BEAM COMMISSIONING STATUS OF SUPERCONDUCTING CRAB CAVITIES IN KEKB

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Abstract

Two superconducting crab cavities have been operated stably without any significant trouble for three years in KEKB since Feb/2007. At present (Dec/2009), maximum beam current with "Crab ON" achieves 1250mA for HER (High Energy Ring, electron) and 1700mA for LER (Low Energy Ring, positron), respectively. Although Piezo actuator broke down frequently at the RF recovery or the beam abort with RF trip of the crab cavity, it was controlled stably by only LLRF (Low-Level-RF) feed-back system without Piezo actuator. Maximum HOM (Higher Order Mode) power, which is measured at HOM dampers made from ferrite powder, is 9.9kW for HER and 14.9kW for LER at the maximum beam current, respectively.

BRIEF HISTORY

Table 1 shows the brief history of crab cavities after the beam commissioning.

Table 1: Brief History of crab cavities

Month/Year	Content
Jan/2007	Installation into the KEKB tunnel
Feb/2007	Beam commissioning started with "Crab ON"
Mar/2007	Cavity voltage of LER Crab dropped suddenly
Jun/2007	Piezo actuator of LER Crab broke down for the first time. Oscillation was observed at high beam current with crabbing collision.
Oct/2007	Physics run started with "Crab ON".
May/2008	Cavity voltage of LER Crab was recovered slightly.
Oct/2008	Lower temperature operation was tried to recover cavity voltage of LER Crab.
Nov/2008	Beam study with "Crab ON" for LHC was tried.
Mar/2009	Lower temperature operation was retried.
Oct/2009	Oscillation was observed again, regardless of setting tuning phase offset and crab phase.
Dec/2009	Beam current with "Crab ON" achieved 1250mA for HER and 1700mA for LER. Beam study with "Crab ON" for LHC was tried again.

BEAM COMMISSIONING

In this section, the various items during the beam commissioning are described.

Interlock System for Crab RF Off

Figure 1 shows the block diagram of the interlock system for crab cavity. When a monitor signal ranges over a threshold, the Crab cavity is switched off. Moreover, at the same time, the beam is aborted rapidly, because of the safety. The explanation for each monitor signal is:

- Breakdown detector; this device judges whether klystron output, cavity voltage and crab phase (only cavity voltage for LER) are normal, or not. This is the most frequent cause of Crab RF trip.
- RF output from pickup probes; these signals come from the coaxial beam pipe and the transmit power.
- Vacuum; each crab cavity has three cold cathode gauges, which are attached at the large beam pipe, the coaxial beam pipe and the RF window of the input coupler. This is the secondary cause of Crab RF trip.
- Temperature; many temperature sensors are attached at the cold and warm parts.
- Arc sensor; this device detects the arc discharge at the RF window.
- He pressure/level; these two signals show the status of the liquid helium.
- Flow rate of cooling water; several channels of the cooling water are attached at HOM dampers, the input coupler and the coaxial coupler.

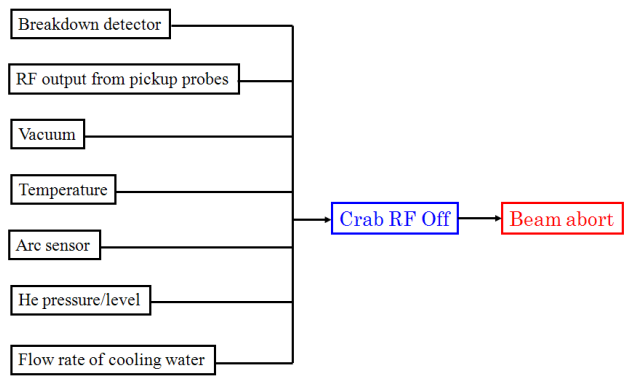

Figure 1: Block diagram of interlock system for crab cavity.

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RF Trip rate with Crab RF Off

Figure 2 shows the RF trip rate with Crab RF Off during the beam commissioning. The HER Crab cavity had the high trip rate at the beginning of the physics run (Period 2), which was 2.8/day for HER and 0.4/day for LER, respectively. However, it gradually lowered and reached below one per day due to the RF conditioning many times and dropping the cavity voltage. At present, the trip rate is 0.8 per day for HER and 0.1 per day for LER, respectively. In the total average, it is 1.3 per day for HER and 0.5 per day for LER, respectively. When it is difficult to recover the crab cavity after the RF trip, the RF conditioning is usually done at the local control room.

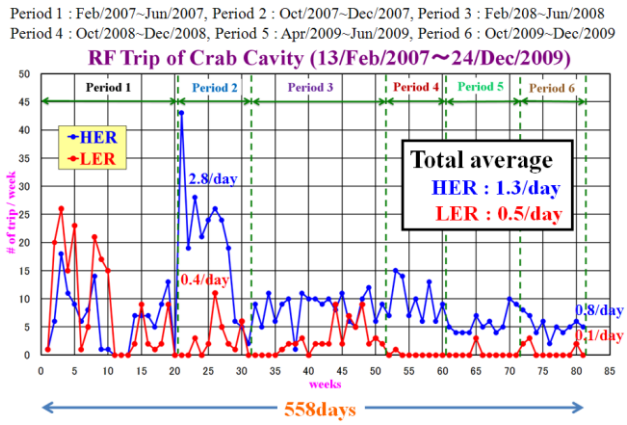

Figure 2: RF trip rate with Crab RF Off during beam commissioning.

HOM Load at HOM Dampers

The High Order Mode (HOM) damper [1], which is made from ferrite powder, is attached at the coaxial beampipe and the Large Beam Pipe (LBP). Moreover, for LER Crab cavity, two SiC dampers are also attached at the downstream of the LBP side, because of the higher beam current. Table 2 shows the summary of the HOM dampers at the maximum beam current, which is 1250mA for HER and 1700mA for LER. In the columns of "Coaxial" and "LBP", the left and right values show the HER and LER Crab cavity, respectively. The HOM load at LBP of LER Crab cavity is beyond the designed value (10kW) at present. The loss factor is estimated from the equation (1). Figure 3 shows the correlation between the each HOM load and the beam current, which maximum value is 1250mA for HER and 1700mA for LER.

Table 2: Summary of HOM Dampers

	Load [kW]	T_{max} [℃]	Flow rate [ℓ/min]	Loss factor k [V/pC]
Coaxial	3.0 / 2.5	34.0 / 31.3	5.0 / 5.0	0.28 / 0.13
LBP	6.9 / 12.4	40.0 / 47.2	7.0 / 7.5	0.74 / 0.68
SiC #1	13.0	39.1	13.0	0.72
SiC #2	12.2	41.5	10.3	0.66

$$\mathrm{k[V/pC]} = \frac{P_{loss}[W] \cdot N_{bunch} \cdot f_{rev}[kHz]}{\{I_{beam}[mA]\}^2} \times 10^{-3} \quad (1)$$

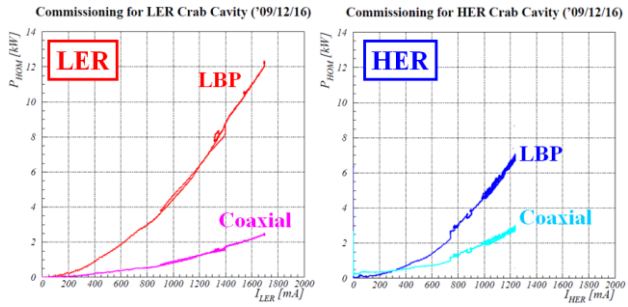

Figure 3: The correlation between the HOM load and the beam current.

Crab Voltage Scanning

The Crab voltage scanning is sometimes carried out as a part of the beam tuning for the higher luminosity. A very careful operation is necessary, because the RF trip of Crab cavity occurs frequently during this operation. During the beam commissioning, the maximum voltage was 1.55MV for HER and 0.98MV for LER at the typical beam energy.

Breakdown of Piezo Actuator

During the beam commissioning, Piezo actuator broke down frequently and was exchanged for the new one. Figure 4 shows a set of Piezo actuator and load sensor (left), and the situation after the breakdown (right). The number of the breakdown is four times for HER and five times for LER within these three years. However, two Crab cavities operated stably without Piezo Actuator, by driving only motor tuner and the LLRF (Low-Level-RF) feedback system. It was not a significant trouble.

Figure 4: A set of Piezo actuator and load sensor (left) and the situation after the breakdown (right).

Cavity Voltage Drop of LER Crab

One month later from the beam commissioning, the LER Crab voltage dropped suddenly from 1.3MV to 1.0MV on 17/Mar/2007. Eventually, it was not recovered, although the various methods for the recovery were tried. However, in 2008, the recovery sign appeared. At present, the LER Crab voltage is gradually increased from 1.0MV to 1.3MV. Table 3 shows the history of the LER Crab voltage. The cause of the recovery may be due to several thermal cycles from the room temperature to 4.2K.

Table 3: History of LER Crab Voltage

Date	Cavity voltage [MV]	Comment
Dec/2006	1.9	Horizontal test
Feb/19/2007	1.5	At beginning of beam commissioning
Feb/22/2007	1.3	Maintenance day
Mar/17/2007	1.3 → 1.0	Suddenly dropped
Mar/23/2007	1.1	After thermal cycle
May/22/2008	1.2	Slightly recovered
Jun/30/2008	1.3	After pulse conditioning
Dec/18/2009	1.3	Not more recovered

Lower Temperature Operation than 4.2K

To recover the LER Crab voltage, the lower temperature operation than 4.2K was tried twice. Although the first trial was done in autumn/2008, it failed due to the unexpected oil reduction of the pumping system. The second trial was done in spring/2009 after some improvements. Actually, though the lower temperature operation was successful and the LER Crab cavity operated stably at 3.6K, the LER Crab voltage was not recovered.

Re-appearance of Oscillation Phenomenon

The beam oscillation phenomenon was observed at the beginning of the beam commissioning in 2007 [2]. Fortunately, the remedy for this oscillation, with the crab phase of above +10 degrees, and the tuning phase offset of +5 degrees for HER and -8 degrees for LER, was found. In 2008, this phenomenon was suppressed perfectly by this remedy. However, in autumn/2009, the oscillation re-appeared, regardless of setting the same values as previous. Therefore, the new remedy was tried, which is to set the crab phase to +19 degrees, and the tuning phase offset to +15 degrees for HER and -10 degrees for LER. The oscillation phenomenon was suppressed again by this new remedy. Figure 5 shows the typical phenomenon for this oscillation.

SUMMARY

Two Crab cavities have been operated stably without any significant trouble for these three years. Figure 6 shows the achieved parameters during the beam commissioning. The HOM load at LBP including two SiC dampers for LER Crab cavity is already beyond the designed value. More careful operation is necessary for the higher beam current. The RF trip rate is quite low for both Crab cavities at present.

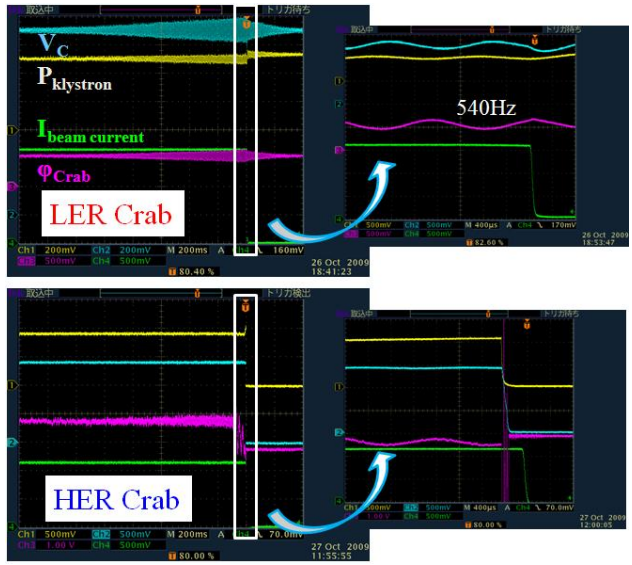

Figure 5: Typical events of beam oscillation for HER and LER at high beam current.

content	unit	LER	HER
Beam current (Crab ON)	mA	1700	1250
Crab voltage (operation)	MV	0.8~1.0	1.3~1.6
Crab voltage (Max.)	MV	1.1~1.5	1.7~1.8
Max. HOM Power	kW	2.5(coax)+12.4(LBP)+13.0(SiC1)+12.2(SiC2)	3.0(coax)+6.9(LBP)
Water temp. @HOM	deg.	31(coax) / 47(LBP) / 39(SiC1) / 42(SiC2)	34(coax) / 40(LBP)
# of total RF trips	count	263	710
# of RF trip / day	count	0.5 (0.4 / 0.1)	1.3 (2.8 / 0.8)
# of Piezo breakdown	count	5	4
operation temperature	K	3.6~4.2	3.6~4.2

Figure 6: The achieved parameters during the beam commissioning.

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REFERENCES

[1] Y. Morita, et al., "Beam-induced RF Modes and RF Power in the Crab Cavity for KEKB", SRF'07, Beijing, China, (2007) , WEP55.

[2] K. Akai, et al., "Commissioning and Beam Operation of KEKB Crab RF System", SRF'07, Beijing, China, (2007) , WEP57.