

## A POSSIBILITY OF CONSTANT ENERGY EXTRACTION AT THE KEK ATF2\*

A. Kalinin

Accelerator Science and Technology Centre  
Daresbury Laboratory CCLRC, Warrington WA4 4AD, UK

### Abstract

Beam energy oscillations of a few  $10^{-4}$  take place at the KEK ATF. The amplitude and phase at the extraction turn randomly fluctuates extraction by extraction. The energy jitter causes a position/angle jitter in the Diagnostic section of the Extraction Line. To have jitter reduced, an energy stabilisation approach is proposed that is constant energy extraction done at the turn where the oscillation passes zero. Improvement by factor of 10 can be obtained even when the extraction is done with uncertainty up to several turns.

For a three-bunch ATF mode, oscillation measurement results are given. An extraction set-up based on a turn-by-turn BPM and a digital processor is proposed. A set of signal processing algorithms is discussed.

### INTRODUCTION

The ATF2 [1] is to be capable to achieve 40nm beam size in a final focus facility and nanometer extracted beam stability that is necessary for development of beam diagnostics and tuning methods. To achieve this, the beam quality attained at the present ATF is to be improved. One of the factors causing position/angle jitter of bunches in the Extraction Line is the energy jitter that manifests itself through spurious dispersion. The energy jitter reaches a few  $10^{-4}$  and should be reduced several times.

Coherent energy oscillation occurring in the ATF Damping Ring (DR) was first observed in multi-bunch trains. [2] Single bunch oscillation investigation and an attempt of beam-based RF system feedback stabilisation are described in [3]. Recently, oscillation in multi-bunch trains was investigated again. [4]

In one of the working modes of the ATF2, one to three bunches spaced about 150ns are extracted from the DR at single turn. Investigating energy oscillations of three bunches, we discovered that bunches oscillate together, as a solid structure. So, for this mode a fine method of energy stabilisation can be suggested based on that circumstance that floating number of the extraction turn makes no difference to ATF2 experiments. Continuously monitoring the energy oscillation, it is possible to pick up the turn where the oscillation passes the energy equilibrium value, and on the next turn execute the extraction.

We describe a set-up based on a BPM measuring the energy oscillation as a horizontal position oscillation, and a signal processor that finds the turn where the oscillation

passes zero, and then generates an extraction permission signal. We consider a set of fast signal processing algorithms based on Fourier Interpolation.

### ENERGY OSCILLATION

Oscillations of three bunches were measured in an April 2005 ATF run. An energy oscillation manifests itself as a horizontal oscillation in the non-zero dispersion DR arcs. For dispersion  $D = 0.1\text{m}$  and energy deviation  $2 \cdot 10^{-4}$  the oscillation amplitude is  $20\mu\text{m}$ .

To measure horizontal oscillation, we used a BPM connected to a pair of the upper button electrodes of the arc 34 pickup. A sum-difference Jitter BPM processor [5] was used. In one shot, the sum and difference multi-turn arrays were recorded by the oscilloscope. The sampling interval was 0.2ns, the memory length was about 300 turns. The arrays were transferred to a computer where bunch selection and intensity normalisation was done prior to oscillation analysis. The BPM was calibrated against the orbit DR BPMs.

A typical picture of oscillation is shown in Fig. 1. Three bunches are shown in different colours. Reverse turn sequence is used, the turn number 1 is the last turn before extraction.

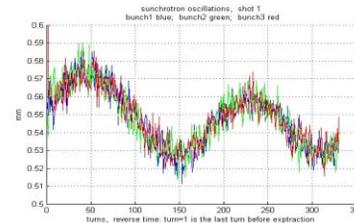


Figure 1. Synchrotron oscillations of three bunches.

Occasionally, the extraction kicker was fired earlier than necessary, giving to the trailing third bunch (shown in red) a weak premature kick. The corresponding offset measured by the BPM is seen in Fig. 1.

The oscillation envelope is unstable. The oscillation amplitude and the phase on the last turn randomly fluctuate extraction by extraction.

To see relative phases of the bunches, oscillation difference spectra were calculated shown in Fig. 2a. The peak of height about  $28\mu\text{m}$  is the spectrum of the first bunch oscillation. The synchrotron tune is 0.005. It is seen that the bunches oscillate together, the difference being buried in the noise floor  $\sim 1\mu\text{m}$ , appears to be significantly less than that. In this particular shot, the phase difference is  $\delta\phi < 2^\circ$ .

\* The work is funded under the PPARC ILC UK FONT Work Package

In Fig 2b the spectrum of each bunch is shown in the vicinity of horizontal betatron tune. The noise-like betatron oscillations are a few  $\mu\text{m}$ , the tune falls on 0.22. All spectra above were calculated using 256 samples (turns), the Hamming window and refinement  $2^5$  times.

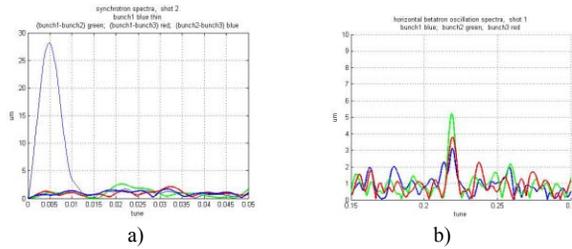


Figure 2. Synchrotron (a) and betatron (b) spectra.

## EXTRACTION SET-UP

A block diagram of the extraction kicker thyatron trigger circuit is given in Fig. 3 (the BPM is not shown). The processor is shown below the dashed line. With processor OFF (or disconnected), the CM is transparent, and the thyatron is triggered in routine way by the start signal ST delayed by the number of turns  $N_R$  in the TD2R and by some number of buckets in the TD2B. [6]

The processor is triggered by the same ST. The processor either leaves the CM transparent, if no oscillation has been detected, or closes the CM to cut the TD2R, if oscillation was detected. In the last case the processor keeping monitoring the oscillation, picks up the turn where the oscillation has come to zero or got the opposite sign, and generates EXTRACT which through an additional TD2E, the CM and TD2B triggers the thyatron. The extraction occurs at the later turn  $N_E \approx N_R + (N_{\text{osc}}/4 \text{ to } 5N_{\text{osc}}/4)$  (see the next Section) where  $N_{\text{osc}}$  is the oscillation period.

## SIGNAL PROCESSING

One bunch is monitored. It can be single bunch or one bunch from two or three spaced by  $1/3$  of circumference.

On each turn, starting with the injection turn, the bunch BPM signal is sampled by the ADC and stacked in the Memory of the length  $M$ . The ADC is triggered by pulses manufactured from the beam signal in the BPM. To cut pulses from other bunches, the gate G is used clocked by revolution frequency. The block diagram Fig. 3 is given for the case when a BPM is used which combines two button electrode signals in one channel, separating them in time. [7]

So, on each next turn, an array is available in the Memory, with its first element recorded last.

The processing is done in the DSP. It starts with the ST and has three stages. First, the DSP reads the array from the Memory, calculates the oscillation amplitude  $A$  and compares it to the established threshold  $a$ . If  $A < a$ , the DSP keeps the CM transparent for the TD2R signal and waits for the next ST. If  $A \geq a$ , the DSP cuts the TD2R.

Next, with oscillation detected, the DSP calculates the number  $\tilde{N}$  of the turn where the oscillation is expected to pass zero.

Finally, the DSP starting with the turn  $(\tilde{N}-n)+j$ , where  $n$  is a few turns and  $j=1, 2, \dots, 2n$ , reads on each turn the array and calculates the sine phase  $\psi_j$ . At the turn where  $\psi_j$  comes to zero or gets opposite sign, the DSP sends EXTRACT and waits for the next ST. To avoid blocking of extraction in the case such turn is not found, the DSP anyway sends EXTRACT after the turn  $(\tilde{N}-n)+2n$ .

Take the ST turn number  $N_{\text{ST}}=0$  and  $N_R = 6N_{\text{osc}}/4$  where  $N_{\text{osc}} \approx 190$  turns, 1 turn  $\approx 0.46\mu\text{s}$ . Then the first stage is to be finished within  $N_R$  turns  $\approx 131\mu\text{s}$ . The number  $\tilde{N}$  falls in the interval  $(N_R + N_{\text{osc}}/4) \leq \tilde{N} \leq (N_R + 5N_{\text{osc}}/4)$ , or  $7N_{\text{osc}}/4 \leq \tilde{N} \leq 11N_{\text{osc}}/4$ . So, the second stage is to be finished within  $(N_{\text{osc}}/4 - n)$  turns  $\approx 20\mu\text{s}$  (for  $n=4$  turns). The calculation of the phase  $\psi_j$  is to be done within  $0.46\mu\text{s}$ .

The DSP works using its built-in clock. The turn-by-turn time is established by a counter clocked by revolution frequency. The counter is triggered by ST.

## ALGORITHMS

The algorithm set below is designed to be fast. However, more investigation is necessary to see whether calculating resources of fastest 16bit DSPs (8 parallel channels, clock 1GHz, up to 4G of elementary operation per second, cache memory) are sufficient for this algorithms applied to arrays of the length, say,  $M=256$ .

For the oscillation tune  $\nu_s$  take  $Q$  as an integer closest to  $1/\nu_s$ . Assume  $Q$  is known.

On the first stage, after reading the signal array  $\langle X_i \rangle$ ,  $i=0, 1, \dots, M-1$ , the DSP first calculates the reverse average signal intensity  $\alpha$  necessary for normalisation. Then the array  $\langle x_i \rangle$  is calculated:

$$\langle x_i \rangle = (\langle X_{i1} \rangle - \langle X_{i2} \rangle) - \frac{1}{M} \cdot \sum_{i=0}^{M-1} (\langle X_{i1} \rangle - \langle X_{i2} \rangle) \quad (1)$$

where the elements  $X_{i1}$  and  $X_{i2}$  are the signals from the button electrodes 1 and 2 respectively. The sum in (1) is the average dc offset.

Next, to enhance the accuracy of Fourier transformation, a suitable window  $\langle W_i \rangle$  is applied to (1). A dc offset generated by the window is subtracted. Finally,

$$\langle w_i \rangle = \langle x_i \rangle \cdot \langle W_i \rangle - \frac{1}{M} \cdot \sum_{i=1}^{M-1} \langle x_i \rangle \cdot \langle W_i \rangle \quad (2)$$

Now using single term of Fourier Interpolation polynomial, the oscillation amplitude and a refined value

