

# A NEW PURIFICATION METHOD FOR SINGLE BUNCH OPERATION AT THE PHOTON FACTORY STORAGE RING

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## Abstract

Recently, the requests for single bunch operation of the Photon Factory 2.5GeV electron storage ring (PF-ring) have gradually increased and the requirements for the impurity, that is the rate of electrons in undesirable buckets to those in the main bunch, becomes severe. A purification method making use of the current dependence of the betatron tune has been applied up to present. However, after the reconstruction of the PF-ring toward low emittance optics[1], it requires a mastery skill to keep an impurity better than  $10^{-5}$  and moreover the transversal motion of the main bunch excited by the method could affect experiments of SR users. In order to overcome the situation and improve the purity, a new single-bunch purification method, that is essentially a "selective RF knock-out (RFKO)", has been developed. The system worked stably during the users time and the typical impurity of  $0.6 \times 10^{-7}$  was achieved. Schematic description of the selective RFKO is shown in Fig.1, and related parameters of the PF-ring are shown in Table.1.

## 1 INTRODUCTION

Single bunch purity is very important for time resolved experiments such as Mössbauer spectroscopy, and the required impurity must be better than  $1 \times 10^{-6} - 10^{-7}$ . The typical impurity after the short bunch injection stays in the order of  $10^{-3} - 10^{-4}$ ; consequently we must purify the spurious bunches in some method.

A transverse coupling impedance causes a shift in coherent betatron tune with the increase of the bunch current. Because the measured tune shift at the PF-ring was about  $-2 \times 10^{-4}/\text{mA}$ , an RF knock-out (RFKO) tuned to the betatron frequency of the weak bunches can destroy the undesirable bunches with small currents but the main bunch with a larger current survives[2,3]. The frequency of RFKO and the aperture of a vertical scraper were adjusted preceded the users time, however, in some cases, it was difficult to keep the impurity better than  $10^{-5}$  and we sometimes must re-configure such parameters. The difficulty is apparent after the reconstruction of the PF-ring because the non-linearity of the restoring forces becomes strong. Initial bunch current for SR users is about 60-70mA and the corresponding vertical tune shift is about 10-15kHz while the spread in the coherent tune is

larger than the tune shift. Namely, the RFKO signal affects not only the spurious bunches but also the main bunch itself.

We developed a new purification method which is very simple and straightforward. An RFKO signal is modulated by a rectangular pulse train with a repetition of the revolution frequency of the beam. Since the pulse train has gaps with a width of the bunch spacing (about 2ns), only a selected bunch passing through the RFKO kicker on the gap timing can survive. In order to avoid effects of non-linearity of the restoring forces acting on the beam, the excitation frequency is frequency-modulated.

Table 1: Main parameters of PF ring

Parameters		unit
Energy	2.5	GeV
RF frequency	500.1	MHz
momentum compaction	0.061	
harmonic number	312	
emittance	36	nm rad
synchrotron frequency	23	kHz
betatron tune ( $\nu_x/\nu_y$ )	9.62/4.29	
RF voltage	1.7	MV
Radiation loss	400	keV

## 2 SYSTEM DESCRIPTION

Figure 2 shows a block diagram of the system. A signal generator (MARCONI Inst., 2023) generates sinusoidal wave tuned to the vertical betatron resonant frequency, namely,  $14 \times f_{\text{rev}} + f_{\beta_y} \cong 22\text{MHz}$ . Frequency modulation (maximum frequency deviation~100kHz, modulation

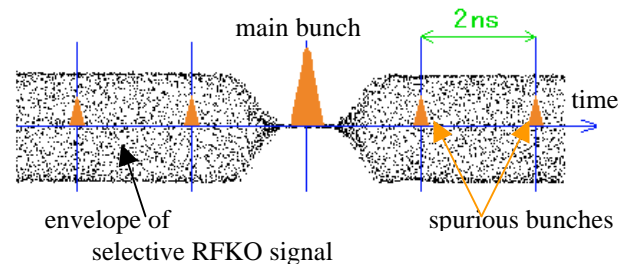
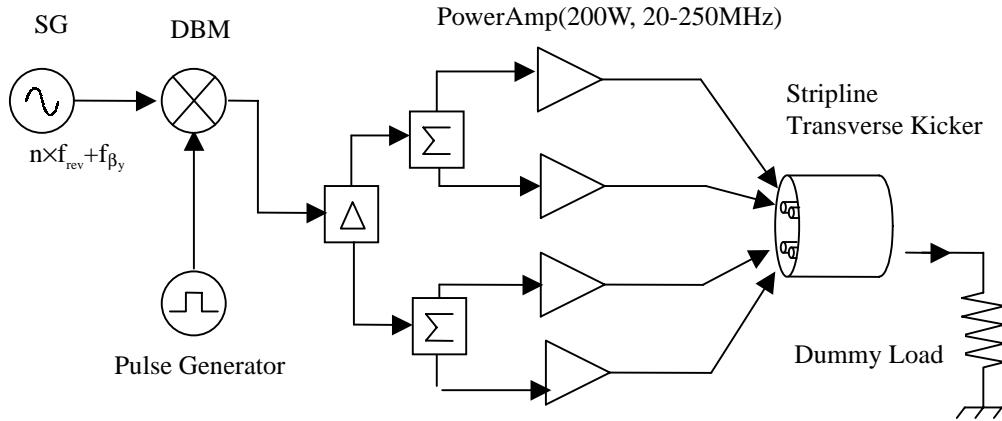


Figure 1: Schematic description of selective RFKO.

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**Figure 2: Block diagram of the system**

frequency  $\sim 4\text{Hz}$ ) is applied in order to avoid effects due to non-linearity of the restoring forces acting on the beam. A double balanced mixer (DBM) is used to turn the KO signal off during the period ( $\sim 4\text{ns}$ ) of passage of the main bunch. We tested several DBMs of several models in order to select a DBM which has excellent isolation between RF and LO port. The pulse generator HP8131A has a rise/fall time faster than the bunch spacing of  $2\text{ns}$ , and an amplitude high enough to switch the DBM. The rise time of the pulse generator is faster than  $200\text{ps}$  and the minimum pulse width is about  $500\text{ps}$  with the amplitude of  $\pm 5\text{V}$ . A timing signal synchronized to the bunch revolution generated by dividing the RF acceleration signal by 312 (harmonic number) is used as the trigger of the pulse generator.

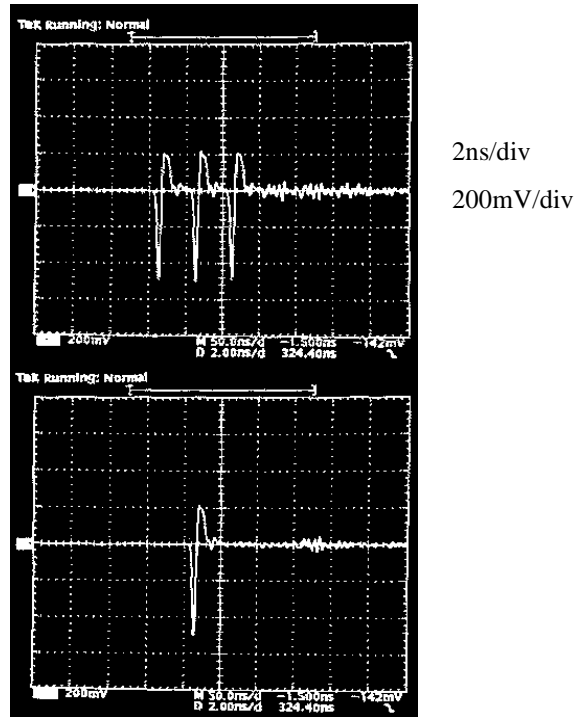
The output of the DBM is splitted by a  $180^\circ$  power splitter (mimi-curcuits), and splitted again with  $0^\circ$  power splitters in order to produce the signal which kick the beam only in vertical direction. The wide-band signal processing is required to maintain the fast rise time of the signal.

Power amplifiers (R&K A250-200-R) were previously used for the bunch-by-bunch feedback system during the high beam current study at the TRISTAN Accumulation Ring[4]. Its bandwidth and maximum power of  $20\text{-}250\text{MHz}$  and  $200\text{W}$ , respectively, are sufficient for our single bunch purification system. Four power amplifiers are connected to stripline electrodes of the transverse kicker. The output signals of the kicker electrodes are fed to the outside of the storage ring and used to adjust the timing of the pulse generator by observing the beam-induced signal and the RFKO signal simultaneously.

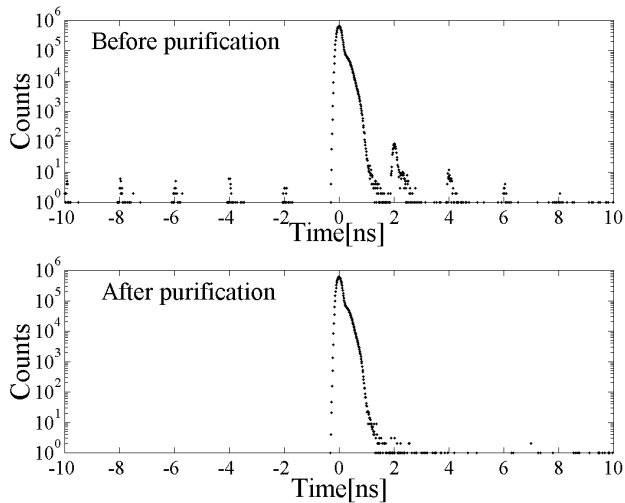
### 3 RESULTS

Figure 3 shows signals from button-type electrode when successive three bunches are injected (top) and removed except for the central bunch with the selective RFKO system (bottom). The pulse width was set to about  $4\text{ns}$  and the opening of the vertical scraper was  $7\text{mm}$  away from the centre of the beam.

A measurement of the bunch population is performed with a photon counting method using a PIN photodiode which has high sensitivity in X-ray region [5-7]. Figure 4 shows an example of photon counting measurement. The abscissa shows the time and the ordinate shows the counts of channels of MCA. Several spurious bunches are recognizable in every  $2\text{ns}$  before the purification(top). It is clearly seen that the spurious bunches are removed with the purification procedure. The measured impurity of the 1st bunch ( $2\text{ns}$  behind the main bunch) was  $8.3 \times 10^{-5}$  and  $5.6 \times 10^{-7}$  before and after the purification, respectively. It took about 300 seconds to measure the impurity.



**Figure 3: Successive three bunches are injected (top) and knocked-out except for the central bunch (bottom). (2ns/div, 200mV/div)**



**Figure 4: Bunch population measured with photon counting method before (top) and after (bottom) purification.**

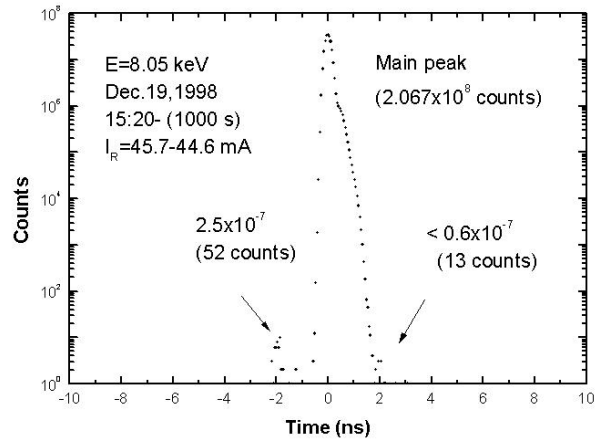
The rise time of the RFKO signal is fast enough, however, there are some ringing lasted for several nano seconds which can affect the main bunch. We decided the procedure of single bunch purification as shown below:

- Inject short bunches (about 70mA)
- Accelerates up to 3GeV to improve lifetime
- Increase H-V coupling to improve lifetime
- Remove leading bunches proceed the main bunch (for about 5sec)
- Remove trailing bunches after the main bunch (all time )

During the users time, we applied the purification system all the time because the impurity grows gradually without the purification. Some electrons thrown out from the main bunch are captured into the trailing buckets because there are openings of the separatrix due to the synchrotron radiation[8]. For example, an impurity of  $4.6 \times 10^{-5}$  was measured one hour after the stop of purification. Because there are no apertures toward the foregoing buckets, the purification of them are performed only once after injection. The vertical scraper is not used in the routine operation because we could accomplish the enough impurity without it.

A typical result impurity measurement during the users time is shown in Fig.5. In this case, the impurity is better then  $10^{-7}$  behind the main bunch. There is a small bunch before the main bunch, however, can be overcome by optimising the purification procedure.

The pulse generator and signal generator are remotely controlled by GPIB via LAN-HPIB gateway. HP-VEE is used for an operator interface for its easy and rapid development environment. It was not necessary to



**Figure 5: Typical impurity measurement during users time (courtesy of S. Kishimoto).**

tune the system and to measure the impurity for every injection.

#### 4 SUMMARY

We installed a new single bunch purification system at Photon Factory. An impurity of  $2 \times 10^{-6} \sim 0.6 \times 10^{-7}$  was achieved during users time. The system works reliably and it becomes to an indispensable tool for single bunch operation. Several parameters (ex. FM modulation index, carrier frequency, clearing procedure) are not optimised yet. The impurity might be improved with the optimisation. We are installing the same system on the PF-AR (PF Advanced Ring).

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