HIRFL OPERATION AND UPGRADE

H. W. Zhao, Y. F. Wang, W. L. Zhan, B. W. Wei and HIRFL team
Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou, 730000, China

Abstract

HIRFL (Heavy Ion Research Facility in Lanzhou) has focused on improving the operation efficiency, the facility reliability and increasing beam intensity in the last couple of years. A series of upgrading programs have been accomplished including a new vacuum chamber of the injector SFC (Sector Focus Cyclotron), a new rebuncher between the injector SFC and the main cyclotron SSC (Seperated Sector Cyclotron), increase of the RF Dee voltage for both SFC and SSC, upgrading control and diagnostic system, and replacing all the power supplies in HIRFL system. All these modifications and upgrading have resulted in a dramatic enhancement of the HIRFL performance. In order to provide high quality beams for HIRFL-CSR (Cooling Storage Ring), some machine studies have been done which are dedicated for beam injection and extraction of the injector SFC, and measurements of the SFC beam energy and its stability.

HIRFL OPERATION STATUS

SFC Operation

After 15 years operation, HIRFL accelerator facility was shut down for fully upgrading and installation of HIRFL-CSR[1] injection beam line in April 2002. The injector SFC has been in operation separately since May 2003 after a new vacuum chamber was installed. The SFC operation statistics from May 2003 to August 2004 are shown in Fig.1. The total operation time during this period is about 9960 hours. Some beams with energy and intensity from SFC are listed in Table 1.

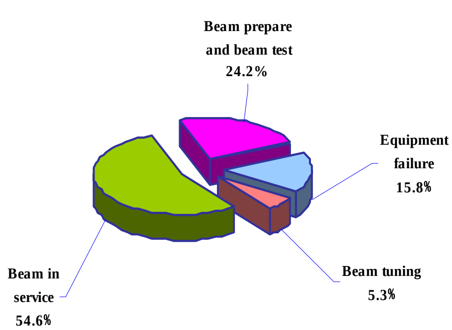

Figure 1: SFC operation statistics from May 2003 to August 2004.

Table 1 demonstrates that beam intensity from SFC has been improved dramatically compared with previous operation. This is resulted from many upgrading programs and some detailed machine studies in the past three years, which are concluded as follows:

- Upgrade of the SFC vacuum chamber is very successful that improves the SFC vacuum by almost one order of magnitude.

Table 1: Beam energy and intensity delivered from SFC.

Ions	Energy (MeV/u)	Beam intensity (eμA)
$^{40}Ar^{12+}$	5.8	1.5
$^{40}Ca^{12+}$	5.8	1.0
$^{129}Xe^{27+}$	2.3	1.0
$^{26}Mg^{8+}$	6.54	1.8
$^{208}Pb^{27+}$	1.1	1.0
$^{20}Ne^{7+}$	7.2	14
$^{16}O^{6+}$	7.99	14
$^{40}Ar^{8+}$	2.35	12
$^{12}C^{4+}$	7.0	13
$^{35}Cl^{12+}$	6.0	1
$^{36}Ar^{11+}$	6.1	3.5

- One of crucial reasons for big enhancement of light ion beam intensity is that the SFC RF Dee voltage is raised up to 90 kV, which is resulted from improvement of the cooling effect for the shorting plate and the RFcavity.
- Two bunchers are necessary for the SFC axial injection beam line. The tests and machine studies demonstrate that it could be beneficial for improving the SFC injection efficiency and buncher efficiency for the intense beams (such as 100-200 eμA Ne^{7+} and O^{6+} at the axial injection beam line) if the buncher is located closer to the SFC central plane (L=2.3 m), in this case the buncher requires much higher voltage to keep higher buncher efficiency. The buncher efficiency could be higher for a few tens eμA beams at the axial injection beam line if the buncher is located little bit farther to the SFC central plane (L=6.0 m).
- Shielding of the stray magnetic field from SFC during upgrade of the SFC vacuum chamber reduces beam losses at the axial injection beam line, and also makes it much easier to achieve optimized parameters of the axial injection beam line in order to reach a good match between the SFC and the beam line.
- A double-90-degree bending magnet located downstream the 90-degree analyzing magnet was removed from the beam line, which reduces beam losses and makes tuning of the axial injection beam line much easier.
- Intense highly charged beams from ECR ion source are very useful to improve beam intensity from SFC.

- Parameter optimizations of the axial injection beam line and the SFC are essential for the machine to reach a high injection efficiency and intense beam intensity.

SSC Operation

The main cyclotron SSC was shut down for more than two years. It was August 2004 that the SSC started in operation again. At the moment, operation beam intensity from SSC is still not very high, only a few hundred nano-amperes, such as 70 MeV/A ^{22}Ne, 500 enA. So the main task of HIRFL upgrading in the next step is to improve SSC beam intensity.

HIRFL UPDRADE AND MACHINE STUDY

SFC Vacuum Chamber

The old vacuum chamber of the SFC has been used for more than 30 years. The vacuum at the central region was very low only 3×10^{-6} mbar. So a new vacuum chamber with size 3445×2865×960 was built to reach the required vacuum 1×10^{-7} mbar at the central region. Structure of the new vacuum chamber was designed with double layer vacuum vessel so that the trim coils could be located into the first layer vacuum vessel. Besides the new vacuum chamber, all the trim coils were re-built and also some additional iron steel sheet with thickness 150 mm was attached on the iron yoke of the SFC magnet to reduce stray magnetic field. The new vacuum chamber was installed into the SFC in April 2003. Finally the vacuum at the SFC central region (without the coaxial rf cavity) can reach 8×10^{-8} mbar. In May 2003, the SFC successfully accelerated 1.1 MeV/u $^{208}Pb^{27+}$ beam. Fig.2 shows how the SFC with a new vacuum chamber looks like.

Figure2: SFC with a new vacuum chamber

New Rebuncher

One of key reasons for low injection efficiency of the main cyclotron SSC in the past years is that there was no operational rebuncher between SFC and SSC. A new rebuncher was built and installed at the beam line to realize longitudinal match between SFC and SSC[2] , as shown in Fig.3. The new rebuncher is based on $\lambda/4$ resonator with double-gap drift tube structure. The resonant frequency is tuned through a shorting plate and two movable plates. The frequency range is from 22 MHz to 54 MHz, and the maximum output power of the amplifier is 40 kW. The maximum bunching voltage is about 150 kV. The RF power is fed into the cavity through a coupling loop. The rebuncher has been in routine operation for more than 2 months, which indicates it achieves the designed requirements. The preliminary test demonstrates SSC beam intensity for energy less than 30 MeV/u could be improved by a factor 2 with this rebuncher, but for higher energy beam, the enhancement of beam intensity is very small due to not enough bunching voltage. Another rebuncher is to be built.

Figure3: A new rebuncher between SFC and SSC

Renovation of HIRFL Power supplies

Most of HIRFL power supplies have been operated more than 17 years. Failures of power supplies were getting higher and higher, and stabilities of HIRFL power supplies were getting worse. In the past two and half years, we have renovated all power supplies in HIRFL system. The total number of the renovated power supplies is 301 including the main power supply of the SSC magnet (4000 A /185 V). Renovations of the HIRFL power supplies have adopted two key technologies, for power higher than 50 kW, thyristor rectifier technology, and for power less than 50 kW, switch type. Up to August 2004, almost all the new power supplies have been in operation. The measurements and operation indicate these new power supplies are more reliable and stable. The ripples are reduced and the power factors are almost doubled, in particular, the sizes are greatly reduced. The main power supply of SSC (4000 A/185 V) has reached 5×10^{-6} stability within 8 hours measurement.

Improving RF Dee voltage for SFC and SSC

In the past three years much effort has been made to improve match between cavity and RF amplifier, to upgrade RF amplifier and its stabilization systems (including magnitude, phase and frequency stabilizations) , to improve cooling effect of RF cavity, for both SFC and SSC so as to raise the RF Dee voltage. The RF Dee voltage of SSC has been raised up to 200 kV from previous 130 kV at frequency 13.5 MHz, and the RF Dee voltage of SFC has been improved to 90 kV from previous 75 kV at frequency 6.5 -15 MHz. This is a great improvement! But a long-term stable operation at such high voltage is still a key issue to be solved. We expect to improve the injection efficiency of SSC with the raised RF Dee voltage.

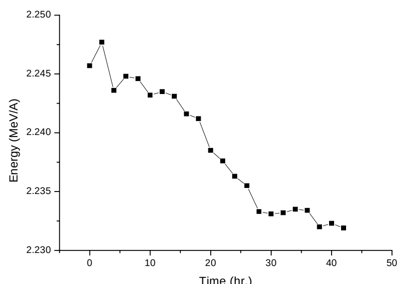

Figure4: SFC Beam energy stability measurement for 2.35 MeV/u $^{40}Ar^{8+}$.

SFC Beam Energy Measurement and Stability Study of Beam Energy

HIRFL-CSR requests 0.5% long-term stability for SFC beam energy. A series measurements and studies were done to study energy stability of SFC beams. Beam energy was measured by time of flight method with two phase probes located at the beam line between SFC and SSC. Figure 4 shows a measurement result for 2.35 MeV/u $^{40}Ar^{8+}$ within 44 hours, which was measured in summer. Figure 5 shows a measurement result for 6.3 MeV/u $^{14}N^{5+}$ within 7 hours, which was measured in winter. It is surprised that in Fig.4 the measured beam energy is about 4% less than the calculated value and the measured beam energy keeps going down, and the beam energy stability within 44 hours is only 0.7%. This could be caused due to temperature effect which is still under investigation. Figure 5 demonstrates the beam energy stability within 7 hours is about 0.25%. The further measurements and studies are still necessary.

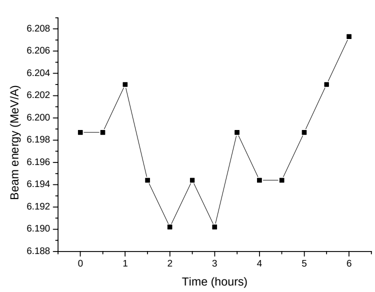

Figure5: SFC Beam energy stability measurement for 6.3 MeV/A $^{14}N^{5+}$.

HIRFL EXISTING PROBLEMS AND KEY ISSUES TO BE SOLVED

The main problems in HIRFL system are as follows:

- Low beam transmission efficiency for SFC axial injection beam line, typical transmission efficiency is only 40-50%. A new axial injection beam line was designed and under construction.
- Low extraction efficiency for SFC, typically 40-50%. This low extraction efficiency could be due to super-abundance acceptance in longitudinal phase space, which results in no clear separation of beam turns at extraction region, large energy spread of extracted beam, and a serious burden to extraction deflector as well. A phase slit was designed and fabricated, and will be installed in the next summer.
- Operation beam intensity from SSC is still not very high, only a few hundred nano-amperes, which is caused by low injection efficiency and low extraction efficiency. Some detailed studies and upgrading programs are underway.

CONCLUSION

After more than 15 years operation, a series of upgrading programs were conducted to enhance HIRFL performance, which have resulted in a dramatic enhancement of the HIRFL performance and operation efficiency. In particular, significant progress of SFC beam intensity and stability have been made. The next step will focus on upgrading SSC to enhance its beam intensity.

REFERENCES

[1] J.W. Xia, Nucl . Instr. and Meth. A488 (2002)11.
[2]. X.H. Zhou, this proceedings.