SUPPRESSION OF COHERENT SYNCHROTRON OSCILLATION OF THE SPRING-8 STORAGE RING

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Abstract

For the realisation of a highly brilliant photon beam in a third generation synchrotron radiation source such as SPring-8, it is very important to eliminate an orbital vibration of the stored electron beam. In the SPring-8 storage ring, coherent synchrotron oscillation with amplitude of 0.2mmp-p was observed by BPM located in a dispersive section. Since the energy oscillation amplitude is proportional to the product of the phase noise amplitude and the inverse of the momentum compaction factor, the energy oscillation amplitude is enhanced by low momentum compaction factor. To make the amplitude of this synchrotron oscillation as low as possible, we checked the performance of synthesiser by measuring the noise level around the synchrotron frequency, and selected a synthesiser with best performance. Furthermore, the remaining amplitude was corrected within about 1/10 by applying frequency modulation to the RF reference signal.

1. INTRODUCTION

The SPring-8 is one of synchrotron radiation facilities of third generation. The momentum compaction factor is low and the beam energy is sensitive to the fractuation of the RF frequency. The small phase noise in the RF system will cause the coherent energy oscillation (the synchrotron oscillation) of the beam. A ripple of a klystron power supply is one of sources to produce phase noise [1]. A phase noise of the signal generator (SG) used for RF reference signal is also the candidate of the noise source. To reduce the coherent energy oscillation of the stored beam, feedback system was developed. The relation to the phase noise and the beam energy is breifly mentioned in this section. The experimental setup is shown in section 2. The result is shown in section 3. And the conclusion is given in section 4.

1.1 Amplitude of synchrotron oscillation

The time deviation τ from the synchronous particle and the energy deviation δ follow the differential equations,

$$\frac{d\tau}{dt} = -\alpha\delta \qquad (1),$$

$$\frac{d\delta}{dt} = \frac{eV}{ET}\sin\left(\omega_{RF}\,\tau + \phi_s + \psi\right) - \frac{U + DE\,\delta}{ET} \qquad (2),$$

where symbols mean

α: a momentum compaction factor (1.46 10^{-4}),
V: an acceleration voltage (16MV),
ω_{rf} :the RF frequency (2π 508.58 10^6 rad/s),
ϕ_s :the synchronous phase angle,
ψ :the phase deviation due to noise or feedback,
U: the energy loss per turn (9MV),
D: the damping coefficient,
E: the beam energy (8GeV),
T: the revolution time (4.8μs).

A phase noise of the RF system reacts to the beam through the RF acceleration voltage. Figure 1 shows the schematic view of this process.

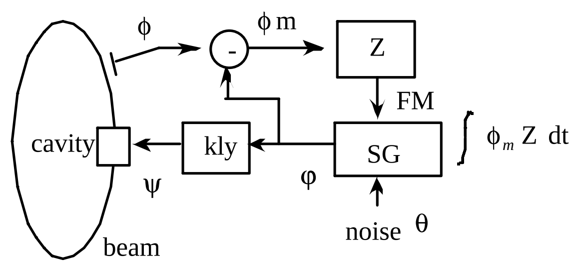

Figure 1: Beam phase and RF system.

In this figure, the symbols mean

$\phi = \tau\,\omega_{rf}$: a beam signal from pickup electrode,
φ : the phase generated from the signal generator,
$\phi m = \phi - \varphi$: the measured beam phase between ϕ and φ ,
ψ : the phase signal fed to the RF acceleration cavities,
θ :the noise generated in the signal generator,
Z : the transfer function of feedback loop.

Here we consider the case that there is no feedback loops. The sine in equation 2 can be expanded if $\omega_{rf}\,\tau + \psi \ll 1$

$$\sin\left(\omega_{RF}\,\tau + \phi_s + \psi\right) \simeq \sin\phi_s + \cos\phi_s\left(\omega_{RF}\,\tau + \psi\right)$$

Using equation 1, the equation 2 can be expressed as

$$\frac{d^2\tau}{dt^2} + 2\alpha_e\frac{d\tau}{dt} + \omega_s^2\tau = \omega_n\psi \qquad (3),$$

$$\omega_n = \frac{\omega_s^2}{\omega_{RF}},\quad \alpha_e = \frac{D}{2T},\quad \omega_s^2 = \frac{\alpha\,e\,V\,\omega_{rf}\cos\phi_s}{ET}.$$

When an external force $\psi = \theta\, e^{i\omega t}$ is applied, assuming $\tau = \tau_0 e^{i\omega t}$, the answer of this equation is as follows

$$\tau_0 = \frac{\omega_n\,\theta}{\left(\omega_s^{\,2} - \omega^2\right) + 2\,\alpha_e\omega\, i}.$$

The energy deviation of the beam $\delta = \delta o\, e^{i\omega t}$ is expressed as

$$\delta_0 = \frac{-i\,\omega}{\alpha}\,\tau_0 = \frac{\frac{-i\,\omega}{\alpha}\,\omega_n\,\theta}{\left(\omega_s^{\,2} - \omega^2\right) + 2\,\alpha_e\omega\, i} \qquad (4).$$

1.2 feedback

In case that the feedback loop shown in figure 1 is activated, the measured beam phase ϕm is amplified and

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pass a filter (expressed as Z) and is fed to the external FM port of the SG. The phase ψ is changed as

$$\psi = \theta\, e^{i\omega t} + \int \phi_{m0} e^{i\omega t} Z\, dt$$

The equation 3 is changed as

$$-\omega^2\, \tau_0 + 2\alpha_e i\, \omega\, \tau_0 + \omega_{sy}^2 \tau_0 = \omega_n \left[\theta + Z\left\{\frac{\tau_0\, \omega_{rf} - \theta}{i\,\omega}\right\}\right]$$

$$\tau_0 = \frac{\omega_n \left(\theta - \frac{Z\,\theta}{i\,\omega}\right)}{\left(\omega_s{}^2 - \omega^2\right) + \left(2\,\alpha_e \omega\, i - \frac{\omega_n\, \omega_{rf}\, Z}{i\,\omega}\right)}$$

$$\delta_0 = \frac{-\,i\,\frac{\omega\,\omega_n}{\alpha}\left(\theta - \frac{Z\,\theta}{i\,\omega}\right)}{\left(\omega_s{}^2 - \omega^2\right) + \left(2\,\alpha_e \omega\, i - \frac{\omega_n\, \omega_{rf}\, Z}{i\,\omega}\right)} \qquad (5)$$

2. EXPERIMENTAL SETUP

2.1 detection of the beam phase

The phase oscillation of the beam is detected as follows. The signal from a button pick-up attached to the vacuum chamber is filtered using a band pass filter whose bandwidth is 1MHz, its center frequency is 508.58MHz. The narrow bandwidth is preferred because the power from the button electrode varied according to the filling of the storage ring when the width is wider than the revolution frequency of 208.8kHz. Then the filtered signal is amplified using a step attenuator and an RF amplifier. The RF reference signal and the beam signal is converted to an intermediate frequency (IF) of 1MHz. The two IF signals are input to the phase detector made by Sankosya. The signals are amplified using comparator and an AND signal are output. The sensitivity of the system is 50mV/deg. The 3dB compression frequency of this phase detector is 30kHz. It is much higher than the synchrotron oscillation frequency. Figure 2 shows the set-up of the beam phase observation system.

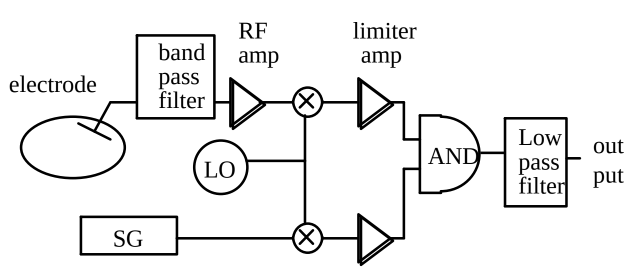

Figure 2: Set-up for beam phase measurement.

2.2 detection of beam energy

The beam energy is detected using signals from button electrodes located at a dispersive section (39cell arc) whose dispersion is 400mm. Figure 3 shows the measurement set-up.

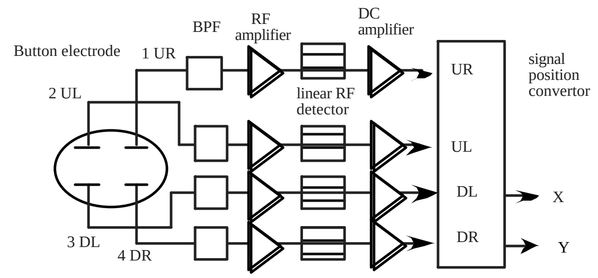

Figure 3: Set-up for the measurement of beam position.

The signals from the electrodes are filtered by a narrow band pass filter (same as used in the phase detection system), amplified by RF amps and detected using diodes. The four detected signals are converted to positional signals using analog ICs (intersil ICL8013 etc). The conversion formula is as follows,

$$V_x = \frac{V_{UR} - V_{UL} + V_{DR} - V_{DL}}{V_{UR} + V_{UL} + V_{DR} + V_{DL}} \cdot 10$$

$$V_y = \frac{V_{UR} - V_{DR} + V_{UL} - V_{DL}}{V_{UR} + V_{UL} + V_{DR} + V_{DL}} \cdot 10$$

x(mm)=Vx(volt)/0.68 .

Then the energy deviation of the beam is expressed as

δ = Vx / (0.68 * 400).

3. RESULT

3.1 Oscillation amplitude and type of SG

The energy spectrum of the synchrotron oscillation was observed with five kind of the signal generators: SMHU58 (Rohde Schwartz), 8662A (Agilent), MG3633A (Anritsu), E4433B (Agilent) and a crystal oscillator (Sankosya). Figure 4 shows the result obtained for the 8662A and E4433B as an example.

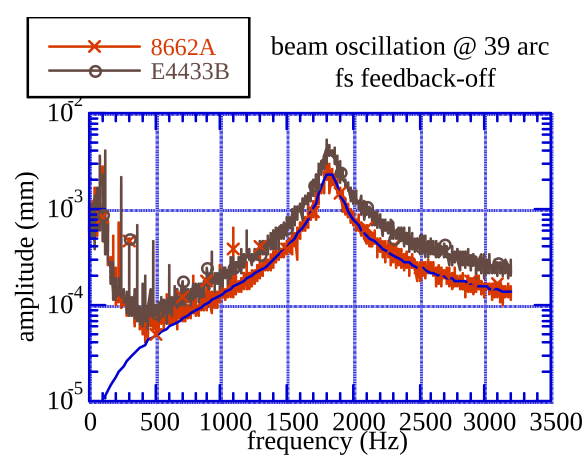

Figure 4: Beam position spectrum measured at 39 arc.

The oscillation amplitudes were almost same for four SGs except that of E4433B whose amplitude is about 2 times larger than that of 8662A. The blue line shown in figure 4 is a fitted curve according to the equation 4 for the data of 8662A. The data and the fitting agree well between 500Hz and 3kHz. The measured amplitude is increased below 500Hz. That is not caused by the synchrotron oscillation but by the vibration of cooling water etc. The synchrotron frequency $fs = \omega s/2\pi$ was 1833Hz at this condition.

3.2 Feedback gain

The performance of the feedback loop was tested. The measured beam phase signal is amplified and is passed through a high pass filter (HPF) whose cut off frequency was 110Hz. The order of HPF is 8th and 48dB/oct. The filtered signal is fed to the external AC input for FM modulation (100Hz/V) of the SG. The beam energy spectrum was measured as a function of the gain of the feedback loop amplifier. Figure 5 shows the result.

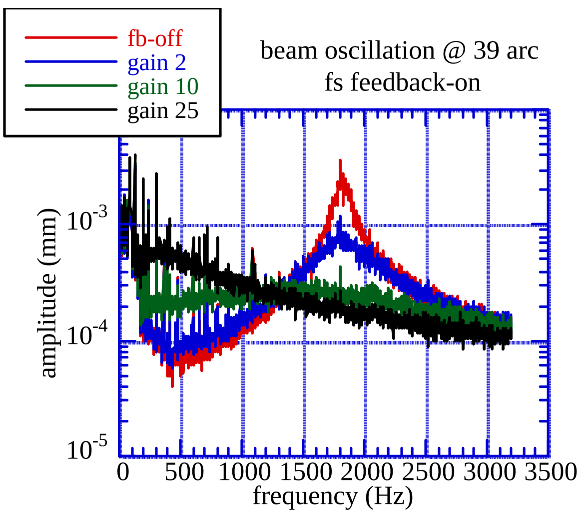

Figure 5: The measured beam position spectrum.

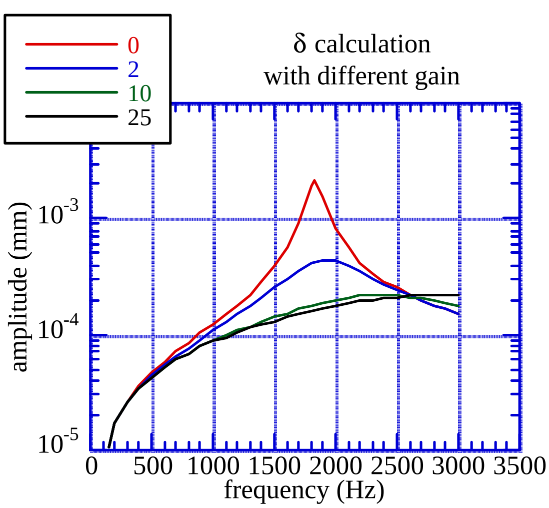

Figure 6: The calculated beam position spectrum.

The peak amplitude at *fs* is reduced as the gain is increased. But the amplitude is increased below 1kHz as the gain is increased. Figure 6 shows the calculated value according to the equation 5. At the low gain the measured value shows geed agreement with calculation. But at the high gain measured amplitude is increased below 1kHz than the calculation. It may be because of the effect of noises produced in phase detector or other components in the feedback loop. The integrated amplitude of the spectrum from 110Hz to 3.2kHz is plotted in the figure 7. The value reaches minimum at the gain of 10. The usual operation is done in this set-up.

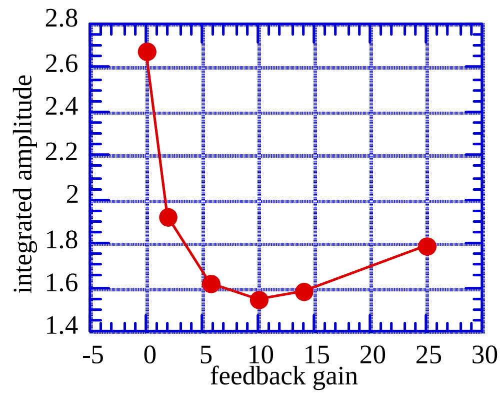

Figure 7: The integrated value of the spectrum as a function of the feedback gain.

4. CONCLUSION

The coherent synchrotron oscillation amplitude is successfully suppressed by selecting a good synthesiser and using the feedback system. With the feedback the reduction of the peak amplitude at the synchrotron frequency is about 20dB. The system is in use at the usual operation of the SPring-8. Further reduction of noise is underway to improve the phase detector, to use another phase-shifter instead of using FM function of SG.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] M. Hara et.al., "Coherent Synchrotron Oscillation excited by a ripple of a klystron power supply", EPAC98, Stockholm, June 1998