Preliminary Results of a Test of a Longitudinal Phase-Space Monitor

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Abstract

A prototype of a longitudinal phase-space monitor has been developed in TRISTAN Main Ring at KEK. The principle of the monitor and its basic components are explained. Also a result of a preliminary beam test is given.

I. Introduction

The phase-space information of a bunch which is circulating in an accelerator is very helpful to us for understanding the dynamics of the bunch motion. In TRISTAN Main Ring, the transverse phase-space monitor has already been installed and it has been successfully operated[1]. Then the next step will be to install a longitudinal phase-space monitor in the ring.

The longitudinal phase-space monitor which we are developing is the semi-real time system, that is, the oscillation will be visualized within a few seconds after the actual motion. Also data can be stored in disks if necessary.

In this article, we discuss the possibility of the longitudinal phase-space monitor and give preliminary results of the beam-test of the monitor in TRISTAN Main Ring.

II. Principle

To make a phase-space plot, two kinds of signals, a position-like variable and a momentum-like variable, must be observed. In the case of the longitudinal motion of particles, the position-like variable is the time at which the bunch center passed by a pickup (relative to the synchronous particle). This relative time is measured directly by comparing the bunch timing with the reference RF signal.

On the other hand, the momentum-like variable is the deviation of the average energy of the particles in the bunch from the nominal energy. This signal is obtained by measuring the transverse position of a bunch at a point where the dispersion is not 0. In general, the transverse position of a bunch, x, is expressed as

$$x = x_{DC} + x_\beta + \left(\frac{\Delta p}{p}\right)\eta, \quad (1)$$

where x_{DC} is the static deviation of the bunch position from the nominal center (COD), x_β is the displacement due to the betatron oscillation and $(\Delta p/p)\eta$ is the displacement due to the energy deviation. η is, as usual notation, the dispersion at the pickup. Thus non-DC component is the superposition of the synchrotron oscillation and the betatron oscillation. If we measure the position of a bunch successively for many turns, the time series of the data can be Fourier-analyzed. Then we can pick up only the synchrotron oscillation component by preparing a window favorable to the synchrotron oscillation frequency. By this technique we can extract the energy deviation from the data of the transverse position.

III. The measuring system

A. Pickups

The longitudinal position and the transverse position are measured by independent pickups, which are installed in the separated positions in the ring. Both pickups are usual button electrodes. The transverse pickups are installed at the southernmost point of the ring and the longitudinal pickup is installed at the position whose distance from the transverse pickup is about 1/8 of the circumference. Naturally, it is desirable that both the data are taken in one point. But it is not a serious problem because the phase of the longitudinal oscillation rotates only $\sim 2\pi/90$ through this distance.

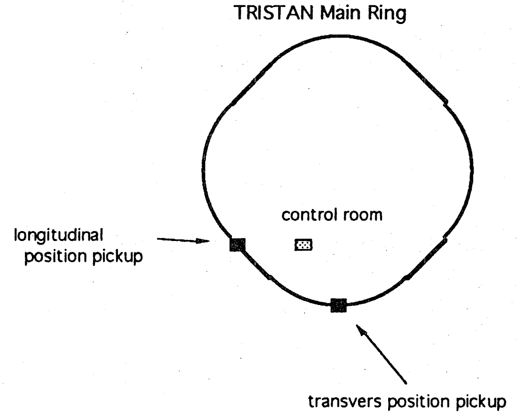

Figure 1: Layout of the pickups and the control room.

B. Electronics

The front-end electronics of the transverse monitor has already been described in ref. [1]. Here we give a brief explanation on the front-end circuit of the longitudinal position detection system[2]. A block diagram of the circuit is shown in Fig.2. The main component is a double balanced mixer (dbm) which detects the phase difference between two signals. One of these two signals is the reference signal that is made by multiplying (6-time) the RF signal which has the common source with the signal for the acceleration. The other signal is obtained by band-pass filtering the output of the pickup electrode. The center frequency of the band-pass filter is 3050 MHz, which is again the 6-times of the acceleration frequency. The DC component of the output of the dbm is proportional to the longitudinal position. In this method, the adjustment of the relative phase of two signals is very important.

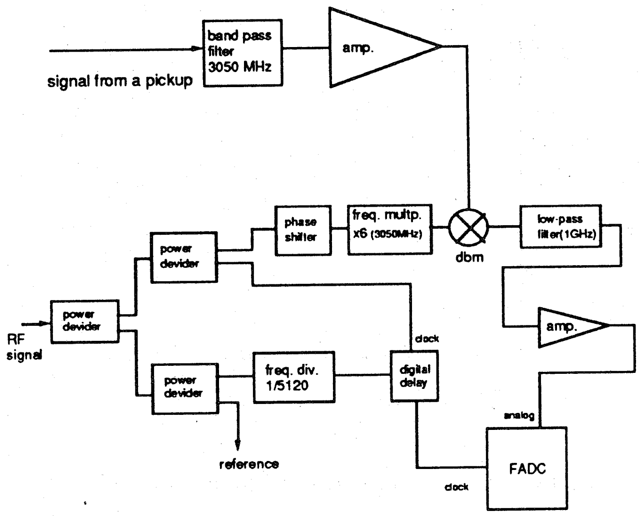

Figure 2: Block diagram of longitudinal position detector.

C. Data acquisition

Both the transverse and longitudinal position signals are input to two input connectors of a flash-ADC module[3]. This module consists of 4 ADC chips (8 bit, 100 Mega samples/s at maximum), a clock circuit, a trigger circuit ("conversion-stop") and memories. The revolution clock of the accelerator (~100 kHz) is fed to the ADC chips as the external clock for the conversion. By a CAMAC command, the ADC chips start conversions synchronizing with the revolution signal of the accelerator, namely the ADC's catch the positions of a bunch turn by turn. When the "conversion stop" signal is accepted, the ADC's stop the conversion and the module becomes ready to be read. Then the data aquisition computer reads the data stored in the module. The memory size is 1 kilo-words/channel, then we are able to catch the succesive position data for 1024 turns at maximum.

For the preliminary test described below, we used the relatively slow computer for data acuisition. But if we use a faster computer, we can observe the plots in the longitudinal phase space in semi-real time manner. In this case a trigger of order of 10Hz will be given to the ADC module and the computer.

IV. Preliminary data

To check the basic performance of the phase-space monitor, we tried to observe the synchrotron oscillation in TRISTAN Main Ring. The bunch current was 0.8 mA and the number of bunch was only 1. The oscillation was artificially excited by shaking the phase of one of the klystrons for the acceleration. The amplitude of the oscillation was roughly measured by an oscilloscope and it was about 80 pico seconds in full width.

The transverse oscillation observed and its frequency spectrum are shown in Figs. 3 and 4. The transverse position, which is the vertical axis of the graph in Fig. 3 is raw data of the output of ADC. The fast Fourier transform was done using the data for 1024 turns. The data in the time domain roughly reproduces the sine-like oscillation. The frequency domain data shows that the main peak is at 0.11, which is just the synchrotron tune of the accelerator.

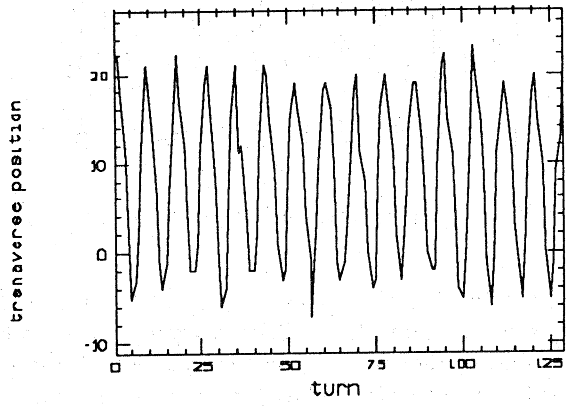

Figure 3: A typical data of transverse position.

A typical data for the longitudinal oscillation is shown in Fig. 5. Again, the vertical value is raw data of ADC output. The oscillation found in Fig. 5 is not symmetric with respect to its average level. Considering the fact that the oscillation is excited by a sine-curved signal, this asymmetry might come from the wrong adjustment of the phase difference which we mensiond previously.

The result of the frequency analysis in the longitudinal direction is shown in Fig. 6. There are three sharp peaks. The peak at the lowest frequency corresponds to the synchrotron tune. The other two peaks are the 2-nd and 3-rd harmonics of the synchrotron tune. The origin of these harmonics should be the asymmetry of the time-domain data explained above.

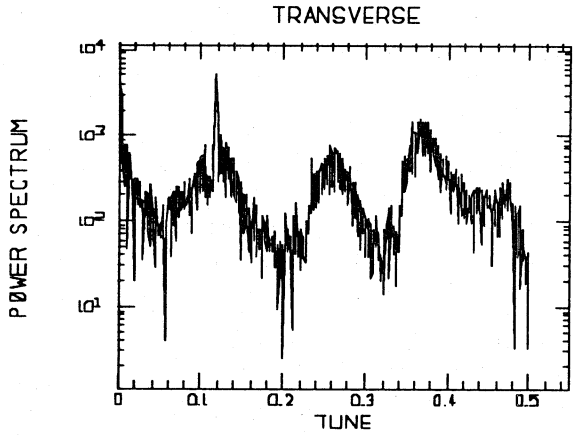

Figure 4: Transverse tune spectrum.

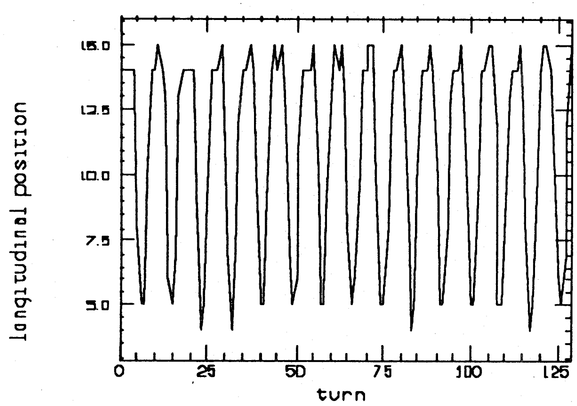

Figure 5: A typical data of longitudinal position.

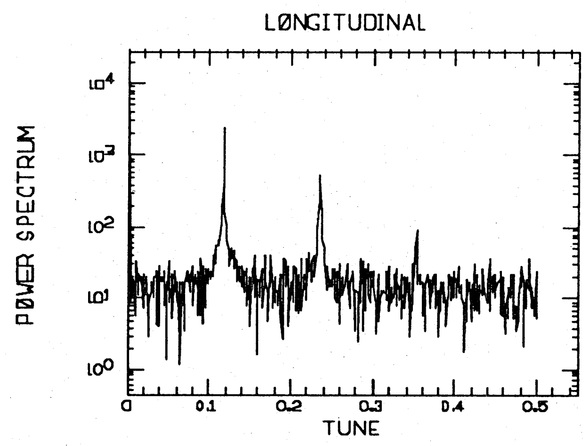

Figure 6: Longitudinal frequency spectrum.

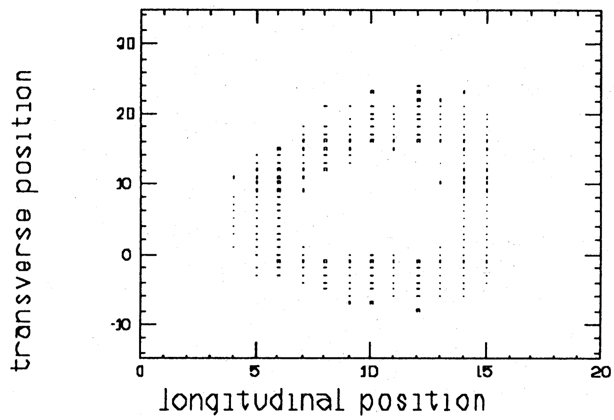

Figure 7: Longitudinal "phase space".

At last, Fig. 7 is the "phase space" plot obtained in this experiment. From the Fourier analysis of the transverse oscillation, the oscillation comes mainly from the energy oscillation not from the betatron oscillation. Thus we use raw data for the transverse oscillation for plotting the graph. The gain of the amplifier for the longitudinal direction signal is not sufficient. Thus the resolution is poor in the longitudinal direction. However, we can catch an ellipse-like pattern as shown in the figure.

V. Plan to the next step

Looking at the figures above, we find that the longitudinal data is less reliable. At first we must establish the technique to adjust the phase difference of two signals. Additionally, the gain of the amplifier for the longitudinal signal is rather low with the bunch current of $\sim$ 8mA. Thus we must prepare a higher-gain amplifier and some adjsutable attenuator to fit the signal level to the input range of the ADC.

VI. Summary

We have constructed a prototype of the longitudinal phase-space monitor. The preliminary experiments show us that this system can be a useful tool in the accelerator machine study.

References

[1] T. Shintake, "Phase-Space Monitor System", Particle Accelerators, Vol. 30, pp.27-32, 1990.

[2] The basic idea of the longitudinal position detection was given by the SLAC B-Factory Accelerator Design Group. See SLAC-372, P. 359.

[3] This module is a product of REPIC Coporation, Japan. The module consists of 4 ADC chips, Analog Devices Company, AD9002, and 4×1-kw memory.