FILLING OF HIGH CURRENT SINGLET AND TRAIN OF LOW BUNCH CURRENT IN SPRING-8 STORAGE RING

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Abstract

The scheme to achieve hybrid filling which is composed of high current singlet bunches and a train of low current bunches is discussed with focusing the control of beam instabilities with bunch-by-bunch feedback.

INTRODUCTION

Hybrid filling modes with high current singlet bunches and a train of low current bunches are requested by users to fulfil the requirements of time response experiments and experiments with high duty photons simultaneously. The hybrid filling modes in the SPring-8 storage ring for the operation in 2008 are listed in Table 1. To achieve these hybrid filling modes, we need to control both single-bunch instabilities of high current singlet bunches and multi-bunch instabilities by the all bunches simultaneously, with bunch-by-bunch feedback under the high contrast of the bunch currents. Also we need to have high feedback strength to obtain high feedback damping rate for single-bunch instability and high dynamic range for the betatron motion excited by the injection bump.

Table 1 : Hybrid filling modes in SPring-8 storage ring. The total current of the ring is 100mA and the harmonics is 2436. Filling Type V_2 has not been achieved yet.

type	filling of train (# of bunches)	# of singlet	bunch current	
			train	singlet
I	1/7 (348)	5	0.24mA	3.0mA
II	2/29 (168)	26	0.38 mA	1.4mA
III	1/14 (174)	12	0.46 mA	1.6mA
IV	4/58 (168)	53	0.28 mA	1.0mA
V_1	3/28 (261)	1	0.34 mA	10 mA
V_2	4/7 (1392)	1	64 μA	10 mA

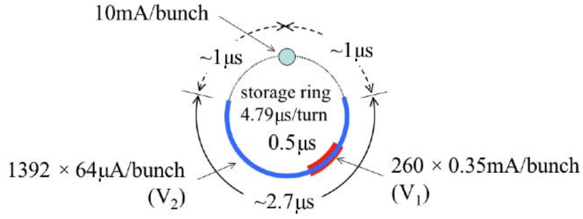

Figure 1 : Examples of hybrid filling modes. The mode V_1 and V_2 in Table 1 are shown. Blue arc shows the train of V_2 which is requested by users, and the red arc is the train of V_1 which we achieved.

BEAM INSTABILITIES

Single-bunch Instabilities

Without transverse bunch-by-bunch feedback, we observe mode-coupling instabilities both in horizontal and vertical planes and their threshold current are ~2.5mA/bunch. Above this threshold, the decrease of the bunch current is observed at injection and we cannot store more. The operation with high chromaticities, 8 in both horizontal and vertical, increased the threshold current to ~4mA/bunch. With bunch-by-bunch feedback for horizontal and vertical planes, we can store up to 12mA/bunch even with low chromaticities ~0. Above this bunch current, the reduction of the bunch current is also observed at injection. The required feedback damping time for the suppression of the single-bunch instabilities is 0.1 ~ 0.2 ms.

Multi-bunch Instabilities

Horizontal and vertical resistive-wall multi-bunch instabilities driven by the resistive-wall impedance of the in-vacuum undulators are observed [1]. Before the introduction of the bunch-by-bunch feedback, the instabilities were suppressed by large chromaticities, ~8 in both planes. The impedance of higher order modes of acceleration cavities are well controlled and, without feedback, do not excite the beam instabilities in most of filling modes of the SPring-8 including the hybrid filling.

With bunch-by-bunch feedback, we can cure those multi-bunch instabilities in any filling modes.

BUNCH-BY-BUNCH FEEDBACK

For top-up operation, we need to reduce the chromaticities to 0 ~ 2 for horizontal and 0 ~ 6 for vertical to increase the injection efficiency which is required to minimize the beam loss in the ring. To suppress beam instabilities in low chromaticities, the bunch-by-bunch feedback system [2] of the bunch rate 508.58MHz is developed (Fig. 2). The system employs three stripline kickers with length (L) 15cm, 40cm and 30cm. The shapes of the kicker electrodes are also shown in Fig.2. Currently, we are using four 40cm stripline kicker electrodes for horizontal plane and two 15cm stripline kicker electrodes for vertical plane.

BUNCH CURRENT SENSITIVE AUTOMATIC ATTENUATOR

The level of the signal of a bunch from a BPM is proportional to the product of the position and the current of the bunch, hence the feedback damping rate is also proportional to both of them. The signal level or the feedback damping rate are adjusted to the bunch current of 0.05mA/bunch which is the bunch current at multi-bunch filling and the minimum bunch current in all the filling modes. In the other filling modes in which the bunch current are nearly one order higher than the multi-bunch filling mode, we use fixed attenuators for the BPM signal to reduce the level. However, the contrast of the bunch current in several filling modes are nearly or more than ten and the feedback cannot handle both bunches simultaneously because of the saturation of the feedback system by large signal level of high current singlet bunches. To overcome this problem, we made a simple bunch current sensitive automatic attenuator (Fig. 3). The bunch current is detected by the sum signal of a BPM and the signal is converted to low frequency signal of 300MHz bandwidth, which is enough to detect the signal of well separated singlet bunches. This signal is compared with the threshold voltage in a discriminator and, if the signal voltage exceeds the threshold, the discriminator outputs a pulse. An ADC-FPGA-DAC board samples this pulse and the data is delayed nearly one turn in FPGA and send to DAC to output the gate pulse to a mixer [3] which attenuates the beam position signal by 1/3 or 1/6. The threshold bunch current is set to be ~1mA in normal operation. In this system, we used the bunch current data one turn earlier than the beam position signal because the gate signal is produced with several RF components and slower than the beam position signal and we avoid the large delay of the analog signal for better SN ratio.

For the elements between the BPM and the mixer, we intend to replace them to the same hardware of the feedback processor with a dedicated FPGA program

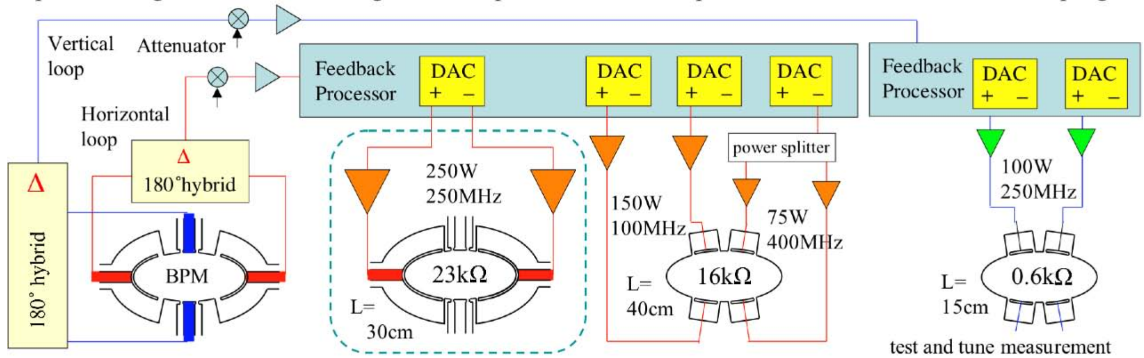

Figure 2: SPring-8 transverse feedback system. The leftmost ellipse is the BPM and right three ellipses are kickers. The numbers inside of the kicker are the shunt impedance. Currently the kicker (16kΩ with four electrodes, L=40cm) is used for horizontal and the kicker (0.6kΩ with two electrodes, L=15cm) is used for vertical. A new horizontal kicker (23kΩ with two electrodes, L=30cm, inside of dashed line) with high power amplifiers (250W) will be installed in 2008 and total feedback strength will be 2.3 times more than current value.

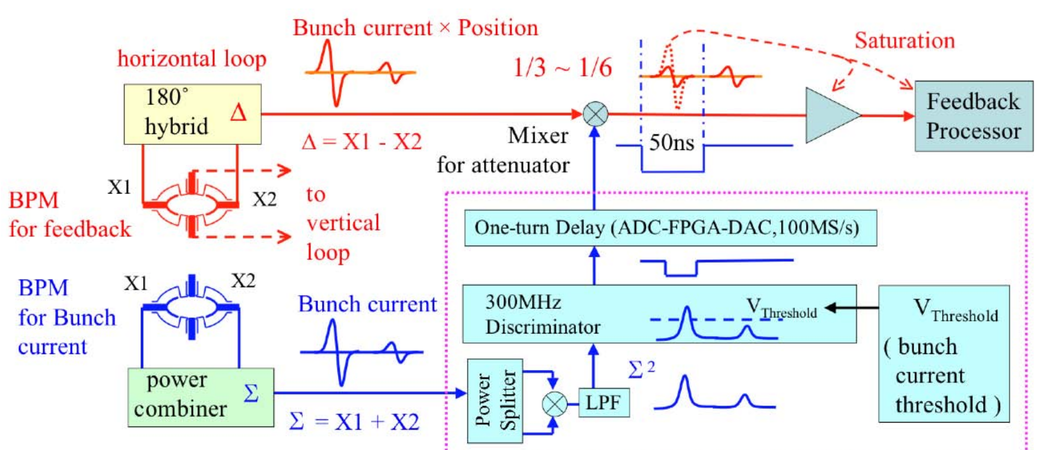

Figure 3: Bunch current sensitive automatic attenuator. The bunch current is sensed by a BPM signal (∑) and the discriminator produces the pulse for the bunch of which current exceeds the threshold level. A mixer is used as an attenuator and the timing between the position signal (Δ) and the pulse at the mixer is adjusted with the one-turn delay.

BETATRON MOTION DRIVEN BY INJECTION BUMP FORMATION

At the injection, a bump orbit is formed by four bump magnets. However, the waveforms of the kick of the four magnets are slightly different each other [4] and this difference produce the horizontal kick and excite the horizontal betatron motion (Fig. 4). The example of the measurement of such betatron motion produced by this kick is shown in Fig. 5 and the distribution of the amplitude of the betatron motion is shown in Fig 6.

The product of the dynamic range of the feedback x_0, (maximum amplitude without saturation) and the feedback damping rate $1/\tau_{FB}$ is proportional to the maximum kick angle θ_{max} which is proportional to square root of the kicker shunt impedance R_{sh} and of the amplifier power P as $x_0/\tau_{FB} \propto \theta_{\max} \propto \sqrt{R_{sh}P_{amp}}$. Then, for large $1/\tau_{FB}$, we have small x_0 or we need a high shunt impedance kicker and/or a high power amplifier to obtain large x_0. The damping rate for singlet bunches needs to be high to suppress the single-bunch instabilities and the attenuation of the automatic attenuator is adjusted to increase the damping rate of singlet bunches compared to low current bunches of which bunch current are below the discriminator threshold. Then the dynamic range for the singlet bunches is rather smaller than that for low current bunches. If the amplitude of the excited betatron motion is so large and the signal level from the BPM exceeds the dynamic rang of the feedback for the singlet bunches, then the signal saturates the feedback system and lead to the loss of the singlet bunch current.

With the current horizontal kicker (16kΩ, L=40cm), we can only fill the region of the bunch address from 840 to 1100 (Fig.1 and Fig. 6). The betatron motion at injection is large outside of this region and we loose the current of singlet bunches. To increase the dynamic range to extend the region of the filling, we are developing a horizontal stripline kicker (23kΩ, L=30cm) with high shunt impedance and, with high power amplifier of 250W, we will have 2.3 times larger dynamic range than the current value. Also the study of the correction of betatron motion with faster pulse magnets are also in progress.

The excitation of the betatron motion at injection by sextupole magnets in the bump orbit is minimized by the tuning of the beam optics [5].

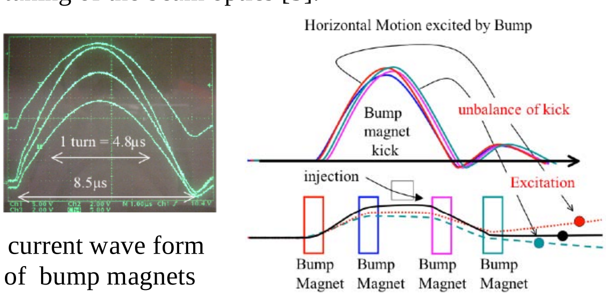

Figure 4: (left) Pulse shapes of the excitation current of four bump magnets. The shape is half-sin with full width of 8.5μs. The revolution period of the ring is 4.8μs which is shown with the arrow “1 turn = 4.8”. (right) Mechanism of excitation of horizontal betatron motion by formation of injection bump orbit. Bump orbit is not closed by small difference of pulse shapes of kicks. In this figure, the bump orbit is simplified and is different from actual bump orbit.

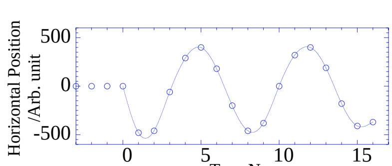

Figure 5: The horizontal betatron motion of a bunch excited by the formation of the bump orbit. The bunch is at address 0 and injection bucket address is 486.

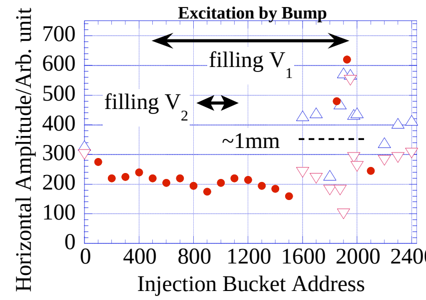

Figure 6: The amplitude of the horizontal betatron motion of a bunch excited by the formation of the injection bump orbit for the injection bucket addresses (horizontal axis). The horizontal scale is the bucket address for injection and the test bunch is stored at address 0. Large shot-by-shot variations of amplitude were observed in address from 1600 to 2000 and the upright triangles and the upside-down triangles show the maximum and minimum values of the observed amplitude, respectively.

VACUUM COMPONENTS AND INSTRUMENTATIONS

Temperature rise of RF shielding fingers of vacuum gate valves was observed with high current bunches and limits the variety of the filling pattern. The reason of this heating is not known and the study on it is in progress. The front-end electronics for the beam position monitor [6] suffers saturation by high peak voltage of high current singlet bunches and shows the filling dependence of the measured beam position. This will be cured by in summer, 2008 with adding some components.

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