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Adjustment of beam alignments for improving transmission efficiency in the KSTAR NBI-2

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1. Introduction

The Neutral Beam Injection (NBI) is one of the effective heating methods for high performance fusion plasma in most magnetic fusion devices. In Korea Superconducting Tokamak Advanced Research (KSTAR), two NBI systems such as NBI-1 and NBI-2 are installed and applied to most plasma scenarios. [1] Each of the two NBI systems has three ion sources, i.e., 1A, 1B, 1C, 2A, 2B, and 2C, and ion sources of NBI-1 and NBI-2 are arranged in horizontal and vertical direction, respectively, as shown in Fig. 1. The two ion sources of 1A and 2A have beam-line direction to plasma core for on-axis current drive and rest of ion sources have inner or outer beam-line direction from

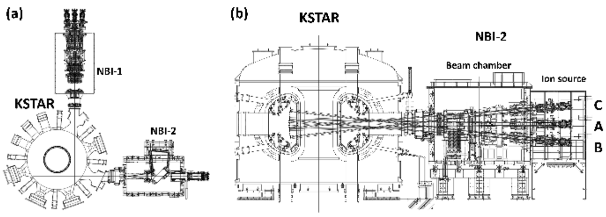

Fig. 1. (a) A cross-sectional view of the KSTAR NBI system, (b) A cross-sectional view of the NBI-2 system. [2]

the core for off-axis current drive.

In terms of delivering NBI beam power to the main plasma, ultimately, transmission efficiency among several beam parameters is thought to be the most important and has to be considered in minimizing beam loss. For optimizing transmission efficiency, so, it is important to adjust beam alignments. In KSTAR NBI, optimization of the beam alignments and transmission

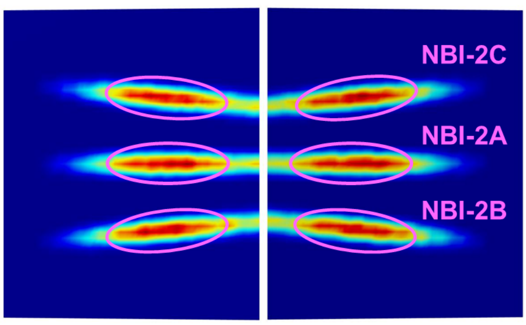

Fig. 2. Heat flux distributions on the calorimeter calculated using COMSOL Multiphysics simulation on the condition of 70 keV NBI-2 beams. [3]

efficiency is actively ongoing with calorimetric analysis. In this paper, we introduce an adjustment method of beam alignments in KSTAR NBI-2 and its results with transmission efficiency.

2. Adjustment method of beam alignments

In KSTAR NBI-2 system, heat flux distribution on calorimeter was simulated using COMSOL Multiphysics simulation in condition of 70 keV NBI-2 beams and Fig. 2. shows simulation results of heat flux distribution with assuming good beam alignments. But, because beam-line length of KSTAR NBI-2 system is long (~10 m), misalignment should be considered. So, first of all, for indicating status of beam alignments well, we chose ThermoCouple (TC) sensor array on calorimeter in NBI-2 and developed a simple tool for

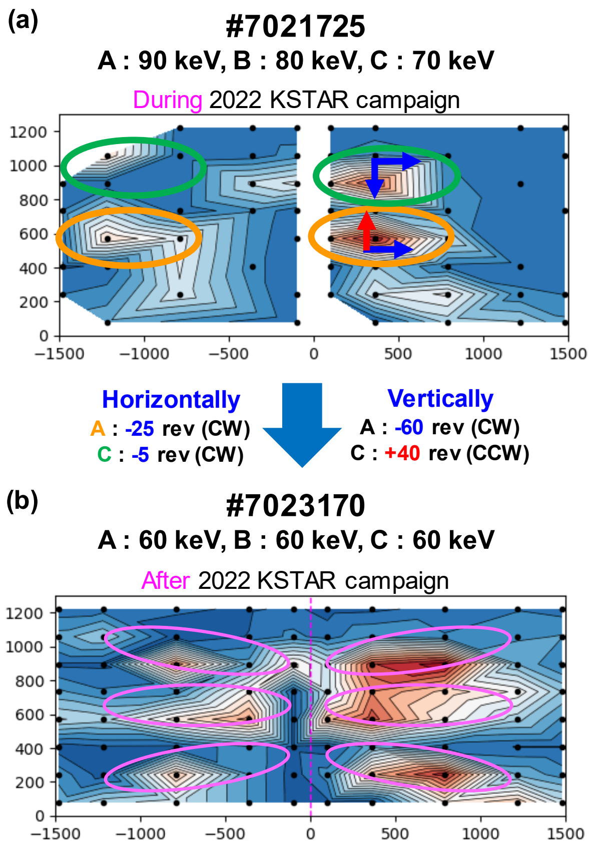

Fig. 3. TC sensor array temperature contour on the calorimeter in KSTAR NBI-2 system with positions of TC sensors (black dots). (a) before alignment, (b) after alignment in horizontal and vertical direction.

Table I: Calorimetric power data in several beam-line components on horizontal and vertical alignments cases in NBI-2A

Cases	Bending magnet scraper	Neutralizer 1-1	Neutralizer 1-2	Neutralizer 2	Calorimeter
1. Horizontal 0 rev, Vertical 0 rev	0.1084	0.0723	0.2209	0.3337	0.7587
2. Horizontal +25 rev Vertical -10 rev	0.0966	0.0765	0.1979	0.2934	0.8131
3. Horizontal +25 rev, Vertical -20 rev	0.0724	0.0844	0.1629	0.2350	0.8652
4. Horizontal +25 rev, Vertical -30 rev	0.0642	0.0882	0.1467	0.2205	0.8706
5. Horizontal +25 rev, Vertical -40 rev	0.0681	0.0887	0.1485	0.2186	0.8630
6. Horizontal +25 rev, Vertical -60 rev	0.0666	0.0985	0.122	0.2041	0.8648

visualizing TC sensor array temperature contour in time. The calorimeter in NBI-2 system consists of right and left sides and is V-shaped. Each calorimeter side has 40 TC sensors in an arrangement of 8 rows × 5 columns as shown in Fig. 3. (black dots on contour indicate positions of TC sensors)

Horizontal and vertical aiming unit system is equipped on KSTAR NBI-2 system for adjusting beam alignments. Using the aiming unit system and TC sensor array temperature contour, alignments experiments are conducted on local shots for beam conditioning. Before beam alignments, NBI-2A and 2C seems to be misaligned on the temperature contours of as shown in Fig. 3(a) comparing with the simulation results. So, 2A and 2C are aligned moving servo motor in aiming unit system. The unit of "rev" in this paper means revolution value of servo motors. In case of NBI-2A, ion source is rotated clockwise (on the top view) in horizontal direction and clockwise (on the side view) in vertical direction. And, in case of NBI-2C, ion source is rotated clockwise (on the top view) in horizontal direction and counterclockwise (on the side view) in vertical direction. Thus, beam alignments seems to be improved as shown in Fig. 3(b).

3. Transmission efficiency results using calorimetric analysis

The beam loss mostly occurs in beam components (i.e. ion source scraper, neutralizer 1, neutralizer 2, bending magnet scraper, beam-line scraper, beam duct scraper, etc.) around the beam-line and can be analyzed in NBI-2A through calorimetric measurements. The six case of alignments in NBI-2A are performed and analyzed. Case 1 and 6 are original status and final status, respectively, and are matched to the temperature contours in Fig. 3. Table I shows calorimetric power data in beam-line components (e.g. Bending magnet scraper, Neutralizer 1-1, Neutralizer 1-2, Neutralizer 2, and Calorimeter) on six cases. As beam aligned to case 6, beam loss powers on bending magnet scraper, neutralizer 1, and neutralizer 2 are decreased and beam power on calorimeter is increased. Especially, in neutralizer 1, beam loss powers on 1-1 (top + right side of the beam-line) and 1-2 (bottom + left side of the beam-line) are changed to equivalent power level. In these cases, transmission efficiency is also calculated as shown in Fig. 4. and increased to almost 77% which is comparable to NBI-2B and 2C. As a result, it is validated that beam alignments by adjustment method is effective in NBI-2A.

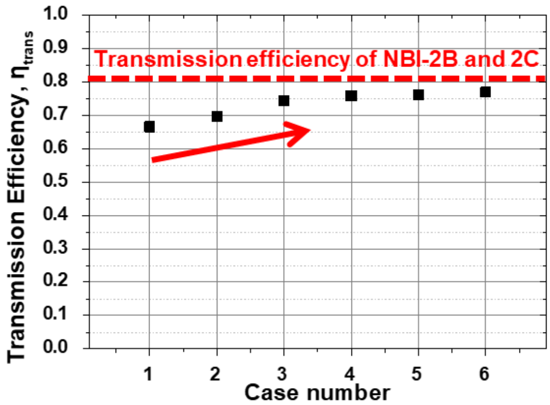

Fig. 4. Changes in transmission efficiency of NBI-2A by adjusting beam alignments (black dots) and transmission efficiency level of NBI-2B and 2C (red dotted line).

4. Conclusions and future works

In this work, we developed a simple tool for visualizing TC sensor array temperature contour in time and adjustment method for beam alignments. Beams are aligned using the aiming system in NBI-2 system and results of beam alignments are validated by the temperature contour change, decreased beam loss, and improved transmission efficiency. In future, we are applying the beam alignments method to not only NBI-2A but also whole NBI system to improve performance before 2023 KSTAR campaign.

REFERENCES

[1] Y.S. Bae *et al.*, Commissioning of the first KSTAR neutral beam injection system and beam experiments, Fusion Engineering and Design, Vol.87, p.1597, 2012.
[2] SeulChan Hong *et al.*, Development of the auto conditioning tool for the KSTAR NBI-1, Korean Nuclear Society autumn meeting, 2021.
[3] Geonwoo Baek *et al.*, Numerical Validation and Experimental Demonstration of Beam Trajectory and Hot Spots in the KSTAR NB-2, Korean Nuclear Society autumn meeting, 2022.

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