# A very high perveance NBI system development for VEST tokamak

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## 1. Introduction

The VEST (Versatile Experiment Spherical Torus)[1] is a spherical tokamak (ST), which has been operating in Seoul National university. One of several research goals of the VEST is achieving an advanced tokamak mode operation. An advanced tokamak operation can be attained when the high beta plasma and the high bootstrap current plasma are realized simultaneously[2]. A spherical tokamak has advantages of high beta, compactness and cost effectiveness[3]. Provided that proper heating power and current drive will be supported, it is not difficult to get the high beta plasma with a high bootstrap current ratio in a spherical tokamak. In order to provide the sufficient heating power for an advanced tokamak operation in the VEST, an NBI system was developed, which can deliver the 0.5MW hydrogen neutral beam into VEST tokamak.

The NBI system was originally designed to deliver two beams of 0.3MW in both co- and counter-current directions[4]. However, it was found from careful simulations that the orbit loss is more serious in the counter-beam than in the co-beam[5] (see Fig.1a), and the shine-through loss is also significant at a beam energy of over 20keV owing to low plasma density of the VEST[5] plasma (see Fig.1b). Therefore, the NBI system was finally modified into a one-beam (co- direction beam) system, still providing a total neutral beam power of 0.5MW. To extract the neutral beam power of 0.5MW at 20kV from an ion source, a very high perveance beam is necessary.

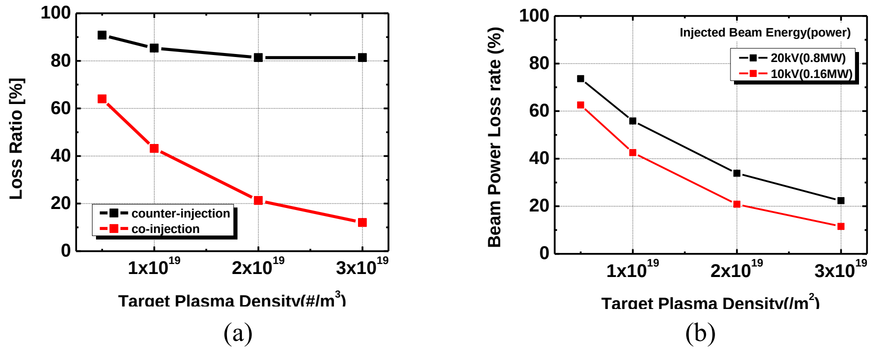



Fig.1 The power loss of the neutral beam in VEST depends on the beam direction (a) and the beam energy (b).

## 2. VEST NBI system

### A. Ion source

In order to meet the requirement of 0.5MW H° beam power at 20keV beam energy, a $H^+$ beam power of 0.7MW is necessary, assuming that the neutralization efficiency of $H^+$ beam at 20keV is 80% and a beam transport loss is less than 10%. The divergence angle of each slit beamlet without focusing is less than 1 degree in horizontal direction and about 2 degrees in vertical direction. Therefore, most of outer beamlets are focused vertically to minimize the beam transport loss. The beam extraction region was enlarged to 120mm x 460mm by 60% compare to the dual beam system. A beam current is necessary more than 35A at 20keV; a high perveance of 12.5uP beam is required. The grid structure was also modified. Fig.2 shows the result of the IGUN code simulation and the grid arrangement. The dimensions of grids are shown in table.1.

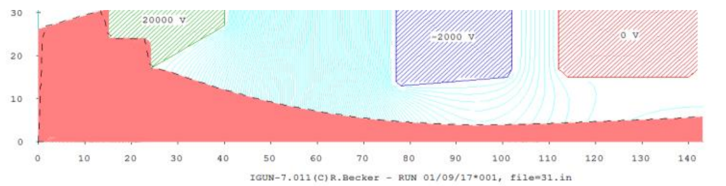



Fig.2 A simulation result by IGUN code

Table.1 Grid dimensions [mm]; half width of a grid slit: w, grid thickness: t, distance between grids: d

| w1 | w2 | w3 | t1 | t2 | t3 | d1 | d2 |
|---|---|---|---|---|---|---|---|
| 1.7 | 1.3 | 1.5 | 2.5 | 2.5 | 3.0 | 3.7 | 1.0 |

### B. Beam line

Considering that a counter direction beam will undergo a serious orbit loss in the VEST, the beam line (BL) configuration was modified from a dual co- and counter-direction injection configuration to a single co-direction injection beam. And the beam injection angle was also determined to minimize the orbit loss, the shine through loss, and a space interference with the Thomson diagnostics next to the BL. The angle between the beam injection direction and the normal line on the plasma surface is 15 degrees. Fig.3 shows the beam direction in the VEST and the BL structure. Through the structure analysis, the BL was constructed with a safety factor of 1.5. The total length of the BL is 1.8m including the 1m long neutralizer. A gas feeding and a vacuum pumping system was installed in the BL. The maximum gas flow rate is 800sccm and the pumping speed of a cryo-pump is 8,000 lit/s. The area and the volume of the BL are $3.5m^2$ and 300 litter, respectively.

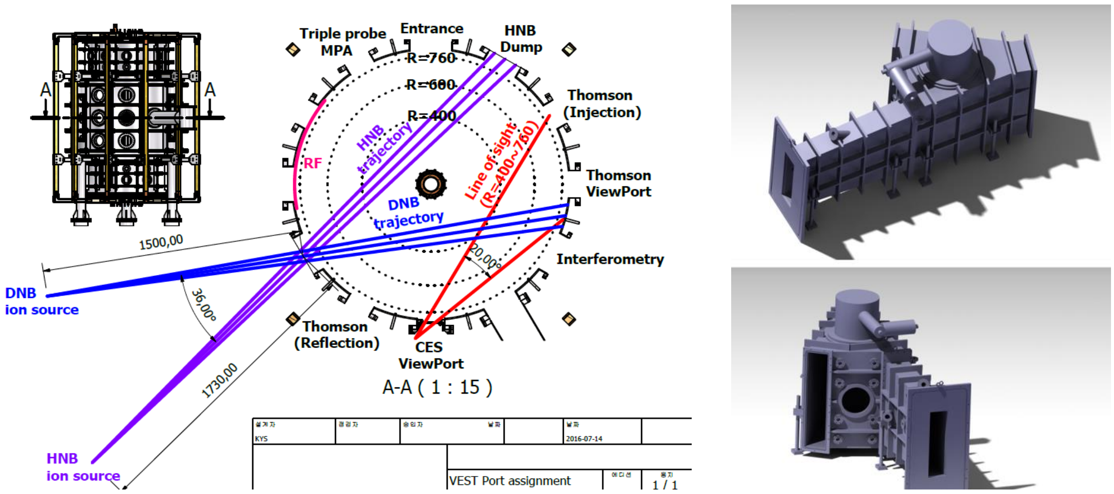
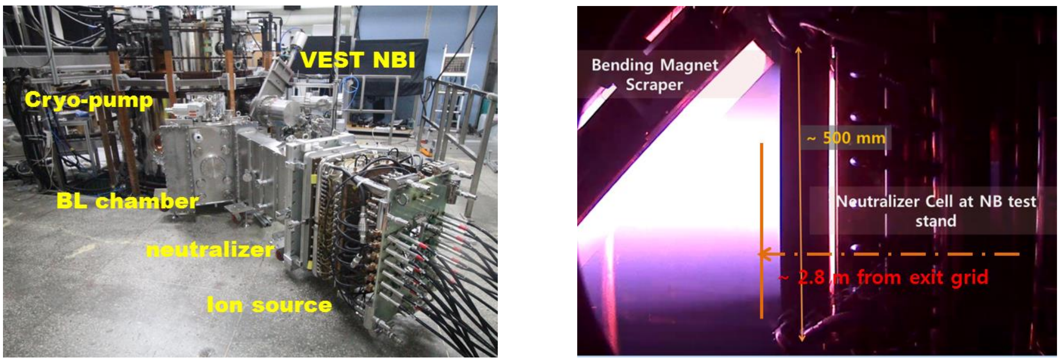



Fig.3 The beam direction and the beamline structure of VEST NBI.

## 3. Experimental results

The development of the VEST NBI system, including an ion source, a beamline system, power supplies[6], and utilities has been completed. Then, the conditioning of the ion source and the beam extraction experiments were carried out. Fig. 4(a) shows the NBI system installed on VEST tokamak and Fig. 4(b) is a still-shot of the beam extracted from the ion source.




(a) (b)

Fig.4 The VEST NBI system(a) ; the extracted beam from the ion source(b)

The open circle in Fig. 5(a) represents the data of each beam extraction experiment; the beam current is increase as the beam energy (acceleration voltage) is increased. The perveance of 12.5uP (red solid line) is a design value of the ion source. A large portion of data is higher than the design value. The perveance is an optimum perveance when a normalized drain current flowing into G2 grid is at a minimum because the accelerator of the ion source is a grid displacement type accelerator for beamlet focusing. As shown in Fig. 5(b), the optimum perveance of the vest NBI ion source is ~22uP and the perveance region for the optimum operation is from 20uP to 25uP. Furthermore, some data are upper side of a dot and dash line which represents an $H^+$ ion beam power of 0.7MW. These data shows that the goal of the VEST NBI was accomplished.

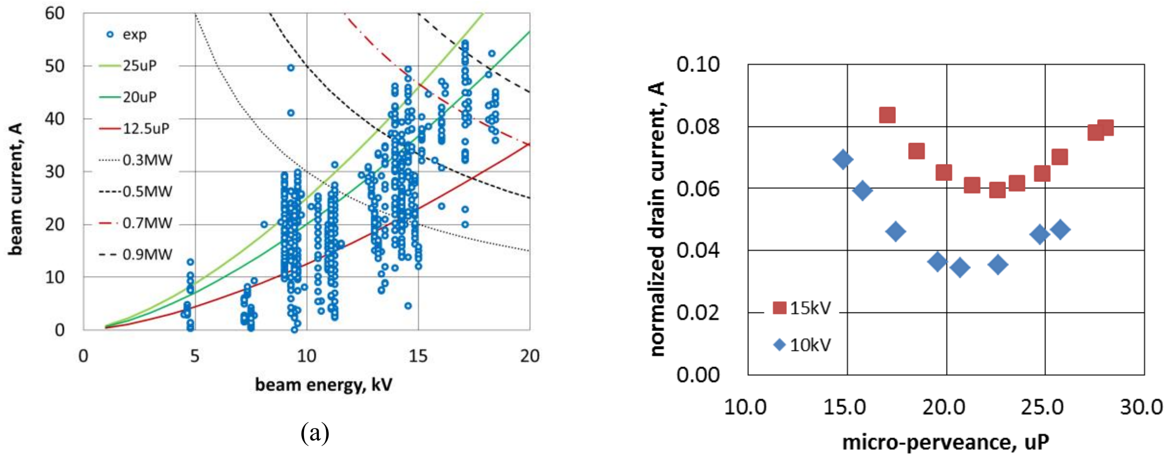



Fig.5 Beam extraction data of the VEST NBI: beam current v.s beam energy(a) ; normalized drain current of G2 grid v.s beam perveance.

## 4. Conclusion

A neutral beam power of more than 0.5MW should be required to realize the advanced tokamak scenario in VEST tokamak. The VEST NBI system with a co-direction beam has been developed. A very high perveance ion source and a low loss beam line system were designed and fabricated. The conditioning of the ion source and the beam extraction experiments were carried out. The $H^+$ ion beam power of more than 0.7MW was achieved at the beam energy of less than 20keV. The optimum perveance of 20~25uP will satisfy the goal of the NBI heating for advanced tokamak operation in VEST tokamak.

## Acknowledgements

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