TEST OF HYBRID FILL MODE AT THE PHOTON FACTORY STORAGE RING

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Abstract

A hybrid fill mode has been tested at the Photon Factory storage ring (PF-ring). Since a bunch-by-bunch feedback system was not available because of the high contrast of currents between the bunch train and the single bunch, we suppressed multibunch instabilities in the transverse and longitudinal planes by using the octupole magnets and RF phase modulation, respectively. We also suppressed single-bunch instabilities by controlling ring chromaticity. As a result, we successfully stored a 450 mA current with the hybrid fill mode: 1/2 filling (400 mA: 2.56 mA/bunch × 156) + 1 single bunch opposite to the bunch train (50 mA/bunch). Although there were three technical problems to be solved for the user operation, we have already obtained possible solutions to them.

INTRODUCTION

The time structure of synchrotron radiation (SR) emitted from an electron storage ring depends on the pattern of filled RF buckets. The fill pattern can be roughly classified into two types: multibunch and single-bunch patterns. Although the PF-ring is usually operated in the multibunch mode with 280 bunches, it is sometimes operated in the single-bunch mode at a user's request for pulsed SR. A hybrid fill mode is a compromise between these two operation modes. This mode consists of a train of low-current bunches and a single high-current bunch. This mode has been popularly adopted as one of the user operation modes in large storage rings such as ESRF and SPring-8 [1, 2]. However, it has not yet been tested in the PF-ring with a relatively higher revolution frequency than ESRF and SPring-8. At the request of single-bunch users, we carried out a feasibility study on the hybrid fill mode. In this paper, we report the details of the test experiment

Table 1: Main parameters of PF-ring.

Beam energy	2.5	GeV
Circumference	187	m
RF frequency f_{RF}	500.1	MHz
Harmonic number	312	
Revolution frequency f_{rev}	1.603	MHz
Betatron tune ν_x / ν_y	9.6 / 5.28	
Damping time τ_x / τ_y	7.8 / 7.8	ms
Stored current (single/multi)	50 / 450	mA
Typical injection rate	0.063	mA/pulse

as well as some future subjects to be solved for the user operation. The main parameters of the PF-ring are listed on Table 1.

EXPERIMENT OF HYBRID MODE

The test experiment of hybrid fill mode was performed in two steps. First, we injected the beam into a series of buckets corresponding to one half of the ring (156 buckets) until the stored current reached 400 mA. Then, we injected the beam into a bucket located at the middle of empty buckets in the other half for a stored current of up to 450 mA. The achieved hybrid fill pattern is shown in Fig. 1. A bunch-by-bunch feedback system, which includes the iGp signal processor developed by the collaboration of KEK, SLAC, and INFN-LNF [3, 4], is not available during this procedure because of the high contrast of currents between the bunch train and the single bunch. In this experiment, we suppressed multibunch instabilities in the transverse and longitudinal planes by using the octupole magnets and RF phase modulation [5], respectively. We also suppressed single-bunch instabilities by controlling ring chromaticity. All procedures were performed carefully while monitoring the beam profile and vacuum pressure at various points around the ring in order to avoid critical heat generation caused by the beam wakefields.
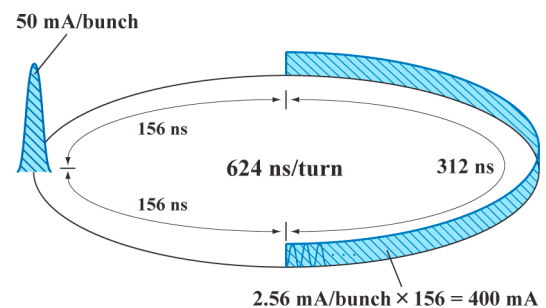

Figure 1: Schematic representation of the tested fill pattern. Total current is 450 mA.

The fill patterns and beam spectra were measured by a wall-current monitor (WCM) and a button-type pickup electrode, respectively. Figures 2 is the fill patterns and beam spectra observed before (a) and after (b) the injection of the single bunch. We observe that the beam spectrum changes to a flat distribution peculiar to the single-bunch mode upon injection of the high-current single bunch into the opposite side of the bunch train. Figure 3 shows the ratio of vacuum pressures in the hybrid fill mode to that in the typical multibunch mode (280 bunches, 450 mA) plotted against the address of the ring components. For comparison, the result of the typical
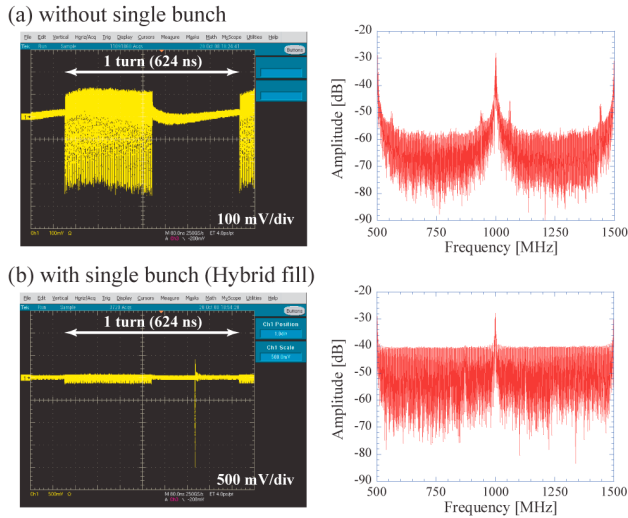
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(a) without single bunch

(b) with single bunch (Hybrid fill)

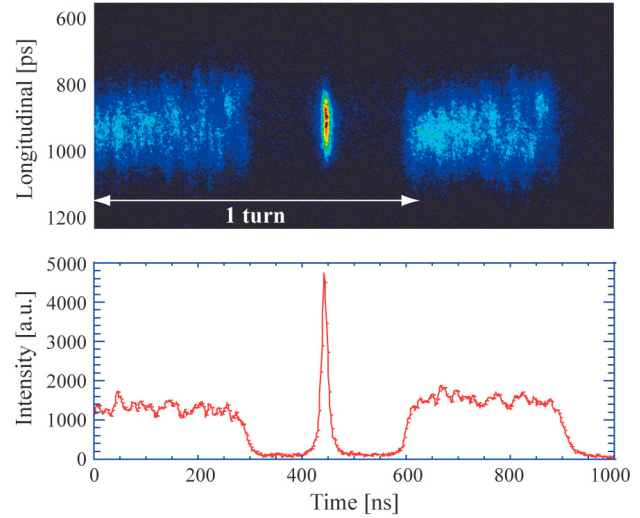Figure 2: Fill patterns and beam spectra observed before (a) and after (b) the injection of the single bunch.
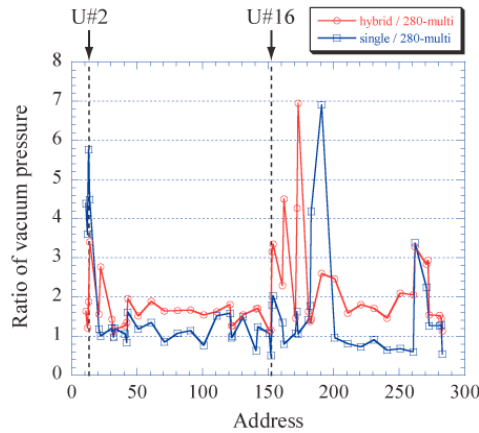

Figure 3: Comparison between the distributions of vacuum degradation along the ring in the hybrid fill and typical single-bunch mode.

single-bunch mode (50 mA) has been indicated with it. The positions where the vacuum was degraded due to local heat generations are not fully consistent, while the distribution of vacuum pressures along the ring and the rate of vacuum degradation are similar for the hybrid fill and the typical single-bunch mode. Figure 4 shows the fill pattern in the hybrid fill mode obtained by using a streak camera (Hamamatsu C5680 with a synchroscan unit M5675 and a dual timebase unit M5679). The root-mean-square bunch length of the single-bunch component is measured to be around 60 ps. This result is roughly in agreement with the previous experimental result [6].

REQUIREMENTS FOR USER OPERATION

To adopt the hybrid fill mode in user operations at the PF-ring, we have three technical problems: (1) a selective application of a bunch-by-bunch feedback to the multibunch component; (2) a cleanup of the front and rear of the single-bunch component; and (3) a stable

Figure 4: Fill pattern in the hybrid fill mode obtained by using a streak camera.

maintenance of the hybrid fill pattern by a top-up injection.

Selective Bunch-by-bunch Feedback

In the multibunch component, several coupled-bunch mode instabilities are observed in the transverse and longitudinal planes when a bunch current increases. As for the transverse instabilities, they can also be suppressed by using the Landau damping effect caused by the octupole magnetic fields, as we have performed in the test experiment. However, the introduction of the nonlinear magnetic fields decreases a dynamic aperture of the ring, and prevents an efficient beam injection. It is especially important for a top-up operation to minimize the amount of the injection beam loss. Although the bunch-by-bunch feedback system can resolve this issue, it is difficult to process the high-contrast signals from the hybrid fill simultaneously without the saturation of analog-to-digital converters. In order to enable us to mask the intense signal from the single-bunch component, we have updated a firmware of the iGp signal processor. This update makes it possible to suppress the transverse instabilities in the multibunch component with a dynamic aperture maintained almost constant.

Single-bunch Purification

At the PF-ring, unwanted electrons gradually accumulate in the buckets not only in the rear but also in front of the single bunch due to the quality of injection beams. In order to keep the bunch impurity better than 10^{-6}, which is the user's request, we must continue to clean up both the rear and front of the single bunch. For this purpose, we will introduce the same technique that is used in the single-bunch operation at the PF-ring: namely, we use an RF-knockout (RF-KO) signal amplified with the broadband power amplifier after mixing with the gating pulse synchronized with the revolution of the single bunch [7]. Since the hybrid fill has the low-current bunches in addition to the single bunch, it is necessary to

change the shape of the gating pulse so as not to kick them.

Maintenance of Hybrid Fill

Since April 2009, the PF-ring has been operated with a top-up injection. To maintain the hybrid fill pattern stably with the top-up injection, we need to inject the beam into the single-bunch component more frequently than the multibunch component because the lifetime of the single bunch is shorter than that of the multibunch due to the Touschek effect. However, since our existing injection system selects the bucket without relation to the actual bunch current, we cannot realize such a flexible injection without any upgrades. In order to apply the top-up injection to arbitrary fill patterns, we have developed a new injection system using a general purpose oscilloscope. A block diagram of the new injection system is shown in Fig. 5. The heart of the system is an oscilloscope labelled "Fill scope" (Tektronix DPO7104). In this oscilloscope, Microsoft Visual C++ is installed as an integrated development environment [8], and an analytical program that can select out the bucket with the most different bunch current from the ideal case is running. In addition, this scope functions as an EPICS-IOC [9], and transfers the bucket number obtained from the analysis to the Linac immediately. This feedback process on the fill pattern allows controlled-injection so that the difference between the actual and ideal bunch currents becomes small. The maximum repetition frequency of the fill pattern feedback is around 25 Hz, which is faster than that of the beam injection. Although the program is sufficiently stable over long time periods, we prepared a script to monitor whether the program is alive or dead for the safety. Figures 6 is a comparison of the fill patterns without (a) and with (b) the fill pattern feedback. The fluctuation in the bunch current over the bunch train has decreased from about 10% to less than 1%. The new injection system enables us not only to smooth the fill but also to generate and maintain the arbitrary patterns such as the hybrid fill automatically. Figure 7 shows some examples of fill patterns generated with the new injection system.

Figure 7: Examples of various fill patterns generated with the new injection system.

SUMMARY

At the PF-ring, we have succeeded in storing a 450-mA current with the hybrid fill mode: 1/2 filling (400 mA: 2.56 mA/bunch $\times$ 156) + 1 single bunch opposite to the bunch train (50 mA/bunch). Although there were three technical problems to be solved for the user operation, we have already obtained possible solutions to them. In near future, we plan to perform a joint study with the SR users, and confirm the usefulness of the hybrid mode.

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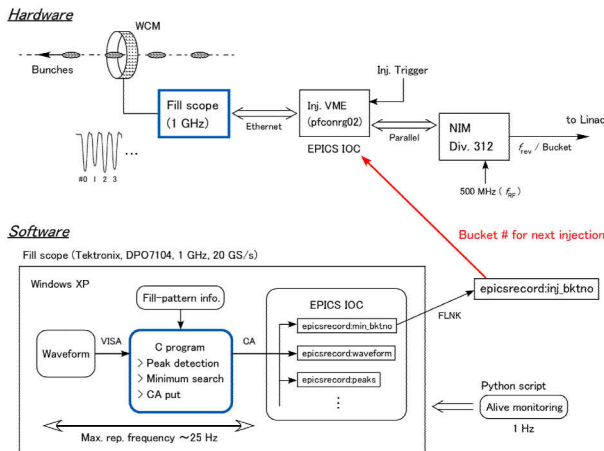[9] http://www.aps.anl.gov/epics/, and links therein.
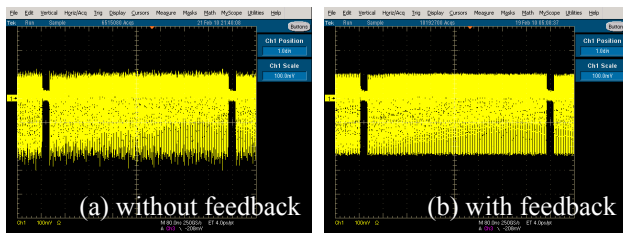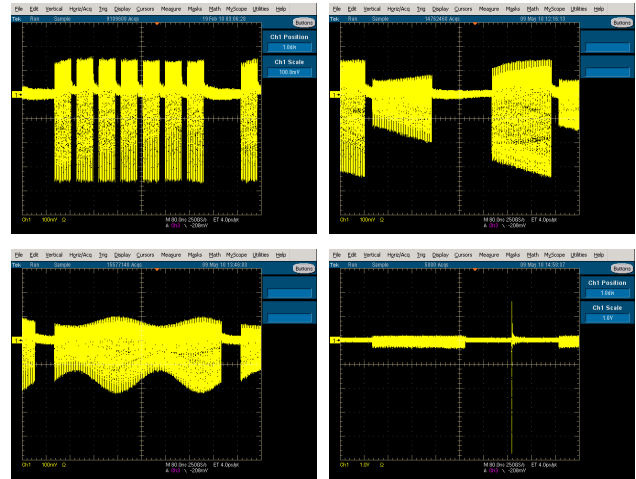
Figure 5: Block diagram of the new injection system.

Figure 6: Fill patterns in the multibunch mode (300 bunches, 450 mA) obtained without (a) and with (b) the fill pattern feedback.