Compensation of Field Shaking due to the Magnet Vibration

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Abstract

Recently, The global feedback scene of the beam stabilization is broadly discussed for the third generation light source. Since the low frequency disturbance of the orbit is mainly coming from the quadrupole magnet vibration of a certain dominate mode, a feedforward sense is developed to cancel the filed shaking without the BPM feedback. We applied the seismic accelerometer to detect the magnet vibration and drove the compensation current into the trim coil of the quadrupole. Better than 99% canceling of the filed shaking due to 10μm magnet vibration was observed in the laboratory. This method is superior to the feedback system in many aspects, such as locality, simplicity and economy.

I. Introduction

The global feedback system for the transverse beam positioning has become a standard subsystem of the third generation synchrotron light source [1]. In this paper, the general idea of the feedback system will be described first. Then, a primitive model is used to estimate the performance of this feedback system in the SRRC case. The result shows that there are limitations for this feedback system.

A low cost feedforward method is proposed to suppress the effect from the vibration source. Hence, the beam jitters can be reduced and the accuracy of the beam orbit estimation can be enhanced.

II. General Description of a Beam Feedback System

Figure 1 is a general block diagram of the linear beam feedback system.

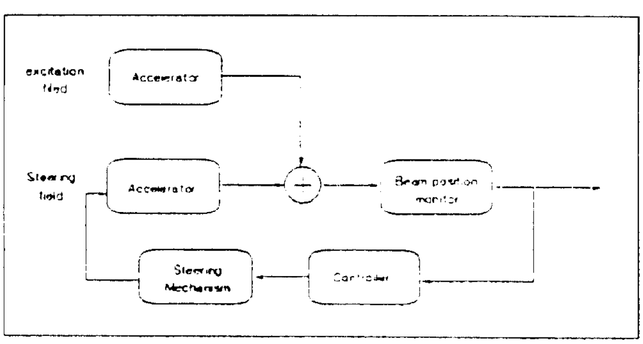

Figure 1. Linear model of beam feedback system.

The transfer function of the accelerator is discussed in another paper of the main author [2]. We will not go into details in this paper. Roughly speaking, the transfer function contains a pair of conjugate poles caused by the damping effect and the betatron oscillation. The beam position monitor, like a radio receiver, contains a pole, which is interested by us. In a digital system, this pole is very important, since it can avoid the aliasing error. The correction signal coming out from the controller is used to control the steering field which is affected by the bandwidth of the power supply, correction magnet, and vacuum chamber. The poles of these components are listed in following two groups.

A. High Frequency Poles

1. Accelerator ~ 300 KHz
2. Beam Position Monitor ~ 1 KHz.

B. Low Frequency Poles

1. Vacuum Chamber (4 mm-thick Aluminum)
   vertical ~ 40 Hz
   horizontal ~ 15 Hz
2. Correction Magnet + Power Supply ~ 200 Hz

Except the bandwidth of the accelerator, the numbers given above have been measured in the laboratory [3].

III. Limitation of the Open loop Gain

To avoid instability and increase the open loop gain in the control system, one pole in the low frequency range has to be compensated. It doesn't make sense to remove poles at high frequency range. Hence, the closed loop unity-gain bandwidth is limited to 200 Hz ~ 500 Hz.

Assumed that the magnet field shaking is mainly caused by the quadrupole vibration. Our measurement on the quadrupole vibration shows that there is a main peak at 20 Hz. With a slop of 20 dB/decade of the open loop gain, there is a 20 dB drop from 20 Hz to 200 Hz. Thus for the unity gain at 200 Hz, the gain at 20 Hz is only ten. It will take too much effort to increase this gain at 20 Hz but with only a poor factor.

IV. Resolution of Beam Observation

Let's say, the resolution of each beam position monitor is 10 μm at 20 Hz. The closed orbit correction in the least square sense can increase the resolution by a factor of $\sqrt{n}$. The "n" is the number of the position monitor. Thus, a factor of seven can be achieved for total 48 BPMs (Beam Position Monitor) in the SRRC storage ring. However, if the quadrupole vibration disturbs the observation, this factor will go down.

V. Reduction of the Field Shaking

In order to get a more stable beam, the effect from the excitation source should be suppressed. If the magnet field is trimmed against the vibration, it is possible to have a large magnet vibration but a stable field. Usually the vibration of the quadrupole is much less than 10 μm. The bore radius of the ring quadrupole in SRRC is 38 mm. The current in the trim coil with the same winding number of the main coil is less than one part in four thousand. With the maximum main-coil current of 250 A , the current in the trim coil will be less than 60 mA (the power supply ripple current is about 5 mA). Thus, the power needed to drive trim coil is less than one millionth of the power in main coil.

A modern piezo type vibration sensor provides a resolution of 0.01 μm at 20 Hz. It is possible to get a higher resolution, if a higher frequency carrier , such as 10 K Hz, is used to reduce low frequency noise.

The other important character is the vibration mode of the magnet. From the three points support, there is no degeneration of vibration at resonant frequency. It means only one sensor located on the magnet is able to detect the three dimensional motion of the resonant vibration.

The field strength of the quadrupole is depend on the main current, which may be changed from time to time for the third generation synchrotron light source. Hence, an adaptive current amplifier with self calibration is considered to optimize the gain.

VI. Dipole Field Compensation Model for Quadrupole Magnet Vibration

For an ideal quadrupole magnet, the higher multi-pole field is very weak, so the scalar potential can be expressed as

$$\phi(x,y) = G \cdot x \cdot y \qquad \text{----(1)}$$

Where G is the gradient field strength. Therefore, the transverse midplane, the magnetic flux density, by definition $\bar{B} = -\bar{\nabla}\phi(x,y)$, can be reduced as Eq. 2

$$\bar{B}(x,y) = G\left(x\,\hat{j} + y\,\hat{i}\right) \qquad \text{----(2)}$$

If the vibration happens on the transverse plane of the quadrupole magnet, there will be an extra dipole field exists on the quadrupole magnet. Thus, the flux equation becomes

$$\bar{B}(x,y) = G\left[\left(x + x_0\cos(w_x t)\hat{j}\right) + \left(y + y_0\cos(w_y t)\hat{i}\right)\right] \qquad \text{----(3)}$$

Where w_x, w_y are the vibration frequency and x_0, y_0 are the vibration amplitude on the transverse plane of the quadrupole magnet. Hence Eq. 3 can be changed to

$$\bar{B}(x,y) = G\left[\left(x_0\cos(w_x t)\hat{j}\right) + \left(y_0\cos(w_y t)\hat{i}\right)\right] + \left[G\left(x\,\hat{j} + y\,\hat{i}\right)\right] \qquad \text{---(4)}$$

This extra dipole field $G\left[x_0\cos(w_x t)\hat{j} + y_0\cos(w_y t)\hat{i}\right]$ will induce a kick angle for the electron beam. In order to compensate this dipole field, the dipole trim current on the quadrupole magnet can be used to produce another dipole field whose frequency is the same as the vibration frequency. The strength of the field induced by the trim current is shown below

$$\bar{B} = \left[-B_y\cos(w_x t)\hat{j} - B_x\cos(w_y t)\hat{i}\right] \qquad \text{----(5)}$$

To create the fields B_y and B_x , a model similar to the Beam Position Monitor model is used. In this model, there are two kinds of dipole trim current to create B_y and B_x fields. The location of the trim coil and the poles on the quadrupole magnet is shown in Figure 2. In this figure, the A, B, C, and D, are the four poles, and the trim current combination for each pole is

$$\begin{aligned} A &= I_x + I_y \\ B &= I_x - I_y \\ C &= -I_x - I_y \\ D &= -I_x + I_y \end{aligned} \qquad \text{----(6)}$$

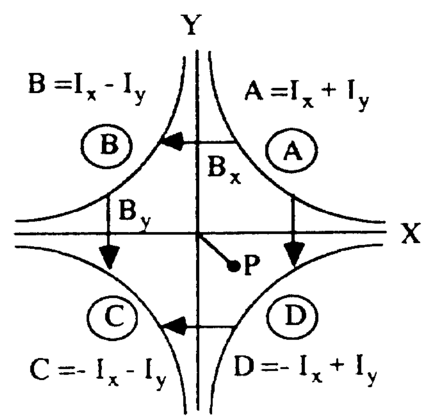

Figure 2. Arrangement of the trim coils and the magnetic poles on the quadrupole.

Combing these pole current equations, the horizontal and vertical current can be expressed as below

$$I_x = (A+B-C-D)/4$$
$$I_y = (A+D-B-C)/4 \qquad \text{----(7)}$$

Hence, the relationship between the filed strength (B_y, B_x) and the current (I_y, I_x) can be expressed as

$$B_y = f(I_y, I_x) - B_{y0}$$
$$B_x = g(I_y, I_x) - B_{x0} \qquad \text{----(8)}$$

Where f, g are functions of trim current (I_y, I_x), and can be calibrated by the magnetic field transfer function. The B_{y0} and B_{x0} are the magnetic field center offset which are obtained from the magnetic field measurement.

Similar to the BPM using four electrode to detect beam position, this model uses four poles (A,B,C,D) to create dipole filed. From this model and Eqs. 4 and 5, the required field strength to cancel the dipole field caused by the vibration can be derived by using following equations .

$$B_y = -G \cdot x_0 \quad \text{and} \quad B_x = -G \cdot y_0 \qquad \text{----(9)}$$

The trim current (I_y, I_x) can then be obtained through the transfer functions f and g in Eq. 8. Thus from the well known gradient field G and the vibration amplitude x_0 and y_0, the required trim current can be obtained. By feeding this trim current into the trim coil, the dipole field induced from the vibration can be cancelled.

VII. Experiment Result

In the laboratory of SRRC, a stepping motor was used to generate a 4 Hz vibration with a level of 10 μm. A hall probe is fixed on the center of the quadrupole and the vibration sensor is mounted directly on the quadrupole. The vibration signal is fed into the trim coil with a dipole winding. Figure 3. is the result of this experiment. It shows the trim current brings the field shaking down to 0.1 μm, when the feed-forward is turned on.

VIII. Conclusion

The field stabilization circuit is able to reduce beam jitters to ultra high quality. It also avoid the impact of ground vibration on the stored beam. Since the low power and low frequency electronics are applied, the cost is rather low comparing with a feedback system. On the other hand , the control system is very compact. The sensor is mounted directly on quadrupole. It turns out this system is a very cost effective solution for the field shaking due to magnet vibration.

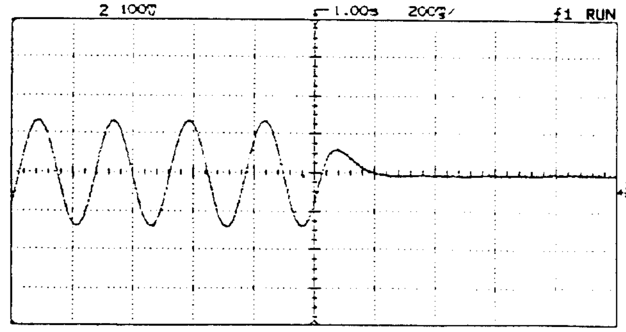

Figure 3. Field shaking killed by the onset of trim correction.

IX. References

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[2] Yao Cheng, "Dynamic Closed orbit Correction", this conference.

[3] SRRC Status Report, (SRRC, April 1993).