Design of a Transverse Feedback System against Multi Bunch Oscillation in KEKB

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Abstract

In B-factories, many bunches should be circulated in their rings, thus making the bunch spacing to be very short compared with that of the present collider machines [1,2]. The impedance of the rings may cause many coupled bunch beam oscillations. One possibility to damp coupled bunch oscillations is to install an active oscillation feedback damper system. This paper discusses the transverse feedback system and the effects of beam dynamics.

1. INTRODUCTION

For such projects as KEKB, high beam currents and multi-bunch operation will be necessary to achieve high luminosity. To circulate many bunches, some methods to damp coherent instabilities become important. In KEKB, oscillation feedback system will be installed to damp coherent instabilities. In this paper the design of a transverse feedback system and its effects are reported.

2. SYSTEM DESCRIPTION OF THE TRANSVERSE FEEDBACK DESIGN

2.1 Bunch-by-bunch betatron oscillation monitor

In KEKB, the time-domain system of the transverse feedback was adopted against instabilities. For the time-domain feedback, a small number of circuits are needed, but its circuit must process wideband signals including every instability spectrum. Because of the large coupling with the beam and the controllable characteristics, a stripline pickup seems to be better as an oscillation pickup electrode. In the design of the KEKB final stage, bunch spacing is 2nsec and therefore short stripline of 75mm is applied. Because a growth rate of the instabilities is proportional to the beam current for a low Q-value impedance, the feedback signal is produced by only subtracting two pickup signals expecting that the feedback is linear to the strength of instability. This bunch-by-bunch oscillation signal can be detected with ultra fast ADC sampler circuit. For precious detection of oscillation against digitizing with an 8bit ADC, a double-digitizer system may be used. Figure 1 shows such a double-digitizer system. The response of this system is shown in figure 2.

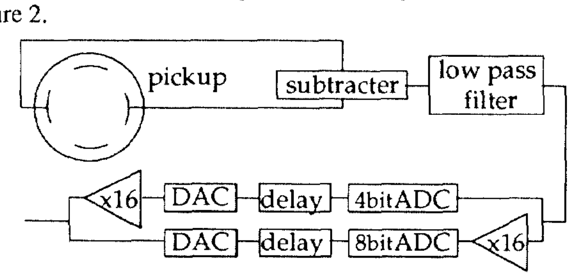

Figure 1: Front end circuit and double-digitizer

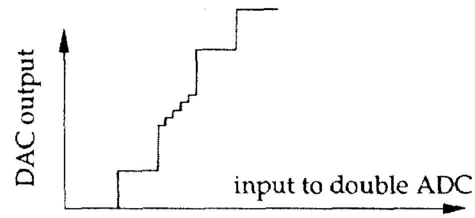

Figure 2: Schematic response of the double-digitizer system.

As the beginning of R&D of the bunch-by-bunch oscillation monitor, the response of beam position detection was checked using the stripline in TRISTAN main ring [3]. The setup of this R&D was almost same one shown in figure 1 except for the single digitizer system. Figures 3 and 4 are the response of the test position monitor when two electron bunches were circulated at symmetrical location in TRISTAN ring. The response which depends on the beam position seems to be within one RF bucket.

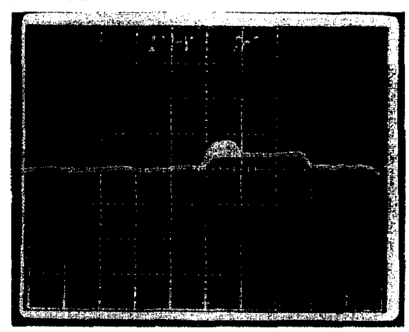

Figure 3: Time response of the test monitor. The vertical axis of the photo is the output of DAC which corresponds to the horizontal beam position. Beam was vibrated by the kicker of the tune measurement system[4]. The tail which does not depend on the beam position remains after the beam passage.

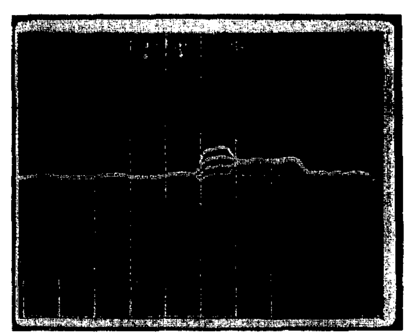

Figure 4: Time response of the test monitor. Beam positions were changed discretely by the excitation of local bump orbit and the photo was multi exposed. The gap between neighboring lines corresponds 100µm of horizontal beam position.

2.2 Effects of position detection resolution and monitoring offset to the bunches

The noise component of the oscillation monitor affect bunches through the feedback kick. Therefore residual beam oscillation remains accumulating in the time range of about the damping time [5]. The probable value of this residual oscillation can be calculated as

$$\sigma_{oscillation} = \sigma_{pickup}\sqrt{\frac{T_{rev}}{\tau}}$$

where $\sigma_{oscillation}$ is the standard deviation of the residual oscillation amplitude at the pickup, σ_{pickup} the standard deviation of the noise of the oscillation monitor, and τ the feedback damping time. When the feedback loop gain would be settled within a small value, $\tau >> T_{rev}$, the bunch oscillation could be damped and reduced within a smaller value compared with the monitor noise.

The monitoring offset of bunch oscillation turns into a miskick in the feedback system and makes COD kink at the location of the feedback kicker. This effect can be calculated as

$$x_{cod}(s) = \delta x' \frac{\sqrt{\beta_{kicker}\beta(s)}}{2\tan\pi\nu}\cos\{\phi(s)-\pi\nu\}$$
$$= x_{pickup}\frac{\sqrt{\beta_{kicker}\beta(s)}\cos\{\phi(s)-\pi\nu\}}{\beta_{pickup}\,2\tan\pi\nu}\frac{T_{rev}}{\tau}$$

where x_{cod} is the change of the COD modified by the offset kick, $\delta x'$ the kick angle of the miskick, and ν the betatron tune. This indicates that the offset component of the monitor which has very low frequency spectrum, $f_{offset} << f_{rev}$, is almost absorbed into the phase shift of the COD kink each turn so that COD modification becomes smaller than the monitoring offset.

The resolution and the offset of the monitor shown in figures 3 and 4 are small enough not to reduce luminosity by the loss of geometrical overlap at the collision.

2.3 Effects due to beam-beam effects in the collider machine

From the point of instability, bunch oscillations in double rings couple with each other by a beam-beam force of main collisions at the interaction point. Parasitic collisions of small crossing angle scheme [6] around the interaction point not only couple bunches among two rings, but also couple before and behind bunches in the ring. Therefore, bunch oscillation is coupled not only linearly by the ring impedance, but nonlinearly by the beam-beam force.

The effect of the beam-beam force has been investigated by Hirata's tracking code [6], slightly modified by the cavity impedance and the feedback action and several errors. In this program, a bunch is regarded as being a super particle, and the beam-beam force is taken into account as a rigid Gaussian model. The errors are vertical crossing angle of 0.0585mrad, the COD error of $0.3\sigma_x$ and $0.3\sigma_y$ at the interaction point, the monitoring offset of the beam position of 100mm, an inequality of σ=12% in the bunch currents, the noise of the position monitor pickup of 16μm, and the digitizing noise of the position monitor of 16μm. The feedback damping time and coupled bunch instability growth time are assumed to be 100turns and 200turns for a low-energy ring and 230turns and 460turns for a high-energy ring. The number of bunches in each ring is two hundred. The beam-beam parameter, ξ, is assumed to be 0.05. The other parameters are the same as the KEKB design parameters [7]. A feedback kick in the program is provided in accordance with the one-turn matrix of linear optics.

The main effect of the beam-beam kick to the feedback is a beam-beam tune shift. A one-turn transfer function with the beam-beam kick diverges from the one-turn matrix of a linear optics. This means that the feedback may become reactive. When the transfer function of feedback signal production was produced according to a linear matrix of multi-turn, in other words, when we used a long delay buffer which corresponds to multi-turn, the feedback system provides a reactive kick to the beam and therefore the bunch oscillation could not be damped. The simulation result assuming a horizontal half crossing angle of 2.5mrad is shown in figure 5.

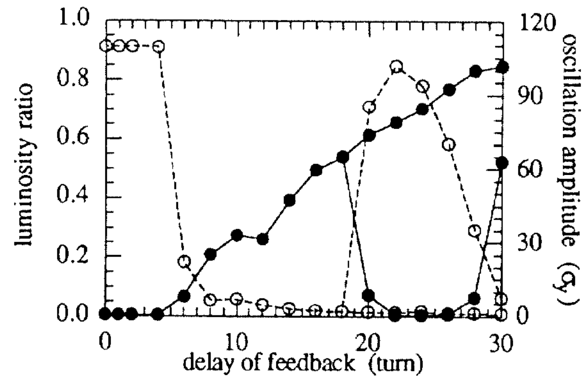

Figure 5: Luminosity ratio reduced from the design value (dashed line) and the residual oscillation amplitude in the vertical direction (solid line).

Figure 5 indicates that the residual vertical oscillation becomes bigger than the beam size when the phase shift in the feedback system is produced in accordance with a linear matrix of more than four turns. It's also interesting that the oscillation can be damped by the feedback with the delay of $1/\xi$=20 turns when smaller oscillation than the beam size is given as the initial condition.

If we produce the feedback kick signal using the digital filter technique, further investigations of the relation between the beam-beam effect and the feedback should be studied [8].

2.4 Required power to provide the impulse of the feedback kick

Required power of kicker driver to produce feedback kick depends not only on feedback damping rate but on the amplitude of coherent oscillation. For large coherent oscillation after the beam injection, a natural stabilizing mechanism of Landau damping caused by the nonlinearity of the lattice will work and oscillation will be damped into a certain amount. Therefore, the required capability of the feedback system is determined by this residual oscillation after smear out by Landau damping.

The effect of Landau damping was estimated by a tracking program. In this program a bunch, which is regarded as being a group of particles, is tracked through an impedance source and a one-turn transfer function which incorporates nonlinearity of non-interleaved sextupole scheme [9]. I also take radiation damping, τ_{rad}=32msec, into account for the low energy ring. Figure 6 summarizes the effect of Landau damping against the coupled bunch instabilities.

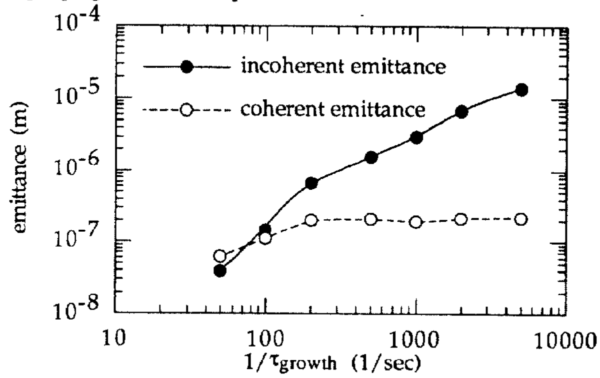

Figure 6: Equilibrium (solid line) and oscillation (dashed line) emittance. τ_{growth} is the instability growth rate in the case of rigid bunch model which indicates the strength of transverse impedance of the ring. The amplitude of the residual coherent oscillation saturates even in the case that the instabilities are serious.

In this figure the solid line represents the equilibrium emittance of the bunch established between a blow-up due to coupled bunch instabilities and Landau damping. The dashed line in the figure indicates the oscillation emittance of the bunch center in terms of emittance. The horizontal axis represents the strength of the impedance source. From the figure, the maximum amplitude of the coherent oscillation to deal with by the feedback system is assumed to be within 2mm. The corresponding power of one kicker driver to establish τ of 1msec in low energy ring is therefore calculated about 1kW.

3. SUMMARY

The calculation, simulation and first R&D with the beam were undertaken for the design of a transverse feedback, and seems to be feasible. Although it required extensive R&D work, including the $\pi/2$ phase shifter of the feedback system and the kicker components, we might be able to cure the coupled bunch instabilities for the KEKB final stage.

ACKNOWLEDGMENTS

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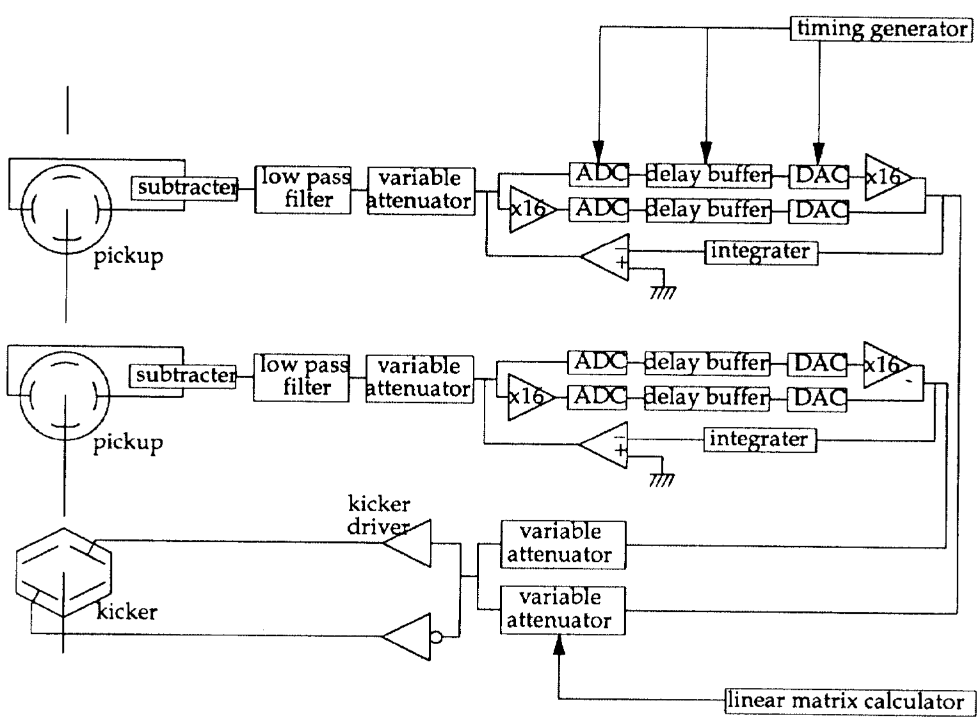

Figure 7: Block diagram of transverse feedback system