ELECTRON BEAM DIAGNOSTICS BASED ON TRANSVERSE FEEDBACK SYSTEM AT DUKE STORAGE RING*

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Abstract

To combat electron beam instabilities, a field programmable gate array (FPGA) based bunch-by-bunch transverse feedback (TFB) has been developed for the Duke storage ring. While it is capable of suppressing transverse beam instabilities for multi-bunch operation, the TFB system has not been needed for typical operation of the Duke storage ring FEL. To explore the great potential of this system, we have focused on the development of TFB based beam diagnostics. A TFB based tune measurement system has been developed using two methods: the tune scan method and tune monitoring method. With the tune monitoring method, a much faster method of the two, we have studied the tune stability of the electron beam in the Duke storage ring. This tune measurement system also allows us to conduct chromaticity measurements more quickly, compared with the existing chromaticity measurement system using a network analyzer. Finally, the TFB based tune system has been used to calibrate the tune knob and chromaticity knob for the Duke storage ring.

INTRODUCTION

The light sources at the Duke accelerator facility include the storage ring based free-electron lasers (FELs) and the High Intensity Gamma-ray Source (HIGS). The accelerator facility is composed of three subsystems: a linac as the pre-injector of electron beams, a top-off booster as the injector and an electron storage ring [1]. In order to maintain a good performance of the light source, bunch-by-bunch feedback systems are installed to sustain a stable electron beam in the storage ring including longitudinal feedback system (LFB) and transverse feedback system (TFB). By suppressing the longitudinal coupled bunch instabilities (CBIs), the LFB system is now playing a critical role in the routine operation of the HIGS facility at Duke University [2]. The transverse feedback system was originally designed as an bunch-by-bunch, single-turn analog feedback system in collaboration with Lawrence Berkeley National Laboratory (LBNL). In order to improve its performance, we have recently upgraded the TFB system (vertical only) with an integrated Gigasample processor (iGp) which is based on a field-programmable gate array (FPGA) [3]. After tuning and optimization, the transverse feedback system is capable of suppressing the transverse beam instabilities although it is not needed for typical operation of the storage ring with either a single-bunch or a two-bunch beam. A typical electron beam feedback system consists of three subsystems: (1) a signal detection system which detects the bunch signal, (2) a digital signal processing system which processes the bunch signal and produces a correction signal and (3) an energy correction system in which the amplified correction signal is applied to the electron bunches via a feedback kicker cavity [4]. With these features, we can develop some electron beam diagnostics based on the feedback systems.

The tune measurement system is one of the most important beam diagnostics for storage rings. The basic approach to measure the tune is to excite the beam and measure its response. At DFELL there are two optical-signal based tune measurement systems, one for the storage ring and the other for the booster [5, 6]. This kind of optical tune measurement system works in the following way: a network analyzer generates an RF drive signal and sends it to a stripline beam position monitor (BPM) to excite the electron beam; the beam motion is detected using synchrotron radiation from a dipole magnet; and finally, the detected signal is compared with the drive signal.

It is obvious that all process of the optical tune measurement system can be realized using an active electron beam feedback system since it can generates signals to drive the beam and detects the corresponding beam response. Furthermore, a bunch-by-bunch feedback system can drive a specified bunch and pick up its bunch signal, which means with this system we can measure the bunch tune for multi-bunch operation of a storage ring. This capability is not possible with the optical tune measurement system.

DEVELOPMENT OF TUNE MEASUREMENT SYSTEM

Like the tune measurement system using a network analyzer, we can develop a similar scanning tune measurement system for the Duke storage ring using the TFB. The sweep signal for excitation is generated by the iGp of the TFB system and applied to the electron beam through a transverse feedback kicker. The sweep signal with a certain span should cover the corresponding tune frequency. In order to get an accurate measurement result, the bandwidth of the sweep should be reasonably narrow. However, a narrower bandwidth means more sweep steps, leading to

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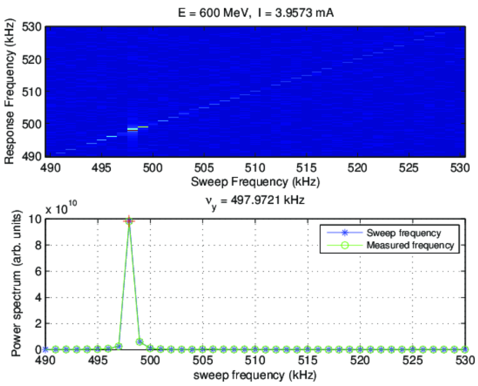

Figure 1: The vertical tune measurement result using the tune scan method. The tune is measured at the energy of 600 MeV with a beam current of 1.2 mA. The span of the sweep is 40 kHz and the bandwidth is 1 kHz, which means that the measurement takes 41 sets of beam signal data in the time domain. The measured vertical tune is 0.1807.

a longer measurement time. Typically we set the bandwidth to 1 kHz. We also need to pay attention to the strength of the drive signal. If the drive signal is too weak, the beam may not be fully excited. On the contrary, too strong excitation may cause tune shift with amplitude. For each drive frequency, the beam signal in time is recorded and the fast Fourier transform (FFT) is performed to find its power spectrum. In this power spectrum, the betatron tune occurs at a frequency of the maximum response. As an example, a vertical tune measurement with a single-bunch beam is shown in Fig. 1.

The tune scan method described above is a rather slow process and a faster tune measurement technique is desirable for beam studies. In a tune monitoring approach, the electron beam is excited with a broadband signal and the beam response in time is recorded. The FFT is applied to the time-domain beam signal to find the betatron tune of the beam. Since the beam is excited once, the measurement takes only a few seconds, which is much faster than the scanning tune measurement. A tune measurement result using this tune monitoring method is plotted in Fig. 2.

DEVELOPMENT OF CHROMATICITY MEASUREMENT SYSTEM

Chromaticity is an important parameter of a storage ring which describes the variation of tunes with beam energy. The chromaticity is defined as (the lowest order):

$$\xi = \frac{d\nu}{d\,(\Delta E/E)},$$

where ν is the tune and E is the beam energy. The definition gives us a direct way to determine the chromaticity, by measuring the tune shift with the beam energy. The change of the beam energy can be achieved by tuning the RF frequency of the storage ring:

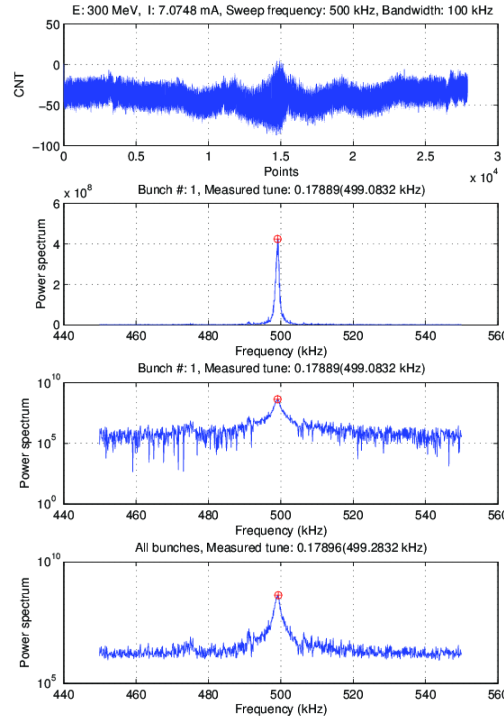

Figure 2: The vertical tune measurement result using the tune monitoring method. The beam is excited by a broadband drive signal with a bandwidth of 100 kHz. The plot on the top shows the overall beam signal in the time domain and the plot on the bottom shows the same signal in the frequency domain. The two plots in the middle show the power spectrum of the bunch signal from bunch #1 in linear scale and in logarithm, respectively. The measured vertical tune is 0.1789.

$$\frac{\Delta E}{E} = -\alpha_c \frac{\Delta f}{f_0}, \tag{1}$$

where α_c is the momentum compaction factor, f_0 is the RF frequency of the storage ring and Δf is the change of the RF frequency. The momentum compaction factor for the Duke storage ring is 8.6×10^{-3}. For a typical chromaticity measurement, the typical range of the (relative) energy change is -0.5% to 0.5%. And in order to perform a good fit to the measured tunes, at least five data points are needed. The tune is measured using the tune monitoring method which greatly shortens the total measurement time. A TFB-based chromaticity measurement result is shown in Fig. 3.

CALIBRATION OF THE TUNE KNOB AND CHROMATICITY KNOB

At Duke storage ring the tune knob and the chromaticity knob are important tools for operation [7]. The tune knob is implemented by adjusting the strength of a certain group of quadrupole magnets in the straight sections of the storage

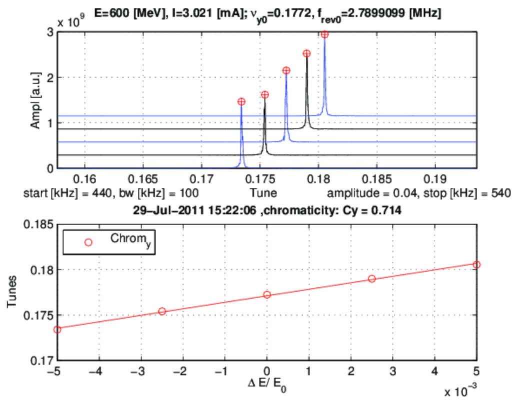

Figure 3: The vertical chromaticity measurement result. The upper plot shows the measured tunes for different energies of the electron beam in the storage ring. The lower plot shows a linear fit to the measured tunes. The slope of the fitted line is used to determine the value of the vertical chromaticity, in this case 0.714.

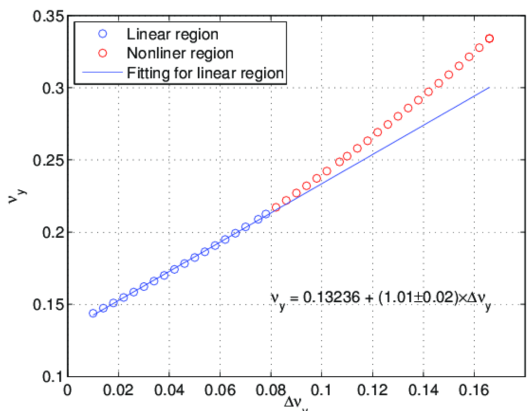

Figure 4: The calibration of the vertical tune knob for the Duke storage ring.

ring. The chromaticity knob is implemented by adjusting the strength of a certain group of quad-sextupole magnets in the arc sections of the storage ring. Using the TFB-based tune measurement tool, we can perform a calibration for the tune knob. The tune knob calibration result is shown in Fig 4. Below 0.08, the vertical tune knob is quite linear as the measured tune follows the set value of the tune knob along a straight line with a slope of 1.01. Beyond this point, the measured tune starts to deviate from the tune knob set value, indicating a finite linear range of this tune knob. The chromaticity knob is also calibrated using the TFB-based chromaticity measurement system. The result is shown in Fig. 5.

SUMMARY

We have developed a new tune measurement system based on the transverse feedback system at the Duke storage ring. This fast tune measurement system is more efficient than the optical tune measurement system which employs synchrotron radiation from a dipole magnet of the storage ring and a network analyzer. Furthermore, the tune monitoring system enables us to measure the bunch tune. We have also developed a chromaticity measurement using this TFB-based tune measurement system. With these two newly developed beam diagnostics, we calibrated the tune knob and chromaticity knob of the Duke storage ring control system.

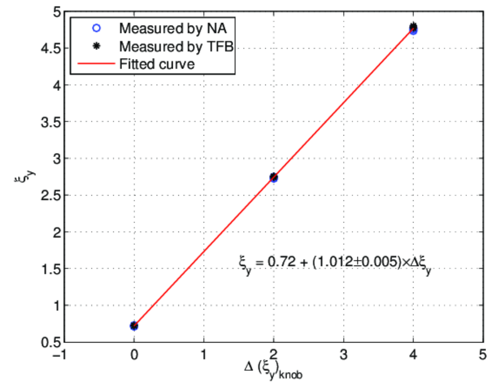

Figure 5: The calibration of the vertical chromaticity knob for the Duke storage ring.

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