CRYOGENIC SYSTEM FOR THE KEKB CRAB CAVITIES

H. Nakai#, K. Hara, T. Honma, K. Hosoyama, A. Kabe, Y. Kojima, Y. Morita, K. Nakanishi, KEK, Tsukuba, Japan
T. Kanekiyo, Hitachi Technologies and Services, Tsukuba-Center, Tsukuba, Japan
T. Yanagisawa, Mitsubishi Heavy Industries, Kobe Shipyard & Machinery Works, Kobe, Japan

Abstract

The superconducting crab cavities, which change the direction of beam bunches to increase the luminosity of the KEKB accelerator, are successfully installed in the KEKB and operated with the stable operation of the large helium refrigerator for the KEKB.

Since the crab cavities requires unique devices, such as long coaxial couplers, the cryostats for the crab cavities have various special features in their design and also in their cooling schemes. This paper describes such features and cooling schemes of the cryogenic system for the KEKB superconducting crab cavities.

Calorimetric measurements on Q-factors of the crab cavities and static heat load (static loss) measurements of the crab cavity cryostats are carried out after the cryostat assembly. The results of these measurements are acceptable, and from these results, it is found that the crab cavity performance does not degrade so much during the cryostat assembly.

#hirotaka.nakai@kek.jp

INTRODUCTION

Two superconducting crab cavities are installed in the KEKB, which has two beam lines: a high energy ring (HER) for 8 GeV electrons and a low energy ring (LER) for 3.5 GeV positrons. Since beam bunches of electrons and positrons intersect at a point with a finite angle, they may introduce synchrotron-betatron coupling resonance. A crab cavity is proposed to change the direction of beam bunches to make head-on collision at the intersection point. It is then possible to avoid synchrotron-betatron coupling and to increase luminosity of the accelerator. At first, it was considered that 4 crab cavities were needed near the intersection point to realize the head-on collision of electron and positron beam bunches. In this case, we would have to manufacture long cryogenic transfer lines, which connect between the crab cavity cryostats near the intersection point and the 6.5 kW helium refrigerator. By the lattice calculation with the introduction of the crab cavities near the helium refrigerator, it was suggested that two crab cavities, one in HER and another in LER, should be installed to

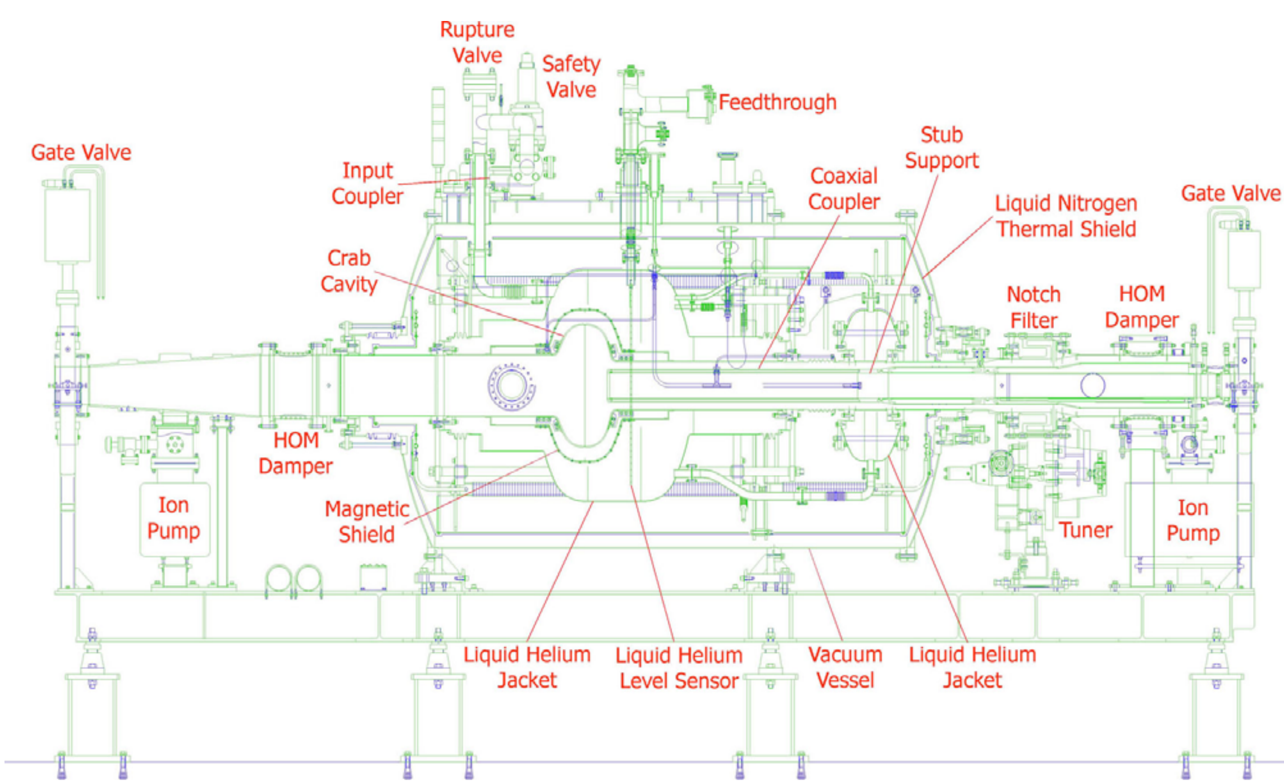

Figure1: Crab cavity cryostat (LER) seen from the side.

make head-on collision of beam bunches and to increase luminosity. Then one can hope that two crab cavities can realize the head-on collision of electron and positron beam bunches at the intersection point, while the crab cavities are located near the helium refrigerator with less modification of the cryogenic system for the KEKB.

CRYOGENIC SYSTEM

Crab Cavity Cryostats

The cryostat of the crab cavity is shown schematically in Figure 1. The crab cavity, made of pure niobium, is surrounded with a magnetic shield in a main helium jacket. To withdraw the unwanted modes from the cavity and also to adjust the resonant frequency of the cavity, a coaxial coupler is inserted into the cavity. Since this coupler is long and made of pure niobium, it is required to support this long coupler in the cryostat and to cool it down below the transition temperature of niobium. Then a stub support is employed to satisfy these requirements. This support is located in a secondary helium jacket, and forms a liquid helium conduit to supply liquid helium to the coaxial coupler. The coaxial coupler should be movable relative to the crab cavity along the beam line for resonant frequency tune. Then the coaxial coupler and the stub support surrounded by the secondary helium jacket is fixed to the frequency tuner and connected to the main helium jacket with bellows.

Cooling Scheme of Crab Cavities

Liquid helium from the cryogenic system is supplied to the main helium jacket through the transfer lines and the connection boxes. Some of liquid helium flows into the secondary helium jacket through the lower connection tube, as shown in Figure 2. Evaporated helium in the secondary jacket flows back to the cryogenic system through the upper connection tube and the main jacket. The coaxial coupler is cooled by liquid helium from the secondary helium jacket through the stub support for the coupler, as shown in Figure 3. Evaporated helium from the coaxial coupler and the stub support flows along the bellows, which connects the main and secondary helium jackets, to reduce the heat load to the helium jackets. The outer conductor of the RF coupler is cooled by evaporated helium from the main helium jacket. The flow rates of evaporated helium through the coaxial couplers, the bellows and the RF couplers can be adjusted by the control valves equipped in the helium return lines.

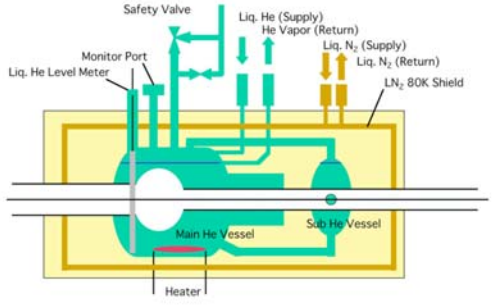

Figure 2: Flow scheme of cryogens.

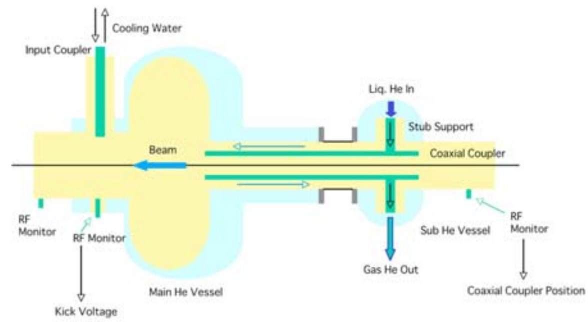

Figure 3: Cooling scheme of devices.

Configuration in the KEKB Accelerator

In the former TRISTAN accelerator of KEK, 16 cryostats for 32 superconducting accelerating cavities, i.e. one cryostat contained two cavities, were employed. Eight cryostats were installed at D10 straight section of the tunnel and other 8 at D11 straight section. To supply liquid helium and liquid nitrogen to each cryostat, 16 cryogenic connection boxes (8 at D10 and other 8 at D11) were located along the main transfer line in the tunnel. These connection boxes are left in the tunnel after removals of the TRISTAN superconducting accelerating cavity cryostats from the tunnel. Eight connection boxes (4 at D10 and other 4 at D11) have been already reused for the KEKB superconducting accelerating cavity cryostats. Two crab cavity cryostats are then connected to the main transfer line through two of eight unused connection boxes (1 at D10 and another at D11), as shown in Figures 4 to 7. The crab cavity cryostats are connected to the connection boxes with high performance transfer lines designed at KEK. The cross sections of the connecting transfer lines are shown in Figures 8 and 9 [2].

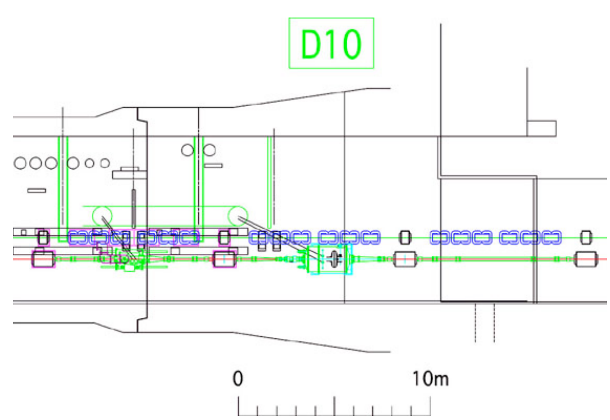

Figure 4: Crab cavity configuration in HER at D10.


Figure 5: Crab cavity cryostat in HER.

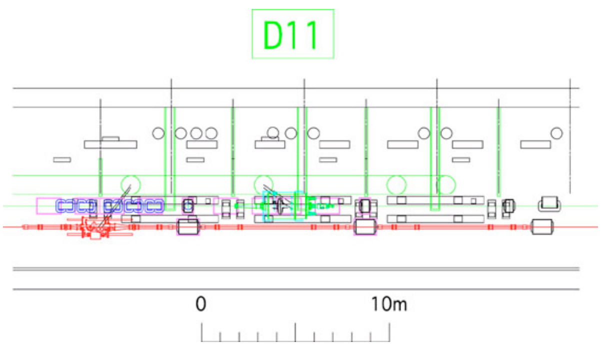

Figure 6: Crab cavity configuration in LER at D11.


Figure 7: Crab cavity cryostat in LER.

CALORIMETRIC MEASUREMENTS

Compensation Heater

A 200 W electric heater is attached at the bottom of the main helium jacket of the crab cavity cryostat, as seen in Figure 10. Since the time constant of the 6.5 kW helium refrigerator is very long, the refrigerator can not

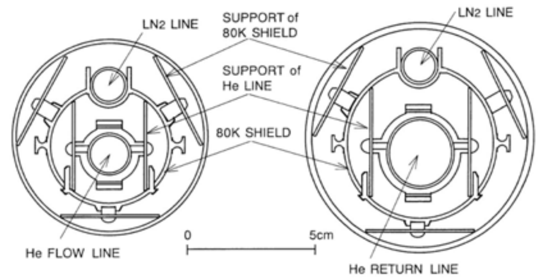

Figure 8: Cross sections of transfer lines.


Figure 9: A photo of a transfer line under manufacture.

follow the rapid variation of the RF loss heat load when the beam disappears suddenly because of some reason, such as break-down of the cavity. To achieve the stable operation of the refrigerator, it is desirable that the apparent heat load to the refrigerator is constant in spite of the variation of the RF loss heat load. The heater in the helium jacket is used to compensate the RF loss variation. Heat generated from the heater is controlled by the refrigeration control system to make the total heat load (RF loss plus heat from the heater) to the refrigerator constant.

Static Heat Load to Cryostats

Though many efforts are made in design and manufacture of cryostats to reduce heat load from the ambient to the cryostats, it is impossible to eliminate the static heat load to the cryostat. This heat load are due to the non-zero thermal conductivity of materials employed in the cryostat, to the residual gas in the insulation vacuum of the cryostat and to the imperfect radiation shield. Hence it is important to estimate and to measure precisely the heat load to the cryostats to design and to construct the cryogenic system. To measure the heat load to the crab cavity cryostats, the compensation heater in the main helium jacket was employed. The descending rates of liquid helium level in the main helium jacket between two fixed levels were measured without any heat input and with some heat inputs from the compensation heater. The static heat load, i.e. the heat

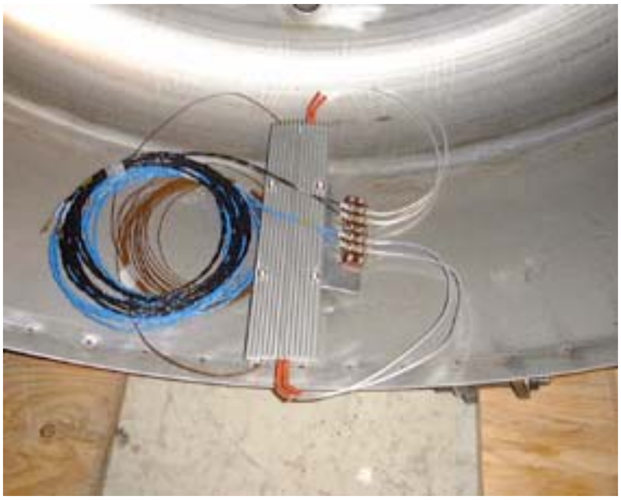

Figure 10: An electric compensation heater at the bottom of the main helium jacket.

load without any active heat input, can be calculated from these descending rates. It should be mentioned that the coaxial couplers, the bellows and the RF couplers were cooled with evaporated helium from the helium jackets during these measurements. Hence one should consider the heat removed by the evaporated helium through these devices. Measured descending rates and calculated static heat loads are listed in Table 1. These heat loads to the crab cavity cryostats are acceptable from the point of view of the refrigeration capacity of the cryogenic system.

Q-factors of Crab Cavities

The loss of the superconducting cavity converts to the heat load to liquid helium surrounding the cavity and this heat load evaporates some amount of liquid helium, the same procedure of the static heat load measurement can be applied to the Q-factor measurement in principle. The measurement of the liquid helium level descending rate is, however, not so accurate, because the liquid helium level waves always and then the definition of the level at the moment is not definite. Then we employ the heater-adjustment method to measure Q-factors of the crab cavities, instead of the heat load measurement method. There is no need to measure the descending rate of the liquid helium level in this method. At first we input some amount of heat, say, 100 W in the main helium jacket by the compensation heater. Then, we adjust the opening of the helium inlet valve to maintain the prefixed liquid level above the top of the crab cavity. With some RF power inputs to the cavity, only the heat input from the heater is adjusted to keep the prefixed liquid level unchanged. The difference between the first heat input without any RF power and the heat input with some RF power input corresponds to Q-factor of the cavity. Q-factors of the two crab cavities in HER and in LER measured in this method are plotted in Figures 11 and 12, respectively, in which the results of the vertical measurements of the cavities are compared. Even though this method still contains some ambiguity, because of

Table 1: Static heat load to crab cavity cryostats.

HER 20061117

Heater [W]	Duration [min.]	Coupler [L/min.]	Coax. [L/min.]	Bellows [L/min.]	Total [L/min.]	Q-flow [W]	Total Loss [W]	Static Loss [W]
0	28	3	139.5	157.5	300	18.67		
20	20	3	137.5	157.5	298	18.54	50.00	31.46
40	15	3	139.0	158.0	300	18.67	46.15	27.48
0	27	3	137.0	156.0	296	18.42		
20	20	3	137.0	157.0	297	18.48	57.14	38.66
40	15	3	138.5	158.5	300	18.67	50.00	31.33
Average						18.57	50.82	32.25

LER 20061223

Heater [W]	Duration [min.]	Coupler [L/min.]	Coax. [L/min.]	Bellows [L/min.]	Total [L/min.]	Q-flow [W]	Total Loss [W]	Static Loss [W]
0	32	4	98.7	137.9	240.6	14.97		
20	21	4	99.5	142.0	245.5	15.28	38.18	22.90
40	16	4	101.2	117.2	222.4	13.84	40.00	26.16
0	32	4	99.3	142.0	245.3	15.26		
20	22	4	95.8	149.4	249.2	15.51	44.00	28.49
40	16	4	96.5	125.0	225.5	14.03	40.00	25.97
Average						14.82	40.55	25.73

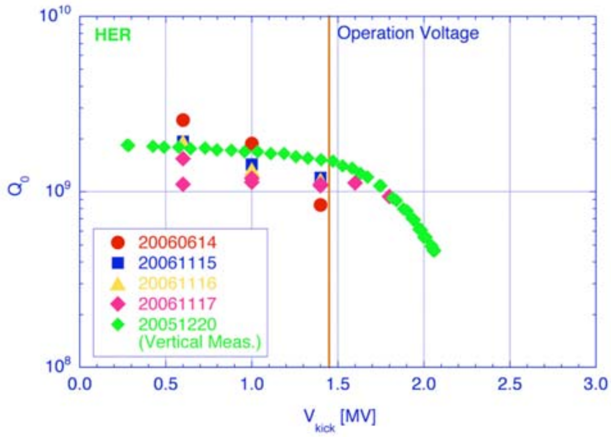

Figure 11: Q-factors of the HER crab cavity.

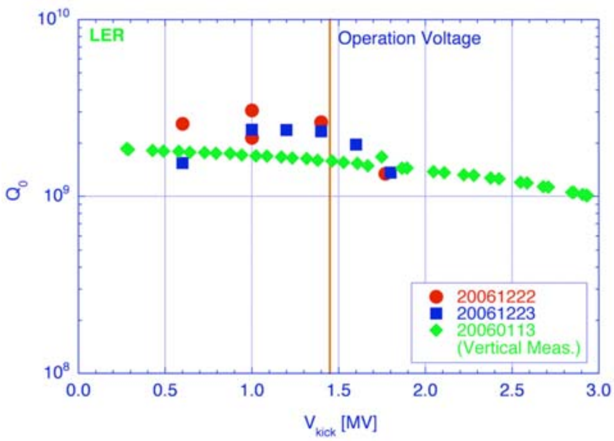

Figure 12: Q-factors of the LER crab cavity.

indirect measurement, it is fair to say that the crab cavity performances does not degrade so much during the cryostat assembly.

SUMMARY

- Two superconducting crab cavities are successfully installed in the KEKB accelerator, and operates stably to increase the luminosity of the KEKB. The helium refrigerator can supply enough amount of liquid helium into the crab cavity cryostats, in addition to 8 superconducting accelerating cavity cryostats of the KEKB.
- Calorimetric measurements of the static heat load to the cryostats and of Q-factor of the crab cavities are carried out, and their results are acceptable. By comparing the results of this horizontal measurement and the previous vertical measurement of the crab cavities, it is found that the cavity performance does not degrade so much during the cryostat assembly.

REFERENCES

[1] H. Nakai, K. Hara, T. Honma *et al.*, “Research Development Program on Superconducting Crab Cavities for KEKB”, SRF2003, Travemünde, September 2003, MoP34
[2] K. Hara, K. Hosoyama, Y. Kimura *et al.*, “Cryogenic System for TRISTAN Superconducting RF Cavity”, *Adv. Cryog. Eng.* **33** (1988) p. 615