CRYOGENICS FOR THE KEKB SUPERCONDUCTING CRAB CAVITIES

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Abstract

Two superconducting crab cavities were successfully installed into the KEKB accelerator in January 2007. Since then the crab cavities have been in stable operation for 3 years up to now, thanks to reliable operation of the cryogenic system of the KEKB accelerator including a large-scale helium refrigerator. This means that the cryostat for the crab cavities was well designed and constructed properly, although there are some technical complexities in the cryostat, such as two liquid helium vessels (jackets) in a cryostat, a movable coaxial coupler which is cooled with liquid helium and so on. The KEKB cryogenic system was also appropriately modified to operate the two crab cavity cryostats stably. This cryogenic system is described in this paper.

A calorimetric method to measure Q-factors of the crab cavities is suggested, which employs an electric compensation heater in the cryostat, instead of the conventional method, which measures the descending rate of liquid helium level in a cryostat. Measurement results of Q-factors of crab cavities after being assembled into cryostats and after being installed into the KEKB accelerator are compared with the vertical test results.

INTRODUCTION

A superconducting crab cavity is a deflector of beam bunches. Since the KEKB accelerator has two beam lines, the High Energy Ring (HER) for electrons and the Low Energy Ring (LER) for positrons, the bunches make collision with a finite angle. The crab cavities change the direction of bunches and the bunches can make a head-on collision. This scheme is expected to increase luminosity of the KEKB accelerator. Two superconducting crab cavities were introduced into the KEKB accelerator in 2007, one in the HER and another in the LER, as reported in our previous paper [1]. For 3 years since then, the crab cavities have operated stably for about 16000 hours and rendered surely good service to increase luminosity of the KEKB accelerator. Our experience on the operation of the superconducting crab cavities for 3 years is described in this paper.

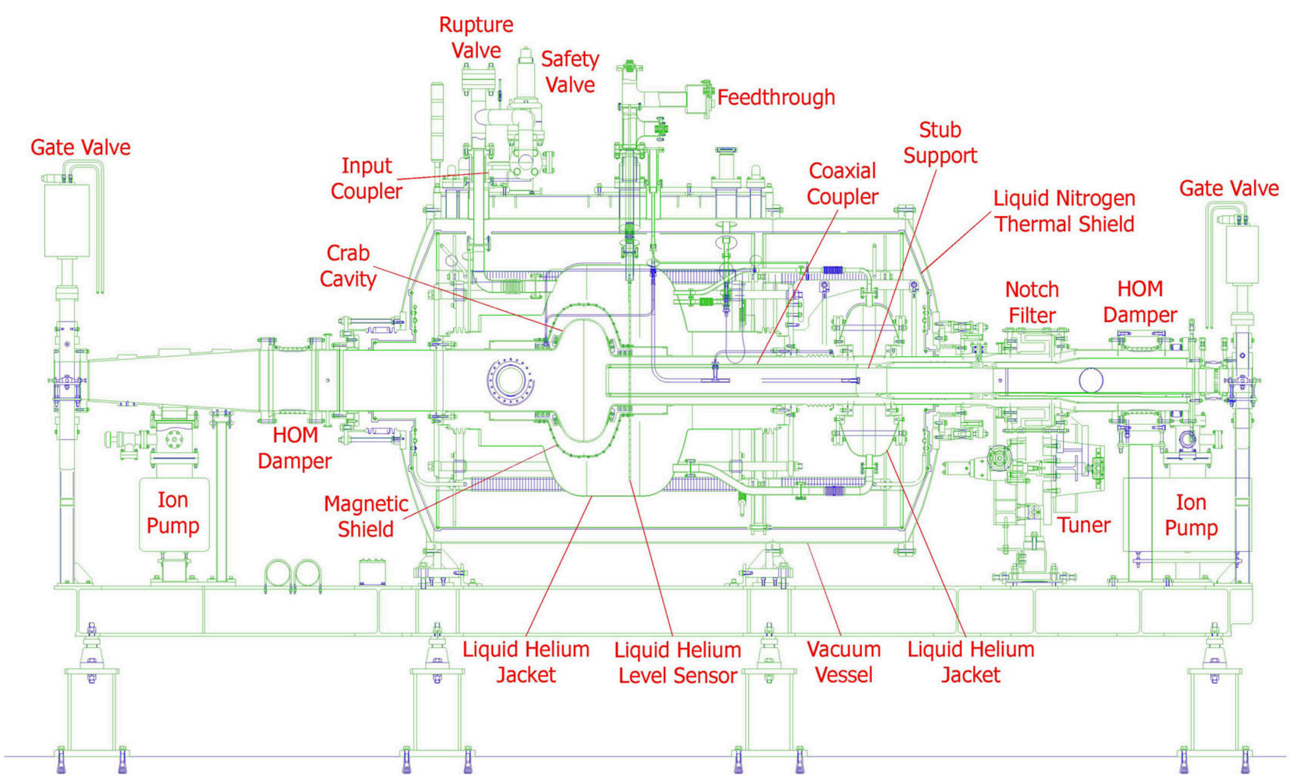

Figure 1: Crab cavity cryostat for the LER (side view).

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It is possible that the performance of a superconducting cavity may degrade when it is assembled into a cryostat, and also when it is installed in a beam line of the accelerator. The cavity performance can be measured by a calorimetric method. The simple way is to measure the descending rate of liquid level in the cryostat with and without rf power input to the cavity, while the liquid helium supply valve is closed. Since the crab cavities are equipped with superconducting coaxial couplers, the helium flow paths are complicated, compared with those for the superconducting accelerating cavities. Hence it is not suitable to apply the same method to measurements for the crab cavities. Another calorimetric method to measure the crab cavity performance has been suggested and applied to measure the cavity performance at the horizontal test stand [1]. This method is again applied to measure the performance of the crab cavities in the beam lines after their operation for 3 years.

CRYOGENIC SYSTEM OPERATION

The two superconducting crab cavities in the cryostats have been connected to the 6.5 kW helium refrigeration system, which was built for the TRISTAN accelerator in KEK [2] more than 20 years ago and reused for the KEKB accelerator. A crab cavity cryostat contains a superconducting crab cavity, a superconducting coaxial coupler, which is movable along the beam line to tune the cavity resonant frequency, two liquid helium jackets, one of which accommodates a crab cavity in it and another does a stub support for a coaxial coupler, and other components, as shown in Fig. 1. Not only the crab cavity but also the coaxial coupler should be cooled with liquid helium to keep them in superconducting state. The two liquid helium jackets are connected with copper bellows, since the coaxial coupler should be movable to adjust the cavity frequency. The bellows are cooled with the evaporated helium gas from the liquid helium jacket. The existing helium pipes for coaxial couplers and bellows turned out to be too small to cool the coaxial couplers and the bellows enough during the operation of the crab cavities. We have added bypass lines to increase the helium gas flow rate through the coaxial couplers and the bellows.

Some of control valves equipped between the crab cavities and the cryogenic system had malfunctioned during the operations of the crab cavities. Major cause of such technical issues was the accumulation of oil from air compressors in instrumentation air pipes. Most of the instrumentation air pipes were installed in the TRISTAN accelerator, and small amount of oil from the air compressors may gradually have stuck on inner surfaces of the air pipes during a long period of operation. After cleaning the instrumentation air pipes thoroughly, there is no malfunctions of the valves anymore.

Apart from these points, we do not have faced to any serious technical problems on the crab cavity cryostats from the cryogenic point of view.

CALORIMETRIC MEASUREMENTS OF Q-FACTORS

For ordinary superconducting accelerating cavities, Q-factors can be calculated by measuring the descending rate of the liquid helium level in a cryostat with some rf power input to the cavity. The crab cavities are equipped with coaxial couplers to tune the resonant frequency, instead of the frequency tuning with the deformation of the cavities for accelerating cavities. These coaxial couplers are cooled with liquid helium, and the evaporated helium flows through the bellows and the power input couplers to absorb the heat load from the ambient environment. Such extra liquid helium in the coaxial couplers and helium vapor flow through the bellows and the input couplers may introduce large errors in the descending rate measurement to calculate Q-factors of the cavities. To avoid such errors another calorimetric measurement is suggested. The liquid helium jacket, which accommodates one crab cavity in it, contains an electric heater to compensate the fast heat load variation caused by rf loss of the crab cavity. This heater in the liquid helium jacket can be employed to produce preset heat loads to the cryogenic system. Without rf power to the crab cavity, preset heat load, say 100 W, is generated by the heater. Then the liquid helium supply valve is set to maintain any liquid helium level constant in the jacket. After confirming the whole cryogenic system is in steady state, some rf power is input to the crab cavity. Because of rf loss of the crab cavity, heat load from the heater should be decreased to keep the liquid helium level unchanged. The difference between the heat load without rf power and the adjusted heat load with some rf power is the rf loss of the cavity. A Q-factor of the crab cavity can be readily calculated from this rf loss.

RESUTLS AND DISCUSSION

The measured Q-factors of the HER and LER crab cavies are plotted against the kick voltage in the cavities in Figs. 2 and 3, respectively. The results measured in the beam lines (green solid triangles) are compared with the vertical measurement results (purple solid rhombi), and with the results measured by this method at the horizontal test stand after the cavity assembled into a cryostat (various solid circles and squares). Though a calorimetric measurement introduces relatively large errors intrinsically, the results at the test stand was rather follows the vertical test results, and then it could be concluded that the cavity performance did not get worse at least even after the assembly into the cryostat [1]. On the other hand, the recent results measured in the beam lines show much lower Q-factors than the vertical test results and the former measurements at the test stand. It may be easily concluded from these figures at first glance that the cavity performance degraded during the operation of the KEKB accelerator. However, data points measured in the beam lines have tendency to decrease as the kick voltage increases, as shown in these figures. This is impossible physically, and the cryogenic system does not suffer any apparent heat load increase during the crab cavity operation. Then, it is fair to conclude that these measurements have larger errors and the cavity performance does not degrade so much. The length of the cryogenic transfer line to the LER crab cavity is about 190 m from the liquid helium dewar of the cryogenic system, and that to the HER crab cavity about 75 m. The transfer line transports liquid helium and liquid nitrogen not only to two crab cavities but also to eight superconducting accelerating cavities. Then the time constant of the cryogenic system including the two crab cavities and the eight accelerating cavities should be very long. It is plausible that the measurement was done much earlier before the whole cryogenic system is settled in the steady state against the variation of the heat load, i.e., heat generated from the electric heater. Though it was aimed, of course, that the measurements should be executed after establishing steady state of the cryogenic system, it might be still transient state as a result. It should come up with various ideas to improve Q-factor measurements in the beam lines.

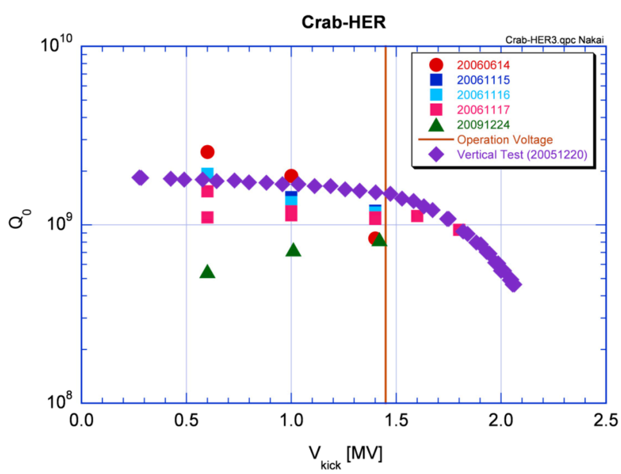

Figure 2: Measured Q-factors of the HER crab cavity.

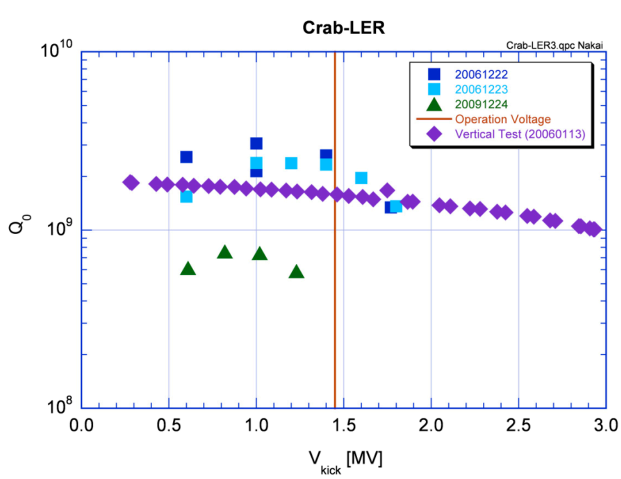

Figure 3: Measured Q-factors of the LER crab cavity.

SUMMARY

- Two superconducting crab cavities have been successfully installed into the KEKB, as the first case in the world, and have operated stably for 3 years (about 16000 hours). These crab cavities contribute to increase luminosity of the KEKB accelerator, and prove that the crab cavities can deflect beam bunches surely.
- A calorimetric method to measure Q-factor of superconducting cavities is introduced and employed to measurements of the superconducting crab cavities for the KEKB accelerator. The measurement results carried out at the test stand show its effectiveness. There is much room for improvement if the measurement is tried to superconducting cavities in the beam lines.

REFERENCES

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[2] K. Hara, K. Hosoyama, Y. Kimura *et al.*, “Cryogenic System for TRISTAN Superconducting RF Cavity”, *Adv. Cryog. Eng.* **33** (1988) p. 615