BEAM BEHAVIOR DUE TO CRAB CAVITY BREAKDOWN

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Abstract

Crab cavities were installed in KEKB in 2007. The function of the cavity is to tilt the bunch of the beam in the longitudinal direction. But if the RF phase gets out of control, the cavity kicks the beam like a steering magnet. To avoid this unwanted kick, the RF phase must be controlled well. In the beam operation, some disturbances may occur such as a discharge, a quench, etc. When such disturbances occur, it is very difficult to control the RF phase precisely. We can't trust measured RF phase at that time. In KEKB, beam is aborted quickly when a disturbance is detected. Beam behavior before detecting the disturbances has been investigated.

MEASUREMENT OF BEAM BEHAVIOR

KEKB has digital bunch-by-bunch feedback systems to suppress beam instability [1]. They measure bunch position continuously to calculate feedback signal. The beam positions in 4096 turns of every bunches are stored in the feedback system. The data acquisition of the recorder is triggered by a beam loss. The sensitivity of the beam position measurement depends on the bunch current. The sensitivity is about 0.01mm/(count·mA), and 127 count is a full range for each direction. When the abort system works and the beam is dumped actually, the transition of the cavity voltage, phase and RF power to feed cavity are recorded by an oscilloscope. Both data may not be taken due to the different trigger signals. In most cases where the RF systems of crab cavities abort are required an abort, beam losses were accompanied before aborts. So, the behavior of the beam positions and the cavity parameters just before abort can be investigated.

MACHINE PARAMETERS OF KEKB

The related machine parameters of KEKB are shown in Table 1 [2] [3]. In KEKB, the horizontal betatron tunes are set very close to the half integer. Even if the crab cavity phase shifts by $\pi/2$, the beam can be maintained from the view point of physical aperture. However, in case of colliding beams of high beam currents, some beam losses occur with this size of COD and the beams are aborted. The Figure 1 shows the COD, when the cavity phase shifts by $\pi/2$. The COD in the Figure 1 is a difference between the cases of the crab phases of $\pi/2$ and zero. In the usual operation, the cavity phase is adjusted at 0.35 rad to suppress horizontal oscillations of the colliding beams [4]. The net kick voltage caused by the phase offset is compensated by steering magnets. The revolution periods of the beam for both rings are 10 μsec. The decay times of the cavity voltage are much longer than the revolution periods of the beams. The beam abort timing and the behavior of the crab cavity voltage are shown in Figure 2, when the crab cavity RF system makes an abort signal. It shows that the cavity voltage is turned off in about 100 μsec, and after a 200 μsec further delay, the beam is dumped.

Table 1: Typical values of related machine parameters of KEKB

Ring	LER	HER	unit
β_x^*	80	80	cm
$\beta_x^{monitor}$	21	39	m
β_x^{cavity}	73	162	m
ν_x	44.506	45.511	-
I_{bunch}	1.0	0.75	mA
V_{crab}	0.95	1.45	MV
ψ_{cav}	0.35	0.35	rad
τ_{crab}	130	84	μsec

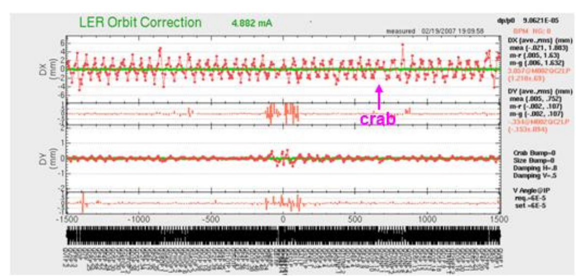

Figure 1: The COD which was appeared when the crab cavity phase shifts $\pi/2$ is shown. This orbit was observed at 1MV kick voltage when the kick voltage and phase were calibrated. The maximum displacement was about 5mm.

BEHAVIOR OF THE BEAM

Breakdown

The crab cavity for KEKB might quench because the cavity is a kind of the superconducting cavity. To protect the crab cavity, an interlock system works. It is called a breakdown detector. It observes the balance of the RF power. When it finds a breakdown, it turns off the RF power and makea an abort request signal. As shown in Figure 3, when a quench happens, the RF output power(klystron out in Figure 3) is increased to prevent

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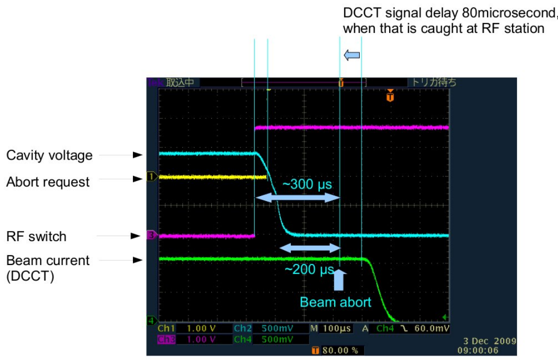

Figure 2: The beam abort timing and the behavior of the crab cavity are shown. When an RF control system of the crab cavity makes an abort signal, the beam is aborted with 300 μsec of the delay time.

a decline of the kick voltage due to dissipation of RF power on the cavity wall. The beam feels decaying cavity field after the interlock works. And the phase is not controlled. Figure 3 shows that displacement was made in the first 100 μsec, and it oscillate for 200 μsec afterwards. The displacement of the beam becomes counter direction in each turn because betatron tune is close to a half integer. In figure 3, the displacement is bigger than the range of the instrument. But the beam is not lost at that time. There is a data that the RF phase shifts 50 degree in 50 μsec after the RF stopped was found.

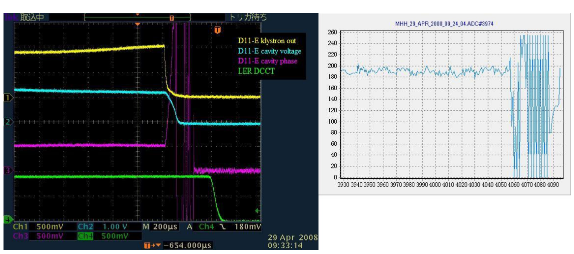

Figure 3: The cavity voltage droped after the interlock worked. The time constant of the decay of the cavity voltage is about 100 μsec(Left). Then the oscillation of the beam grew. The oscillated beam survived for 200μsec afterwards(Right).

Turbulence in the cavity

Some turbulence might happen in the cavity. The cause of the turbulence might be a discharge, a phase noise or others. The phase error appears as the results. Because the phase changes, the beam is kicked. The corresponding displacement was observed by the bunch-by-bunch feedback system. Figure 4(Left) shows a behavior of the cavity phase and voltage when a big turbulence occurred. It is confirmed that a big discharge happened by the evidence of the deterioration of the vacuum in the cavity at that time. The shape of phase deviation and the beam displacement are corresponding well.

Figure 5 shows a strange phenomenon related to the RF feedback system. The crab RF phase oscillates at 580Hz continuously. This phenomenon have not been analysed fully yet. It seems that they are induced by a coupling of the RF feedback loops of both rings through the two beams which interant at IP. The amplitude of phase oscillation was about 4 degree. To avoid this phenomenon, the cavity phases for both rings and tuning offset angles were shifted (see Table 1) [4]. In this case, corresponding beam oscillations were also observed. In Figure 5, the beam was finally aborted by a vacuum interlock.

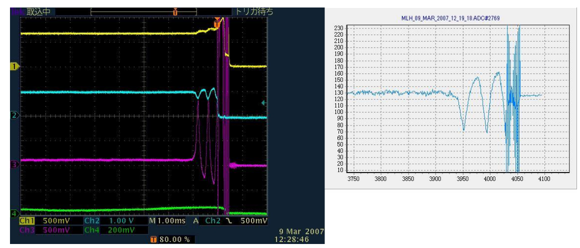

Figure 4: The cavity phase was shifted from the set value. Discharges and vacuum pressure rising were observed at that time(Left). The displacement of the beam corresponding to the phase change was observed(Right). After that, the RF was turned off, and uncontrolled horizontal oscillation was started.

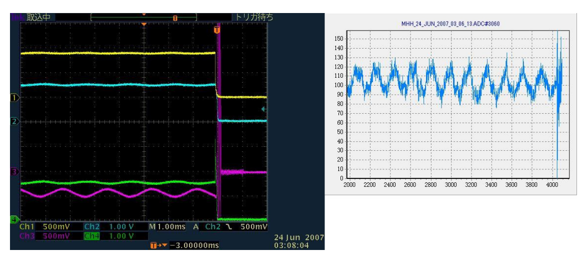

Figure 5: A sinusoidal phase oscillation caused by the interaction of the RF control systems for each rings and beam-beam kick at IP was observed in the high beam current operation(Left). In this case, the beam abort was done first, and then the RF was turned off. The oscillation of the beam corresponding to the phase oscillation was observed(Right). When the RF was fed, the displacement of the beam was controlled.

RF turn-off without beam abort

In case of data shown in Figure 6, the beam was not aborted, although the RF was turned off. No beam loss can be find in Figure 6(3). Figure 6(1) shows the horizontal beam oscillation. The oscillating beam circulated for 2msec. A beating stracture was observed because the betatron tune is not a half integer accurately. Figure 6(2) shows a vertical beam oscillation. The beam survived for about 230 turns after starting the oscillation. The RF power was stopped at 4850th turns in Figure 6(2). That means that the horizontal oscillation was generated immediately after the RF was turned off. The uncontrolled cavity phase kicks the beam horizontally. But that oscillation seems to decay. The vertical oscillation was observed both before and after the RF was turned off as shown in Figure 6(3). The amplitude was small and did not grow. But the beam was aborted by a loss monitor system and a discharge sensor attached at the coaxial part of crab cavity . We have changed the abort logic of the crab cavity to abort the beam when the RF is turned off.

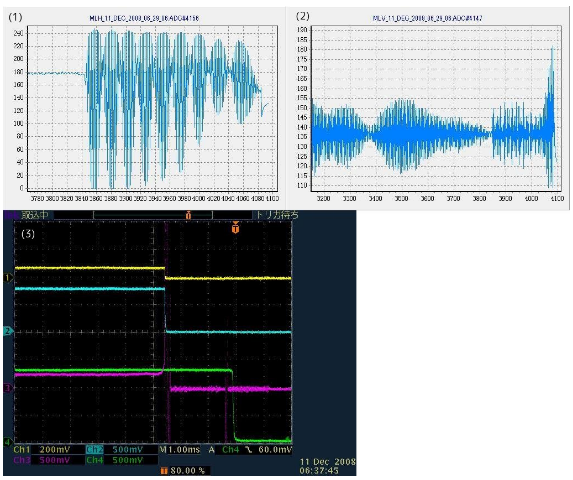

Figure 6: (1) The beam was kicked horizontally by the phase error of the crab cavity. (2) The corresponding vertical oscillation of the beam is shown. (3) The beam survived for 2msec after the RF had been turned off.

CONCLUSION

In KEKB, the time constant of the crab cavity is about 100 μsec and the revolution periods of the beam for both rings are 10 μsec. When the crab cavity RF is turned off, the beam passes the cavity the voltage of which is decaying several times. And the cavity phase is not controlled, because the RF is turned off at that time. It is expected that the beam is kicked by the uncontrolled or residual RF power of the crab cavity. It was confirmed that the beam was kicked horizontally when the interlock system turn off the RF power indeed. To avoid beam losses on the beam chambers, it is required that the aperture can allow COD of the assumption when the cavity phase shifts $\pi/2$ rad. Or the beam should be aborted before the RF is turned off.

If sufficiently large aperture is secured, the RF cut might be allowed. But it is required to condition the cavity for beam induced field. It was required that the holizontal oscillation don't make additional beam instability.

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