HORIZONTAL TESTS FOR CRAB CAVITIES IN KEKB

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Abstract

Two Crab cavities were fabricated at KEK in 2006. After the completion of the assembly, a horizontal test is normally carried out for a superconducting cavity in KEK. The horizontal test is an overall test for the cavity without a beam. Both cavities achieved above an operational kick voltage of 1.4MV. Although the HER (High Energy Ring for electron) Crab cavity had no trouble, the LER (Low Energy Ring for positron) had a trouble of tuner operation. Due to the limited time, both cavities were installed into the tunnel at the beginning of Jan. in 2007. After the beam commissioning, it was found that this problem was not so much significant for the operation. The LER Crab cavity is being operated above 1A at present.

INTRODUCTION

The assembly of two Crab cavities was started from the beginning of 2006 [1, 2]. Figure 1 shows the situation of the assembly to the cryostat and the transfer to the horizontal test area. Figure 2 shows the assembly layout of HER Crab cavity. LER is designed in a mirror-symmetry for HER. HER Crab cavity was completed in April and the first horizontal test was carried out in May. The horizontal test is an overall test for a superconducting cavity before a tunnel installation without a beam. Although the kick voltage achieved 1.4MV, a tuner performance was not operated smoothly. It was necessary to improve it largely. The improvements were a large frequency stroke and a smoothed movement for the coaxial beam pipe. After these improvements, the horizontal tests were done for both cavities again. In this paper, these results are reported in detail and a recent status is described briefly.

Figure 1: Photos of the assembly to the cryostat and the transfer to the horizontal test area.

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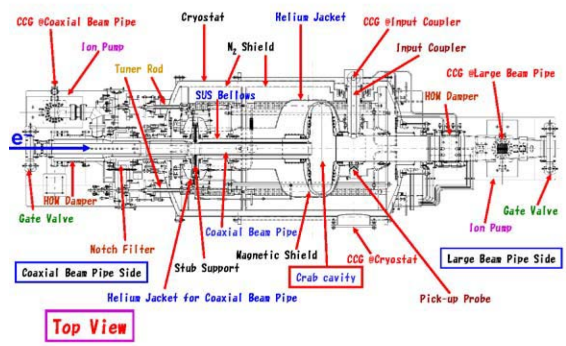

Figure 2: The assembly layout of Crab cavity.

ASSEMBLY TO THE CRYOSTAT

It was very difficult to assemble the coaxial beam pipe to the cryostat at first. It is a very complicated component. The precision in the alignment is within 200 micro-meter. It takes a few days to assemble the coaxial beam pipe into the cryostat. After several months, the first assembly to the cryostat was successfully finished, because of an improved assembly jig.

After the first horizontal test, it was found that HER Crab cavity had several problems. Therefore, it was necessary to improve some components around the coaxial beam pipe. The most important thing was a smooth movement of the coaxial beam pipe. The cavity is normally tuned on the resonance frequency by moving it during the horizontal test. If this part is not moved smoothly, the cavity stays the off-resonance and the tuner phase is unstable. And then, a new improved jig was introduced for the movement and a new bellows made by stainless steel was attached at the coaxial beam pipe.

These improvements enabled the tuner of HER Crab cavity to move smoothly in the second horizontal test, while that of LER Crab cavity was not moved smoothly. Although this problem is described in detail later, the reason is still not clear.

HORIZONTAL TESTS

A superconducting cavity is normally measured in the horizontal test area at D10 site around NIKKO in KEKB after the completion of the assembly. It is an overall test for the superconducting cavity without a beam. The main routine is shown in Table 1. The test is separated into the three situations, that is, the room temperature, during the cool-down and the warm-up, and 4.2K. In the following, the test result in these situations will be described in detail.

Table 1: Routine of the horizontal test.

Room Temp.	• Tuner Drive Test • Input Coupler Conditioning
Cool-Down & Warm-Up	• Monitoring f_0 and Q_L • Monitoring the shrinkage of the cavity • Cool-Down Rate Adjustment @2K/hour (for slow cooling)
4.2K	• Adjustment of the Cavity Frequency • Adjustment of the Coaxial Beam Pipe • Tuner Drive Test (Motor & Piezo) • Cavity/Coupler/Coaxial Beam Pipe Conditioning • Q_L Measurement (using high-power) • Tuner Phase Check • Tuner Feedback Check • Eigen Oscillation Check • Q_0 Measurement • Static Loss Measurement • HOM Measurement (using low-power) • Checking the Radiation Level around the Pit

Room Temperature

At the room temperature, the tuner performance is tested. It is the most important test at the room temperature. The tuner of the Crab cavity is composed of a main motor and a piezoelectric oscillator. Although the main motor has a large stroke in the resonant frequency, the operation is slow. On the other hand, the piezoelectric oscillator has the small stroke and the fast operation. If these tuners have any trouble, it is found at this stage. For the tuner of LER Crab cavity, it was found that the movement was not smooth. Although it was a serious trouble, the cavity was cooled down because of the limited time.

After the tuner test, an input coupler conditioning is carried out with high power RF from a klystron. Due to the room temperature, the cavity is detuned. The maximum power is above 100kW with the situation of the total reflection. In the bench test, the maximum power was above 200kW. Three input couplers including a prototype were operated with no trouble [3].

During Cool-down and Warm-up

During cool-down and warm-up, the frequency and the loaded Q value of the Crab cavity were monitored with a network analyzer every several hours. Figure 3 shows the result of the frequency change. The difference of the frequency from the room temperature to 4.2K between both cavities was almost same. A dip of the frequency change around 250K is due to the effect of the refrigerator operation. Figure 4 shows the change of the loaded Q. The loaded Q value was about 1.6~1.7x10^5 around 4.2K. It was almost same as the result of the calculation by HFSS.

Figure 5 shows a time profile of the cavity temperature and vacuum for both cavities. The cool-down rate was about 2K/hour, which was very slow, to avoid the vacuum leakage. There was no vacuum leakage at this situation in the four horizontal tests including a cold test for the prototype. The vacuum level of LER Crab cavity was high from the room temperature to 50K. It was found that this was not the vacuum leakage, because of carrying out the several leakage tests.

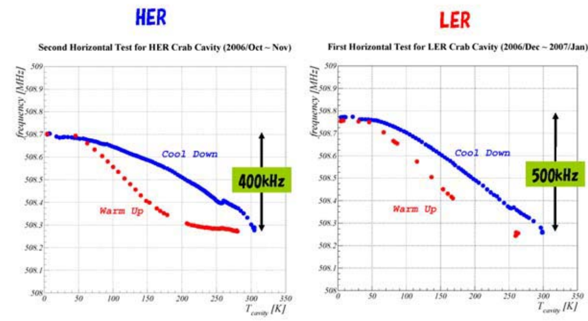

Figure 3: The frequency change during cool-down and warm-up.

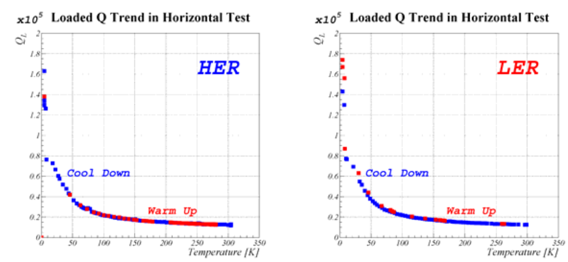

Figure 4: The loaded Q during cool-down and warm-up.

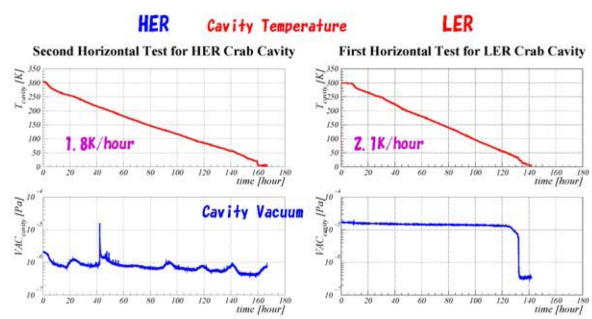

Figure 5: The time profile of the temperature and vacuum during cool-down.

Figure 6 shows the time profile of the cavity temperature and vacuum around the warm-up. The warm-up rate was slow same as the cool-down. The vacuum level of LER was higher than HER during the warm-up. The element of the outgas was analyzed by a quadrupole mass analyzer. It was found that there was much gas with A=28 (A is a mass number for the atom). They were identified as the nitrogen or carbon mono-oxide gas.

Figure 7 shows the correlation between the vacuum level and the temperature of the cavity. It is clear that the vacuum level of LER Crab cavity was above 10^{-5} Pa above 50K. During the warm-up, it achieved above 10^{-2} Pa around 50K.

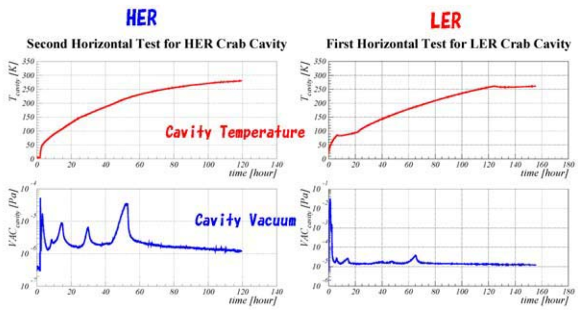

Figure 6: The time profile of the temperature and vacuum during warm-up.

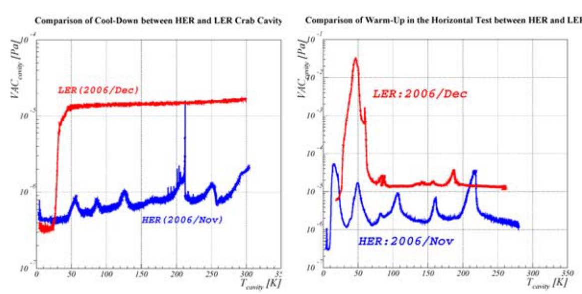

Figure 7: The vacuum vs. temperature during cool-down and warm-up.

4.2K

After the cool-down, the superconducting cavity is tested for a variety of the contents. As an operational frequency is 508.8875MHz in KEKB, it was necessary that the resonant frequency was tuned to it at first. This was easily accomplished by deforming an end plate of the cavity. After that, a coaxial beam pipe is adjusted on the center of the cavity. When it stays around the center, a signal from a pick-up antenna at the coaxial beam pipe becomes smallest for a "Crab mode" of 508.8875MHz. These were adjusted by monitoring the spectrum on the display of the network analyzer.

After the above adjustment, the tuner operation was tested at 4.2K same as the room temperature. In the second horizontal test, the HER Crab cavity had no trouble for it. In the third test, the LER Crab cavity had a trouble for it. It was not smoothly operated and the backlash was observed in the operation. Figure 8 shows the distribution of the tuner phase during the high power RF test. Although that of HER is a Gaussian-like distribution, that of LER is deformed and has two peaks. The sampling time for HER and LER Crab cavity were 100 and 500msec, respectively. Due to the unstable operation of the tuner, the tuner phase was changed largely and the kick voltage was changed accordingly. This problem was eventually not clear in the horizontal test. Due to the limited time, the cavity was advanced to the tunnel installation. It was expected that a much faster feedback in the beam commissioning would enable the cavity to operate with no trouble. The beam phase is used for the feedback in the beam commissioning instead of the tuner phase.

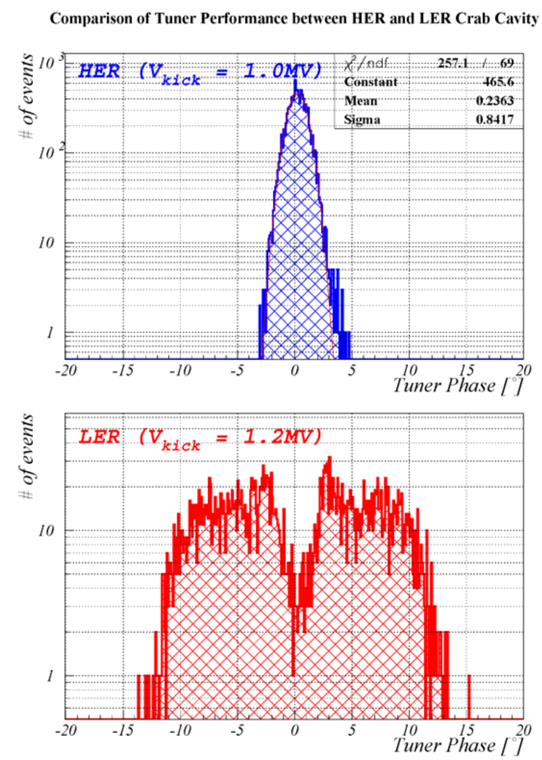

Figure 8: The tuner performance during the RF processing.

In the high power RF test, a various ways of the RF conditioning was tried. Only the input coupler was conditioned with the detuned cavity. After setting the coaxial beam pipe apart from the center of the cavity, it was conditioned. And, a pulsed-conditioning was tried for the cavity by using a function generator. Figure 9 shows the status during the RF conditioning for both cavities. HER Crab cavity did not achieve the operational kick voltage at first in the first horizontal test. After the temporary warm-up up to 80K, the cavity achieved it with ease. This situation was same in the second horizontal test. On the other hand, LER Crab cavity achieved it in the first day. The maximum kick voltages for HER and LER Crab cavity were 1.80MV and 1.93MV, respectively. The different input power between HER and LER Crab cavity was due to the different loaded Q value (described later). Figure 10 shows the vacuum status during the RF conditioning. The vacuum of the input coupler was occasionally discharged. When the coaxial beam pipe was off-centered, the vacuum of the coaxial beam pipe was discharged, because the "Crab mode" can propagate into it. Figure 11 shows the correlation between the vacuum of the input coupler and the tuner phase during the RF conditioning. When the tuner phase stayed around -13°, it was observed the phenomenon that the vacuum of the input coupler was intensely discharged. After the conditioning for a few hours, it disappeared eventually. When the cavity was detuned, the tuner phase stayed around 90°.

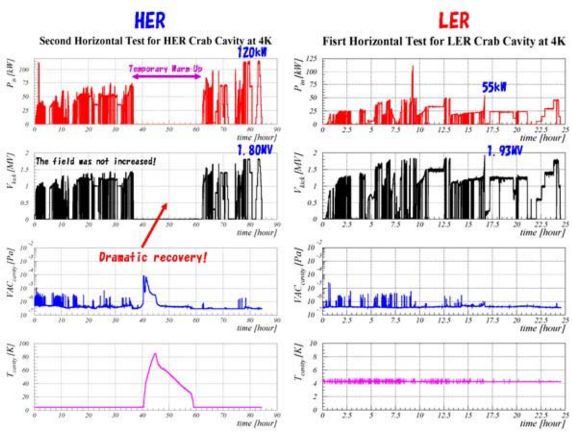

Figure 9: The time profile of the klystron power, the kick voltage, the vacuum and the temperature of the cavity during the RF processing.

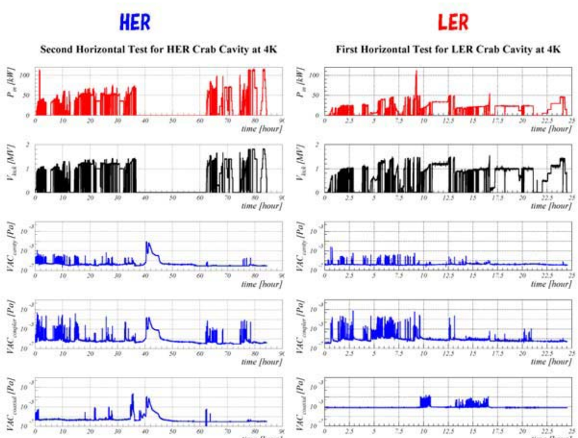

Figure 10: The time profile of the vacuum at the three cold cathode gauges (cavity/input coupler/coaxial beam pipe) during the RF processing.

Table 2 shows the result of the measurement and calculation for the loaded Q. The loaded Q was measured by two different methods using the high power RF. In the case of the band width method, it was not slightly correct due to the fluctuated power. The value for the decay time method is normally used as the correct one. An expected value by HFSS was $1.6x10^5$. These measured values were consistent with the calculation within ±20%. There is a difference between the first and the second result for HER Crab cavity, although the same cavity and the same input coupler were used for the assembly. It seems that this shows an error of the assembly.

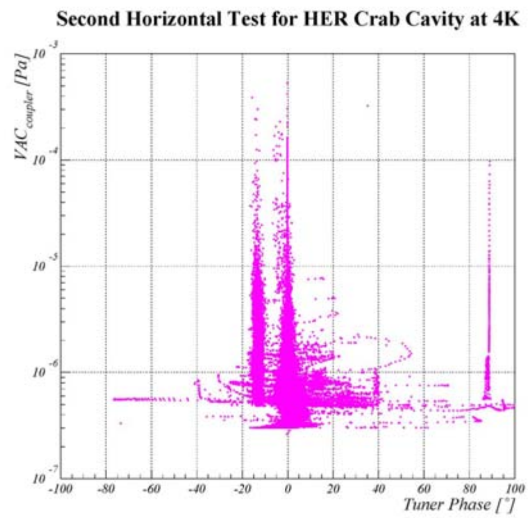

Figure 11: The correlation between the vacuum level and the tuner phase of the cavity during the conditioning.

Table 2: The loaded Q between the various ways.

			HER		LER
Condition	P_{in}[kW]	Method	Q_L (Jun/2006)	Q_L (Nov/2006)	Q_L (Dec/2006)
High power	20	Decay time	$1.66x10^5$	$1.34x10^5$	$2.07x10^5$
High power	10	Band width	$1.59x10^5$	$1.64x10^5$	$1.86x10^5$
Simulation		HFSS (ver. 9.2)	$1.6x10^5$		

Figure 12 shows the results of the Q_0 vs. E_{peak} curves between the vertical and horizontal test. The unloaded Q was almost same for both cavities between these tests [4].

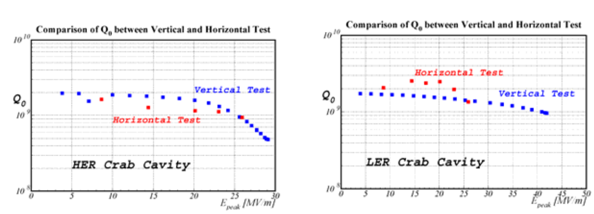

Figure 12: The comparison of Q_0 vs. E_{peak} curve between the vertical and horizontal test.

TUNNEL INSTALLATION & BEAM COMMISSIONING

After the horizontal tests, two Crab cavities were installed into the KEKB tunnel at the beginning of Jan in 2007. The tunnel installation was successfully finished. Figure 13 shows the situation for both cavities during the installation.

Figure 13: The photos during the tunnel installation.

From Feb in 2007, the beam commissioning was started. At first, both cavities were detuned and monitored at the low beam current. After one week, the cavities were operated with on-resonance. And, the beam current was gradually increased. At the end of June, the beam current for HER and LER achieved 700mA and 1000mA, respectively. With the detuned cavity, they achieved 1350mA and 1700mA. The temporary warm-up was effective for the frequent RF trip. It was found that the fast feedback using the beam phase enabled the cavity to operate stably. The unstable tuner operation was not significant in the beam commissioning [5-9].

SUMMARY

Two Crab cavities were fabricated and tested at KEK. Both cavities achieved above the operational kick voltage of 1.4MV in the horizontal tests. The various ways of the RF conditioning were tried. The tuner performance for LER Crab cavity was not smoothly operated. Although the reason is under investigation at present, it is actually not significant in the beam commissioning. During the warm-up for LER, the vacuum level became much higher than HER due to the outgas.

At present, the LER Crab cavity achieved above 1A in the beam commissioning, while the HER cavity achieved 700mA. The beam commissioning with Crab cavities will be kept for at least one year.

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