OPTIMIZATION AND UPGRADE OF SLOW EXTRACTION CONTROL SYSTEM FOR HIRFL CSR MAIN RING

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Introduction

The heavy ion beam from Heavy Ion Research Facility in Lanzhou (HIRFL) CSR Main Ring (CSRm) is slowly extracted by using a third-order resonance driven by sextupole magnets and delivered to various experimental facilities, or extracted in fast extraction mode to CSR Experiment Ring (CSRe) [1, 2]. In slow extraction mode, many physical, material, biological, and medical experiments require high-quality spill that has flat structure and low ripple noise [3]. For CSRm, the resonant slow extraction is driven by RF-KO exciter. In the new spill control system of CSRm, the host machines are employed to calculate amplitude modulation curve and spill duty factor, publish the control variables, and manage the various parameters that are often stored in the database. In addition, two FPGA boards are dedicated to control RF power amplifier and a pair of fast quadrupole (FQ) magnets.

RF-KO exciter unit

The host machine (Industrial PC) is used to manage parameters and database access, calculate amplitude modulation (AM) function, and publish the control variables to the network-based accelerator control system. The FPGA target is dedicated to control the amplitude and frequency of the output voltage for RF power amplifier, generate the white noise, and parse the event sequence number. The database stores the all relevant parameters of the RF-KO exciter.

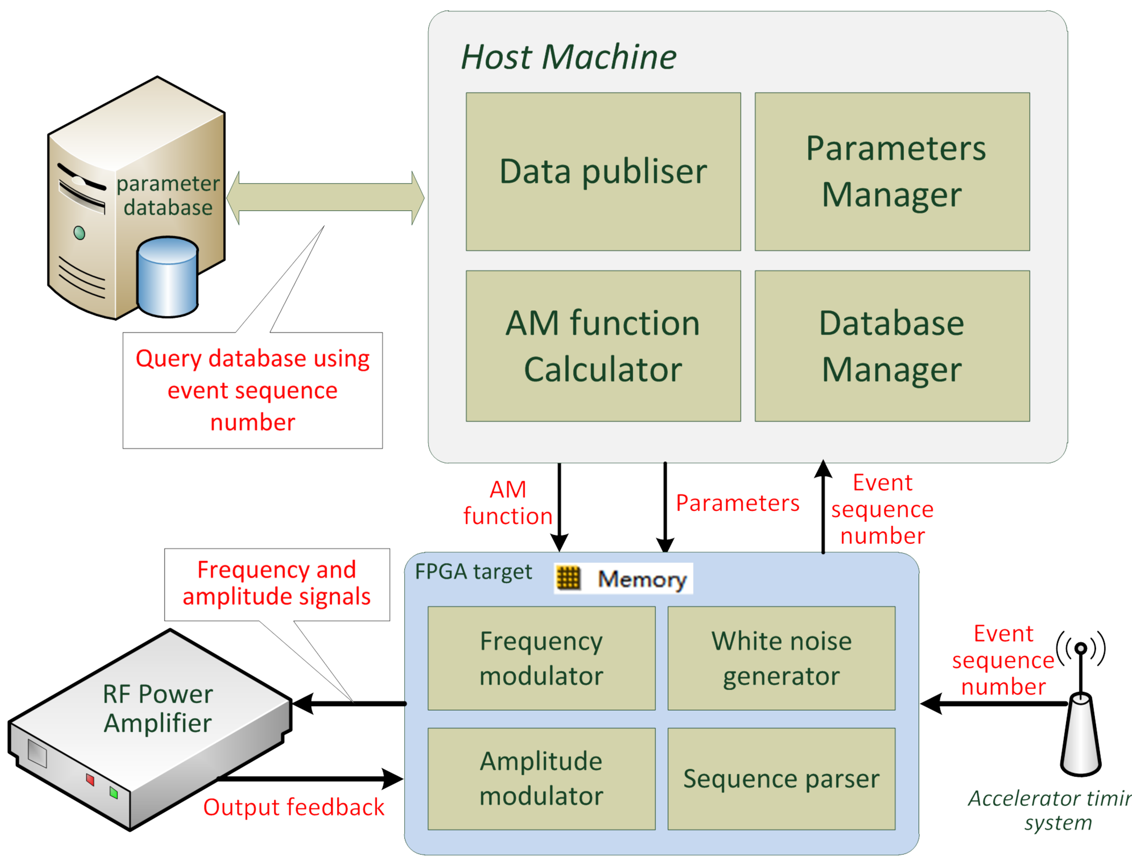

Figure 1: Block diagram of the RF-KO exciter unit

To improve the slow extraction efficiency and beam time structure, frequency modulation (FM) based on white noise and amplitude modulation based on the best AM function curve had been introduced into RF-KO exciter control unit in the course of designing.

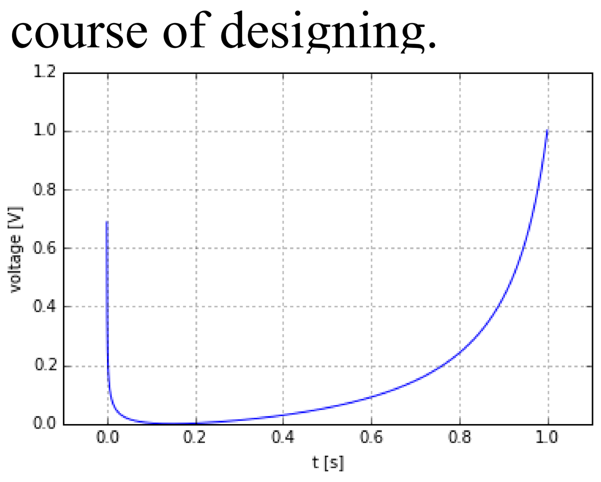

Figure 2: The best AM funciton cruve for RF-KO exciter

Spill feedback unit

The spill feedback unit consists of the host machine to manage parameters and database access, to calculate the spill duty factor, and to publish the control variables that can be accessed by the other network devices, the FPGA target to handle the spill signals and to calculate the exciting current pattern for FQ magnets by using a digital PID controller, and the database for storing feedback parameters proportional gain (Kc), integral time (Ti, min), derivative time (Td, min), and PID loop rate.

A couple of FQ magnets were symmetrically installed in CSRm. The beam intensity is monitored by ionization chamber in the experimental terminals, and a Q/f convector, which generate TTL pulse signal, is used to connect the FPGA target and the ionization chamber.

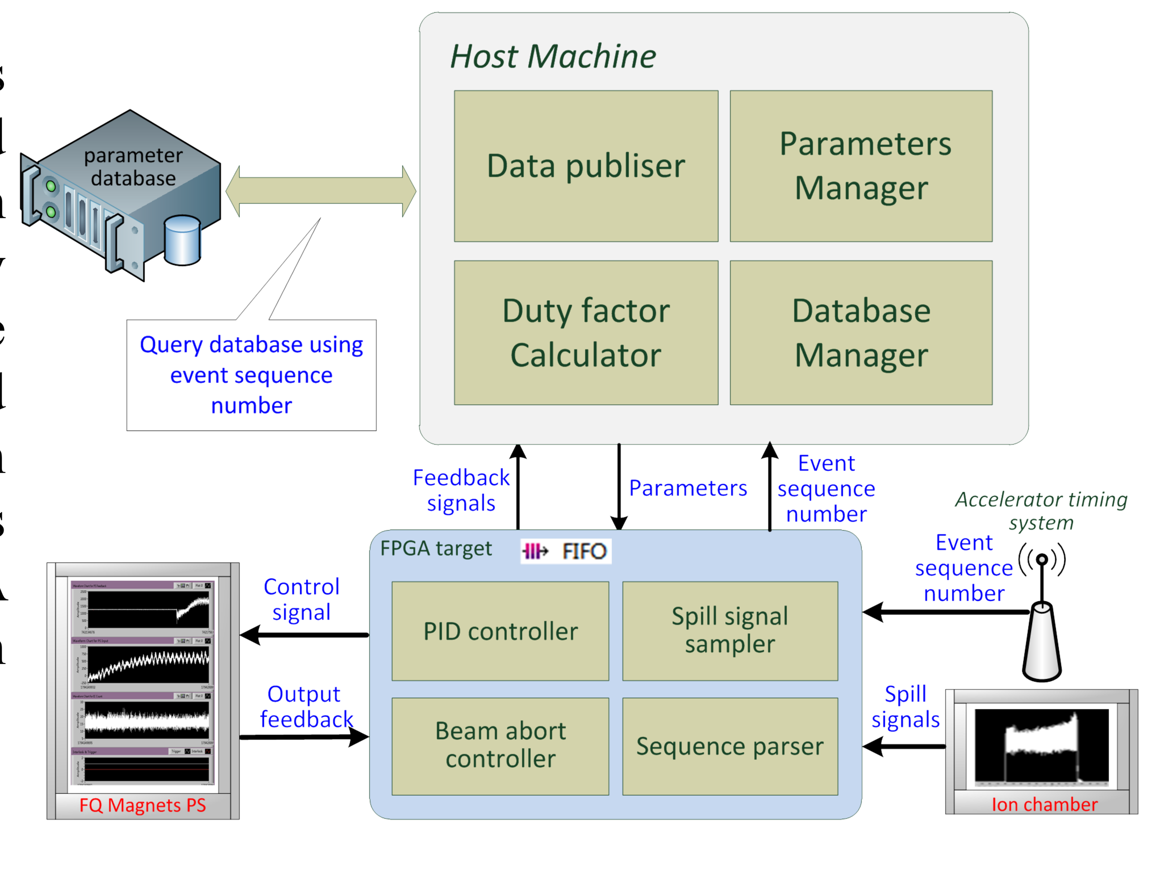

Figure 3: Block diagram of the feedback unit.

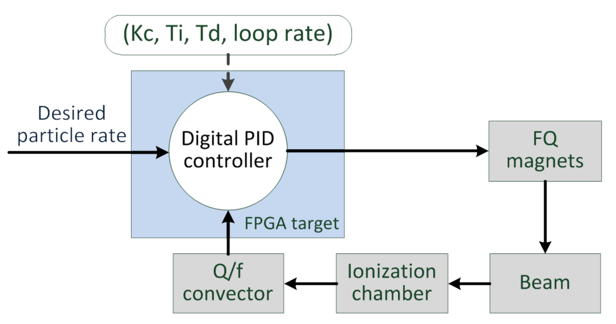

Figure 4: The spill feedback processing

Experimental results

$$\text{Duty Factor} = \frac{\left[\int_0^T I(t)dt\right]^2}{\int_0^T dt \cdot \int_0^T I^2(t)dt} \quad (1)$$

The effectiveness of RF-KO exciter and feedback units had been verified by beam commissioning in HIRFL CSRm. We evaluate the beam time structure by spill duty factor. The formula (1) [4] is used to calculate the beam structure duty factor. A higher value of spill duty factor indicates that the beam time structure is closer to the flat structure.

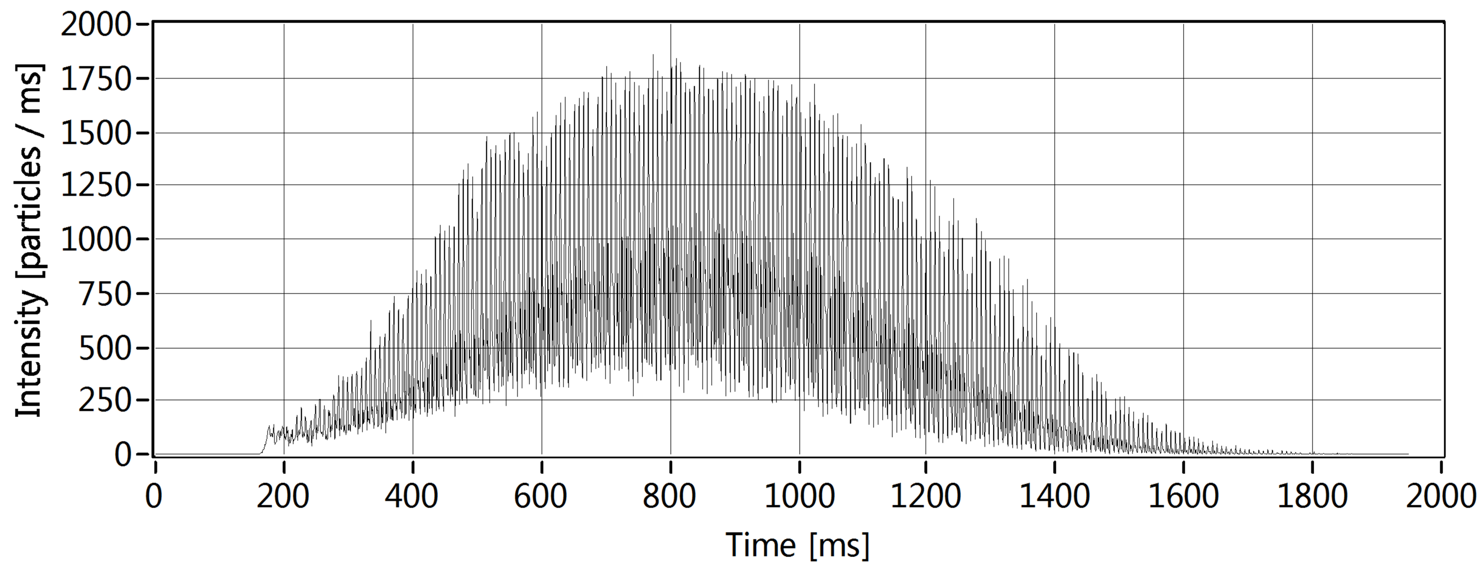

Figure 5: Beam structure before upgrading. Here: Carbon beam, energy E = 190 MeV/u, duty factor = 35.98%

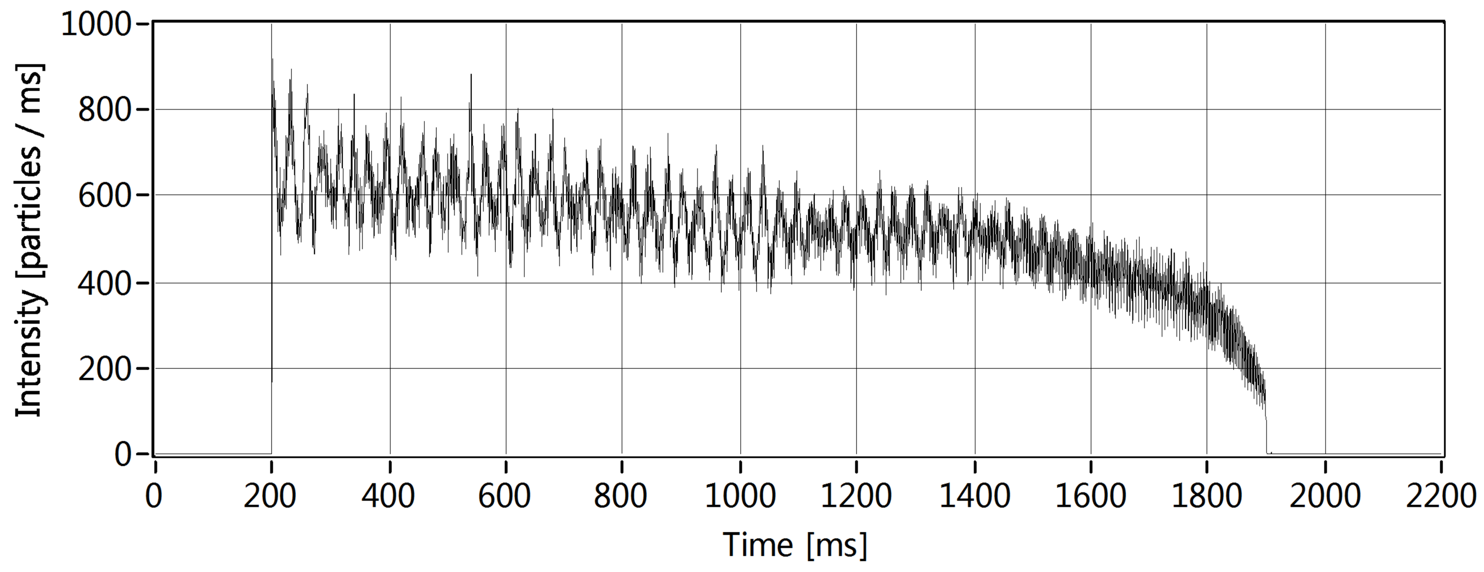

Figure 6: Beam structure without FQ feedback after upgrading. Here: Carbon beam, energy E = 190 MeV/u, duty factor = 89.19%

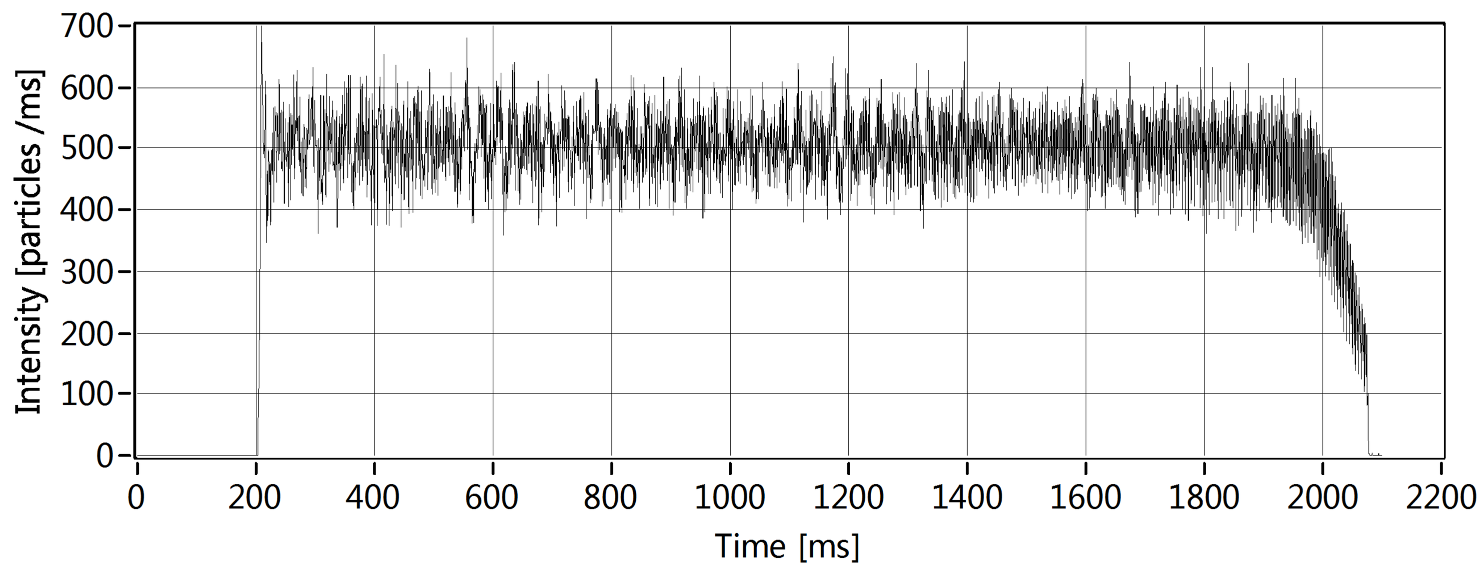

Figure 7: Beam structure with FQ feedback after upgrading. Here: Carbon beam, energy E = 190 MeV/u, duty factor = 92.13%

Fig. 5 shows the time structure of slow beam-extraction before upgrading. The spill duty factor is just 35.98%, so the flatness of beam structure needs to be further optimized by improving excitation and feedback methods. Fig. 6 shows the time structure of slow beam-extraction without feedback unit after upgrading. The spill duty factor is improved to 89.19%, but particles are not evenly distributed in phase space, thus it is very hard to achieve a smooth and flat spill by the RF-KO exciter unit alone [5]. Fig. 7 shows the time structure of slow-extraction with feedback unit after upgrading. The spill duty factor is further improved to 92.13%, and spill quality is much better.

Conclusion

We carried out beam test in HIRFL CSRm. The effectiveness of our new design is verified by experimental results. The RF-KO exciter and feedback units do effectively improve the beam characteristics. The spill duty factor is improved from 35.98% to 92.13%. The old control devices will be soon replaced by new solution via FPGA-PC-Databse. This makes the slow extraction system more effective.

References

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