CAVITY DIAGNOSTICS USING ROTATING MAPPING SYSTEM FOR L-BAND ERL SUPERCONDUCTING CAVITY

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Abstract

We are developing the superconducting (SC) cavity for Energy Recovery Linac (ERL) in Japan. In order to survey the electron emission and the heating spot of the cavity inner surface in detail, cavity diagnostics with the rotating mapping system was applied. Two types of sensors, one of which is the carbon resistor and the other is the Si PIN photo diode, were set to detect the temperature rise and electron emission. By rotating the sensor arrays around the cavity axis, a lot of information is obtained all over the cavity surface in detail. This paper reports the results of vertical tests by using this rotating mapping system with Nb single cell ERL-shape cavities.

INTRODUCTION

The ERL project in Japan has been started with the cooperation of KEK, JAEA, ISSP and other SR institutes, to realize 5 GeV class ERLs [1]. Especially, more than 100 mA beam current operation will be expected. For this goal, we have started to develop SC accelerating cavities for the main linacs, which are one of the key components of the ERLs. Accelerating gradient of 15-20 MV/m with high Q-factor is required. A most challenging issue is a strong suppression of HOMs excited in accelerating cavities; the beam-breakup (BBU) instabilities are caused by the dipole and quadrupole HOMs and the heat loads are caused by the monopole HOMs. For this purpose, we started to design the superconducting cavity for the ERL main linac. The TESLA 9-cell cavity, which is designed for linear collider and/or XFEL project[2], was modified to meet our requirements.

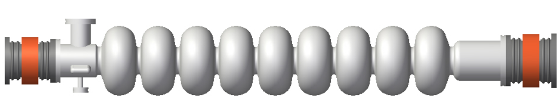

Figure.1: KEK-ERL model-2

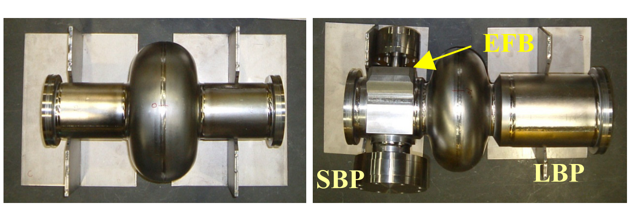

Figure 2: C-single (left) and E-single (right).

Fig.1 shows the KEK-ERL model-2. The basic idea is the extraction of HOMs through the enlarged beam pipe with RF absorbers. One is 120mm as Large Beam Pipe (LBP) and the other 100mm as Small Beam Pipe (SBP) for propagating the HOMs to the RF absorbers. We selected 80 mm as the iris diameter to achieve lower the impedances of HOMs and keep the high R/Q for the accelerating field. Detailed approach for the optimisation is described in Ref.[3]. In order to extract and damp the quadrupole HOMs, we newly propose the eccentric fluted beam pipe (EFB) [4]. Due to its asymmetric shape, the quadrupole modes can be partly transformed into dipole modes. Therefore, they propagate through the beam pipes and are absorbed by the RF absorbers.

In order to validate the cavity shape of KEK-ERL model-2, fabrication and surface treatment processes were tested on two single-cell Nb cavities, C-single and E-single, which are shown in Fig. 2. C-single has the same cell shape as that of the central cell of the 9-cell structure. E-single has the shape of the end cell equipped with both beam pipes of the 9-cell cavity. Especially, it is important for ERL to clarify that this newly designed cell-shape, enlarged beam pipes and EFB does not enhance the heat load and electron emission in Nb cavity. The cavity diagnostics with the rotating mapping system was applied for the vertical tests of our cavities.

SETUP

Fig.3 shows the set-up of the vertical test. E-single was set on the vertical test stand. In order to survey the spot size and profile of the electron emission and the heating spot of the cavity inner surface in detail, we applied the cavity diagnostics with the rotating mapping system around its cavity. This mapping system allows us to reduce the channel of data taking system and also reduce the static loss come from the large number of cables compared with the fixed mapping system. Two types of sensor, one of which is the carbon resistor (Allen-Bradrey, 50Ω) and the other is the Si PIN photo diode (HAMAMATSU, S5821-02), were set to detect the temperature rise and the radiation distribution due to emitted electron. The 13 carbon resistors and Si photo diodes were arranged along the cavity axis and fixed to the support in a left figure of Fig.4. By rotating the support with sensor arrays around the cavity axis, a lot of information is obtained all over the cavity surface. The rotation angle of the sensors on the support is given by the motor control system. All carbon resistors were embedded in the stycast base so that it works as a heat sink and pushed by the plate springs in order to obtain the sufficient contact between carbon resistors and Nb cavity surface. Each resistor was provided with 0.1 mA for taking the data of the change of resistance. The generated current at the PIN diode was converted to voltage and

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amplified 10 times at operational amplifier. These data including sensors, power meters and rotating angle were taken by the real-time data acquisition system (YOKOGAWA, MX-100). Data was taken every 500 ms to average the AC noise come from the amplifiers of diodes. A Si diode thermo sensor (Lakeshore) was located on the SBP to measure the temperature of cavity itself in Fig. 3. All resistors were calibrated with this Si diode thermo sensor under cooling from room temperature to 2K and fitted by the equation in Ref [5].

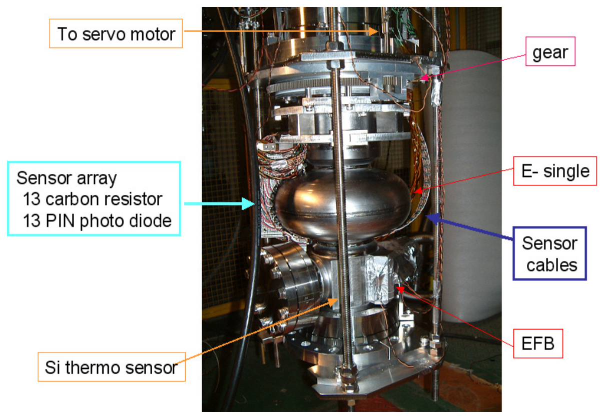

Figure 3: A setup of vertical test with rotating mapping system. Two sensors were arranged around E-single.

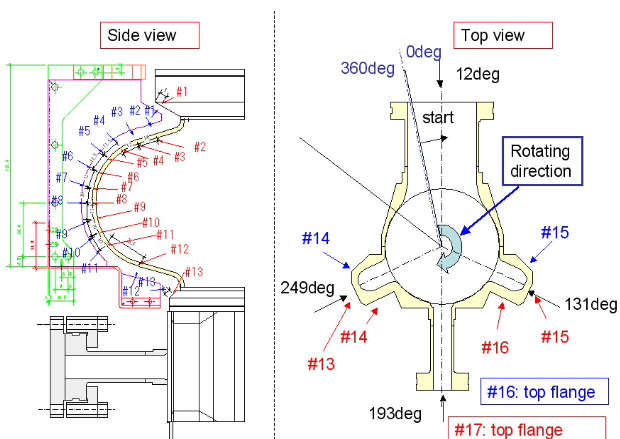

Figure 4: Detailed arrangement of two sensors. 13 carbon sensors (blue) and PIN photo diodes (red) were arranged every 10 mm spacing (left). The additional fixed sensors were set on the top flange, bottom flange and EFB (right).

RESULTS

We carried out the 2 vertical tests of C-single and the 4 vertical tests of E-single after the surface treatments, which are a mechanical grinding, barrel polishing, electropolishing (EP), annealing in vacuum, 2nd EP, ultrasonic cleaning and high pressure rinsing inside the cavity. Detailed fabrication procedure and the parameters of the surface treatments are expressed in Ref.[6]. Fig.5 shows the Q-E plot obtained from all vertical tests except for the 2nd vertical test of E-single. C-single cavity has no field emission and reached the 37 MV/m accelerating voltage. In this cavity, we did not find the radiation and temperature rise on the cavity surface. On the other hand, E-single finally satisfied the specification of 20 MV/m with the unloaded-Q of 1×10^{10}. However, 1st and 3rd test does not satisfy the specification due to the field emission. And we also found the field emission in 4th vertical test. To clarify the radiation source of cavity in detail, we measured the temperature rise and the field emission around E-single by using this rotating mapping system.

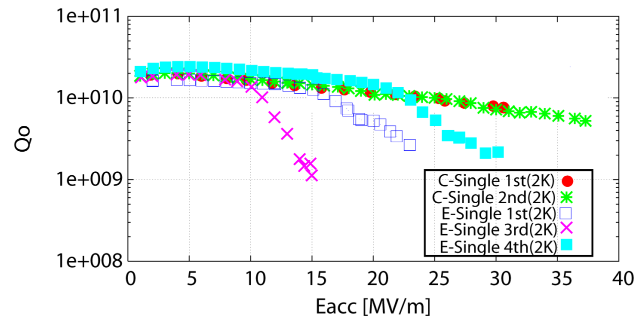

Figure.5:Results of the vertical tests of single-cell cavities

First vertical test of E-single

Fig. 6 shows the temperature rise and radiation mapping on 1st E-single vertical test at 20MV/m accelerating voltage, where the field emission was much appeared. The vertical axis of left (right) side shows the sensor output (the accelerating voltage) under rotation. The horizontal axis shows the rotating angle as defined in a right figure of Fig.4. The number of each channel associated to that of sensors as shown in a left figure of Fig.4. The rotation speed was usually 4 min per turn. We have clearly seen the x-ray radiation at the 310° point near the SBP iris. Furthermore, some radiation traces were observed at the 50°, 150°, 290° and 350°. On the other hand, no signal was observed from the carbon resistors.

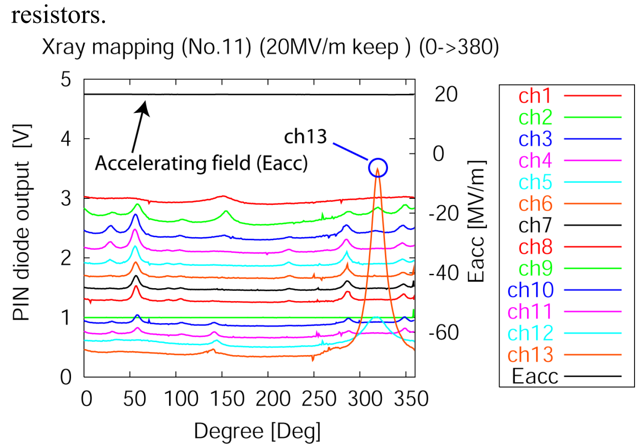

Figure 6: Mapping data of PIN diodes of 1st vertical test.

We also noted that the heating spot was obtained by using this system on the self-pulse mode, where the quench was intentionally raised. Fig.7 shows the heating spot under RF processing of the cavity on a self-pulse mode. The vertical axis shows the temperature rise on a spot of cavity surface. The heating spot was appeared on #2 near the iris point of LBP and #11 of the midpoint of equator of cavity and the iris of LBP from 150° to 220°. Fortunately, this heat spot disappeared by RF processing and reach the maximum field to 20MV/m in Fig.5. The maximum field was limited by the large radiation at 310° near SBP iris point as shown in Fig.6.

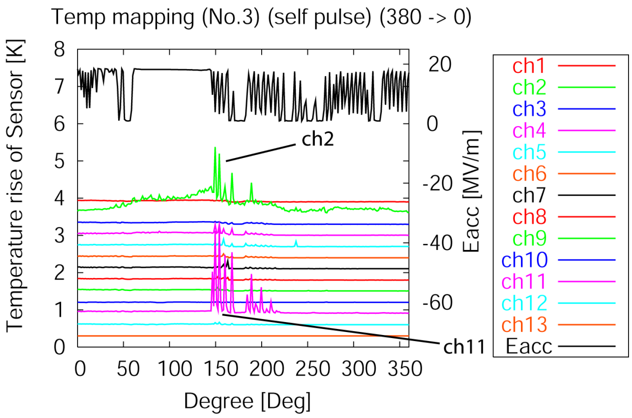

Figure 7: Temperature mapping data of 1st vertical test.

Third vertical test of E-single

We carried out the 2nd vertical test in order to see the reproducibility of Q-E plot and the radiation profile come from the field emission and so on. In the 2nd vertical test, however, we did not feed the RF power into the cavity due to a problem of an input coupler. Therefore, prior to the 3rd vertical test, we re-opened the input port in a clean room and then repair the input coupler. After repairing the coupler, and baking at 130 °C for 12 hours, we retried the vertical test without the additional surface treatment. Attainable maximum field was reduced down to 15 MV/m in Fig.5. Fig.8 shows the results of the surface condition at the 15MV/m accelerating field by using rotating mapping system. By modulating the input power instead of a self-pulse mode, we clearly found the heat spots at 150° of iris near LBP and 350° of the midpoint of equator and the iris of LBP in the upper figure of Fig.8. These heat spots associated with the radiation trace on the same angle. Compared with the previous measurement, maximum radiation spot was changed. but we also found the radiation trace on the same angle between previous and this measurement at 150° and 350°. From these results, field emissions of two measurements would be connected with these heat spots and radiation traces. Therefore, we decided to refresh the surface condition by applying the additional EP to E-single.

Fourth vertical test of E-single

After removing 30 μm in thickness by the additional EP, we carried out the vertical test again. There was no signal all over the surface up to 20 MV/m accelerating field by using this mapping system. That agreed well with the degradation of Q-E plot. The surface condition was improved. We found a lot of radiation traces according to increasing the field emission above 20 MV/m. From this result, field emission was much connected with the radiation mapping. On the other hand, no clear heat spot was found by a temperature mapping.

We noted that no signal concerning with the field emission was obtained on EFB by the additional fixed resistors and PIN diodes on EFB through these three vertical tests.

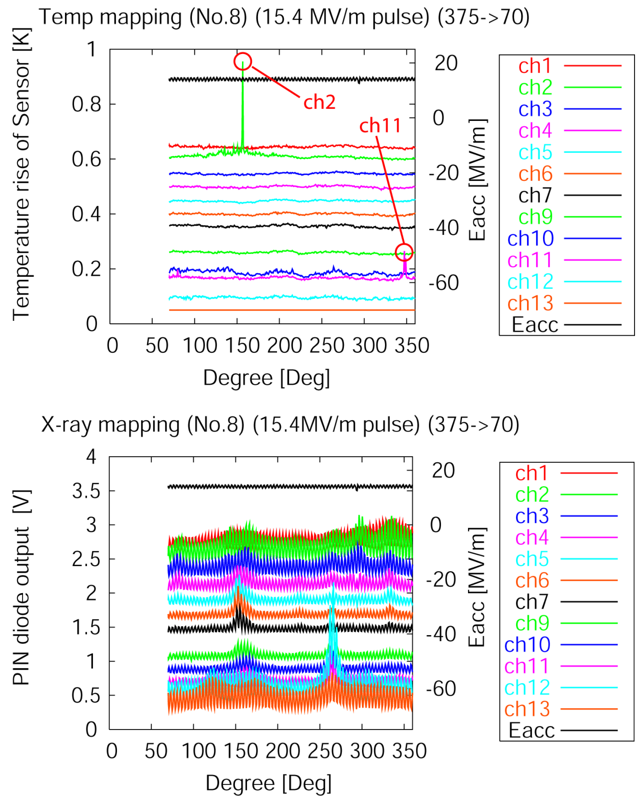

Figure 8: Mapping data of carbon resistors (upper) and PIN photo diodes (lower) of 3rd vertical test.

SUMMARY

We have applied the rotating mapping system on E-single. When the field emission increased inside the cavity, large radiation spots and radiation traces were observed by using this system. The heating spot was also observed on a self-pulse mode. EFB does not become the source of electron emission and any other heating spot. We are planning to apply the rotating mapping system to the 9-cell Nb KEK-ERL model-2 cavity.

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