BEAM SPILL STRUCTURE FEEDBACK TEST IN HIRFL-CSR*

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Abstract

The slow extraction beam from HIRFL-CSR is used in nuclear physics experiments and heavy ion therapy. 50Hz ripple and harmonics are observed in beam spill. To improve the spill structure, the first set of control system consisting of fast Q-magnet and feedback device based FPGA is developed and installed in 2010, and spill structure feedback test also has been started. The commissioning results with spill feedback system are presented in this paper.

INTRODUCTION

HIRFL-CSR [1] is the post-acceleration system of Heavy Ion Research Facility in Lanzhou (HIRFL), which consists of double cooling storage ring system(CSR) and a radioactive beam line (RIBLL2). The beam is accumulated, cooled and accelerated in the main ring (CSRm), and will be extracted [2] in fast extraction mode to experiment ring (CSRe) for internal-target experiments, or extracted in slow extraction (RF-knockout) mode for external-target experiments and cancer therapy.

To prevent the pileup events in particle detectors [3], and to improve the lateral dose distribution in the irradiation for heavy ion therapy [4], the ripple noises of beam spill should be suppressed. We developed a test set of the spill feedback system, which consists of two quadrupole magnets, commercial FPGA card and waveform generator.

SPILL CONTROL

In CSRm, the RF-knockout method is employed for slow extraction. Normally, the horizontal tune in CSRm is set to 3.662 by using normal quadruple pairs during slow extraction, and additional sextupole magnets are used to excite the third-order horizontal resonance. The centre frequency of RF–KO is about 1.666 times of the beam revolution frequency, and the span is 0.5%.

To improve the beam time structure, one commonly used method is RF-KO with amplitude modulation (AM) and frequency modulation (FM) [4-7], and the spill ripple can be suppressed by using fast Q magnets[8-11]. The FQ control signal should be the reverse phase of ripple noise [9], Figure 1 shows the example of FQ control signal. Figure 2 shows the block diagram of the spill feedback system in CSRm.

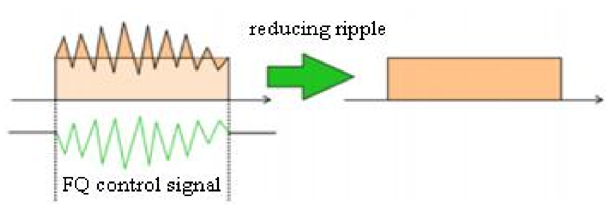

Figure 1: Spill control by FQ. [9]

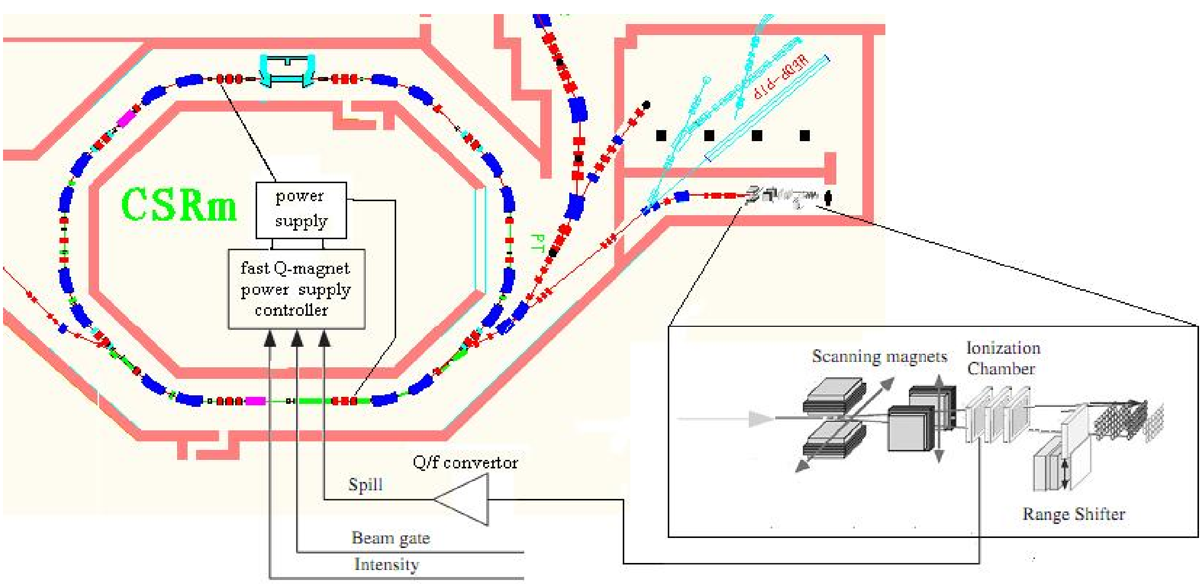

Figure 2: Block diagram of the spill feedback system.

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The test set of spill control system in CSRm is based on the two methods mentioned above, system consisting of two fast Q-magnets, feedback device based FPGA and waveform generator. The beam current is measured by ionization chamber, and the output signal from Q/f convertor is TTL pulse[12], for example one pulse for 814 particles (200MeV/μ $^{12}C^{6+}$). The fast Q magnet power supply controller is (NI 7830R)[13], the parameters is shown in table 1, 1MS/s is enough for suppress the ripple lower than 500Hz. Figure 3 shows the block diagram of spill feedback processing, the maximum loop rate is 1MHz.

Table 1: Specification of NI 7830R

AO resolution	16 bits
AO update rate	1MS/s
max clock rate	40MHz
FPGA type	Vitex-2 Virtex-II 1M

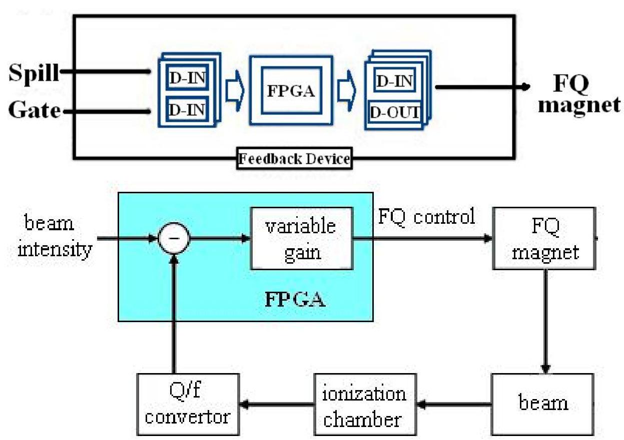

Figure 3: The spill feedback processing.

The best amplitude modulation curve [7] for RF-KO should like Fig. 4 curve(a), but the waveform generator TEK3252 [14] we have does not support real-time change of output amplitude, so we use curve(b) instead of curve(a), use software to change the output amplitude through GPIB port, refresh rate is about 35Hz.

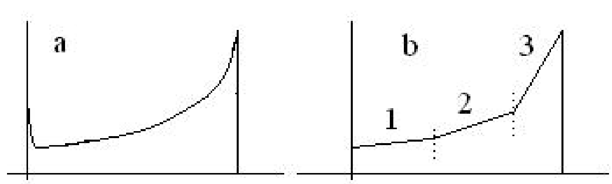

Figure 4: The AM curve for RF-KO, (a) best curve, (b) three lines.

There are two fast Q magnets symmetrically installed in CSRm, so the lattice will not change by using FQ(Fig. 5). The horizontal and vertical tune value will be change at same time because of FQ, but the change of the vertical tune value is acceptable. Table 2 shows the fast Q magnets specifications.

Figure 5: FQ and power supply.

Table 2: Fast Quadrupole Magnets Specifications

Core Material	0.5mm thick lamination steel
Bore Radius	85 mm
Magnet Length	0.30 m
Coil Turn Number	3
Field Gradient	0.2T/m@370A
Inductance	0.3mH
Resistance	4mΩ

BEAM COMMISSIONING

The commission result is shown in Figure 5. The beam in CSRm is 200MeV/μ $^{12}C^{6+}$. Normally, horizontal tune value in CSRm is set to 3.662, and RF-KO set constant RF power, Fig. 6(a) shows the beam spill. If we change the RF amplitude during extraction, beam spill and FFT result is shown in Fig.6 (b).

Because the FQ magnet power supply is still under construction, we install one BUMP magnet power supply for temporary use. This power supply is single polarity, fall time (200A-0A) is 50μs, and rise time (0A-200A) is 200μs. Before the feedback system is turn on, horizontal tune value is set to 3.660-3.661, and we find that the beam cannot be extracted without feedback system turn on under this condition. Turn on the feedback system, and carefully change the parameters set in FPGA program, finally the beam spill become flat, the best result is shown in Fig. 6(c), ripple of 50Hz and its harmonic lower than several hundreds hertz is reduced.

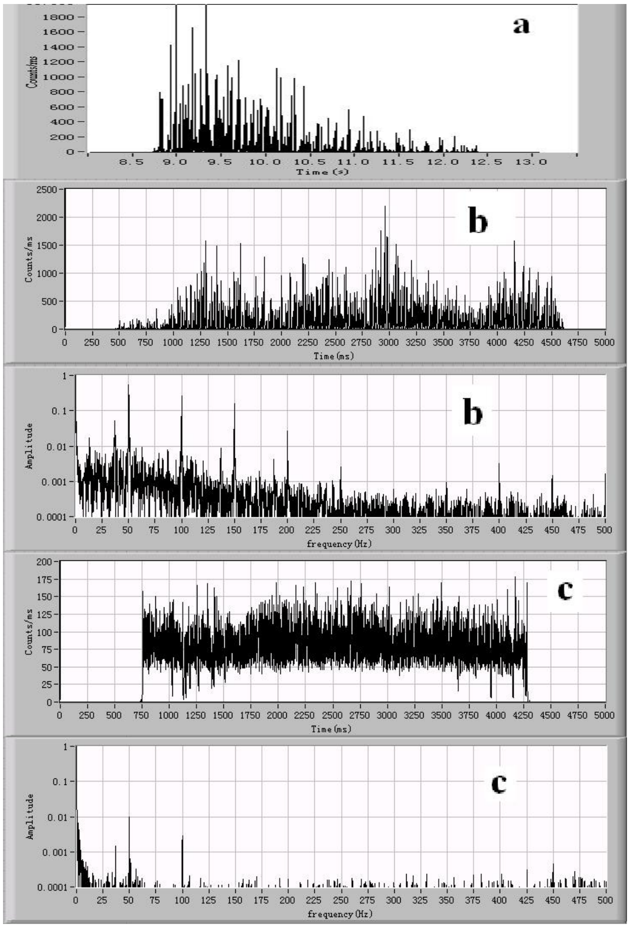

Figure 6: Beam spill structure and FFT results. (a) feedback off and RF-KO with constant RF power, (b) feedback off and RF-KO with amplitude changing, (c) feedback on and RF-KO with amplitude changing. Sample rate is 1KS/s. (200MeV/μ $^{12}C^{6+}$).

CONCLUSION AND NEXT STEPS OF DEVELOPMENT

- We finished developing the test set of spill feedback system, which consists of two fast Q-magnets, one feedback device based on FPGA, and one RF exciter based on waveform generator, and carried out the experiments in CSRm. The feedback system improved the spill structure, ripple of 50Hz and its harmonic is reduced.
- It's difficult to commission by using the single polarity power supply, so the bipolar power supply is really needed.
- The core material of fast Q magnets is 0.5mm thick lamination steel, now we begin to construct new one with 0.2mm lamination steel.

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