

Operation Status of Beam Test Stand at KOMAC

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1. Introduction

The RFQ-based compact accelerator at KOMAC which is named as Beam Test Stand (BTS) provides beam acceleration up to 1 MeV/u. Designed to support a mass-to-charge ratio (A/q) of up to 2, this system functions as a preliminary testing platform for the 100 MeV main proton accelerator, enabling the evaluation of new hardware and control strategies. In addition, the facility is frequently utilized for beam diagnostics and beam physics research, benefiting from its versatile operational capabilities. The present paper introduces the diverse range of studies performed using the KOMAC beam test stand during the last three years.

2. Beam Test Stand (BTS)

This section provides a brief introduction to the Beam Test Stand (BTS) before detailing the specific research conducted. The Beam Test Stand (BTS) is an RFQ-based accelerator system consisting of an ion source, a Low Energy Beam Transport (LEBT) section, an RFQ, and beam transport lines and figure 1 shows the layout of Beam Test Stand.

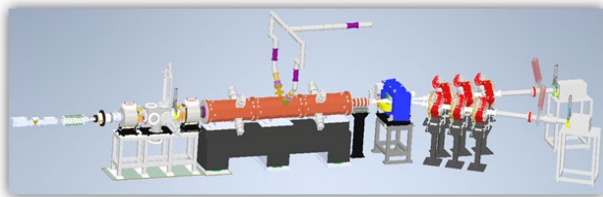


Fig. 1. Layout of Beam Test Stand (BTS).

The ion source extracts a beam with an energy of 25 keV/u and delivers a current of approximately 20 mA for proton beams during the flat-top period. The LEBT includes two solenoids and one diagnostic chamber to match the beam from the ion source to the RFQ. The RFQ is designed to accelerate the 25 keV/u beam to 1 MeV/u and can accommodate ions with a mass-to-charge ratio (A/q) of up to 2. Two main transport lines are available, including a straight line and a 30-degree bending line. The straight line is currently the primary choice for operation and is equipped with seven magnetic quadrupoles.

3. Research on Beam Diagnostics

The beam test stand has been most actively utilized in the field of beam diagnostics. This section introduces various beam diagnostics research projects conducted at the BTS.

3.1 Allison scanner development

The first study focuses on the development of an Allison scanner. This instrument is widely recognized for its ability to directly measure beam phase space in low-energy regions. KOMAC designed and fabricated an Allison scanner for integration into the 100 MeV proton accelerator. The main 100 MeV accelerator operates primarily for user services, which necessitates thorough pre-installation testing of new diagnostic hardware. Researchers therefore constructed a prototype system and performed experimental evaluations at the BTS to verify its operational reliability and measurement accuracy.

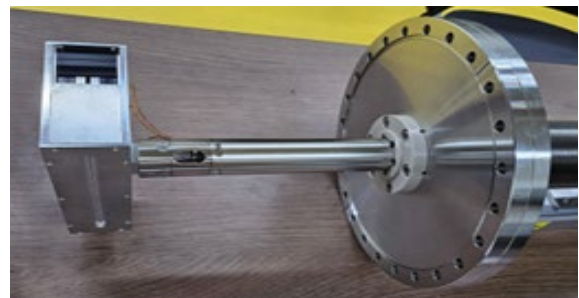


Fig. 2. Photo of prototype Allison scanner.

Figure 2 displays the Allison scanner prototype. Beam experiments using this prototype identified a manufacturing error in the scanner head. The actual slit width measured approximately 0.3 mm despite a design specification of 0.1 mm, which resulted in high uncertainty regarding the various beam size. These findings were incorporated into the design and fabrication of a new Allison scanner for the 100 MeV proton accelerator. The following figures illustrate the newly fabricated Allison scanner installed on the 100

MeV proton accelerator and the measurement results for x axis.

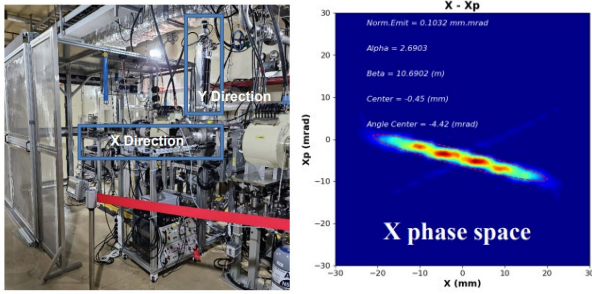


Fig. 3. Photo of installed Allison scanner at 100 MeV proton linac (left), Measured phase space at 100 MeV proton linac (right).

3.2 4D phase space measurement with multiple slit

Another study related to beam diagnostics at the BTS involved four-dimensional (4D) beam phase space measurement using multiple slits. Modern proton accelerator development focuses on increasing beam current to improve overall output power. Effective control of beam loss is essential for ensuring system reliability at these higher currents, which creates a growing need to understand high-dimensional beam phase space beyond standard 1D or 2D perspectives.

KOMAC performed validation experiments at BTS to demonstrate high-dimensional phase space measurement techniques in response to these technical requirements.

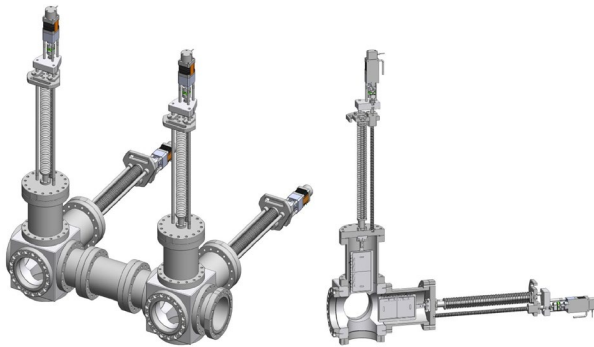


Fig. 4. Schematic of 4-dimensional phase space measurement system with multiple slits.

Figure 4 presents the schematic of the 4-dimensional phase space measurement system. This system includes four slits and one Faraday cup. Two of the slits are dedicated to the x-direction, while the other two control the y-direction. Direct measurement of the 4D phase space is achieved by scanning all four slits sequentially. An amplifier was positioned after the Faraday cup to enable detection since the beam current decreases to an extremely low level after passing through the four slits. The measurement process required approximately 3 to 4 days because it involved scanning a combination of all four slits. The measurement results are shown below.

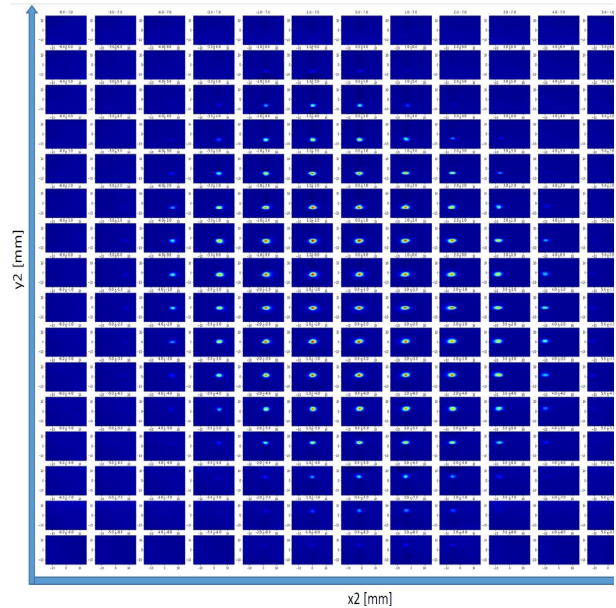


Fig. 5. Measurement result of 4-dimensional phase space measurement system with multiple slits.

3.3 Virtual pepper pot method development

The pepper-pot measurement method is a highly useful technique because it can determine the 4D beam phase space in a single measurement. Structural limitations exist, however, as improving the resolution of the pepper-pot method requires reducing the hole size of the mask. Smaller hole sizes inherently increase fabrication difficulty and decrease beam signal strength, which complicates noise filtering. The virtual pepper-pot method is one proposed alternative to overcome these challenges. This approach utilizes an L-shaped slit to measure x and y beamlets independently. Measured x and y beamlets are subsequently overlapped to generate results equivalent to those of the standard pepper-pot method. Previous studies have demonstrated this technique for electron beams, but validation for proton beams has not yet been established. Researchers installed both a standard pepper-pot and a virtual pepper-pot system at BTS to demonstrate the feasibility of the virtual method for proton beams and to verify its measurement accuracy.

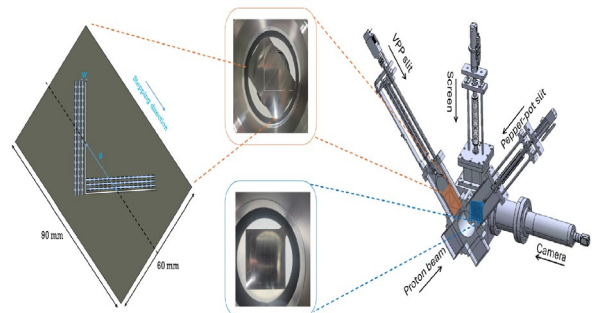


Fig. 6. Schematic view of pepper-pot & virtual pepper-pot measurement system.

Figure 6 shows the measurement systems for both pepper-pot and virtual pepper-pot. The left side of the setup includes an L-shaped system for the virtual pepper-pot, which is adjusted by a step motor. The right side features a pepper-pot slit that is controlled through pneumatic pressure. A quartz screen and a CCD camera positioned behind these components measure the beamlets generated by the L-shaped or pepper-pot slits.

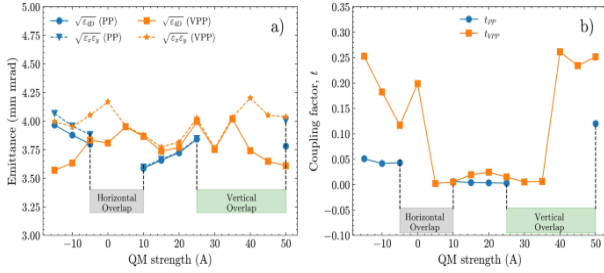


Fig. 7. Measurement result for pepper-pot and virtual pepper-pot system and its comparison.

Measurements were conducted while varying the settings of the quadrupole magnets, and Figure 7 illustrates these results. Data from the pepper-pot and virtual pepper-pot methods show very similar values. The experiments further confirmed that the virtual pepper-pot method can perform measurements even in regions where the beam size is extremely small. This capability allows for measurements in ranges where the standard pepper-pot method is not feasible.

4. Miscellaneous Research Applications

4.1 Pulsed plasma ion source development

Currently, the ion source of the proton accelerator operates at KOMAC extracts a pulsed beam by applying continuous wave (CW) RF power and operating the extraction and bias power supplies in pulsed mode. However, this method has the drawback of requiring high-voltage switching—specifically, 25 kV for the BTS ion source and 50 kV for the 100 MeV proton accelerator. Furthermore, the application of CW RF power poses disadvantages for thermal management and accelerates the degradation of the ion source. Accordingly, we aim to develop a pulsed ion source by operating the RF in pulsed mode; as a preliminary step, we have developed an ion source that operates both the RF and the high-voltage switches in pulsed mode.

The ion source itself, including the plasma chamber, extraction electrodes, and solenoids, was kept unmodified. Previously, RF power was applied in CW mode using a microwave generator; however, in this work, we adopted a method of injecting pulsed RF using a solid-state power amplifier (SSPA).

Utilizing the aforementioned configuration, installation and beam extraction tests were conducted at the BTS. The installed setup is shown in below figure.

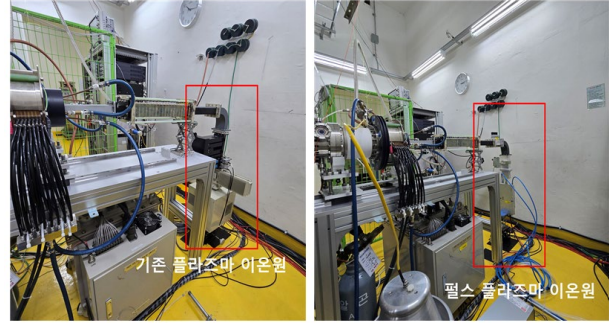


Fig. 9. Comparison between original ion source and pulsed plasma ion source.

Beam extraction experiments were conducted for both 25 keV and 50 keV extraction energies, employing repetition rates of 1 Hz and 10 Hz, which are typically used in standard accelerator operations. Figure 8 illustrates the results from one specific case of the beam extraction tests. In this instance, the repetition rate was 1 Hz, the extraction voltage was 50 kV, and the extracted beam current was measured to be approximately 20 mA.

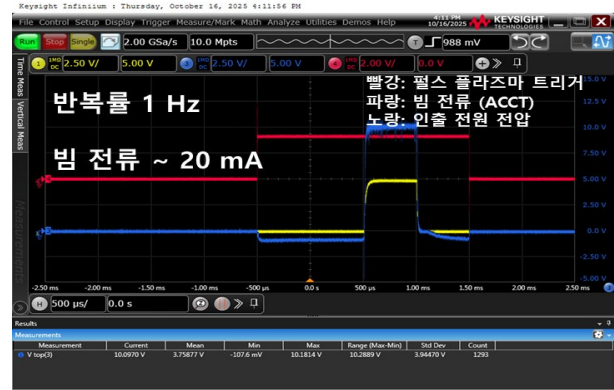


Fig. 8. Experiment result for pulsed plasma ion source (1 Hz, 50 keV)

4.2 Space charge compensation with various gas

The LEBT section of the BTS features a diagnostic chamber containing an Allison scanner. By employing an ADC, the scanner allows for the acquisition and storage of time-dependent beam data. This capability was leveraged to study the beam physics of space charge compensation in the LEBT by using Allison scanner.

Space charge compensation is widely applied in many high-current proton accelerators to mitigate space charge effects. Although inert gases such as Ar and Kr are frequently used, there has been limited quantitative measurement regarding the specific numerical effects of these gases. Accordingly, by varying the amount of injected gas, we conducted time-resolved measurements using an Allison scanner to observe the changes in the beam characteristics resulting from space charge compensation.

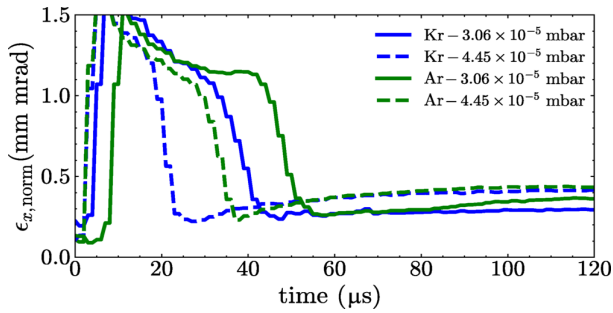


Fig. 9. Time resolved measurement result with various injected gas.

The figure above shows the results of time-resolved measurements using an Allison scanner when different types of gases were injected at various pressures. It can be observed that Kr, which has a larger cross section, exhibited a faster stabilization time for space charge compensation; however, the emittance values after reaching stabilization were generally similar across the different cases.

5. Summary

The Beam Test Stand (BTS) has been a site of active research and equipment development over the past few years. This paper briefly introduces those activities, which include the development of an Allison scanner [1] and the measurement of 4D phase space using four slits [2]. Furthermore, a beam diagnostic technique based on the virtual pepper pot method was developed [3]. In addition to these diagnostic advancements, a pulsed plasma ion source was developed, and space charge compensation was investigated through time-resolved phase space measurements using the Allison scanner in the LEBT section [4]. These diverse research efforts contribute significantly to enhancing the performance and operational stability of the 100 MeV proton accelerator. In the future, the BTS will continue to be utilized for various research and development purposes.

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