TUNING OF THE FAST LOCAL BUMP SYSTEM FOR HELICITY SWITCHING AT THE PHOTON FACTORY

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Abstract
The fast local bump system for helicity switching was installed at a long straight section (B15-B16) at the Photon Factory storage ring in the spring 2008. Recently we have introduced new control system for the fine tuning. In this paper, we present of the system, a tuning method, a demonstration at a slow switching frequency, and a performance at the switching frequency of 10 Hz.

INTRODUCTION
The fast local bump system for helicity switching is expected as a good method to measure the photon helicity-dependence of the material like circular and linear dichroism using a lock-in technique [1]. In order to realize the fast helicity switching, two variably polarizing undulators and five identical bump kickers are going to be installed at a long straight section of 8.9 m at the Photon Factory storage ring (PF-ring). The second undulator will be installed into the ring in this summer.

After the construction of the magnets and the power supplies for the bump system, magnetic field measurements were carried out and then the magnets were installed with the first undulator in the spring 2008. We started the tuning studies of the bump system using the beam, and we succeeded in the orbit switching up to 0.1 Hz with orbit distortion smaller than 10% of beam size outside of the bump and 70 Hz with larger orbit distortion [2].

However, it was impossible to suppress the orbit leakage down to the required values (less than 30 μm in the horizontal direction and 5 μm in the vertical direction) using the previous control system which is consisting of two 4ch DAC (digital analogue converter) modules. Thus, we decided to upgrade the control system since it was difficult to generate completely smooth sinusoidal curve with a high resolution of the amplitude and phase adjustments. Consequently, we introduced four 2ch AFG (arbitrary function generators) modules and voltage-controlled 6ch attenuator modules as new control system in this spring. At the same time, we have developed new tuning methods to use the phase information of the orbit distortion.

NEW CONTROL SYSTEM
Four 2ch AFG modules and voltage-controlled 6ch attenuator modules were adopted for new control system.
Table 1: Parameters for Kick Angle Waveform

<table>
<thead>
<tr>
<th></th>
<th>$K_{DC}$ [mrad]</th>
<th>$K_{AC}$ [mrad]</th>
<th>$\delta$ [rad]</th>
<th>$I_{DC, set}$ [A]</th>
<th>$I_{AC, set}$ [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>1.15</td>
<td>1.15</td>
<td>0</td>
<td>26.27</td>
<td>26.25</td>
</tr>
<tr>
<td>K2</td>
<td>-1.2</td>
<td>1.2</td>
<td>$\pi$</td>
<td>-29.94</td>
<td>29.93</td>
</tr>
<tr>
<td>K3</td>
<td>0.3</td>
<td></td>
<td></td>
<td>7.59</td>
<td></td>
</tr>
<tr>
<td>K4</td>
<td>-1.2</td>
<td>1.2</td>
<td>0</td>
<td>-29.84</td>
<td>29.84</td>
</tr>
<tr>
<td>K5</td>
<td>1.15</td>
<td>1.15</td>
<td>$\pi$</td>
<td>26.40</td>
<td>26.39</td>
</tr>
</tbody>
</table>

Figure 4: Averaged excitation curve. For the linear part, $B[T] = 0.001897 \cdot I[A]$. The dotted line “diff” shows the difference ratio between measured magnetic field and linear term. The saturation effect seems enough small about current up to about 60 A.

as shown in Fig. 1. In order to produce the local orbit bump with a fast switching, the following kick angle waveform is required for each kicker,

$$\theta_j = K_{DC j} + K_{AC j} \sin(\omega t + \delta_j)$$

where the parameters are listed in Table 1 and kick angle (ie. magnetic current) waveforms are shown in Fig. 2. Bump shape of typical three phases are represented in Fig. 3; phase is $\pi/2 + 2n\pi$ for (a), $2n\pi$ for (b), $3\pi/2 + 2n\pi$ for (c) with integer $n$.

**ORBIT DISTORTION SOURCES**

**Phase and Amplitude Errors**

Considering with the errors, the oscillating component of the kick angle can be written by

$$\theta_{ACj} = (A_j + \Delta A_j) \sin(\omega t + \delta_j + \Delta \phi_j)$$

where, $\Delta A_j$ is the amplitude error of bump kicker $j$ and $\Delta \phi_j$ the phase error. Taking the linear and oscillating term of these errors, the error kick is

$$\Delta \theta_{ACj} = \Delta A_j \sin(\omega t + \delta_j) + A_j \Delta \phi_j \cos(\omega t + \delta_j).$$

The orbit distortions from the amplitude error have the same phase as kicker, and those from phase error the phase difference of 90 degrees. In order to realize the tuning of the system, we need to separate these two components by using the phase information.

**Resolution of the Control System**

For the AFG, voltage can be fixed by 0.001 V step. The voltage control of the power supply is carried out by $\pm 100$ A/$\pm 10$ V. From the magnetic field measurement, it can be shown that a magnetic current of 0.01 A generates a kick angle of about 0.4 μrad. For the AFG, the phase can be fixed by about 0.01 degree step (ie. about 170 μrad step). When we take typical amplitude of the kick angle waveform as 1.2 mrad from Table 1, the effective kick angle is corresponding to about 0.2 μrad. From the response matrix of the PF-ring, the ratio of the maximum COD amplitude to error kick angle is about 10. The kick angle of 0.4 μrad generates about 4μm orbit distortion. If we take the permissive beam oscillation amplitude as 1/10 of the beam size, it is typically 30 μm for horizontal direction. Thus the control system allows us to achieve the sufficient resolutions.

**Effect of Eddy Current, Saturation and Hysteresis**

From the frequency response measurements of the magnets, when the magnetic field is not saturated, the delay of the phase due to the eddy current almost only depends on the frequency. All kickers may have the same delay at a fixed frequency and thus the eddy current have little effect on the orbit distortion.

The averaged excitation curve of the bump kicker is shown in Fig. 4. The maximum magnetic current of the bump system is about 60A and the saturation effect is enough small for this current. When beam energy is increased for 3GeV, however, the magnetic field may be saturated. For such case, even if the magnetic current is ideally sinusoidal waveform of a fixed frequency, the magnetic field has the higher order frequency term;

$$B(t) = cI + c'I^2 \cdots = cI_0 \sin \omega t + c'I_0^2 \sin^2 \omega t \cdots$$

$$= cI_0 \sin \omega t + c'I_0^2 \left(1 - \cos 2\omega t\right) + \cdots.$$

The maximum field of five bump kickers are different and thus the orbit distortions with higher order frequencies may be observed.

The cores of the magnets are made by the silicon steel that has the hysteresis effects. The illustration of the
A typical hysteresis loop is shown in Fig. 5. When we approximate the field difference from linear case by ellipse and take the parametric representation, the magnetic field difference due to the hysteresis effect can be written as

$$\Delta R_j = \sqrt{1 + \frac{\Delta \beta_j}{\beta_j} R_j + \tilde{R}_j \Delta \phi_{12}}$$

here $\Delta \beta_j$ is difference of beta function and $\Delta \phi_{12} \approx 0.03$ betatron phase advance between K1 and K2. $\tilde{R}_j$ is a factor of the same magnitude of $R_j$. From this expression, difference between $R_{j1}$ and $R_{j2}$ seems about a few %. Thus distortion from K2 can almost be corrected by K1. The tunings of balance of kick angles and relative phase between K1 and K2 are more important than absolute amplitudes and phases of each kicker.

### DEMONSTRATION FOR SLOW FREQUENCY CASE

In order to demonstrate the correction method, the bump system is operated and tuned with switching frequency of 250 $\mu$Hz (one period is about 1 hour). With the usual 65 BPMs, the orbit distortion was measured as shown in Figure 6-(a). It can be seen that the amplitudes are almost optimized and the effects of the phase errors are dominant. After the tuning, the orbit distortion reduced as shown in Figure 6-(b). The new method was successfully demonstrated.

### FAST SWITCHING TEST

Finally, 10Hz operation was tested. At present, the measurements of orbit distortions were carried out by eight fast BPMs. With manual cable switching, the orbit distortions from 19 BPM places are measured as shown in Fig. 7. When we change the amplitude of one kicker, the change of the orbit distortion may be observed only in “sine” or amplitude-error component. By using this method, we can set the optimum target of the phase tuning. (In principle, any phase can be fixed as “zero” phase.) The iteration of the phase tuning can fix all kickers to “zero” phase.)

In the next beam study, we will try to suppress the orbit distortion for 10Hz case.

### REFERENCES
