DEVELOPMENTS OF ION SOURCES, LEBT AND INJECTION SYSTEMS FOR CYCLOTRONS AT RCNP

#T. Yorita, M. Fukuda, K. Hatanaka, K. Kamakura, Y. Yasuda, S. Morinobu, T. Saito, T. Kume , S. Hara , H.W. Koay, R. Yamanoshita,
RCNP, Osaka University, Osaka, Japan

Abstract

Several developments for cyclotrons at Research Center for Nuclear Physics (RCNP) Osaka University have been carried recently in order to improve the high intense ions in MeV region.

The additional glazer lens on axial injection of AVF cyclotron has been installed to improve the beam transmission to inflector of AVF cyclotron. Additional buncher for the heavy ion injection like Xe beam which requires high voltage bunching in comparison with the proton case also has been installed. Extension of baffle slits on injection line of Ring Cyclotron also has been done to extend the flexibility of injection orbit. Modification of low energy beam transport (LEBT) from ion sources to AVF injection axis including the development of real time emittance monitors also has been carried. This new fast emittance monitor realizes the more efficient tuning of ion source beam which should be matched to acceptance of cyclotron.

INJECTION AXIS OF AVF CYCLOTRON

To improve the beam current accelerated by AVF cyclotron, two components have been installed on the injection axis of AVF cyclotron. Those are additional buncher and glaser lens.

Buncher

To improve the beam current of heavy ion, especially of Xe, additional buncher has been installed on injection axis. In Fig. 1, existing buncher is shown by "b" and located 2550mm above median plane (MP) of AVF. This existing one makes saw wave by RF combining with 1x, 2x and 3x harmonics and maximum saw voltage is +-600V. This buncher can bunch lighter ion which has small m/q and is accelerated with higher frequency, but the voltage or distance from median plane are not enough for heavy ion like Xe. So additional new buncher is installed to help to improve beam current in combination with existing one. This new buncher makes saw wave by charge-discharge circuit with maxmum voltage of 0~+1200 V at 2 MHz operation, 0~+600 V at 6 MHz and 0~+200 V at 20 MHz. The installation position is 4600 mm above the median plane as shown in Fig. 3 by "a".

The beam test has been done for several ions. For the proton with acceleration frequency of 9.32 MHz, the optimized beam current at extraction of AVF cyclotron is 4.1μA with existing buncher only, 0.57μA without any buncher, 3.5μA with new one only, and 5.0μA with both bunchers. For the 12C5+ case with 10.2 MHz RF, the optimized beam current at extraction of AVF cyclotron is 400 nA with existing buncher only, 175 nA without any buncher, 550 nA with new one only, and 760 nA with both bunchers. These show that new buncher works well especially for heavier ion with combination with existing one.

Glaser Lens

To improve the efficiency of AVF injection, additional glaser lens has also been installed. Previously the injection axis has only 3 glasers shown as d, e and f in Fig. 1, it was hard to deliver the beam through the region of 0~2000 mm above the median plane where the beam pipe size is narrow of 57 mm in diameter and only the beam with the size up to 5 mm at the iris slit shown by "g" in Fig. 3 can be delivered. So new additional glaser is installed at the position of "c" shown in Fig. 1. With this new additional glaser, now the beam with the size of 10 mm at the iris slit can be delivered.

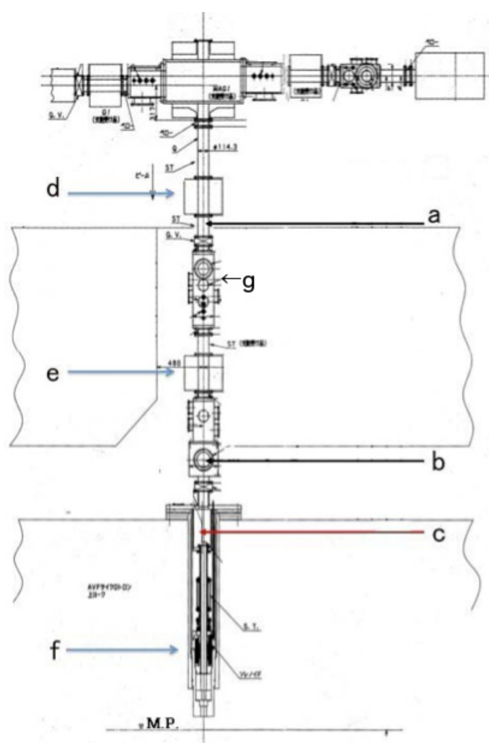

Figure 1: Schematic side view of injection axis of AVF Cyclotron. a: new buncher, b: existing buncher, c: new glaser, d~f: existing glaser, g: iris slit.

#yorita@rcnp.osaka-u.ac.jp

ISBN 978-3-95450-167-0

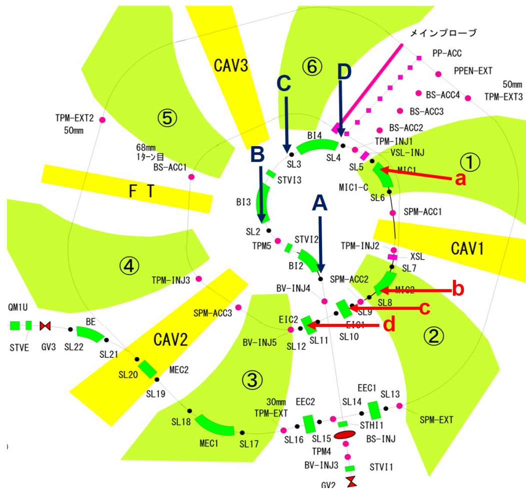

Figure 2: Schematic view of Ring cyclotron: A~D are baffle slits on injection line, a and b are slits of magnetic channel and c and d are electrostatic channel.

INJECTION TO RING CYCLOTRON

To improve the injection efficiency of Ring cyclotron, extensions of baffle slits on beam injection line have been done to expand the flexibility of beam injection orbit. In Fig. 2, A~D show the baffle slits of injection line, a and b are the slit of magnetic channel, and c and d are electrostatic channel. These slits have been extended as far as protection of components works. Figure 3 shows the examples of the extension. After these slit extension, optimum current of MIC2 shown in Fig. 2 has drastically decreased, the current ratio of this MIC2 and analyzing magnet downstream of AVF extraction takes smaller value of 1.3~1.9 than the previous of 2.0~2.5. This means that the optimum trajectory has been changed due to slit extensions.

Figure 3: Examples of baffle slit extension: left figure shows magnetic channel slit extended from 15 mm X 15 mm to 33 mm X 30 mm and right figure shows slit of B in figure 4 which extended from 30 mm X 24 mm to 36 mm X 30 mm.

The injection efficiency represented by the ratio of beam current at BS_ACC1 and BS_INJ shown in Fig. 2 also seems to be improved from 25~65% to 67~97%. To clarify that this efficiency improvement is due to slit extension and to improve the efficiency more, further study should also be done for transport line between AVF cyclotron and Ring cyclotron.

FAST EMITTANCE MONITOR ON LEBT

For higher efficient tuning of ion beam, development of new Pepper Pot Emittance Monitor (PPEM), which can do real time measurement, has been done referring to several another works [1,2]. Existing emittance monitor [3] is fast but it takes 70seconds to get emittance εx, εy, that is far from real time measurement. This new PPEM consists of pepper-pot mask, multichannel plate (MCP), mirror, and CCD camera as shown in left figure of Fig. 4. The material of pepper-pot mask is phosphor bronze of 50 μm in thickness. The hole size of the mask is 70 μm in diameter and hole pitch is 3mm at a regular pattern as shown in right figure of Fig. 4. MCP is HAMAMATSU F2226 and its effective diameter is 77 mm. The fluorescence screen of MCP is P46 (Y3Al4O12:cerium). The wavelength of the fluorescence is 530 nm, and decay time of afterglow to 10% of the peak brightness is 0.2~0.4 μs. The pepper-pot mask and MCP are install on beam axis at right angle. The distance between pepper-pot mask and MCP is 50 mm. Surface reflex mirror is also installed on beam axis at 45 degrees to reflect the MCP screen image to CCD camera via view port with quartz window. Those pepper-pot mask, MCP and mirror are mounted on a plate, and can move away from beam axis by air cylinder when the PPEM doesn't measure the emittance. CCD camera is SONY XCD-U100 for the fast measurement and the image data is transferred to PC via IEEE1394b. Its bit rate is 800Mbps. The CCD size is 7x5.3 mm2 with 1600x1200 pixels. The grey scale depth of the image is 8 bit, that is, 256. The focal length of C mount lens used here is 25mm, and the

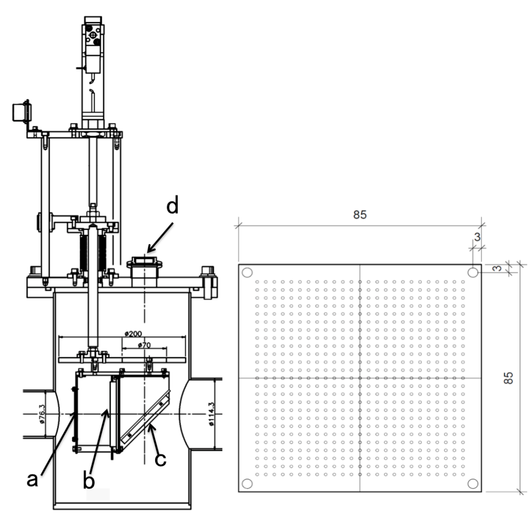

Figure 4: Right figure shows pepper-pot mask and left figure shows the schematic view of PPEM. 'a' is pepper-pot mask, 'b' is MCP, 'c' is mirror and 'd' is view port for CCD camera. 'a'~'c' components are placed on the beam axis.

ISBN 978-3-95450-167-0

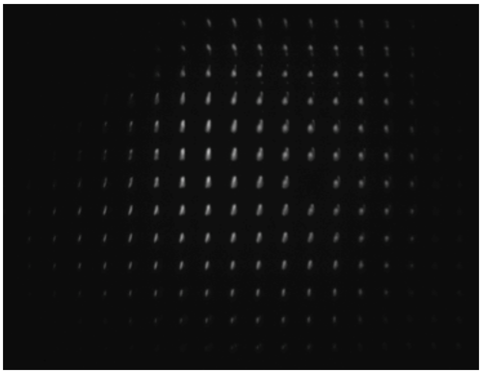

Figure 5: Typical image data. 4 D-distribution is clearly seen.

between the lens and MCP screen is about 400 mm on optical axis, then the image size of 3 mm on MCP screen is corresponding to 45 pixels. The F value of this lens is 1.4 in order to get the bright image as much as possible.

MCP is operated with high voltage (MCP HV) of 600~700V. The voltage between MCP and screen is set to 2kV. Typical image of the PPEM is shown in Fig. 5 and a regular pattern can be seen. Intensities of each elements of the pattern show the beam distribution in (x, y), and every element shows the (x', y') distribution at corresponding each (x, y). So 4-dimensional (4D) distribution G(x, y, x', y') of the beam is directly obtained from this CCD image. And then the phase space distribution g(x, x') can be obtained by integrations of this G(x, y, x', y') over y and y'.

Beam test for PPEM has been done with 2C5+ beam and the measures value of emittance is 70% consistent with existing one. Measurement time of PPEM is now 0.5 second that is fast enough for efficient ion source tuning.

CONCLUSION

Several developments have been done for the purpose of improve the current of the beam accelerated by cyclotrons: additional buncher and glaser have been install on injection axis of AVF cyclotron, the baffle slits on injection of Ring cyclotron have been extended and PPEM monitor on LEBT has been developed. Those components work well. For further improvement of beam current, more detail development with those components and existing components combination would be done.

REFERENCES

[1] A. Pikin, A. Kponou, J. Ritter, V. Zajic, BNL-note C-A/AP/#244 July 2006.

[2] H. R. Kremers, J. P. M. Beijers, and S. Brandenburg, *Rev Sci Instrum.* 2013 Feb;84(2):025117 .

[3] K. Kamakura *et al.*, *IEEE Transactions on Nuclear Science*, vol. 63, no. 3, p. 1710, 2016.