FEEDBACK OF SLOW EXTRACTION IN CSRM*

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Abstract

The transverse tune of the beam in the synchrotron will fluctuate due to the quadrupole current ripple, which lead the spill ripple through the variation of the separatrices area. In order to reduce the ripple of the spill, a pair of fast response quadrupole (FQ) is adopted to compensate the tune ripple caused by other quadrupoles. After using the FQ feedback, the amplitude of the spill ripple within 800Hz has been reduced to 1/10 times from the normal mode. This method will be used in the HITFiL (Heavy Ion Therapy Facility in Lanzhou).

INTRODUCTION

The CSRm [1] is the main cooler storage ring in the national laboratory of heavy ion accelerators in China. The slow extraction [2] has been realized in CSRm in June 2008. In order to suppress the spill ripple which modulated by the quadrupole power ripple, a group of fast response quadrupole has been adopted in the synchrotron. The spill structure is improved greatly compare with the normal mode.

THE MECHANISM OF SLOW EXTRACTION

The RF-Knock Out [3] slow extraction method is adopted in CSRm. The work point of the synchrotron has be set to near the 1/3 resonant line, then the phase space is divided into 2 parts by resonant sextupoles. The particle is stable until it reaches the unstable area by transverse RF. The emittance of the stable area is described as [4]:

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

Where, $q = Q_x - Q_{res}$ is the difference between the particle tune and the resonant tune. In ideal situation the q keep constant during the extraction process, actually, the current of the quadrupoles will fluctuated with the external power grid. The tune of the particle which lies on the strength of the quadrupoles in the synchrotron will fluctuated, i.e., the q will fluctuated with the external power grid, which cause the stable area fluctuating. Since the emittance of the beam increased smoothly, the stable area fluctuation will bring the spill ripple. If the emittance growth rate is less than the fluctuation of the stable area, the spill will appear discontinuity [4].

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THE NORMAL MODE OF SLOW EXTRACTION IN CSRM

Status of Normal Mode

Figure 1 shows the experiment result of normal mode in CSRm. The duration of the extraction time is set as 5 seconds. As one can seen in the figure,

- the spill ripple is large, and there is no beam extraction in the later part; The spill is not continuous but a series linear peak;
- The spill ripple in 50Hz and its harmonic under 250Hz is visible;

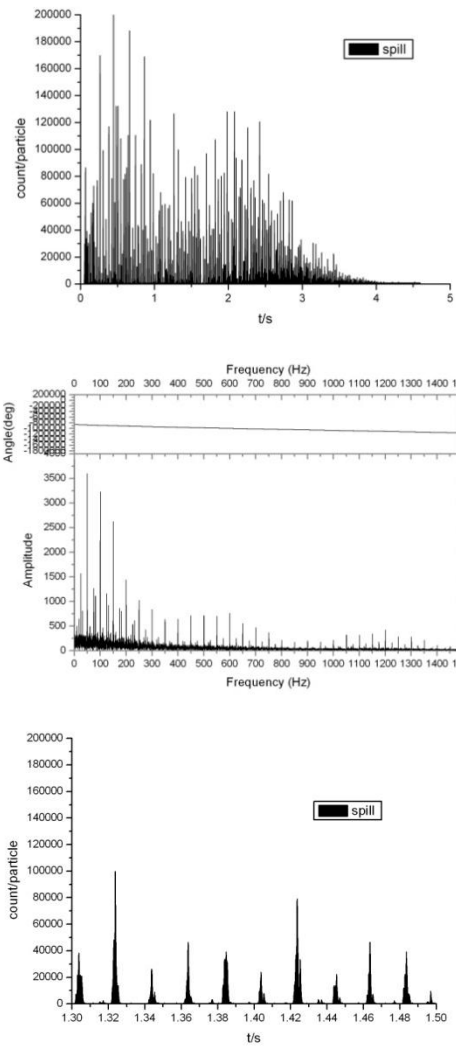

Figure 1: Spill in normal mode (sample rate is 10 kHz). (a) Structure of one spill, (b) The FFT of one spill, (c) Detailed spill structure in 1.3s-1.5s.

Analysis

The emittance of the particle growth with the transverse RF voltage until it reaches E_{stable}, but for the actual cases, the stable area changes its size with the quadrupole magnet power ripple, so maybe the particles reach the unstable area with the emittance larger than E_{stable}, and the stable area will be reduced in the rest power ripple cycle, then the spill ripple generated. Since the particle density in the phase space get smaller and smaller in a extraction cycle, the spill intensity will be reduced with time (as shown in Fig. 2(a)). The amplitude modulation method can be used to overcome this problem [5] [6].

The main ripple of the spill is 50 Hz and its harmonics, which is consistent with the quadrupole power ripple in the actual machine commissioning.

THE SLOW EXTRACTION WITH FEEDBACK

The Mechanism of Feedback

In order to compensate the affection of the quadrupole power ripple, many works have been done in HIMAC, such as using the AM modulation feedback [7], keep the tune of the beam away from the resonant line [8], and so on. Fig.3 is the schematic diagram of the feedback control loop in CSRm. A pair of fast quadrupole (FQ1, FQ2 in Fig.2) has been adopted to compensate the fluctuation of the work point in CSRm. The ionization chamber in the cancer therapy room will monitor the intensity of the spill real time. When the intensity deviate from the theoretical intensity (reference value), the FQ will change the work point of the synchrotron through the current strength to keep the spill intensity unchanged. In other words, the work point fluctuation will be compensated by FQ to make the spill uniform. Table.1 shows the parameters of the FQ. The ceramics vacuum chamber is adopted for the FQ to meet the fast response.

Table 1: parameters of the FQ and transverse RF

Element	Number	Strength	Rise Time
FQ	2	0.23T/m	170T/ms^{-1}
RF	1	15V/cm	-

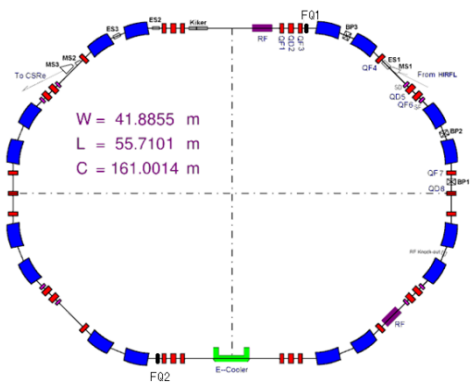

Figure 2: Layout of FQ, RF-KO.

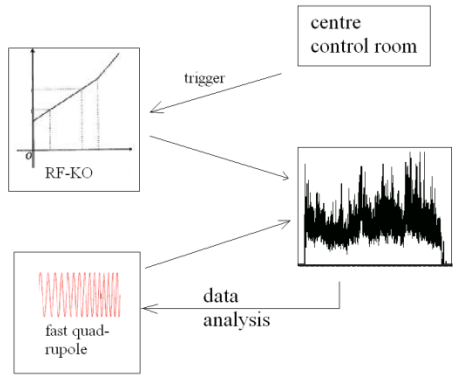

Figure 3: Schematic diagram of feedback.

Result and Analysis

Figure 4 is the spill structure and corresponding analysis. As seeing from the figure,

- The time structure of the spill has been improved a lot compared to the normal mode, though obviously there are still many spikes. Because the reference intensity is too larger, the spill time is less than the set time (5 seconds).
- As one can seen from the Table.1, the 370 Hz and below ripple will be suppressed, but actually the spill ripple below 800 Hz has successfully been suppressed to the 1/10 of the normal mode (as shown in Fig.4b). That is because the fast quadrupole does not need to reach the extreme value, so the response frequency can exceed 370 Hz. The time needed from the spill intensity signal be measured and the spill structure been changed by the FQ is nearly 1 ms, so the spill ripple near 1 kHz is larger than normal mode.
- The blank gap between the spikes has been disappeared, but there are still many spike in the spill.

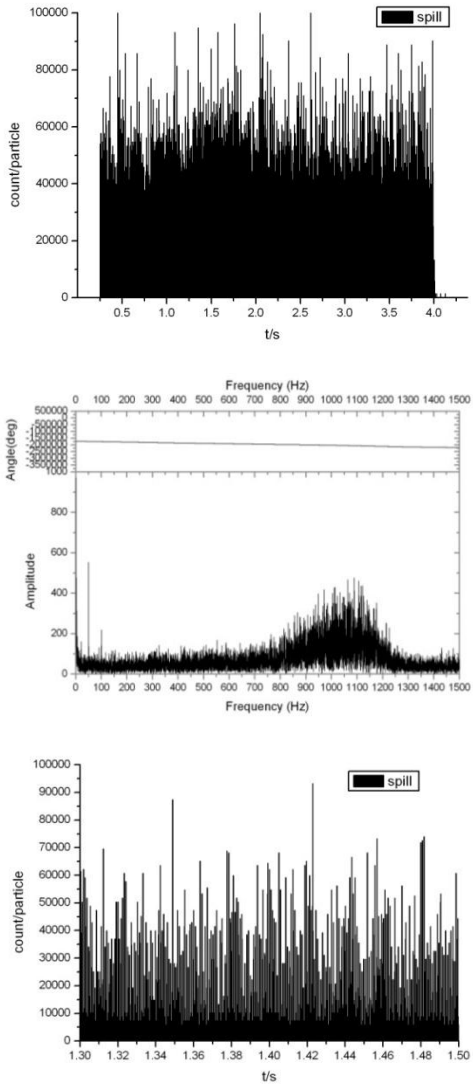

Figure 4: Spill in feedback mode(sample rate is 10 kHz). (a) Structure of one spill, (b)FFT of one spill, (c) Detailed spill structure in 1.3s-1.5s.

CONCLUSION

After the FQ has been adopted in the CSRm, the spill ripple has been suppressed greatly. Because of the delay of the FQ action, the spill is not smooth enough. The thickness of the lamination steel is 0.5 mm,to reduce the delay time of the fast quadrupole, a new pair of FQ with the lamination steel thickness of 0.2 mm is under consideration. All in all, the quadrupole power supply ripple is too large, the fundamental method is to reduce the power ripple of the quadrupoles.

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