Tune Measurement and Beam Damping System for PLS

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Abstract

PLS is a third generation, 2GeV storage ring dedicated to the beamline applications since 1995. After the initial commissioning of the machine, various kind of beam physics experiments were performed for the optimization of machines. Among these efforts, beam instability was the most complicated object for us to characterize and suppress. Tune measurement system and the active beam damping systems were thought to be the essential tools for the study and cure of the problem. Since then there was progress in the development of the transverse and longitudinal beam damping system. We will describe on the PLS tune measurement system and the transverse beam damping system for PLS storage ring.

INTRODUCTION

After the dedication of the storage ring to the photon beamline experiments, much progress has been made in the characterization and stabilization of the PLS storage ring such as the accurate measurements of beam parameters, energy ramping to 2.5GeV, suppression of the beam instabilities, upgrade of the machine components, etc.[1] Tune measurement system was an important tool for the beam physics study and the measurement of beam parameters. Beam instabilities are the most active topic for us to diagnose and cure extensively. Low frequency transverse oscillation below 100Hz was dominant phenomena we have experienced. This low frequency oscillation is thought to be caused by ion effects.[2]

Recently, we used tune measurement system as the prototype transverse beam damper for the suppression of the transverse beam instability. As a result of the test, a dramatic damping of the low frequency transverse beam oscillation was observed. The complete transverse damping system has been developed and will be installed during this summer shutdown.

TUNE MEASUREMENT SYSTEM

In PLS storage ring, tunes are monitored all the time during the normal operation without disturbing the photon beam stability. The design value of the storage ring tunes are $\nu_x = 14.28$ and $\nu_y = 8.18$ respectively. For the quiet measurement of tunes without disturbing the photon beam stability, we chose sweep generator and a spectrum analyzer instead of the beam disturbing impulse excitation for the wideband measurement. Tune measurement system has played a very important role for the beam physics study and the upgrade of the storage ring performance. Maintaining the tune measurement system in the optimum calibrated condition, therefore, is very important for the operation of the storage ring.

Tune measurement is done by the beam excitation and detection of the resonance frequency of the response signal. A block diagram of the PLS tune measurement system is shown in Figure 1.

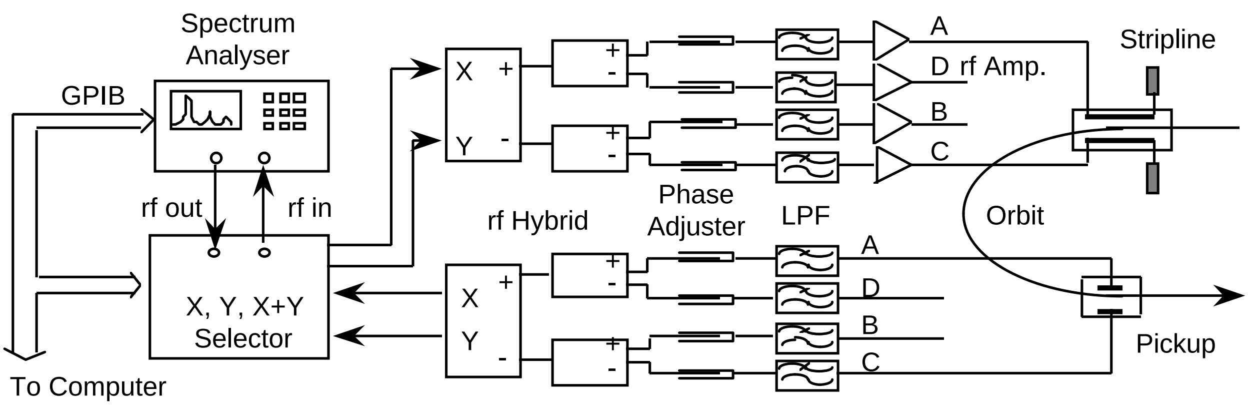

Figure 1. Schematic diagram of the tune measurement system

For the beam excitation we use a tracking generator, signal distribution circuit, rf power amplifiers and stripline kickers. Tracking generator is plugged in the HP8560E spectrum analyzer. Sweep range is 300kHz - 2.9GHz and the output power is 3dBm max. Signal distribution circuit consists of a monolithic rf hybrid and two 180° power dividers. Line lengths between the signal distribution circuit and the striplines are matched within 10ps or less than 2° at 500MHz using phase adjusters. Four power amplifiers have 225 - 512MHz bandwidth and 47dB gain. The kicker consists of four striplines of 150mm long, 17mm wide. Starting from the empirical formula w/d = 5, where w is the width of the stripline, 50Ω input impedance was matched by fine adjustment of the gap d between the stripline and chamber wall.

Detection of the beam oscillation mode is done with pickup electrodes, signal conditioning circuits, x, y, and x+y selector and a spectrum analyzer. Pickups are home-designed button type electrodes with N-type feedthru welded on the vacuum chamber. It responds up to 6GHz without significant ringing of the signal. Pickup signal lines are also phase matched within 10ps. Signal conditioning circuit is exactly the same in the reverse direction to the signal distribution circuit. We can measure tunes selectively among x, y, or x+y mode. Normally x+y mode is displayed. The frequency range of the HP8560E spectrum analyzer is 300kHz - 2.9GHz and the noise level is less than -130dBm by averaging the video output. Out of 225 - 512MHz frequency band of the tune measurement system, we chose the sideband of the 300th harmonic of 1.06855MHz storage ring revolution frequency for the tune detection. Normally it sweeps between 320.5 - 321MHz for the tune measurement. With an optimum setting of the spectrum analyzer parameters, we were able to get 0.001 stability in the tune measurement by averaging 100 video outputs. Spectrum analyzer is connected to the console computer via GPIB interface for the automatic measurement of the tune and display it on the console rack monitor.

TRANSVERSE DAMPING SYSTEM

After the commissioning of the storage ring, various kind of beam instabilities have been observed in the PLS storage ring.[2] Coupled bunch mode instability is thought to be caused by the higher order modes of rf cavity. However, very low frequency transverse oscillation was the typical phenomena. By extensive study of the relation between the beam modes and the cavity conditions, we learnt that the low frequency oscillation seems to be caused by ion effects and some longitudinal beam instabilities were quieted by tuning rf cavities. Remaining beam instabilities should be suppressed by installing the transverse and longitudinal beam damping system.

Recently, both transverse and longitudinal bunch-by-bunch beam damping system have been developed for PEP-II and ALS.[3] In PLS we also developed a transverse beam damping system as shown in Figure 2, which is similar to the PEP-II and ALS model. By choosing a proper vector-like combination of two pickup signals as $x(t) = \alpha x_1(t) + \beta x_2(t)$, the phase is adjusted to $\pi/2$ between the pickup and the kicker which will be located at arbitrary positions. The phase relation can be automatically controlled according to the change of the tune by adjusting the variable attenuators via computer. To realize a bunch-by-bunch feedback, the system bandwidth must be at least 250MHz for the PLS storage ring where the bunch to bunch spacing is 500MHz(2ns).

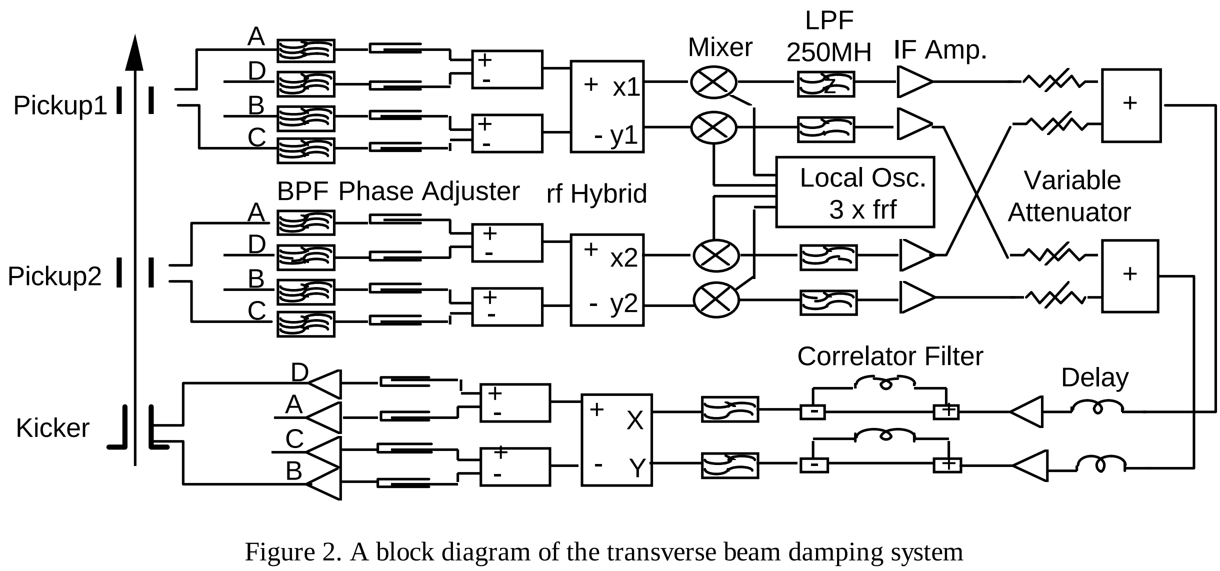

Figure 2. A block diagram of the transverse beam damping system

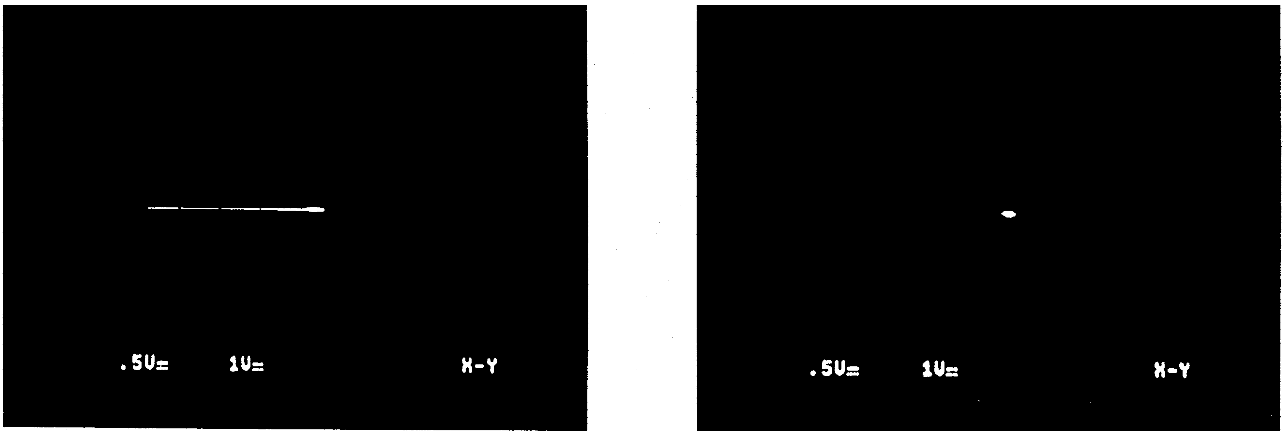

Figure 3. Photo of the oscilloscope showing damping of the horizontal oscillation before and after turn-on of the transverse damping system.

Pickup signals are detected at the third harmonics of the rf frequency in the frontend electronics. In PLS, BPM6-6 and BPM7-6 are selected for the pickups. The phase differences between two pickups are $\phi_x = 68°$ and $\phi_y = 65.4°$ respectively. Signal intensity from the pickups are -15dBm at 1.5GHz, 100mA.

A correlator filter is used to suppress the strong revolution harmonics from the beam signal.[4] By subtracting two signals apart by one revolution period, we can make a notch filter as $x(t)=\alpha x_0(t)-\beta x_0(t-T)$ where T is the revolution period and $\alpha=\beta$ are cable losses. We achieved better than -40dB notches at the revolution harmonics with this filter. Matching of the delay as well as losses between two paths are very important to get the deeper notch depth. To make -50dB notches, less than 1% difference of input loss between two paths has to be maintained. Phase of the filter output is changed by $\Delta\phi = \tan^{-1} [(\alpha-\beta\cos(\omega T)) / \beta\cos(\omega T)]$. When the losses are the same, i.e., $\alpha=\beta$, $\Delta\phi=\omega T/2=\pi\nu$ where ν is the tune number. This phase delay has to be compensated in the design of the feedback system. By a simple calculation of the system gain, we expect the damping rate will be less than 1msec.

We used tune measurement system as the preliminary test setup of transverse beam damper. In this setup, only one pickup signal was used and the delay was carefully adjusted. Total system gain was 30dB maximum. However, very low frequency beam oscillation below 100Hz was damped completely with the test setup. In the low frequency damping, stripline kicker seems to act like a clearing electrode. Further study will be done to verify this supposition. Figure 3 shows a photograph of the low frequency damping effect taken from the oscilloscope screen. High frequency betatron sideband was not effectively suppressed with the fullband test setup, because of the bad signal to noise ratio of the test setup caused by using many rf components and power amplifiers. By limiting the system bandwidth to 30MHz via a band pass filter in the signal processor, we observed about 10dB damping of the horizontal betatron sideband and better than 15dB damping in the vertical plane. In this experiment, the storage ring bunch frequency was 12.8MHz with 12 bunches filled.

A complete transverse damping system has been developed at present and will be installed during the summer shutdown period.

CONCLUSION

Tune is monitored all the time during the operation of the PLS storage ring. Recently we exploited tune measurement system as the preliminary test setup of the transverse beam damper. Very low frequency beam oscillations were completely damped by the prototype damping system. The betatron oscillations were also significantly damped by limiting the bandwidth of the test system to 30MHz. A new transverse damping system is completed at present. Longitudinal damping system is also under development in PLS now.

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