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Feedback of slow extraction in CSRm

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ABSTRACT

The transverse tune of the beam in a synchrotron will fluctuate due to the main quadrupole power supply ripple, which leads the spill ripple through the variation of the separatrices area. To reduce the spill ripple, an additional pair of fast-response quadrupoles (FQ) is adopted to compensate for the tune ripple caused by the main quadrupoles. After using the FQ feedback, the amplitude of the spill ripple with a frequency of less than 800 Hz has been reduced to a tenth of that in the normal mode.

1. Introduction

HIRFL-CSR [1], a heavy ion accelerator system, is the major national facility focusing on nuclear physics, atomic physics, heavy ion applications and interdisciplinary research in China. CSRm is the main synchrotron with an e-cooler in HIRFL-CSR. The process of slow extraction [2] was realised in CSRm in June 2008. To suppress the spill ripple, which is modulated by the main quadrupole power supply ripple, an additional group of fast-response quadrupoles has been adopted in the synchrotron. The spill structure is greatly improved compared to that of the normal mode.

2. The mechanism of slow extraction

The RF knock-out [3] slow extraction method is adopted in CSRm because of the fast beam cut-off time [4,5] and the need to maintain the lattice of the synchrotron as a constant [6]. The work point of the synchrotron is set near the 1/3 resonant line. The phase space is then divided into 2 parts by the resonant sextupoles; one space is the region inside the separatrices, called *stable area*, the other space is the region outside the separatrices, called *unstable area*. A particle is stable until it reaches the unstable area by the emittance blow-up caused by the transverse RF field. The emittance of the stable area is described as follows:

$$E_{stable} = 48\sqrt{3}\pi \frac{q^2}{S^2} \tag{1}$$

where $S = \frac{1}{2}\beta^{3/2}kl$ is the normalised sextupole strength, $q = Q_x - Q_{res}$ is the difference between the particle tune and the resonant tune; the value of q is constant during the extraction process in the ideal situation. In reality, the current of the main quadrupoles fluctuates with the external power supply grids, and the particle tune, which depends on the strength of the main quadrupoles, also fluctuates. This phenomenon means that the value of q will fluctuate with the external power supply grids, which causes the stable area to fluctuate. Because the emittance of the beam nearly increases smoothly, the fluctuation of the stable area causes the spill ripple. If the emittance growth rate is less than the fluctuation speed of the stable area, the spill appears as a discontinuity [7].

Table 1
The experimental conditions.

Beam	C^{6+}, 250 MeV/u
Bare tune	(3.662, 2.62)
Chromaticity	(0.0, −6.2)
f_{rev}	1.145 MHz: revolution frequency
f_k	1.900–1.910 MHz: transverse RF
d_{fk}	10 kHz: bandwidth
A	1.2×10^{-4}: ripple magnitude of the horizontal tune in 50 Hz
δk	0.8 μrad: max. kick angle of RF-KO

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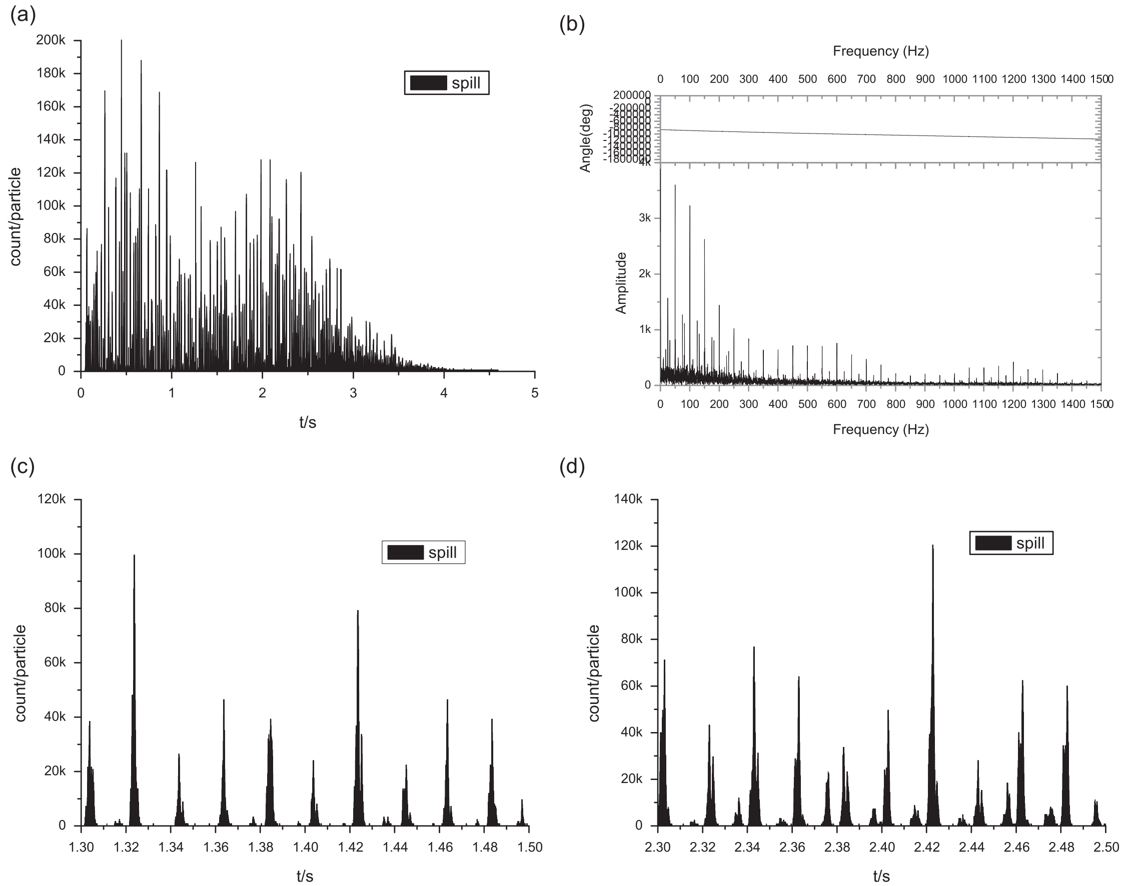

Fig. 1. Spill in the normal mode (sample rate is 10 kHz). (a) Structure of one spill, (b) the FFT of one spill, (c) the spill structure in 1.3 s–1.5 s and (d) the spill structure in 2.3 s–2.5 s.

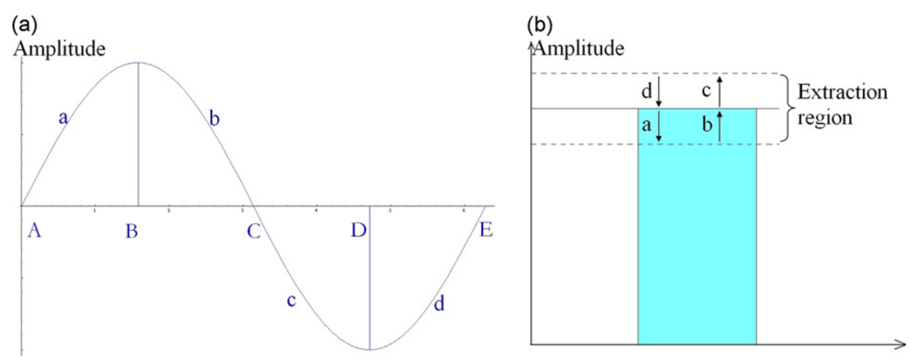

Fig. 2. Schematic diagrams of the power supply ripple and Steinbach diagram. (a) The ripple of the power supply, which is a sinusoidal wave. (b) The Steinbach diagram. The area between r_b and r_a is the extraction region.

3. The normal mode of slow extraction in CSRm

3.1. The situation of the slow extraction

The experimental conditions are summarised in Table 1. In the extraction flattop, the longitudinal RF is turned off, and the work point is set from its original value of 3.65–3.662 to obtain a larger spill ripple [8]. Fig. 1 shows the experiment results of the normal mode in CSRm. The duration of the extraction time is set as 5 s. The following are shown in Fig. 1: (a) the spill is not continuous but has a series of linear peaks, and there is no beam extraction in the later part; (b) the spill ripple at 50 Hz and its harmonic under 200 Hz are obvious; (c) the peaks are separated by blank gaps, so the beam spill duty cycle is nearly one-quarter of the total time and (d) the spill ripple is mainly the 50 Hz component in 1.3–1.5 s but contains higher frequency components in 2.3–2.5 s.

3.2. Analysis

Let us ignore the influence of the FM, the power supply ripple of dipole, and assume that the main quadrupole power supply ripple is a sinusoidal modulation with a frequency equal to 50 Hz, as shown in Fig. 2(a). The fluctuation period can be divided into 4 parts identified by a, b, c and d. Fig. 2(b) is the Steinbach-diagram, the solid line represents the extraction separatrices in an ideal situation, and the dash lines represent the maximum and minimum amplitude position of the extraction separatrices. The area between the two dash lines is the extraction region. Actually,