A LONGITUDINAL PHASE SPACE MONITOR AT THE PHOTON FACTORY STORAGE RING

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Abstract

A phase detection circuit was developed to observe a synchrotron oscillation of the beam turn-by-turn at the Photon Factory Storage Ring (PF ring). A phase deviation from RF frequency was measured using the circuit connected to one of the button-type electrodes of the beam position monitor (BPM). A momentum deviation of the beam was simultaneously measured using a transverse beam position circuit of BPM placed on the dispersion section of the ring. These circuits were controlled with the on-line computer through GP-IB interface. Experimental data were taken in a stored single-bunch beam at a current of 10 mA. The resolution and the dynamic range of the phase detection circuit were less than 0.136 deg and over 8 deg, respectively. Then the tracking of the large coherent synchrotron oscillation caused by an RF phase modulation and a longitudinal single-bunch instability was displayed with a good accuracy on the longitudinal phase space.

1 INTRODUCTION

The PF ring, which is a dedicated synchrotron light source, has been stably operated for more than ten years. The high-brilliance project of the ring is now in progress [1]. By doubling the number of quadrupole and sextupole magnets in the normal cell sections, the beam emittance will be reduced to 27 nm•rad. The other accelerator components are also upgraded with the project. Especially a new RF-acceleration cavity has been developed [2]. The cavity is a higher-order-mode (HOM) damped type, which was designed to reduce the impedances due to HOM resonances. Consequently some coupled-bunch instabilities will be cured. So the existing four cavities are going to be replaced by the HOM-damped ones. It is very important to cure the coupled-bunch instabilities in order to store the higher current beam in the multi-bunch operation [3]. Because the coupled-bunch instabilities occur the beam size increases and then the brilliance of the synchrotron radiation decreases. The problem of the single-bunch

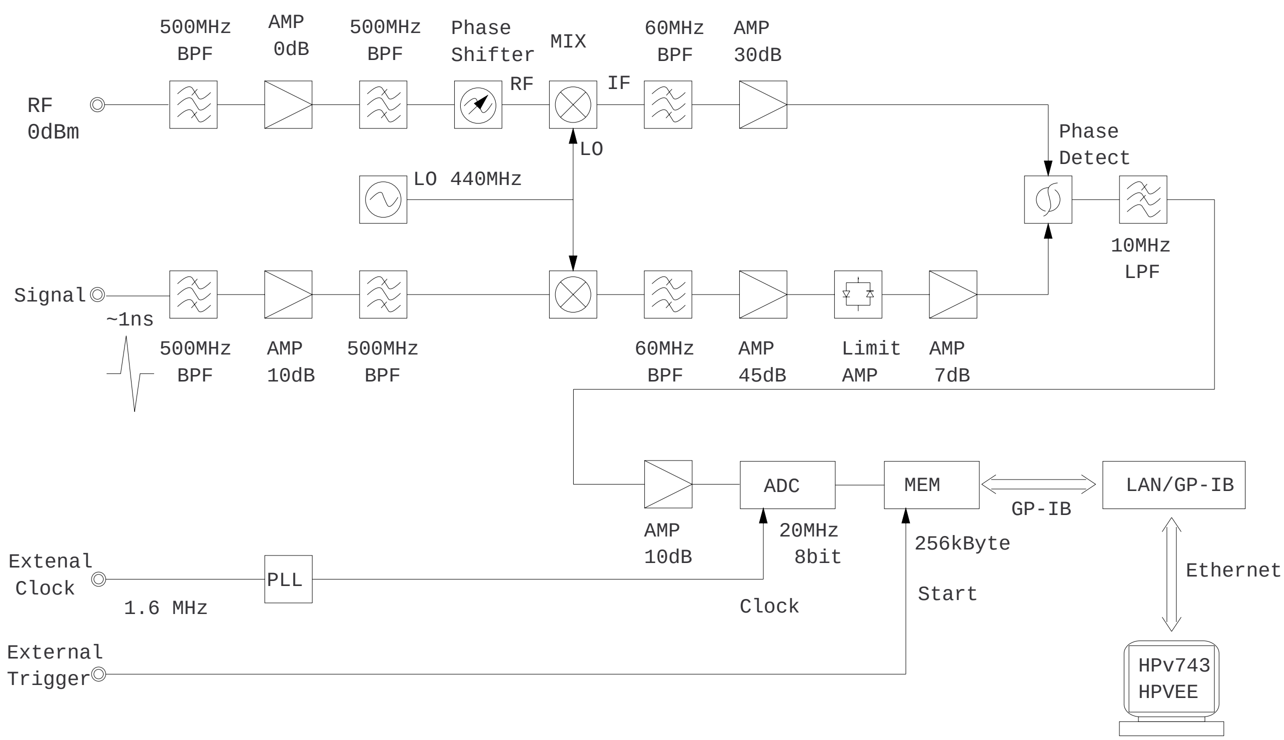


Figure 1: A block diagram of the phase detection circuit

instabilities is also important. For the FEL experiment the longitudinal feedback system was constructed to cure the single-bunch instability in the low-energy operation at the PF ring [4]. Much effort was also devoted to investigate the bunch-lengthening mechanism by measuring the bunch shape [5]. Recently the interesting experiments for a longitudinal nonlinear beam dynamics have been performed using a longitudinal phase space monitor at IUCF [6]. The transverse phase space monitor was already developed at the PF ring [7]. So we developed a phase detection circuit as a diagnostic tool for the longitudinal nonlinear beam dynamics study.

2 ELECTRONICS

The phase deviation ϕ of the synchrotron motion was determined by measuring the phase difference between the signals from BPM (SIG) and the RF master oscillator as a reference (REF), whose frequency is near 500.1 MHz. A block diagram of the phase detection circuit is shown in Fig.1. At first both of SIG and REF signals were passed through 500 MHz band-pass filter (BPF). They are converted to IF signals of 60 MHz using mixers and a 440 MHz local oscillator. In the REF line a phase shifter is added for the phase adjustment. For avoiding the current dependence a limiting amplifier is implemented in the SIG line after IF conversion. Then the phase difference between the SIG and the REF is made using a phase detection circuit. The output signal is digitized with 20 MHz 8 bit flash ADC after it is passed through 10 MHz low pass filter (LPF) to remove any RF components. It is immediately sent to the stored memory. The external clock signal (1.6 MHz: a revolution frequency of the PF ring) is made from dividing the signal of RF oscillator. It is employed for a start timing of ADC and a memory control after the phase is adjusted with a phase lock loop circuit (PLL). The accumulated data in the memory are transferred to the on-line computer through GP-IB interface.

On the other hand, the momentum deviation δ is easily found using a transverse beam position circuit of the BPM placed on the dispersion section. The monitor measures the horizontal position of the beam Δx. Then the momentum deviation can be obtained from $\delta = \Delta x / \eta$, where η is a value of dispersion.

3 EXPERIMENT

The experiment was performed in the single-bunch operation mode. The orbit and RF related parameters are shown in Table 1. The beam was stored at a current of 10 mA during this experiment. As a performance check of the phase detection the response of the beam to RF phase modulation was first measured. The phase modulation was achieved by modulating the RF control signal using a phase shifter whose control voltage was

Table 1: Orbit and RF related parameters of the PF ring

Beam Energy	E (GeV)	2.5
Betatron tune	ν_x / ν_y	8.45/3.30
RF frequency	f_{RF} (MHz)	500.1
RF voltage	V_{RF}(MV)	1.7
Harmonic number	H	312
Revolution frequency	f_{rev} (MHz)	1.6029
Energy Spread	σ_ε	0.00073
Synchrotron tune	ν_s	0.023

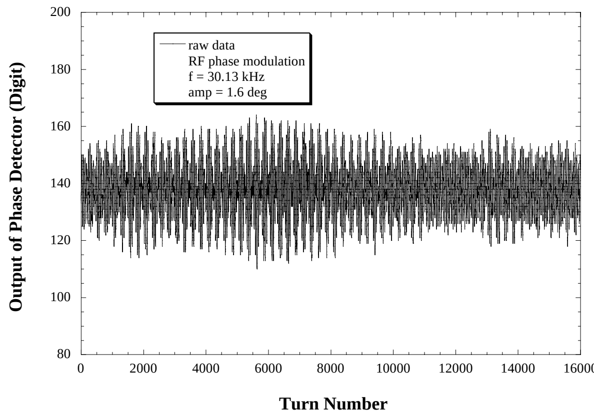


Figure 2: Digitized output data of 16000 turns

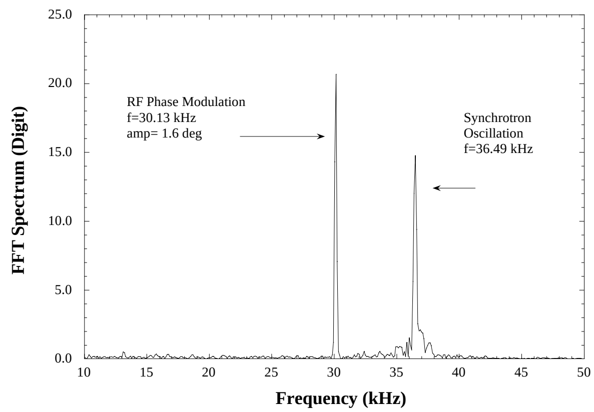


Figure 3: FFT spectrum of the data

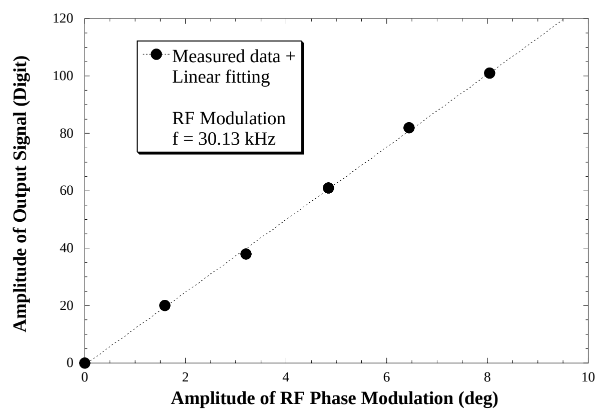
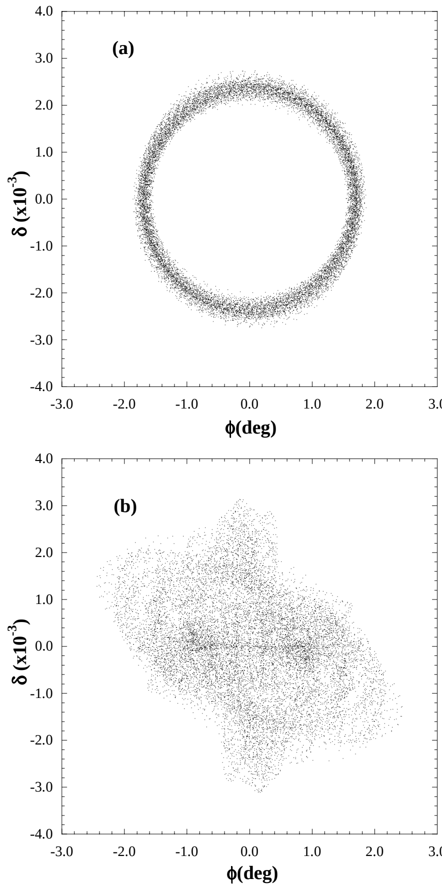


Figure 4: Calibration for converting the output digital data to the phase value

supplied by a function generator. The relationship between the voltage and the phase shift was already calibrated in the other experiment. The frequency and amplitude of the phase modulation are set to be 30.13 kHz and 1.6 deg, respectively. Figure 2 shows the digitized output data of 16000 turns. The FFT spectrum of the data is displayed in Fig. 3, but frequency range is set to be from 10 to 50 kHz. Two peaks were observed in this range; the first peak of 30.13 kHz is due to the RF phase modulation and the second one of 36.49 kHz is due to the coherent synchrotron oscillation caused by a longitudinal single-bunch instability. The calibration for converting the output digital data to the phase value was done with changing the modulation amplitude. Figure 4 shows the amplitude of the RF phase modulation versus the amplitude of the output digital data from the FFT spectrum. The figure shows a good linearity of the phase detection circuit over 8 deg. The phase resolution is about 0.136 deg, whose value was deduced after some signal processing.

As shown in Fig. 3, measured data includes the contributions from the RF phase modulation and the longitudinal single-bunch instability. Since the instability is so strong, we could not remove it in the experiment. So they were distinguished using a conventional signal processing method on the off-line computer. The momentum deviation was also deduced using the same method. Then, the longitudinal phase space plots of the oscillation caused by the RF phase modulation (a) and the single-bunch instability (b) are displayed in Figs. 5, respectively. Data of 16000 turns are plotted in the figures.



Figures 5: Longitudinal phase space plots of the oscillation caused by the RF phase modulation (a) and the single-bunch instability (b).

4 SUMMARY

The phase detection circuit was developed at PF ring. The good performance was obtained in the experiment. The momentum deviation was also measured using a transverse beam position circuit. Then the tracking of the large coherent synchrotron oscillation caused by an RF phase modulation and a longitudinal single-bunch instability was displayed with a good accuracy on the longitudinal phase space.

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