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RECENT BEAM COMMISSIONING OF LEAF AT IMP

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Abstract

LEAF (Low Energy intense-highly-charged ion Accelerator Facility) has been successfully commissioned with several beams in CW regime, covering the M/Q from 2 to 7, such as H_2^+, He^{2+}, C^{4+}, O^{4+}, He^+, Kr^{13+}, N^{2+} *et al*. This paper presents recent beam commissioning results.

INTRODUCTION

LEAF is a user facility, designed to produce and accelerate heavy ions, from H_2 to U with M/Q between 2 and 7, to the energy of 0.5 MeV/u. The facility is mainly composed by a 45 GHz ECR ion source FECR, a 300 kV high voltage platform, a high intensity low energy beam transport line, a CW 81.25 MHz 4-vane radio frequency quadrupole (RFQ), and a medium energy beam transport line and several experimental terminals. Figure 1 shows the layout of the complex. A permanent-magnet ECR source has been being used for current commissioning since the superconducting source is still under development. The RFQ beam physics design is optimized to minimize the longitudinal emittance of the accelerated beam. For this purpose an external MHB (Multi-Harmonic Buncher), which includes three harmonics operating at 40.625, 81.25, 121.875 MHz, respectively, is employed in LEBT upstream of the RFQ, and the RFQ only accepts the well bunched core particles for further acceleration avoiding capture of the small fraction particles in the tails of the distribution. The beam commissioning started in May 2018. Early beam commissioning and characteristic measurement without MHB were reported in [1-2]. The MHB was installed in Sep. 2018. This paper will report recent beam commissioning with the MHB operational. A nuclear physical method based on $^{12}C(p,\gamma_0)^{13}N$ reaction has been implemented to measure the beam energy spread of H_2^+ from the RFQ. The measurement is consistent with the calculation. A specific feature of the platform is the possibility to provide so-called "cocktail" beams, which are a mixture of ≥2 species of heavy ion beams. Two types of "cocktail" beams have been successfully tested and measured. The mechanism and preliminary experimental results will also be reported in this article.

BEAM COMMISSIONING

With MHB operational, the MHB was tuned with beam and the RFQ transmission was measured. Figure 2 shows the measured and simulated acceleration efficiencies of the RFQ for ~100 eμA N^{2+} beam under different MHB operation conditions. The full transmission efficiency, including non-accelerated current, was measured by two AC current transformers (ACCT) situated on both sides of the RFQ. The measured transmission was higher than 97% which is similar to the simulated value. The acceleration efficiency is the ratio of the beam currents at faraday cup (FC4) located after the MEBT quadrupole triplet and ACCT-1 before the RFQ. Simulations predict that the non-accelerated particles would be over-focused and lost in the triplet focusing channel due to the widely different rigidity from the synchronous particles. Good agreement between the measurements and simulations was demonstrated, while the small difference can be due to the measurement errors and the deviations of the simulation model. However, due to the power limitation of the amplifier, the third harmonic with frequency of 121.875 MHz hardly has contributions to the beam intensity in the measurement. To investigate the validity of the third harmonic, the measurement was conducted with the minimum M/Q ion He^{2+}, as shown in Fig. 3. With the third harmonic working the accleration efficiency increased by 2%, comparing with that using two harminics.

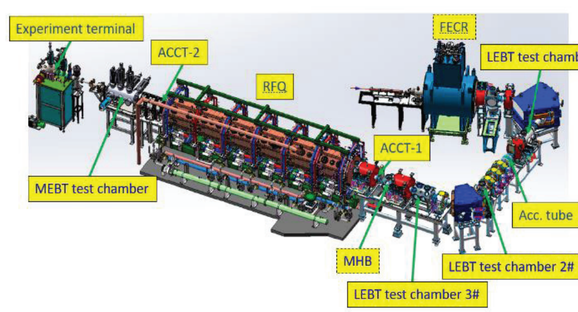

Figure 1: Layout of LEAF.

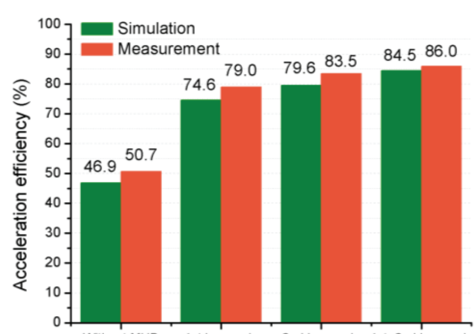

Figure 2: Measured and simulated acceleration efficiencies of the RFQ for ~100 eμA N^{2+} beam under different MHB operation conditions.

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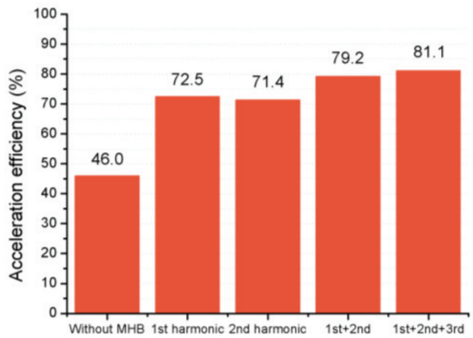

Figure 3: Measured acceleration efficiencies of the RFQ for He2+ beam under different MHB operation conditions.

Figure 4 shows the beam longitudinal bunch shape detected by a Fast Faraday Cup (FFC) which has a time resolution of 80 ps (bandwidth limitation of 12.5 GHz). It is observed that primary bunches and secondary bunches are arranged alternatively in time. That's because the fundamental frequency of MHB is half of the frequency of RFQ.

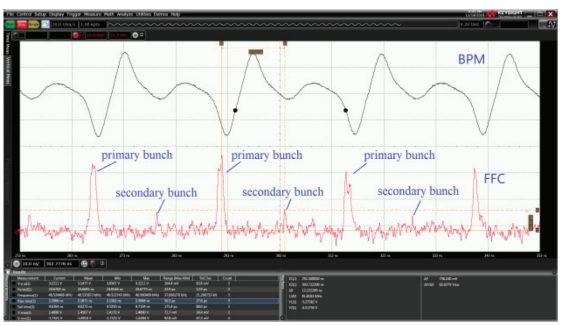

Figure 4: Measured beam longitudinal bunch shape by a Fast Faraday Cup.

ENERGY SPREAD MEASUREMENT

A Silicon detector (SiD) [3] has been installed in the MEBT test chamber to measure the energy spectrum of the beam from the RFQ. However, our measurements indicated a much larger energy spread than that in the simulation. We think the measurements have a large error coming from the scattering gold foil with thickness of 100 nm. Collaborating with nuclear physicists we adopted a nuclear physical method based on $^{12}C(p,\gamma_0)^{13}N$ reaction to measure the energy spread of H_2^+ beam [4]. Figure 5 demonstrates the experimental principle. The beam particles (H_2^+) react with ^{12}C target, producing gamma-ray which is detected by a HPGe detector. Figure 6 shows the measured gamma-ray energy spectrum, where the 6.5-keV peak is from the background gamma-ray radioactivity and its width is due to the intrinsic energy resolution of the HPGe detector. The 22-keV peak is from the p+^{12}C reaction. Its width includes both the effects of the detector resolution and the energy spread of the H_2^+ beam. By analysing the gamma-ray energy spectrum, a maximum energy spread of about ±1.24% was concluded, which is well consistent with the simulation. Figure 7 shows the simulated beam longitudinal phase space of H_2^+ beam after the RFQ, which indicates a maximum energy spread of ±1.25%.

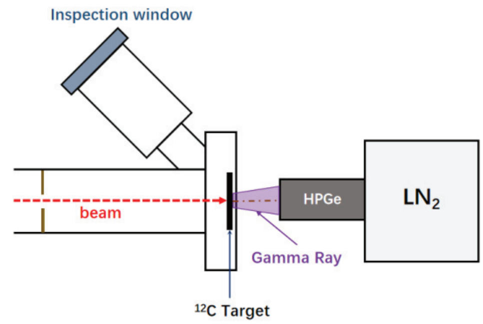

Figure 5: A sketch of experimental setup.

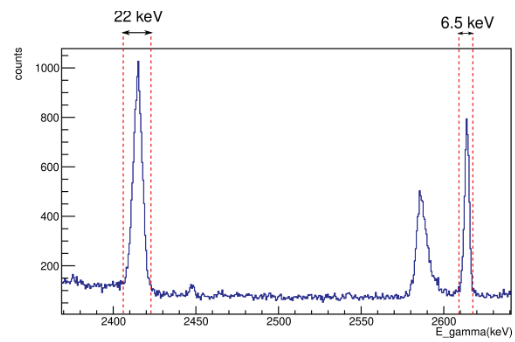

Figure 6: Measured Gamma-ray energy spectrum.

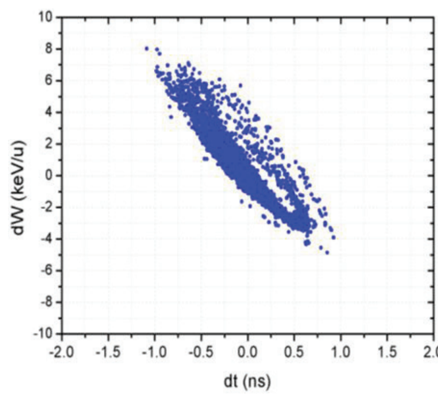

Figure 7: Simulated beam longitudinal phase space of H_2^+ beam after the RFQ.

"COCKTAIL" BEAMS

"Cocktail" beams, like "H_2^++$^4He^{2+}$+$^{58}Ni^{28+}$" and "$^4He^+$+$^{16}O^{4+}$+$^{129}Xe^{33+}$", have important applications in ion beam irradiation research. The mixed beam with multi species is produced and extracted from the source simultaneously. The ion species with same M/Q, such as "H_2^++$^4He^{2+}$", and "$^4He^+$+$^{16}O^{4+}$", run together through the LEBT and RFQ. The "cocktail" beams, composed of different M/Q ions, will be delivered in time sharing mode by changing the currents of the LEBT dipoles alternately, while the voltages of source extraction and acceleration tube are maintained. Therefore the velocities of the ions injecting into the RFQ is different. With the MHB operational, the starting phase of the RFQ should

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also be adjusted accordingly. Two issues should be resolved in "cocktail" beam operation. One is how to control and identify the mixture ratio of the ions with identical M/Q? The other is how fast is the beam switching from one M/Q ion to another?

Two types of "cocktail" beams have been tested. One is for producing the mixed beam of "$^4He^+$&$^{16}O^{4+}$". Both helium and oxygen gases were injected into the source chamber. The mixture ratio of the two ions can be adjusted by controlling the gas inflow into the source and identified by using the SiD. Figure 8 shows a measured energy spectrum for the mixed beam including both He^+ and O^{4+} with the SiD. By taking the cross section of Rutherford scattering of the particle on the gold foil into account, the mixture ratio of the two beams can be deduced according to the counts of the scattered ions on the silicon.

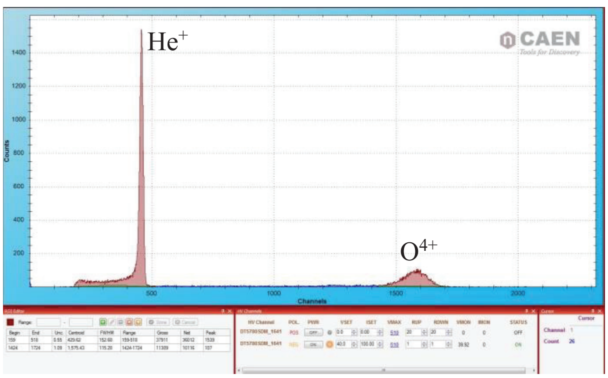

Figure 8: Measured energy spectrum for both He+ and O4+ with the SiD.

Another "cocktail" beam is for production of "$^{86}Kr^{12+}$+$^{14}N^{2+}$" ions, whose M/Q ratios are slightly different. Figure 9 shows the measured charge state distribution after the ion source. Although the N^{2+} and Kr^{12+} ions generally overlap on the plane, they have different orbits. The time sharing mode is to tune the LEBT dipoles to transport the two beams alternately. Figure 10 shows the measured beam current after the RFQ. The switching time is about 300~500 ms, which is limited by the hysteresis effect of the dipoles. In this test, the MHB was not used, therefore the phase of the RFQ was kept unchanged. The transmissions of the RFQ for both ion beams were higher than 97%. However, the acceleration efficiency for $^{86}Kr^{12+}$ is 46%, which is slightly lower than that for N^{2+} (50% acceleration efficiency). That is because both the injection energy of the beam into RFQ and the RFQ vane-voltage were optimized for N^{2+}. Further commissioning of "cocktail" beam should base on the MHB operation. The chopper in LEBT can be adopted to remove the "tails" of beam pulse by setting the time sequence between the dipoles and chopper.

CONCLUSIONS

Beam commissioning with the MHB operational was presented. Beam energy spread was measured for the beam of H_2^+ ion with a nuclear physical method. All the measurements have a good agreement with simulations. As a specific feature of the facility, so-called "cocktail" beams were tested. Future beam commissioning should increase the beam current to mA level, and the beam qualities, especially in the longitudinal direction after being bunched by the MHB, will be studied.

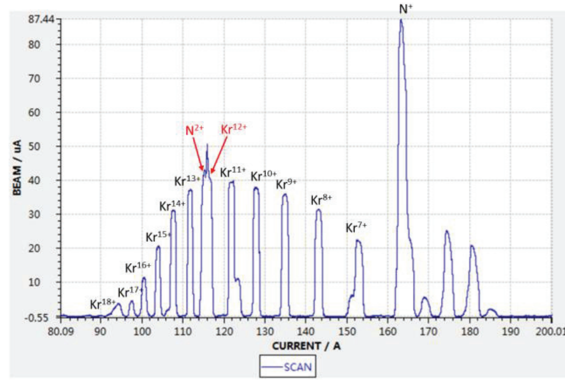

Figure 9: Measured charge state distribution after the source.

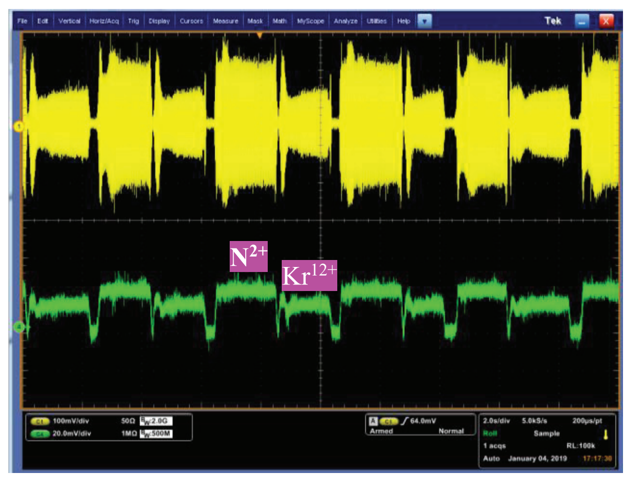

Figure 10: Measured beam currents for "86Kr12++14N2+" "cocktail" beam after the RFQ.

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