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COMMISSIONING OF A 70 MeV PROTON CYCLOTRON SYSTEM OF IBS, KOREA*

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Abstract

A 70 MeV H- cyclotron system was installed at the Shindong campus of Institute for Basic Science from Nov. 2021. Installation was guided by precision survey so as to locate main components to their final positions. Electrical cables and utility lines were then connected and validation was followed for the control and safety systems. Internal beams were accelerated in May and utilized to isochronize the magnetic field by Smith-Garren method involving a series of magnetic shimming. A beam of 70 MeV was firstly extracted in July and two beam lines were commissioned for the beam energies of 40-70 MeV. Site acceptance tests were carried out with a temporary beam line installed to measure beam profiles at the location of ISOL target, Finally, a maximum beam power of 50 kW was successfully tested for six hours.

INTRODUCTION

Institute for Basics Science (IBS), Korea made a contract with IBA, Belgium for a 70 MeV cyclotron and two beam line systems in July, 2019 as part of Rare Isotope Science Project (RISP) [1, 2]. Table 1 lists main parameters of the cyclotron [3] to be used as a driver of ISOL system. The building was in fact already built prior to this contract, so that pre-survey could be carried out in the end of 2019.

Table 1: Main Cyclotron Parameters

Parameter	Value
Energy	30-70 MeV
I_{max}	750 μA
Number of sectors	2
Hill field B_{max}	1.6 T
Harmonic number	4
Rf frequency	61 MHz
Ion source I_{max}	10 mA
Weight	140 tons

When cyclotron yokes were transported to the Shindong site in Nov. 2021 we started to install entire system. A crane of 1200 tons was used to rig a half of cyclotron yoke weighing around 70 tons because of the need of a long arm. Components were located to their final positions guided by precision survey, which took about two weeks to complete for the cyclotron and main beam line components.

By the end of March 2022, most of utilities were connected to the cyclotron and beam line components. Then connections were verified by involving the control system. Furthermore, since IBS PLC system dedicated to personal safety overlooking building interlocks was already available, secure cables were simply connected to IBA PLC, which handles beam safety enabling beam on and off.

A temporary beam line was installed in a cave to measure beam properties using beam profile monitor at the position of ISOL target. At the end of the beam line, a beam dump was attached along with a collimator defining the beam size. A beam wobbler placed a few meters upstream was used to manipulate beam shapes at the profile monitor. High-power beam tests were then performed in the other cave. Beam tests for site acceptance were completed at the end of Oct.

INSTALLATION AND TESTS

The facility layout is shown in Fig. 1. Two caves are prepared for ISOL uses, but only one is equipped with modules in Cave A that can be remotely handled. Two beam lines were first installed up to the entrance of ISOL tunnels, ending with beam dumps capable of handling up to 50 kW of beam power. Beam line commissioning was performed using 40 and 70 MeV protons to check beam alignments while measuring beam properties.

Spare area shown in Fig. 1 is ready to be used for future expansion when a new beam line is constructed to 2nd extraction port, where switching magnet already exists to adjust beam trajectories of different energies.

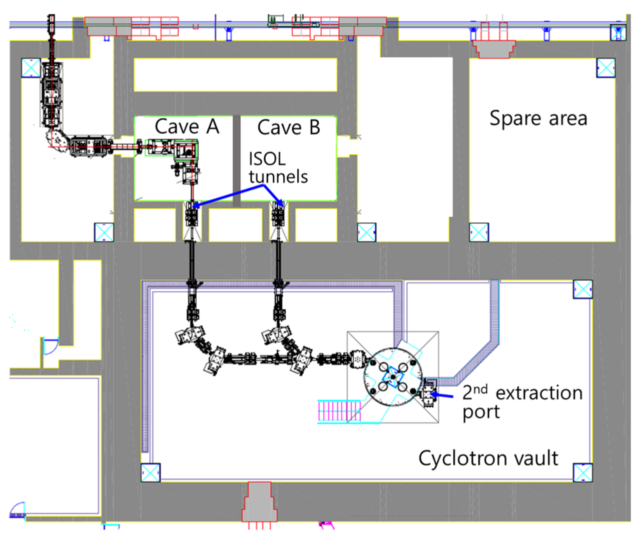

Figure 1: Layout of the cyclotron facility showing two caves and spare area.

Most of utilities such as electricity, compressed air and cooling water were connected by April, 2022. Since power supply room shared by control room is located in first floor

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while the cyclotron vault is located 10 m below ground, cable pulling through vertical penetration holes took a few weeks as new cable trays were also needed. Remaining penetration holes and empty holes were then filled with high-density silicon compounds for radiation shielding. Figure 2 shows a photo of cyclotron vault when installation was nearly completed.

Figure 2: Cyclotron and two beam line components installed in cyclotron vault.

The injection line was tested with a radial probe placed near cyclotron center to stop the beam. A multi-cusp ion source biased at 30 kV can provide a maximum current of 10 mA and its beam shape at the exit was checked with a paper burn. Considerable increase of injection efficiency was observed by turning on rf buncher in the injection line. The efficiency increased almost 10% for a beam current of tens of μA, but it reduced less than a few percent when the beam current is higher than a few hundreds of μA.

RF voltage at the center was checked by measuring beam profiles using a differential radial probe. The design voltage of 50 kV was confirmed by well-defined turn separation and radial gains per turn.

Magnetic shimming using thin steel plates was carried out based on Smith-Garren method, which takes iteration of beam current measurement versus main-coil current as a function of radius. A main-coil current margin of 0.2 A was achieved as shown in Fig. 3 so as to maintain isochronism against some changes of magnet temperature for instance.

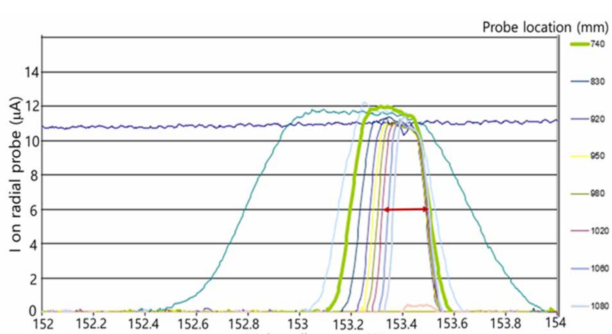

Figure 3: Beam current measurement versus main coil current at different radii known as Smith-Garren method.

BEAM MEASUREMENTS

A beam of 70 MeV was delivered to the beam dump in cave A in early Oct. 2022 for the first time. A temporary beam line was set-up as shown in Fig. 4. The beam line ends at the beam dump attached with a collimator (ϕ2 or 5 cm). Beam profile and position monitors were placed upstream to see the beam shapes and positions, respectively.

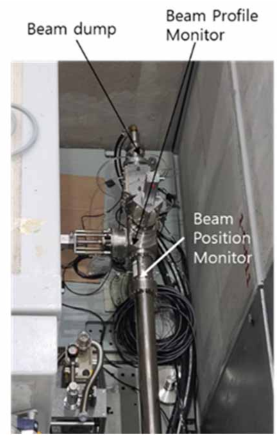

Figure 4: Temporary beam line set-up for beam measurement as site acceptance.

The beam position monitor (BPM), which was built in house, was calibrated using a precision wire system moving in steps of 0.1 mm at a detector lab of Pohang Light Source as shown in Fig. 5. A rf wave of 61 MHz was applied to the wire using waveform generator. For signal handling Libera Spark HL™, which is tuned for single pass hadron beam, was used.

Figure 5: Beam position monitor calibrated using a moving wire system at Pohang Light Source.

The control screen of BPM is displayed in Fig. 6 when a beam was turned on twice during the first beam delivery in Cave A, showing that Δx is around 1 mm and Δy less than 0.5 mm. Off-center of the beam in horizontal direction is apparent. The beam current read at the beam dump was around 10 μA, which allows calibration of beam current reading by BPM.

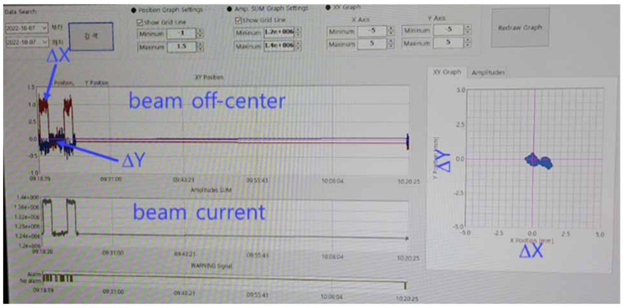

Figure 6: Display of beam position monitor's control screen showing beam off-centers in both transverse planes and also beam current. On the right-hand side dots of 2D beam positions accumulated are shown.

A beam profile measured at 70 MeV in Cave A without wobbling is shown in Fig. 7. One sigma can be varied by controlling focusing quadrupoles to a range of 1.5 ~ 6 mm for both transverse planes. This profile monitor uses two moving wires made of $\phi = 0.5$ mm thick tungsten and takes a few seconds to scan each plane.

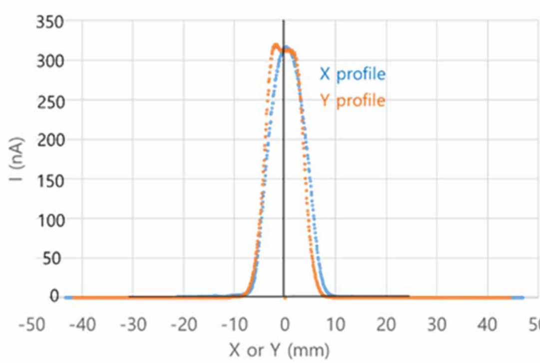

Figure 7: Beam profiles measured at a waist without beam wobbling applied.

Before wobbling, the beam shapes of both planes should be controlled as similar, so that the wobbled beam shape can be axially symmetric. Beam shapes formed by turning on the wobbler at two energies of 40 and 70 MeV are shown in Fig. 8. Two different beam profiles flat and hollow in the center are demonstrated with the controls of beam width. Wobbling frequency is 60 Hz.

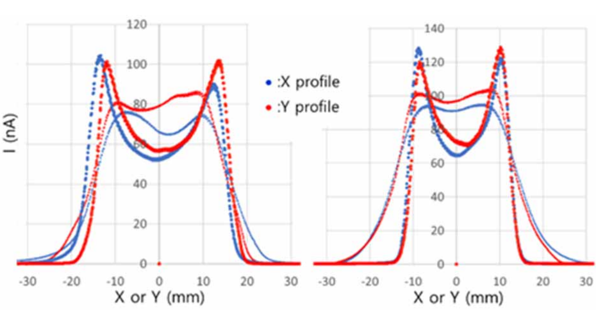

Figure 8: Two different beam profiles obtained by wobbling at two different energies of 40 MeV (left) and 70 MeV (right).

Tests of high-power beams were performed in Cave B using wobbling to reduce maximum power deposit on the vacuum window made of Ti. Transverse spread of the beam by wobbling was monitored by beam losses at the 4-jaw collimator. Before performing this high-power test for six hours, ISOL tunnel of Cave B was heavily shielded using concrete blocks around the beam dump to localize radio-activation. Screen display of beam currents measured at the dump and 4-jaw collimator is given in Fig. 9. During six-hour operation there were many rf voltage trips, but overall the system operated stably with quick recovers.

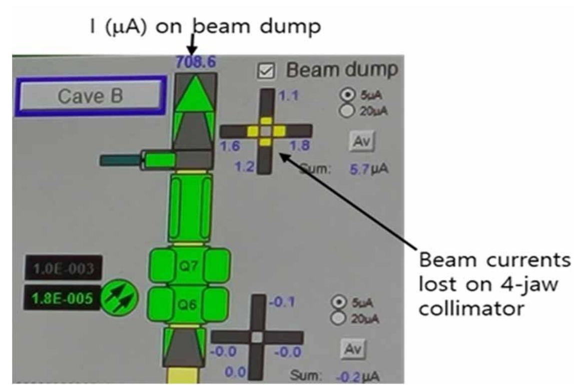

Figure 9: Screen display of beam currents measured at the beam dump and 4-jaw collimator.

CONCLUSIONS

A 70 MeV cyclotron system was installed at the Shindong campus of IBS from Nov. 2021. Beam tests started from May 2022 and ended in the end of Oct. It took about three years from contract to completion. The cyclotron and beam line in Cave A is now prepared to deliver a beam for ISOL operation. The wobbler will be used to shape beam profiles for ISOL target as tested for acceptance. Beam tests were carefully planned to minimize unnecessary facility activation and radiation exposure to workers. In Cave B the maximum beam power test was finished in the next day after the beam current extracted reached over 700 μA for the first time. Since 2nd extraction port is currently not used, future addition of a new beam line will allow a full operation of the cyclotron sending two beams at the same time for different applications.

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