DIGITAL LONGITUDINAL BUNCH-BY-BUNCH FEEDBACK SYSTEM FOR THE HLS II

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Abstract

In order to suppress the longitudinal coupled bunch instabilities, a digital longitudinal bunch-by-bunch feedback system will be developed in the upgrade project of Hefei Light Source (HLS II). The longitudinal feedback system consists of a pickup BPM, a front-end/back-end signal processor unit to detect the phase errors of all electron bunches, an iGp signal processor to calculate correction signals of those bunches, two RF power amplifiers, and a longitudinal kicker to supply proper correction energy kicks to individual bunches. A new waveguide overloaded cavity longitudinal feedback kicker has been designed with broadband and high shunt impedance. In this paper, we describe an overview of the new longitudinal feedback system.

INTRODUCTION

In the synchrotron light source, a storage ring of electron beam with many bunches is necessary to meet the demand for the high brightness. The electromagnetic field created by these bunches can interact with the surrounding metallic structures generating 'wake fields', which act back on the trailing bunches producing growth of the oscillations. If the growth is stronger than the damping, the longitudinal coupled bunch instabilities occur and the oscillation becomes unstable. In addition, the higher order modes (HOM's) of RF cavities in the storage ring can also cause the longitudinal coupled bunch instabilities.

During the operation of Hefei Light Source (HLS), the longitudinal coupled bunch instabilities were observed, but there were no effective measures to suppress these longitudinal instabilities. It was one of the main limitations of beam intensity. To overcome this obstacle, a brand new digital longitudinal bunch-by-bunch feedback system whose main design parameters are listed in Table 1 will be installed in the storage ring during the upgrade project of Hefei Light Source (HLS II), and the beam intensity will increase to more than 300 mA. This paper describes an overview of the longitudinal feedback (LFB) system and mainly introduces the development of the longitudinal kicker.

LONGITUDINAL FEEDBACK SYSTEM

The digital longitudinal feedback system for the HLS II consists of a beam position monitor (BPM), a front-end/back-end signal processor, an integrated Gigasample processor (iGp12-45F), two RF power amplifiers and a longitudinal feedback kicker [1]. The functional block diagram of the system is shown in Figure 1.

Table 1: Main design parameters of the LFB system

Parameters	Value	Unit
beam energy	800	MeV
RF frequency	204	MHz
revolution frequency	4.53	MHz
harmonic number	45	
number of FIR taps	32	
central frequency of kicker	969	MHz
bandwidth of kicker	102	MHz
shunt impedance of kicker	2083	Ω

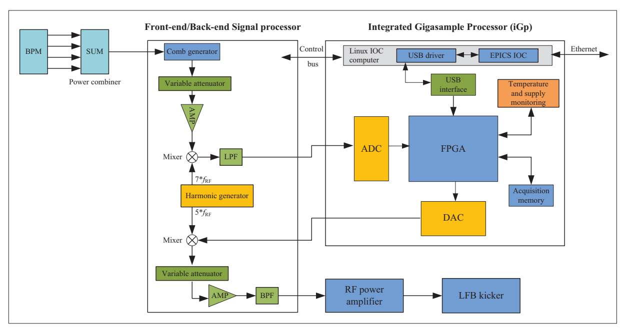

Figure 1: Functional block diagram of the longitudinal feedback system.

The signals from the BPM pickups are combined and then transferred to a 2-cyle comb filter to produce a coherent tone burst at seventh harmonic of the RF frequency. The phase error detection is performed by the double balanced mixer where the signal from the comb generator is compared with one 1428 MHz (=7×f_{RF}) signal coming from a harmonic generator. After being sent to a low pass filter (LPF) to reduce the noise, the detected phase error signals are fed to the digital signal processing subsystem (iGp12-45F processor) which consists of a high-speed 12-bit analog-to-digital converter (ADC), a field programmable gate array (FPGA), and a high-speed 12-bit DAC, all driven by the RF frequency clock. The detected phase error signals can be sampled and digitized by the ADC. The feedback correction output signals are calculated by programmable 32-taps finite impulse response (FIR) filter algorithm at

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the FPGA. The DAC converts those kicking output signals into analog signals which are upconverted to 1020 MHz carrier for driving the RF power amplifiers and LFB kicker. Two broadband, 100 W RF power amplifiers AS0102-100 from MILMEGA supply the required power for the longitudinal kicker. The design of the LFB kicker cavity is described in the next section.

LONGITUDINAL FEEDBACK KICKER

As a key component, a single-ridged waveguide overloaded cavity with two input ports and two output ports for the LFB system kicker has been designed using HFSS code. The LFB kicker consists of a pillbox cavity, single-ridged overloaded waveguides, and racetrack shape beam pipes which can connect smoothly with the octagonal vacuum chamber of the storage ring, see in Figure 2. This type of longitudinal feedback kicker with high shunt impedance and broadband was developed at DAΦNE at first and then was adopted by many other accelerator laboratories, such as PLS, DUKE, TLS, etc.

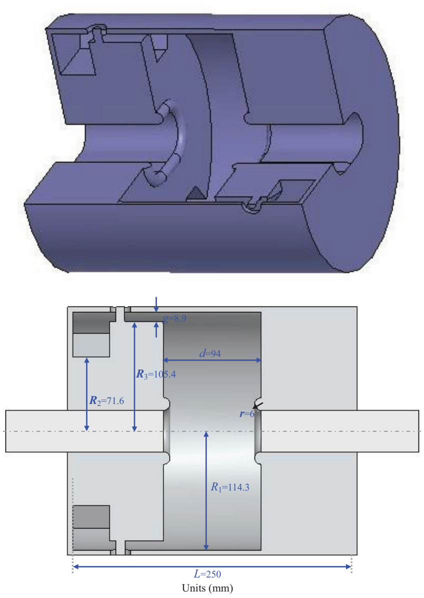

Figure 2: 3-D model and side cut-view of the LFB kicker.

Central Frequency and Bandwidth

Since the RF frequency is 204 MHz, the bandwidth of the longitudinal kicker must be wider than 102 MHz to cure all coupled bunch mode instabilities (CBMI).The central frequency f_c of the kicker cavity should be chosen as $(p\pm1/4)\cdot f_{RF}$ with an integer p [1, 2]. For the HLS II LFB kicker, we choose $(p - 1/4)\cdot f_{RF}$ and p=5, so its central frequency is 969 MHz.

The resonant frequency for the pillbox cavity of the longitudinal kicker, operated in the TM_{010} fundamental mode, is mainly determined by the cavity radius R_1, which is given by:

$$f_c = \frac{c}{2\pi} \cdot \frac{2.405}{R_1} \tag{1}$$

According this formula, R_1 should be 118.5 mm to achieve the resonant frequency of 969 MHz. Additionally, we also must consider the influences of the other internal structure parameters (such as waveguide gap g, back cavity height R_2, cavity gap d, etc) to the physical design of the longitudinal kicker. The final geometry parameters are shown in Figure 2. The simulation of S parameters of the longitudinal kicker is shown in Figure 3, the central frequency is 968.8 MHz and the bandwidth is 106 MHz.

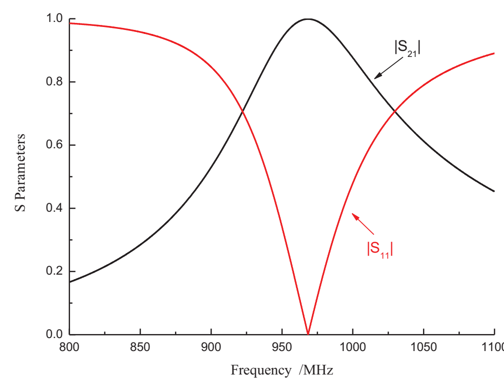

Figure 3: The S-parameters of the longitudinal kicker.

Shunt Impedance

The shunt impedance is a main parameter to describe the efficiency of the longitudinal kicker. For the input power P, assuming no power loss in the cable and waveguide, the shunt impedance is given by:

$$R_s = \frac{V_{gap}^2}{2P} \tag{2}$$

where V_{gap} is the cavity gap voltage.

For a fixed input power, a high gap voltage can be obtained with a high shunt impedance to provide enough energy kick to each bunch. The nose cones attaching the edges of the beam pipe, which can concentrate the E-fields along the z axis, are adopted to increase the shunt impedance.

The electromagnetic field doesn’t remain unchanged during the particles traverse the kicker. The transit time factor was introduced to consider the effect of this field’s time variation [3, 4]:

$$T = \frac{\sin\theta}{\theta} \tag{3}$$

$$\theta = \frac{\omega d}{2\upsilon} \approx \frac{\pi f d}{c} \tag{4}$$

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where v is the particle velocity, $f\,(=\omega/2\pi)$ is the operating frequency of the power amplifier, and d is the gap size.

Considering the transit time factor, V_{gap} can be obtained through calculating the E-field integration along the kicker axis by using HFSS field calculator:

$$V_{gap} = \int_{-L/2}^{L/2} E_z(z) e^{-i[\varphi_z(z) - 2\pi f z/c]} dz \qquad (5)$$

where L is the length of the kicker.

Then the shunt impedance can be calculated by the formula (2), as shown in Figure 4. The maximum of the shunt impedance is 2083.2 Ω which appears at 964 MHz.

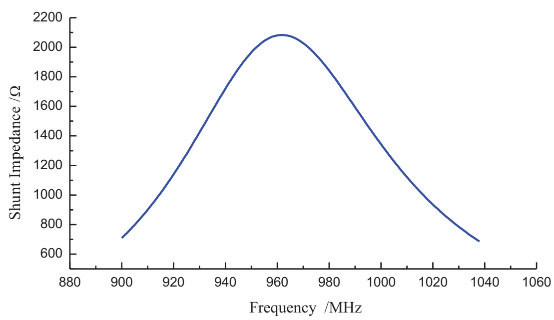

Figure 4: The shunt impedance of the longitudinal kicker vs. frequency.

Higher Order Modes

The higher order modes (HOM's) of the longitudinal kicker cavity which are under the cutoff frequency of the vacuum chamber of the storage ring can also excite coupled bunch instabilities. The strong waveguide coupling of this kind of longitudinal kicker leads to a remarkable damping of all the cavity HOM's.

Since the octagonal vacuum chamber of the HLS II storage ring is small, it has a higher cutoff frequency (about 4.36 GHz). After further analysis of the beam spectrum, the frequency range which we need to check becomes smaller. The signal of a bunch with Gaussian distribution in time domain is:

$$f(t) = \frac{A}{\sigma_\tau \sqrt{2\pi}} \exp(-\frac{t^2}{2\sigma_\tau^2}) \qquad (6)$$

where σ_τ is the bunch length.

The Fourier transform is another Gaussian distribution:

$$F(\omega) = \frac{A}{\sqrt{2\pi}} \exp(-\frac{\sigma_\tau^2 \omega^2}{2}) \qquad (7)$$

For HLS II, σ_τ is 150 ps. So we have:

$$\sigma_f = \frac{1}{2\pi\sigma_\tau} = 1.061\,GHz \qquad (8)$$

The normalized beam spectrum is show in Figure 5. According to the Figure 5, it is sufficient to consider the HOM's of the longitudinal kicker cavity below the 3 GHz which are listed in Table 2, where Q_L is the loaded

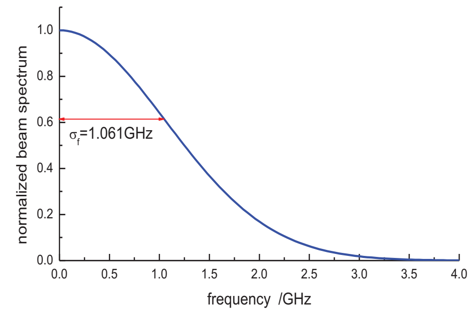

Figure 5: The normalized beam spectrum.

Q factor. The shunt impedances of these HOM's are less than 4% of that of the fundamental mode, so they are not going to be a significant source of beam instability.

Table 2: The modes of the longitudinal kicker

mode	f/GHz	BW/MHz	Q_L	R_s /Ω	R_s/Q_L /Ω
0	0.969	106.0	9.14	2039.0	223.10
1	1.562	46.7	33.5	12.1	0.36
2	1.705	33.8	50.4	9.3	0.18
3	2.242	44.1	50.8	67.8	1.33
4	2.418	33.5	72.2	41.2	0.57

SUNMARY AND FUTURE PLAN

The iGp12-45F bunch-by-bunch feedback signal processor and front-end/back-end processor have been put in place and the longitudinal kicker will be manufactured recently. The whole digital longitudinal bunch-by-bunch feedback system will be installed in the storage ring of the HLS II. We expect that the LFB system can effectively damp all the longitudinal coupled bunch instabilities generated during the operation.

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