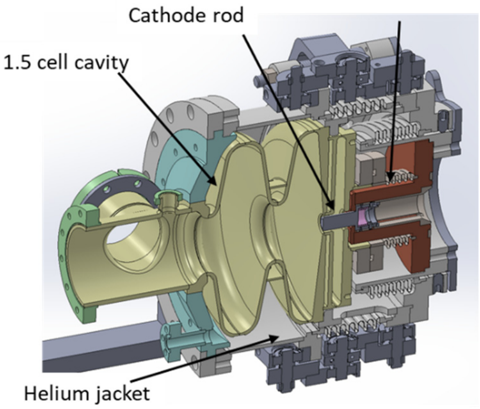

Figure 8: Design of SRF GUN #2 helium jacket and holder.

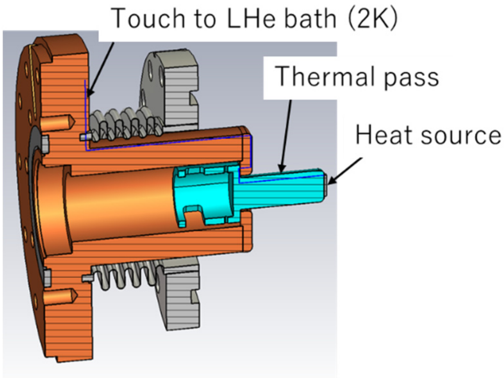

Figure 9: Cathode rod and cathode rod holder for CST simulation.

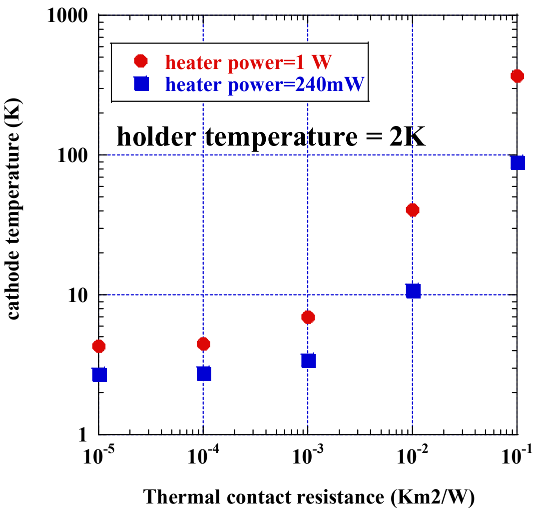

Figure 10: Cathode rod temperature dependence on the thermal contact resistance.

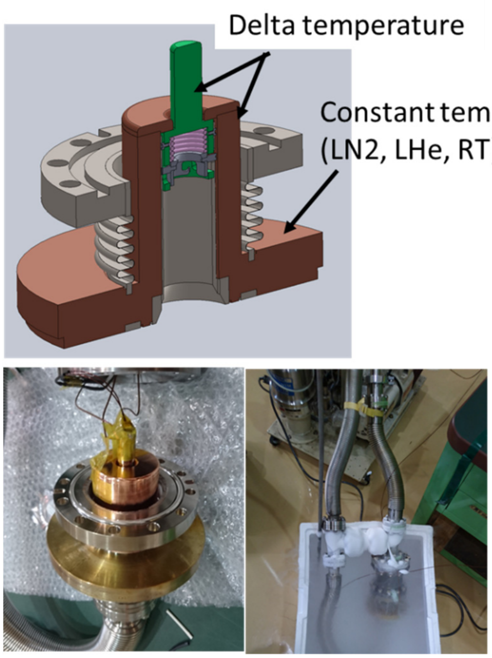

Figure 11: Measurement set up for thermal contact resistance.

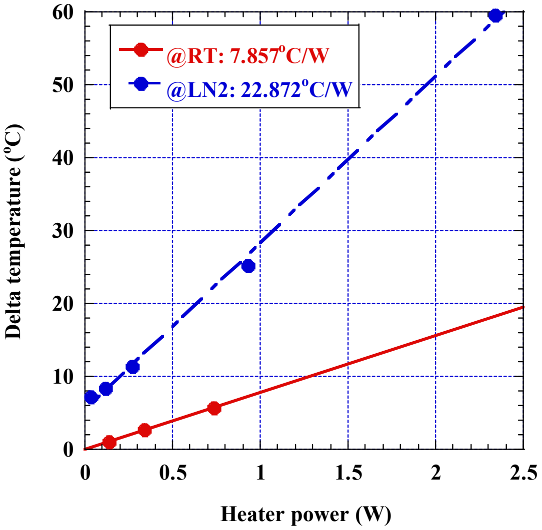

Figure 12: Measurement result of the thermal contact resistance.

FUTURE PLAN

We are preparing the SRF gun #2 for the beam test with small current beam in the horizontal test cryostat. Fig. 13 shows the layout of the SRF gun #2 in horizontal cryostat. Helium jacket was fabricated and support jigs to install cavity are under fabrication, short diagnostic (beam energy and emittance) line will be designed. The experiment using the horizontal test cryostat can be divided to three stage. 1st stage is the cooling test. We will measure the additional heat load from the cathode holder and cathode position adjusting structure. 2nd stage is high gradient test without beam. We will measure the QE curve dependence of the cathode rod position and demonstrating particle free cathode transportation by monitoring the increasement of the field emission. 3rd stage is the small current beam test (<1 μA). Dark and beam lifetime of the photocathode in the cavity is the most interesting. And we will measure the RF field error from the design by using beam.

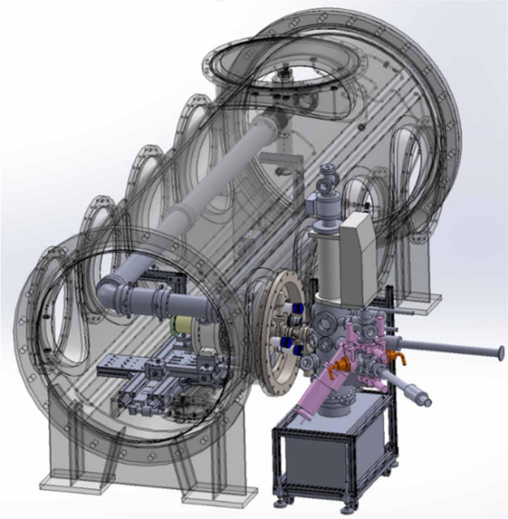

Figure 13: Layout of the SRF GUN #2 in horizontal cryostat.

SUMMARY

KEK has been developing the SRF gun. The fabrication of the KEK SRF gun #2 was successfully completed. Maximum surface peak electric field reached 75 MV/m. It is satisfied the target. The fabrication of the cathode rod and holder was completed. However, the thermal contact resistance is higher than expected. We will apply mirror polishing to the contact surface. We are planning to test the beam performance using the horizontal test cryostat.

REFERENCES

[1] T. Konomi *et al.*, “Development of SRF Gun Applying New Cathode Idea Using a Transparent Superconducting Layer”, in *Proc. ERL'17*, Geneva, Switzerland, Jun. 2017, pp.1-3. `doi:10.18429/JACoW-ERL2017-MOIACC002`

[2] SOLIDWORKS help, `http://help.solidworks.com/`