Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Preliminary Measurement of Beam Power Transmission in KSTAR Neutral Beam Test-Stand

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1. Introduction

A neutral beam test-stand (NBTS) was constructed to develop 300-sec deuterium beam extraction of 120 kV/65 A as an auxiliary heating system of KSTAR. The ion source is composed of a plasma generator and a tetrode accelerator. The beamline components include an optical multi-channel analyzer (OMA) duct, a neutralizer, a bending magnet (BM), an ion dump, a calorimeter, and a cryo-sorption pump system. Beam deposition along the NBTS has been measured by water flow calorimetry (WFC) and 96 % of the extracted beam power ($V_{acc} \bullet I_{acc}$) was counted for a beam of 97 kV/22.2 A. Maximum power transmission efficiency, which is the ratio of transmitted power on the calorimeter to the extracted beam power, was 0.77 with an optimum perveance of 1.1 microperv.

2. Experimental Setup

2.1 Prototype Long Pulse Ion Source (LPIS)

The prototype LPIS consists of a magnetic bucket plasma generator and a set of tetrode accelerators with circular copper apertures [1]. The arc discharge of LPIS was operated successfully up to an arc power of 120 kW (100 V/1200 A) with hydrogen and deuterium gases. Before the initiation of arc discharge (about 0.1 s), filament heating voltage was step-up of approximately 10%. This process is essential to escape the mode change of arc discharge by the initially excessive filament heating. The step operation of filament heating was not necessary for the discharge of deuterium gases.

The accelerator of LPIS was cooled by water supply system of 5 bar. Two separate cooling paths are provided for each electrode, and the accelerator column has been designed for a maximum pressure of 10 bar.

2.2 Neutral Beam Test-Stand (NBTS)

All the beamline components are actively cooled by a 2 MW water cooling system. The NBTS has four cryo-sorption pumps, and the pumping speed of each cryo-pump is 90,000 l/s. The flow rates of cooling water in the accelerator column and the beamline components are summarized in Table 1 with an input water pressure of 5 bar.

3. Analyses and Results

3.1 Beam Extraction from LPIS

An arc discharge of 100 kW supports a 3-sec hydrogen beam of 97 kV/22.2 A, as shown in Fig. 1. The accelerating and decelerating voltages, which are tied firmly on time sequence, were always applied before the arc discharge. Thus, the ion beams were initiated by the arc discharge. The extracted beam reaches a flat-top in 1~2 seconds. The gradient grid voltage was 81% with respect to the accelerating voltage, and the decelerating voltage was applied with 2.5 kV

Table 1. Water flow rates of accelerator column and beamline components.

NBTS Component	Flow Rate (LPM)
Plasma Grid	6.9, 6.9
Gradient Grid	6.1, 6.0
Suppressor Grid	7.4, 6.4
Exit Grid	7.1, 5.3
OMA duct 1, 2	226, 242
Neutralizer	940
BM scraper	112
Ion Dump 1, 2, 3	865, 955, 970
Calorimeter	970

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3.2 WFC of Beamline Components

The WFC is used typically for measuring the extracted beam energy. By monitoring the temperature rise of cooling water, one can estimate the total deposited energy as the following:

$$Q = \int_0^\infty \dot{m} c_p \Delta T(t) dt ,$$

where, $\dot{m}$ is the mass or flow rate of the water, c_p is the specific heat of water (4.2 J/g^{o}C at room temperature), ΔT is the time dependent water temperature difference. The WFC is an absolute measurement of beam power delivered to a target and other components

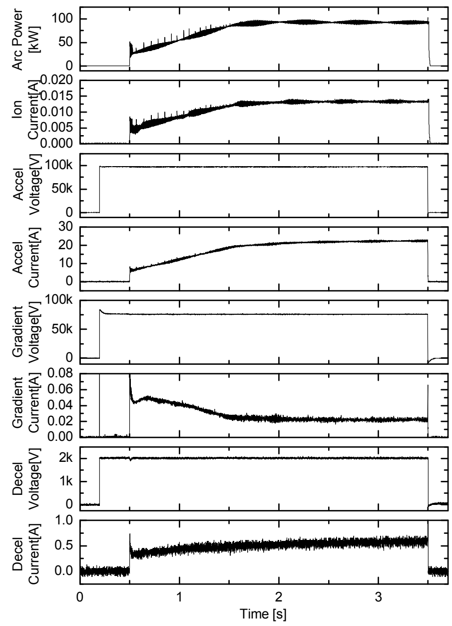

Figure 1. Output waveforms of 97 kV/22.2 A hydrogen beam with an arc power of 100 kW for 3 seconds

The beam power loss within the accelerator column was about 2.3 %. This loss is due to beam ion collection into electrodes and also the backward acceleration of resulting electrons produced by the ionization in an accelerator column. Beam power is scraped off by the walls while passing along the OMA duct and the neutralizer (total length is about 2.5 m). Beam area is limited again to the BM scraper located at the downstream side of neutralizer and in front of the BM entrance. The BM structure is installed with 45 degree to the beam axis. Total heat load on the beamline components was about 96.5 % with 3-sec hydrogen beam of 97 kV/22.2 A.

A Maximum power transmission efficiency, which is the ratio of transmitted energy on a calorimeter to an extracted beam energy, was 0.77 with 3-sec hydrogen beam at 80 kV. This result indicates an optimum perveance of 1.1 microperv (1 microperv=10^{-6} A•$V^{-3/2}$), as shown in Fig. 2. The power transmission rates of an accelerator and beamline components are summarized in Table 2. The simulation results of beam power transmission are shown in Table 2 as estimated by a beam transmission code (BTR code). BTR code was assumed a beam divergence of one degree. In BTR code, the power loss in the accelerator column is not included. The total power accounting by the BTR is 96.4 % excluding the power loss in the accelerator column. The simulation results of BTR code are used for the design basis of beamline components in the NBTS.

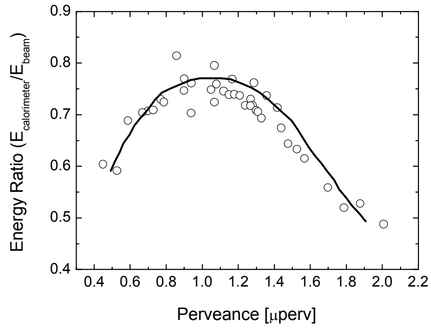

Figure 2. Power transmission efficiency on the calorimeter with 3-sec hydrogen beam at 80 kV, as a function of beam perveance.

Table 2. Beam power accounting of NBTS components, normalized to accelerator (V_{acc}•I_{acc}).

NBTS Component	Power Loading (%)	BTR rate (%)
Plasma Grid	1.4	
Gradient Grid	0.37	
Suppressor Grid	0.07	
Exit Grid	0.46	
OMA duct 1, 2	4.3, 6.0	8
Neutralizer	8.3	5
BM scraper	4.3	1.6
Calorimeter	73.6	81.8
Total	98.8	96.4

It was found that is not exactly symmetric on the left-right scrapers as measured the BM TC and the OMA duct TC. This non-symmetry of heat load in the beamline components believed due to mis-alignment of beamline components and the accelerator column.

4. Conclusion

Power transmission rates of accelerator column and beamline components were measured initially by using the water flow calorimetry in the NBTS. Maximum power transmission rate of 77 % to the calorimeter was obtained at an optimum beam perveance. It was found that the heat load of horizontal direction was not symmetry, and this problem can be solved by properly aligning the beam path in the NBTS. Total power accountability of 96.5 % was achieved.

REFERENCES

[1] Doo-Hee Chang, Seung-Ho Jeong, Byung-Hoon Oh, Kwang-Won Lee, and Chang-Seog Seo, Plasma Sources Sci. and Technol., Vol.14, p.336, 2005.