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The Commissioning Progress of the Cooler Storage Ring HIRFL-CSR in Lanzhou

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Abstract. HIRFL-CSR is a multi-purpose cooler-storage-ring system constructed at the Institute of Modern Physics, Chinese Academy of Sciences in Lanzhou, China. Construction of the HIRFL-CSR storage ring complex has been finished, and passed the government check and acceptance, recently. The first stored beam in the CSRm was obtained in January 2006 using stripping injection. The commissioning got great progress in 2007. In early January 2007 electron cooling in CSRm was successfully done, and the multiple multi-turn injection was successively realized for $^{12}\text{C}^{6+}$, $^{36}\text{Ar}^{18+}$ and $^{129}\text{Xe}^{27+}$ beams, respectively. The $^{129}\text{Xe}^{27+}$ was extracted from the main ring by fast extraction. The $660\text{MeV/u}^{12}\text{C}^{6+}$ was injected into the experimental ring and reached an intensity of 15mA there. The first two physics experiments were done in December 2007 including the mass measurement in isochronous mode in the experimental ring. The $300\text{MeV/u}^{12}\text{C}^{4+}$ ions were successfully slow-extracted from the main ring in early 2008. This paper presents the main commissioning results.

1. Introduction

HIRFL-CSR is a multi-purpose cooler-storage-ring system in the National Laboratory of Heavy Ion Research (HIRFL) in Lanzhou, China [1,2] including a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line (RIBLL II) connecting the two rings. Heavy ion beams in an energy range of 8–30 MeV/u from the HIRFL will be accumulated, cooled and accelerated to the energy of 1 GeV/u ($^{12}\text{C}^{6+}$) and 500 MeV/u ($^{238}\text{U}^{72+}$) in the main ring, and then extracted to produce secondary beams (radioactive ion beam or highly charged heavy ions). The secondary beams will be accepted by and stored in the experimental ring for internal-target experiments or for high-precision spectroscopy with beam cooling. The experimental ring CSRe can accept highly charged ions with energies up to 750 MeV/u ($^{12}\text{C}^{6+}$) and 500 MeV/u ($^{238}\text{U}^{92+}$). The double-ring system provides flexibility in the production of highly charged ions and of radioactive ion beams, thus offering opportunities for nuclear physics and atomic physics research as the facility at GSI in Germany [3]. Construction of the HIRFL-CSR storage ring complex has been finished, and passed the check and acceptance organized by the National Development and Reform Commission (NDRC) in July 30, 2008.

2. The commissioning of the HIRFL-CSR project

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The commissioning of the HIRFL-CSR system began in 2005. The first stored beam in the CSRm was obtained on January 23, 2006 using 6.897 MeV/u C^{4+} as the injected beam in combination with stripping injection mode. The commissioning got considerable progress in 2007 (Table 1). In early January 2007 electron cooling in CSRm was successfully done and 1GeV/u $^{12}$C^{6+} ions up to 1.6mA (corresponding to the ion number of $8 \times 10^8$) have been accumulated by using cooling stacking. The multiple multi-turn injection (MMI) was then realized for $^{12}$C^{6+}, $^{36}$Ar^{18+} and $^{129}$Xe^{27+} (Fig.1) beams, respectively. In this injection mode the ions are injected into an unoccupied outer region of phase space with non-integer tune which ensures many turns before the injected beam re-occupies the same region [4]. The first MMI was done for $^{12}$C^{6+} in CSRm with e-cooling on April 1, and MMI for $^{36}$Ar^{18+} in CSRm with e-cooling was tested on April 25 reaching an intensity of 180μA. For the MMI test for Xe ion, the 2.9MeV/u $^{129}$Xe^{27+} ions provided by HIRFL-SFC was injected into CSRm, accumulated to 500μA (1×10^8 ions) by using MMI and accelerated to 235MeV/u. The kicker for fast extraction with the parameters of $I_{max} = 2700$A, $V_{max} = 60$ kV and rising time=150ns was tested on-line, and the 235MeV/u $^{129}$Xe^{27+} beams was first extracted from CSRm by fast extraction in August 2007.

In October the 7MeV/u $^{12}$C^{4+} provided by SFC was accumulated and accelerated to 660MeV/u in CSRm and then extracted fast to RIBLL II. The 660MeV/u $^{12}$C^{6+} transferred through RIBLL II was injected into CSRe and reached an intensity of 15mA (corresponding to the ion number of $1.56 \times 10^{16}$pps) in CSRe (Fig.2). This was the first successful commissioning of the whole HIRFL-CSR system.

| Date               | Commissioning conditions       | Results                                             |
|--------------------|--------------------------------|-----------------------------------------------------|
| January 23, 2006   | Stripping injection 6.897 MeV/u C^{4+} | Stored beam in CSRm                                  |
| January 2, 2007    | $^{12}$C^{6+}                  | Cooling Stacking + Ramping, 1GeV/u, 1.6mA, CSRm      |
| April 1, 2007      | $^{12}$C^{6+}                  | multiple multi-turn injection (MMI), CSRm            |
| April 25, 2007     | $^{36}$Ar^{18+}                | MMI, 1 GeV/u, 180μA, CSRm                           |
| June 25, 2007      | 2.9MeV/u $^{129}$Xe^{27+}      | MMI, 235MeV/u, 500μA, CSRm                          |
| August 4, 2007     | 235MeV/u $^{129}$Xe^{27+}      | Fast extraction from CSRm                           |
| October 6, 2007    | 660MeV/u $^{12}$C^{6+}         | Stored in CSRe, 15 mA                               |
| December 12, 2007  | Radioactive ions produced, isochronous mode in CSRe | Mass measurements, $\Delta M/M \sim 10^{-5}$   |

The first two physics experiments were done in December 2007. In one of the experiments a Be target of 5 mm was installed at the primary target position of RIBLL II, secondary beams such as $^{34}$Cl, $^{32}$S and $^{30}$P and so on were produced and injected into CSRe which was set in the isochronous mode. The masses of the stored secondary ions could be determined from the revolution time spectrum of the ions measured by using a time-of-flight (TOF) detector system. The stored ions went through a carbon foil of the TOF detector and emitted secondary electrons. The electrons were deflected by a perpendicular magnetic field and detected by a multi-channel plate giving the timing signal. The frequency resolution of the stored secondary ions reached $\Delta f/f \sim 10^{-7}$, and the mass resolution of $10^{-5}$ was obtained (Fig.3).
Fig. 1 Multiple multi-turn injection and acceleration in CSRm for 2.9 MeV/u $^{129}$Xe$^{27+}$

Fig. 2 Multi time injection in CSRe for 660 MeV/u $^{12}$C$^{6+}$

Fig. 3 Mass measurement in CSRe in isochronous mode
During the first mass measurement experiment, the HIRFL-CSR system was set in the full running mode shown in Fig. 4. In this full running mode the $^{36}\text{Ar}^{8+}$ ions produced by ECR source was first pre-accelerated to 2 MeV/u by HIRFL-SFC, and to 22MeV/u by HIRFL-SSC. The 22MeV/u $^{36}\text{Ar}^{8+}$ changed to $^{36}\text{Ar}^{18+}$ after passing through a stripper, and then injected into CSRm by MMI, accelerated to 368MeV/u by CSRm. The 368MeV/u $^{36}\text{Ar}^{18+}$ ions extracted from CSRm transferred through RIBLL II, and injected into CSRe for the mass measurement experiment.

In early 2008, the 300MeV/u $^{12}\text{C}^{4+}$ ions were successfully slow-extracted from CSRm. This is an important milestone of the HIRFL-CSR project which makes the external target experiments at RIBLL II and the cancer therapy at the therapy terminal possible.

The first phase experiments at the HIRFL-CSR include the internal target experiments in the CSRm, the external target experiments with RIBLL II and the internal target experiments in the CSRe. The experiments cover a wide range of hadron physics, radioactive ion beam physics, highly charged atomic physics, high energy density physics, biological medical physics and so on.

Fig. 4 Full running mode of the HIRFL-CSR system

3. References

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