Single-Bunch Instabilities in the SPring-8 Storage Ring: Comparison with Simulation based on Estimated Impedance

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1 Introduction

The comparison between the observation of the single-bunch instabilities at the SPring-8 storage ring reported in this conference[1] and the result of the simulation based on estimated impedance was shown in this paper. The results of the observation in ref.[1] is not shown here but they are used for the comparison with the simulation results.

2 Estimated Impedance

Impedance of the beam-pipe components are estimated with a simulation code MAFIA[2] using model impedance. The estimated value of the longitudinal impedance is

$$Z^{\parallel} = -i\omega L + R + Z_C \frac{1+i}{\sqrt{\omega}}$$

where L =5.22×10^{-8} H , R = 875 Ω and Z_c = 1.15×10^{8} Ω s^{-1}. For transverse impedance, the estimated value is

$$\langle \beta Z^{\perp} \rangle = -i \langle \beta L^{\perp} \rangle + \frac{\langle \beta R^{\perp} \rangle}{\omega} + \langle \beta Z_C^{\perp} \rangle \frac{1+i}{\omega\sqrt{\omega}}$$

where $\langle \beta L^{\perp} \rangle$ = 1.8×10^{8} Ω, $\langle \beta R^{\perp} \rangle$ =1.7×10^{5} Ω s^{-1}, and $\langle \beta Z_C^{\perp} \rangle$ = 2.1×10^{20} Ω s$^{-3/2}$. β is the beta function and <> is the averaged value in one revolution of the ring.

The estimation of the impedance above was performed using the MAFIA results for the bunch length around 5mm, which means that for the longer bunch, the error of the estimation of the impedance and the difference of the simulation and the observation may increases.

The source of the 90% of resistance R and $R^{\perp}$, which are the main source of transverse instabilities, is the bellows.

3. Longitudinal Motion

The code SISR (Single-bunch Instabilities in Storage Rings)[2] are used to simulate the instability using the estimated impedance.

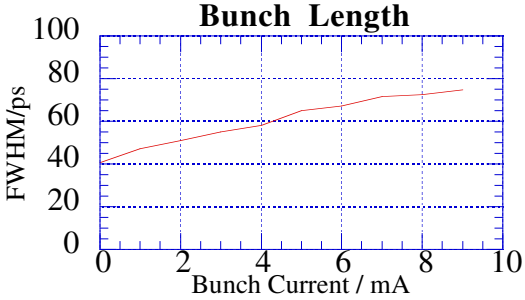

Fig.1 Bunch length vs. Bunch current

The bunch current dependence of the bunch length, the bunch shape and the synchronous phase obtained by the simulation are shown in Fig. 1, Fig. 2 and Fig. 3, respectively. In the simulation results, the bunch length is rather shorter and the bunch shape do not have long tail compared with the observation[1].

The energy spread obtained by the simulation is constant and keep natural value.

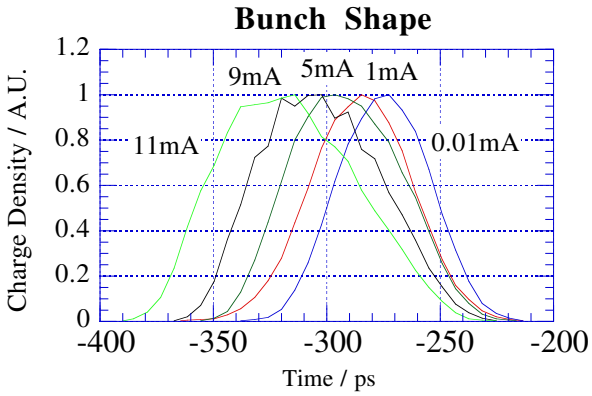

Fig.2 Bunch shape vs. bunch current.

4 Transverse Motion

In frequency response of the betatron motion with finite chromaticity, we can see several peaks whose frequency is $f=\Delta\nu\, f_0 \pm m\, f_s$ where Δν is the fractional part of the tune and f_0 and f_s is the revolution frequency and synchrotron frequency respectively. From instability theories[3], we may expect that the head-tail instability of m=0 peak may occur at negative chromaticity and at non-negative chromaticity, mode-coupling instability or head-tail instability of |m| =1 may occur. At head-tail instabilities in negative chromaticity, the growth rate of m=0 peak gradually increases as bunch current increase and when it exceeds the radiation damping rate, the betatron motion of the centre of mass of the bunch is driven and the instability arises. At non-negative chromaticity, m=0 peak of betatron frequency decreases as bunch current increases and if m=0 peak merges with m=-1 peak, mode-coupling instability occurs. Until the merge of two peaks, no growth rate of mode-coupling instability is exist.

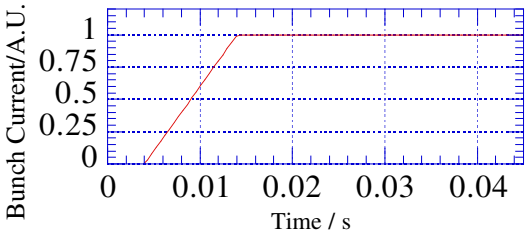

Fig.3 The increase of the bunch current in the simulation.

Chromaticity = - 4

The threshold current is 0.4mA/bunch. The frequency response of the betatron motion is shown in Fig. 4. The m=0 peak (central peak) become higher as the bunch current increases. The increase of the betatron amplitude of the bunch vs. time is shown in Fig. 5 in which we can see that the gradual increase of growth rate of the instability as the increase of the bunch current. These property of the instability shows that this is m=0 head-tail instability.

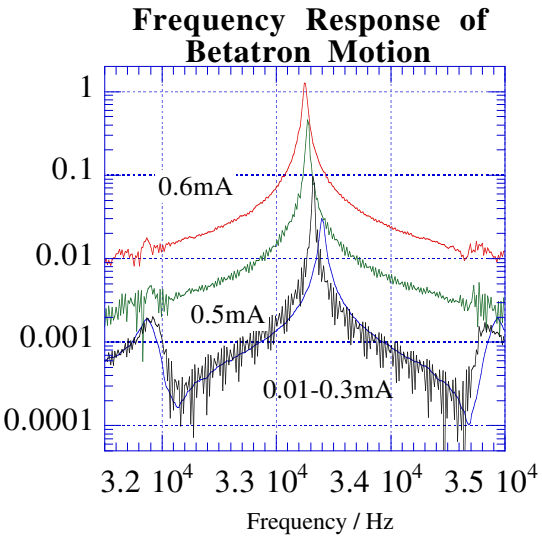

Fig.4 Frequency response of the vertical betatron motion at chromaticity -4.

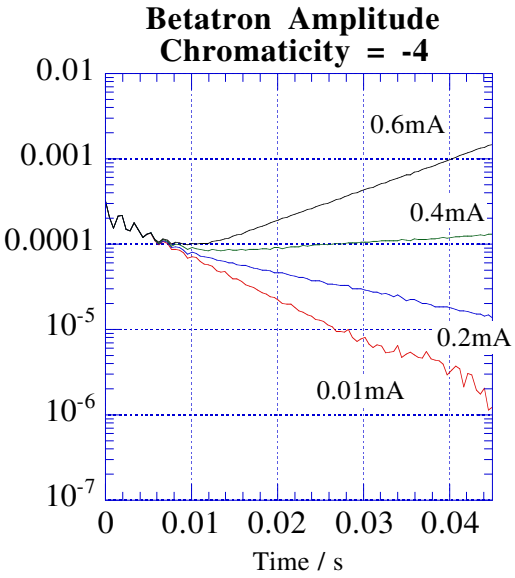

Fig.5 Betatron amplitude growth vs. bunch current. The bunch current is increased as in Fig. 3. The growth rate of the instability is gradually increased as the bunch current.

Chromaticity = 0.24

The threshold current is 4mA/bunch in the simulation. The frequency response of the betatron motion is shown in Fig. 6 and we can see the merge of m=0 peak and m=-1 peak at the threshold current. The instability should be the mode-coupling.

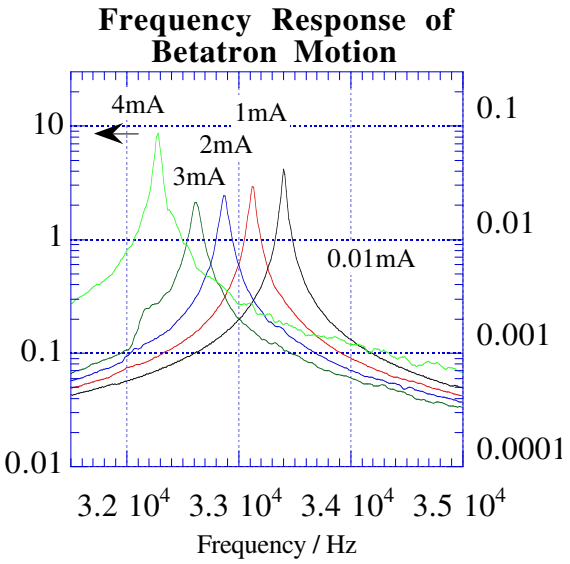

Fig.6 Frequency response of the vertical betatron motion at chromaticity 0.23.

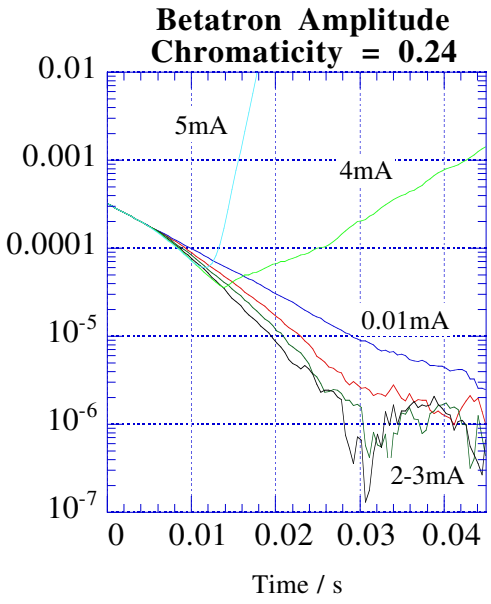

Fig.7 Betatron amplitude growth vs. bunch current. The bunch current is increased as in Fig. 3. The growth rate of the instability is suddenly increased at threshold bunch current. At low bunch current, the head-tail damping can be seen.

Chromaticity = 3.7

The frequency response of the vertical betatron motion in the simulation is shown in Fig 8 and 9. Instability arises at the bunch current above 12 mA/bunch but the bunch length is more than twice of natural value and the simulation results at this bunch length may differ from the observation. With almost the same operation parameters, we had the bunch current more than 15mA/bunch without instabilities in the SPring-8 storage ring.

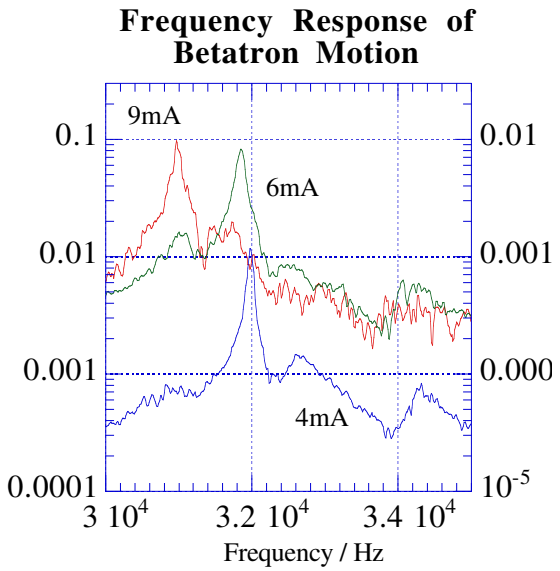

Fig.8 Frequency response of the vertical betatron motion at chromaticity 3.7

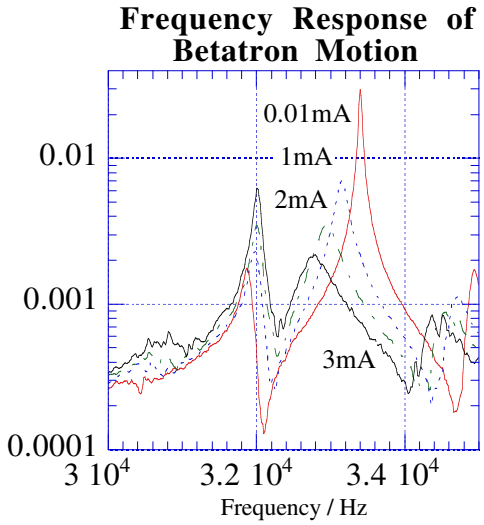

Fig.9 Frequency response of the vertical betatron motion at chromaticity 3.7.

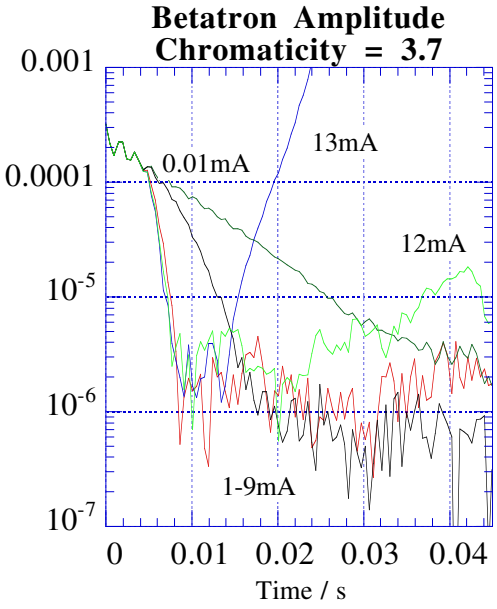

Fig. 10 Betatron amplitude growth vs. bunch current. The bunch current is increased as in Fig. 3.

5 Conclusion

By the simulation based on the estimated impedance by MAFIA, we reproduced the result of the observation and we could estimate the type of instabilities. The estimated impedance is for rather short bunch length, which is enough to estimate the phenomena at a few mA/bunch, but and at longer bunch at high bunch current, the discrepancy become larger such as bunch shape or instability threshold above 10mA. One possibility to extend such case is the direct usage of the wake-function obtained by MAFIA, which takes lots of CPU power.

References

[1] T. Nakamura et. al., "Observation of the Single-Bunch Instabilities in the SPring-8 Storage Ring", this proceedings

[2] SPring-8 Annual Report 1996

[3] For example, A. W. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators", John Wiley & Sons, 1993