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Development of the auto conditioning tool for the KSTAR NBI-1

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1. Introduction

In various tokamak devices, Neutral Beam Injection (NBI) is a widely used non-inductive heating method. Two heating NBI systems are initially planned for ITER external heating system [1], and Korean Superconducting Tokamak Advanced Research (KSTAR) is currently equipped with NBI-1 and 2 heating systems [2,3]. In particular, in KSTAR, NBI plays an essential role in various advanced scenarios and high-performance experiments.

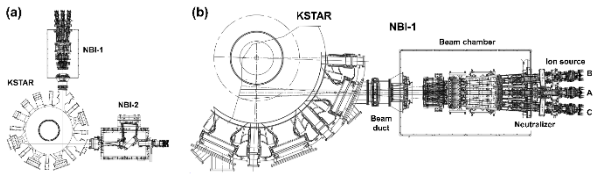

Fig. 1. (a) A cross-sectional view of the KSTAR NBI system. (b) A cross-sectional view of the NBI-1 system [4].

Reliable operation of the NBI is essential for these experiments and can be achieved through NBI conditioning. However, the conditioning process of the NBI system is carried out daily, and this routine conditioning consumes a lot of time and human resources due to the complex nature of the NBI operations. In this work, we developed an auto conditioning tool that can perform conditioning automatically to improve the conditioning process and reduce the time and cost of human resources. A brief introduction to NBI conditioning performed in the KSTAR NBI system and details of the auto conditioning tool will be presented.

2. NBI conditioning in KSTAR

Conditioning of the beam system is a critical process that determines whether a high energy beam can be injected or not. In KSTAR, conditioning is performed through four main procedures: Filament, Arc, Hi-Pot (High Potential test), and Beam mode. The ion source of the KSTAR NBI is a filament-arc ion source that heats a filament to generate electrons and uses it to create arc plasma. To generate enough seed electrons from the filament, impurities must be removed from the filament surface, which is filament conditioning. Second, arc conditioning is performed to ensure that the desired arc plasma mode is created and stable arc plasma generation under harsh pressure conditions. Hi-Pot conditioning applies high voltages between grids to identify high voltage power systems anomalies and uses arc events between grids for grid conditioning. Beam conditioning is carried out by beam extraction, beam optics verification, and grid conditioning using arcing events between grids.

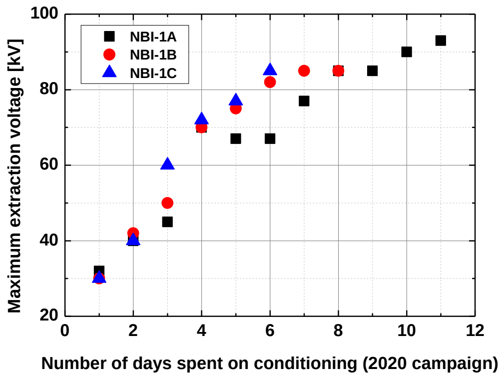

Fig. 2. Maximum extraction voltage as a function of the number of days spent on conditioning in the 2020 campaign. The black square, red circle, and blue triangle symbols are from ion sources A, B, and C.

By performing NBI conditioning, the state of the NBI system can be improved. Fig. 2 shows that the maximum available injection voltage increases as conditioning progresses.

3. The auto conditioning tool for the KSTAR NBI-1

Daily performed KSTAR NBI-1 conditioning requires approximately 20 shots, which take a total of one and a half hours. Although NBI conditioning is a very routine process, it is a burden on the operator because it must be performed with the monitoring of the system issues occurrence. Therefore, having a tool that can quickly identify system problems and perform conditioning automatically can significantly reduce the burden on the operators.

The NBI-1 control system is based on Experimental Physics and Industrial Control System (EPICS). The developed auto conditioning tool uses Process Variables (PV) of EPICS and PyQt module from python to configure the auto conditioning tool GUI. Control and monitoring logic consists of python code. The auto conditioning tool prepares and operates for the discharges and can detect system issues. The operator only performs simple tasks such as start and emergency stop through the GUI.

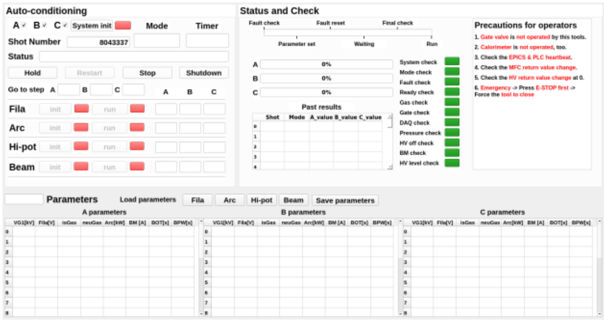

Fig. 3. The main page of the auto conditioning tool. The tool consists of several buttons for preparing the system, start the conditioning, and an indicator to inform the system status.

The tool consists of a control panel where the operator can start and end the auto conditioning and a "Status and Check" panel where the operator can view overall system issues of the NBI in real-time.

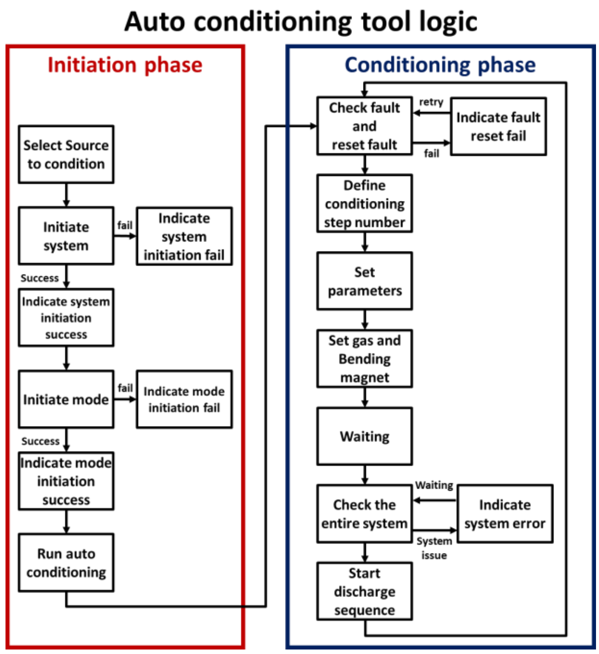

Fig. 4. The main logic of the auto conditioning tool. After several sequences of the initiation phase, the process enters the main loop, which is the auto conditioning phase.

The control logic of this auto conditioning tool is as shown in Fig 4. First, perform the NBI global system setup and then set the conditioning mode. Each setting is commanded through the EPICS. Upon successful completion of the start phase, the sequence enters the conditioning phase. During the conditioning phase, the tool continuously checks for system problems and performs discharges.

A system check is a crucial part of auto conditioning. If there is a problem with the NBI system, it can seriously damage the device during beam injection. Therefore, real-time monitoring of system is performed on the 11 checklists that need to be monitored.

Table I: Auto conditioning tool's checklists

Checklists	Description
System	System initiation check, local mode check, G2 pump check
Mode	Mode initiation check, power supply initiation check, LTU check
Fault	Fault number check
Parameter	Parameters setting check
Gas	Gas setting check, gas injection parameters check
Gate	Gate valve check
DAQ	DAQ status check
Pressure	Pressure level check
BM	Bending magnet status check, bending magnet parameters check
HV level	High voltage value check
HV off	High voltage switches off check

The auto conditioning tool solves a simple problem with the NBI system, and conditioning is performed again. However, if a critical issue arises, the auto conditioning tool will wait for the operator to solve the problem.

4. Summary

In this work, we developed the NBI-1 auto conditioning tool to reduce the high cost of the NBI-1 conditioning process and identify system issues more directly. Developed in July 2021, this tool is continuously used for daily conditioning routines in KSTAR NBI-1 and shows reliable auto conditioning results. Since the NBI-2 control system is also based on EPICS, a conditioning tool that reflects the specifics of the NBI-2 system is created based on the NBI-1 auto conditioning tool.

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