CONSTRUCTION OF THE 6 MV TANDEM ACCELERATOR SYSTEM FOR VARIOUS ION BEAM APPLICATIONS AT THE UNIVERSITY OF TSUKUBA*

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Abstract

The 12UD Pelletron tandem accelerator at the University of Tsukuba was completely destroyed by the Great East Japan Earthquake on 11 March 2011. A replacement has been designed and constructed at the university as part of the post-quake reconstruction project. We planned to install a new horizontal-type 6 MV tandem accelerator. A three-year plan for the new accelerator's construction was started in 2012. The new accelerator system consists of the 6 MV tandem accelerator, four new ion sources, the Lamb-shift polarized ion source, and twelve beam courses. The 6 MV tandem accelerator will be used for various ion beam applications. Routine beam delivery and experiments will start in 2015.

INTRODUCTION

The University of Tsukuba's Tandem Accelerator Complex (UTTAC) is a major center of ion beam research in Japan. We had the 12UD Pelletron tandem accelerator, a 1 MV Tandetron accelerator, a 1 MV high-resolution Rutherford back scattering (RBS) system, and a positron annihilation spectrometry system. The 12UD Pelletron accelerator was a vertical-type large tandem accelerator made by National Electrostatic Corp. (NEC), USA; and was installed at UTTAC as a first Pelletron tandem accelerator in Asia in 1975 [1]. Its main accelerator tank was 17.9 m long and 4.8 m in diameter; its total weight was 120 metric tons. The maximum terminal voltage of 12 MV was available for various ion beam applications.

The Great East Japan Earthquake (9.0 magnitude) of 11 March 2011 severely damaged the 12UD Pelletron tandem accelerator [2]. A seismograph at the University of Tsukuba (part of the National Research Institute for Earth Science and Disaster Prevention, Kyoshin-Net infrastructure [3]) measured the earthquake's maximum acceleration as 371.7 cm/s^2 (gal) and its duration as about 300 s. The vertical-type tandem accelerator was damaged by the sustained shock of the earthquake, and all the high-voltage accelerating columns collapsed in the accelerator tank. Repairing the 12UD Pelletron tandem accelerator was not feasible, and it was shut down in 2011.

We planned to install a new horizontal-type 6 MV tandem accelerator in the experimental room on the first floor to replace the damaged accelerator. The 6 MV tandem accelerator will be used for various ion-beam research projects, such as accelerator mass spectrometry (AMS), microbeam applications, particle-induced X-ray emission (PIXE) analysis for geoscience and materials research, heavy ion RBS and elastic recoil detection analysis, nuclear reaction analysis for hydrogen in materials, and high-energy ion irradiation for semiconductor and nuclear physics.

In this paper, we report the construction status of the 6 MV tandem accelerator and the research programs at the University of Tsukuba.

DESIGN OF THE 6 MV TANDEM ACCELERATOR FACILITY

All experimental equipment is installed on the first floor at UTTAC. Figure 1 gives an overview of the equipment on the first floor. The new accelerator system consists of a horizontal-type 6 MV tandem accelerator, four new ion sources, the Lamb-shift polarized ion source (S1 in Figure 1), and five new beam courses. After the 105° analyzer magnet, the beam line is separated in two directions by the 40° switching magnet in the accelerator room. A high-energy beam transport line equipped with a vertical ion-irradiation system is connected from the accelerator room to the existing experimental room, which houses seven beam courses. A total of 12 beam courses will be available for nuclear physics, ion beam applications, and AMS.

The Lamb-shift polarized ion source was used as the injector of polarized proton and deuteron beams to the old tandem accelerator on the 9th floor at UTTAC [4]. After the earthquake, this ion source was moved to a new experimental building outside the accelerator building. In the accelerator room, there are four negative-ion sources. In Figure 1, S2 is a high-current Cs-sputtering negative-ion source (SNICS II), and S3 is a radio frequency charge exchange ion source (Alphatross) to produce He$^-$ beams for injection into the 6 MV Pelletron tandem accelerator. S4 and S5 are the multi-cathode Cs-sputtering negative-ion sources (MC-SNICSs) for AMS.

In the accelerator room, the ion beam analysis (IBA) system equipped with a high-precision four-axis goniometer is located on the L1 beam course. The L2 beam course has a large environmental testing chamber (1 m diameter) that will be mainly used for the radiation-resistant testing of semiconductor devices for space satellites. The L3 beam course is constructed as the microbeam system for high-sensitivity PIXE analysis of structural materials. The L4 beam course is the rare-particle detection system for AMS. The L5 beam course is a general-purpose line for ion beam applications. Figure 2 shows a photograph of the accelerator room.

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In the experimental room, there are two large magnetic spectrographs (A6 and A7 beam courses) for nuclear physics. Other beam lines are used for ion beam channeling (A2 beam course), 3D fabrications with swift heavy ions (A3 beam course), and hydrogen analysis (A4 beam course). There is also a large general-purpose chamber (A5 beam course).

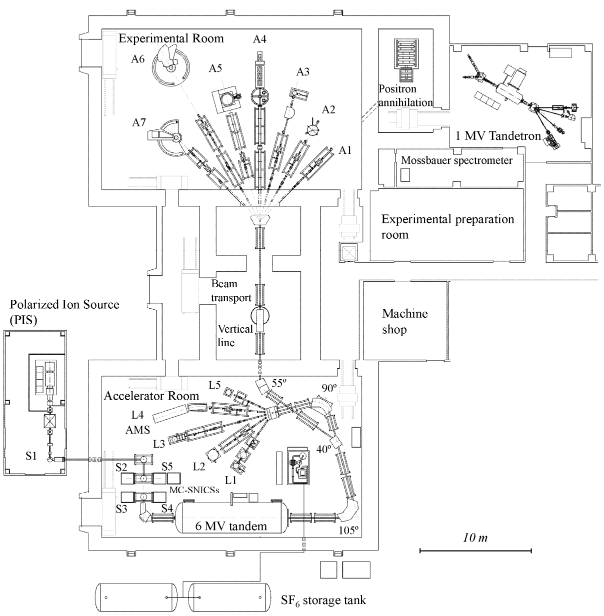

Figure 1: Overall view of the first floor at UTTAC.

Figure 2: Full view of the accelerator room.

DETAILED DESCRIPTION OF THE 6 MV TANDEM ACCELERATOR

Injector (Ion Sources)

At the low-energy side, the injection energy from the ion sources is 65 keV. There are three 90° retractable electrostatic spherical analyzers (ESAs) with a 200 mm radius and 35 mm plate separation to provide for each of the five ion sources. The 90° high-mass-resolution double-focusing magnetic analyzer with a 457 mm radius has a mass energy product of ME/Z^2 = 15 amu MeV with a mass resolution of up to 200. A 15 kV pulsed power supply is provided to bias the 90° magnetic analyzer chamber for the sequential injection of up to four different beams. Downstream of the 90° magnetic analyzer, two movable offset Faraday cups are located to measure particle transmission through the accelerator and the beam intensities of lower-mass beams during higher-mass beam injection. In front of the accelerator tank, there is a beam attenuator to adjust the transport for high-beam current by decreasing one-tenth of the beam current. Figure 3 details the injection system of the 6 MV tandem accelerator.

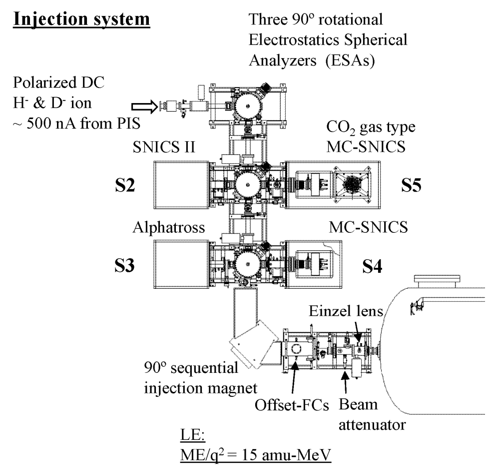

Figure 3: Injection system of the 6 MV tandem accelertor.

Accelerator

The main accelerator (model 18SDH-2 Pelletron accelerator developed by NEC, USA) is a dual acceleration electrostatic accelerator. The accelerator tank is about 2.74 m in diameter and 10.5 m long. Figure 4 shows a cross-section drawing of the accelerator tank. It was delivered to Tsukuba in March 2014.

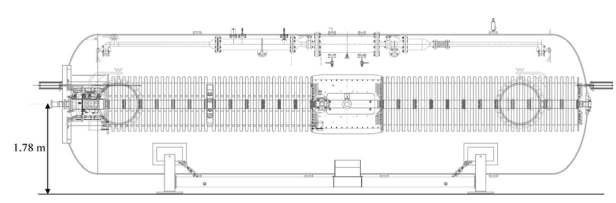

Figure 4: Cross-section drawing of the accelerator tank.

The high-voltage terminal has a long gas stripper tube assembly and a foil changer with 80 foil holders for equilibrium stripping ions. Carbon stripper foils will be mainly used for heavy ions to obtain a high charge state. The stripper gas canal is about 10 mm in diameter and 95 cm long. The generator operates reliably to terminal voltages as high as 6.3 MV. Stability is estimated to be better than

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1 kV at a 6.0 MV terminal voltage. Maximum beam currents are predicted to be up to 50 μA for heavy ions. Specifications for the 6 MV tandem accelerator are shown in Table 1. It will be capable of accelerating various ions with a wide range of energy. Figure 5 shows an estimation of ion beam energy range.

Table 1: Specifications of the 6 MV Tandem Accelerator

・Model: 6 MV Pelletron Tandem (18SDH−2, National Electrostaics Corp., USA)		
・Accelerator Tank Size:	Length:	10.5 m
	Diameter:	2.74 m
	Line Height:	1.78 m
	Weight :	17,420 kg
・Terminal Voltage:	0.5 − 6.0 MV	
・Voltage Ripple:	≤ 750 V p−p at 6.0 MV	
・Voltage control: GVM & Slit Current Feedback System		
・Maximum Beam Current:	H :	3 μA
	Heavy ions:	~50 μA
・Terminal Stripper:	Gas (Ar or N_2)	
	Foil Unit (80 Foil Holders)	
・Insulation Gas:	SF_6 (0.6 MPa)	
・Beam Courses : 12 Lines and Vertical Transport Line		
・Ion Sources:		
Cs Sputtering Negative Ion Sources	NEC SNICS II	
	NEC MC-SNICS	
	NEC CO_2 Gas Type MC-SNICS	
RF Ion Source (NEC Alphatross)		
Lamb-shift Polarized Negative Ion Source		
・Mass Energy Product (ME/Z^2):	15 amu MeV (LEBT)	
	176 amu MeV (HEBT)	

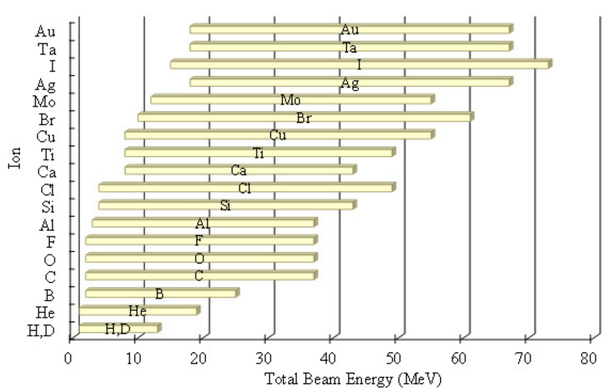

Figure 5: Ion beam energy range for the 6 MV tandem accelerator.

High-energy Beam Transport Line

A high-energy beam transport line after the accelerator has a mass energy product of ME/Z^2 = 176 amu MeV. The 105° analyzer double-focusing magnet (1.27 m radius) has a resolution of M/ΔM = 725. After the 105° analyzer magnet, three movable Faraday cups are set to intercept precisely the various beams of interest. A 90° deflection double focusing magnet (1.27 m radius) is provided along the beam line. Two magnetic quadrupole triplet lenses are arranged to control divergence and focus ion beams between the 105° analyzer magnet and the switching magnet. The switching magnet is installed at the end of the beam line in the accelerator room, and has five beam ports.

Rare-particle Detection System for AMS

One of the important researches in ion beam application is AMS for the 6 MV tandem accelerator. The rare-particle detection system (Tsukuba 6 MV AMS system) is set on the −20° port on the switching magnet (L4 beam course). A 22.5° ESA (3.81 m radius) is provided to filter out unwanted ions whose mass energy product (ME/Z^2) is the same as the rare isotope of interest. The 22.5° ESA has a resolution of E/ΔE = 200. A five-electrode gas ionization detector is installed on the end station of the rare-particle detection system. The Tsukuba 6 MV AMS system is expected to measure all standard AMS species routinely (e.g., ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{129}I) [5].

CONCLUSION

The 12UD Pelletron tandem accelerator that was over 35 years old at the University of Tsukuba was destroyed by the Great East Japan Earthquake in 2011. It was replaced by the new 6 MV tandem accelerator that was installed at UTTAC in 2014, and then used to regulate beam transport. This new multi-purpose tandem accelerator will see various uses, including, AMS, IBA, ion irradiation, and nuclear physics. The new system will start routine experiments on ion beam applications in 2015.

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