Development of KSTAR Diagnostics for the Advanced Tokamak Operation

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Abstract. The KSTAR is aiming at the successful performance of the advanced tokamak (AT) mode of operation as well as the steady state operation with fully superconducting magnets. To support the current density and pressure profile control experiments for AT operations, development activities are being concentrated on the profile diagnostics such as the motional Stark effect (MSE) polarimetry, the Faraday Rotation polarimetry and densitometry, interferometry, and reflectometry. Even for active feedback control of the MHD unstable states of plasmas, extensive sets of magnetic diagnostics are being prepared and tested. The edge and divertor areas are also going to be actively diagnosed to understand the multiply-coupled characteristics with the AT operations. The present status and activities for the development of the KSTAR diagnostics will be described with test results obtained by utilizing HANBIT mirror plasmas.

1. Introduction

The KSTAR (Korea Superconducting Tokamak Advanced Research) [1,2] is aiming at the successful performance of the advanced tokamak (AT) mode of operation. Though this AT mode can be realized in present tokamaks, it is usually a transient phenomenon. The KSTAR, however, will pursue steady state AT operation with fully superconducting magnets and with state-of-the-art plasma control schemes. After achieving the first plasma milestone, the KSTAR operations for testing AT modes will be performed in order according to the availability of heating and other ancillary systems. KSTAR diagnostics are also installed in a phased manner according to the operation scenario, availability of related technologies and required time for development. Table 1 shows a list of the KSTAR diagnostics system that will be developed in three phases according to the KSTAR operation scenario. The whole diagnostics are classified in three categories by the measurement requirements as the Machine and Control, Core, and Divertor and edge. The whole set was listed in three phases in the order of development as Basic, Baseline I, II, III and Mission-oriented. The Basic set consists of a minimal diagnostics for the Day One plasma operation of KSTAR. Most of magnetic diagnostics and relatively simple diagnostic sets for measuring basic parameters such as electron temperature and density, ion temperature, impurity behavior, neutral pressure, and run-away electron detection. Monitoring TV viewing inside vacuum vessel in the visible and IR region will also be in this phase of development. As other ancillary systems are installed to KSTAR, relevant diagnostics is going to be added in parallel. Thus for the baseline campaign when important physics experiments will be performed with intensive heating capabilities and a divertor configuration, profile measurements of important parameters should be provided. Baseline I, II and III diagnostics sets are prepared for this purpose. Some diagnostics are still in consideration for development for KSTAR since it may not be urgent or technology has not been evolved enough. The time for starting development of such diagnostics will be determined as the demands and necessities are raised along the way of KSTAR operation or as the technical problems are to be solved and resources are ready.

Even though the development are delayed for certain diagnostic system, the port allocation was done for all specified system together to minimize the space interference due to the phased development. Figure 1 shows all the diagnostic systems located around KSTAR including other ancillary systems such as heating and vacuum systems.

TAB. 1. A LIST OF KSTAR DIAGNOSTIC SYSTEM

Diagnostic Set		**Control and Machine Diagnostics**	**Core Plasma Diagnostics**	**Divertor/Edge Diagnostics**
Basic		Magnetic Diagnostics: Rogowski Coil Flux/Voltage Loop Magnetic Field Probe Saddle/Locked-Mode Coil Mirnov Coil (In-board) Diamagnetic Loop Vessel Structure Current Monitor mm-wave Interferometer (single-channel) Hard X-ray Detector Survey IR TV Survey Visible/H-alpha TV Torus Ion Gauge Residual Gas Analyzer Inspection Illumination Glow Discharge Probe	Visible Survey Spectrometer H-alpha Monitor Visible Bremsstrahlung Array X-ray Pulse Height Analyzer ECE Heterodyne Radiometer X-ray Crystal Spectrometer	Fast Neutral Pressure Gauge Reciprocating Langmuir Probe (Single-head)
Baseline	**I**	Charge Exchange Spectroscopy	μ-wave Reflectometer Core Thomson Scattering Soft X-ray Array VUV Survey Spectrometer	Movable Langmuir Probe Divertor IR TV Divertor Visible/H-alpha TV
	II	Motional Stark Effect (q) Magnetic Diagnostics: Mirnov Coil (PFC) Vertical FIR Interferometer/ Polarimeter	Bolometer Array X-ray Pinhole Camera Multichord Visible Spectrometer ECE Grating Polychromator	Divertor Thermocouple Edge Langmuir Probe Array
	III	Modified MSE (Er, q)	Tangential FIR Interferometer/ Polarimeter Soft X-ray Spectrometer Visible Filterscope Escaping Fast-ion Detector	Divertor Bolometer Array Divertor VUV Survey Spectrometer Divertor μ-wave Interferometer Edge Thomson Scattering Edge Density Reflectometer
Mission-Oriented		Diagnostic Neutral Beam (Impurity) Pellet Injector	mm-wave Reflectometer CX-NPA Beam Emission Spectroscopy Poloidal Rotation CES ECE Imaging System Epithermal Neutron Detector Neutron Collimator Neutron Fluctuation Detector	Electron Cyclotron Absorption (ECA) Reciprocating Langmuir Probe (Multi-head) Divertor Thomson Scattering Laser-induced Fluorescence

2. Technical Challenges

The mission of KSTAR is to explore the advanced tokamak operation regime and to achieve steady-state operation with high performances. Though the operation parameters of KSTAR are not exceeded those of present machines, the planned long pulse (>300 s) operation will require new specifications for technologies currently applied to the various diagnostics. ITER also made great efforts to resolve similar problems during their R&D phase such as radiation damage on the mineral insulated cables and cassette-type port access. For KSTAR diagnostic systems, similar criterion and concepts will be taken for radiation damage assessments and the efficient port access, respectively.

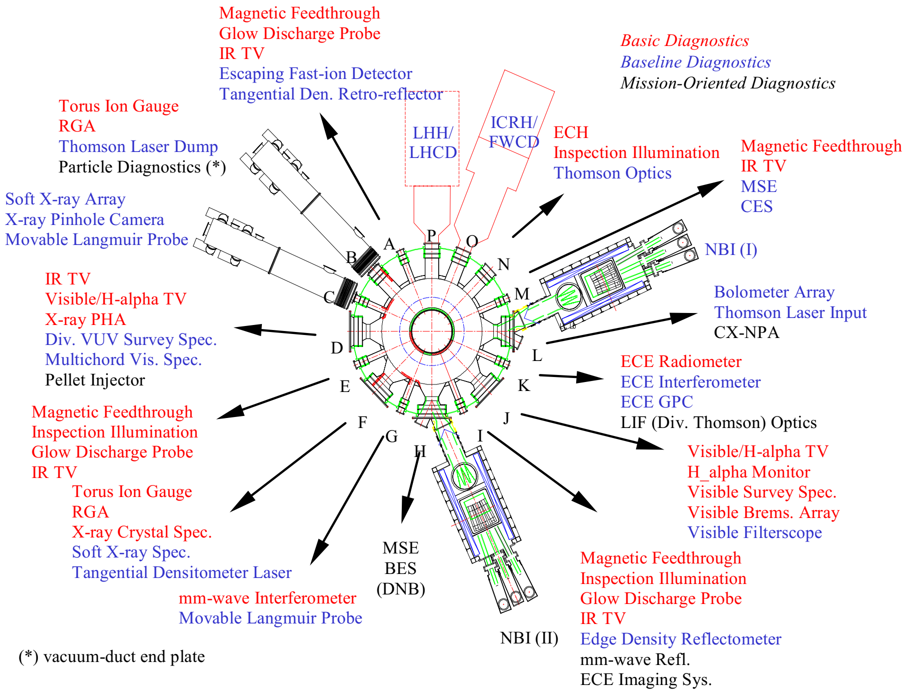


FIG. 1. Layout of the KSTAR Ancillary Systems

In KSTAR magnetic diagnostics, due to the high temperature environment MgO insulated cable will be used. The outer sheath is made of stainless steel and the inner conductor is Ni-clad copper. The radiation effect due to long pulse operation on the insulating voltage and the temperature effect on cable inductance and resistance should be examined. The port access to view the plasma is another problem in a superconducting tokamak because of the long length through the cryostat. Though its level is not severe as much as ITER, viewing plasma through diagnostic ports is sure to be a puzzle since various inner components route around inside vessel and the neutral beam armor tiles are also obstacles. A cassette concept was adopted and its usefulness was illustrated. However, maintainability, alignment over many cycles of baking-cool down-operation, and the effect of the disruptions through electromagnetic forces on the cassettes should be examined in detail. Devise of calibration techniques covering wide range of dynamic ranges, assessment of particle bombardments on the optical components, methods to cover full spectral and spatial ranges, and new requirements of data acquisition, storage and retrieval schemes are a few of other challenges that KSTAR is facing with.

3. Diagnostics for KSTAR AT Operations

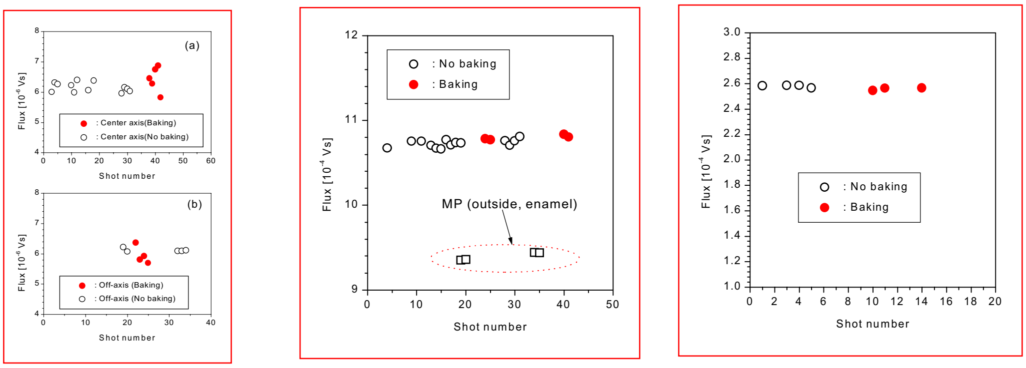
The AT operations imply high beta and high bootstrap current fraction obtained by optimized pressure and current density profiles. To support this mission, KSTAR diagnostics will be concentrated on an accurate and reliable measurement of profiles of related plasma parameters [3]. For the current density measurements, two polarimetries are under consideration; the motional Stark effect (MSE) and the Faraday rotation. Each of these methods has pros and cons. The Faraday rotation technique requires a full view of plasma and information from other diagnostics to overcome difficulties caused by uncertainty of information near edge and on axis. However, it provides excellent temporal resolution. The MSE technique requires either diagnostic or heating beam line, which is a major drawback. However, this technique can measure the current distribution with a good time resolution and relatively good accuracy. Simultaneous use of both systems is being considered for KSTAR to cover from the core to the edge region of the plasmas. For measuring the pressure profile, many parameters are involved such as plasma density and temperature, impurity and fast beam ions. Thomson scattering is a conventional tool for electron temperature and density measurement and the electron cyclotron emission (ECE) measurement complements it for the transient phenomena. Interferometry will fulfill the requirements for the electron density measurements. Densitometry based on Faraday rotation angle measurement is also being prepared. One drawback is that to obtain the profile data transformation via Abel inversion is required since both methods are based on the chord-averaged measurements. Profile diagnostics are also very important for the measurements of an evolving internal transport barrier (ITB), which is a distinct phenomenon of the transient AT operation with a reversed shear configuration. Measurements of the amplitude of turbulence are also very important to assess the effect of the formation of the ITB.

For obtaining high beta in AT operations, MHD stability needs to be sustained. A critical issue for AT operation in a steady state tokamak is thorough understanding and extending the MHD stability limits through active feedback control of plasma configurations. To support this goal, an extensive and reliable set of magnetic diagnostics as well as ECE and reflectometry is being prepared.

The plasma boundary and divertor regions are multiply-coupled to the performance of the AT operations and there still remains uncertainty of the compatibility of the AT operation with edge particle and power handling capabilities. More diagnosis of current and density profiles and flow in the edge region is demanded for a better understanding of the core and edge coupling. To resolve the uncertainty of compatibility and to extend boundary control techniques, radiation monitoring, spectroscopy and optical techniques will be used. However, accessibility is highly limited for the divertor region due to passive plates, armor, and toroidally and poloidally distributed piping and support structures. More elaborate technical solutions are being actively pursued.

4. Status of KSTAR Diagnostics R&D

Since magnetic sensors will be placed near the plasma, radiation resistance is a crucial requirement for the cable. A cable insulated with MgO was chosen and a prototype of each sensor was fabricated and tested for assessment of the effect of thermal expansion due to baking and magnet cool-down. Figure 2 shows a temperature effects on various probe samples. Since a sample Rogowski coil showed significant error with baking, its design was changed properly to eliminate this problem. A Mirnov coil was also redesigned to have a wide frequency response up to 1 MHz according to the test results. A vacuum feedthrough for sensors was also designed and tested. Due to the long pulse operation, long term drift of the integrator should be compensated. A compensation technique is under development as a part of the design work of a reliable integrator itself.



(a) (b) (c)

FIG. 2. Temperature effect of sample coils for (a) Rogowski coil (b) Magnetic field probe and (c) flux loop. A substantial error is shown in the Rogowski coil case due to loosely wound coil inlet part.

The machine protection is a critical issue for the advanced tokamaks that will usually be operated in long pulse with high beta conditions. Fast plasma position detection and visible/IR plasma TV are important in this sense. Also a disruption prevention or mitigation provision should be included with the plasma control system that maneuvers plasma position and profiles to find better operation conditions. For visible/IR TV system, a periscope should be used for KSTAR for viewing a large area of inside surface of vacuum vessel and for better observation of plasma discharges. Figure 3 shows a installation layout of the periscope. Because of the long distance from the port to the plasma owing to the cryostat region, cassettes for most of diagnostic systems will be needed for better access to the plasma region. Physics and engineering prototypes are being fabricated and will be tested in HANBIT.

Charge exchange spectroscopy and motional Stark effect (MSE) polarimeter are important diagnostics for physics experiments. Since there is no test facility in Korea with neutral beam injector, a 35 kV, 1 A diagnostic neutral beam injector is being developed for HANBIT mirror machine and few beam-aided diagnostic systems will be tested[4]. Profile diagnostic systems such as Thomson scattering system and ECE, interferometer and reflectometer are also installed and operated in HANBIT for developing measurement techniques for the AT operations in KSTAR.

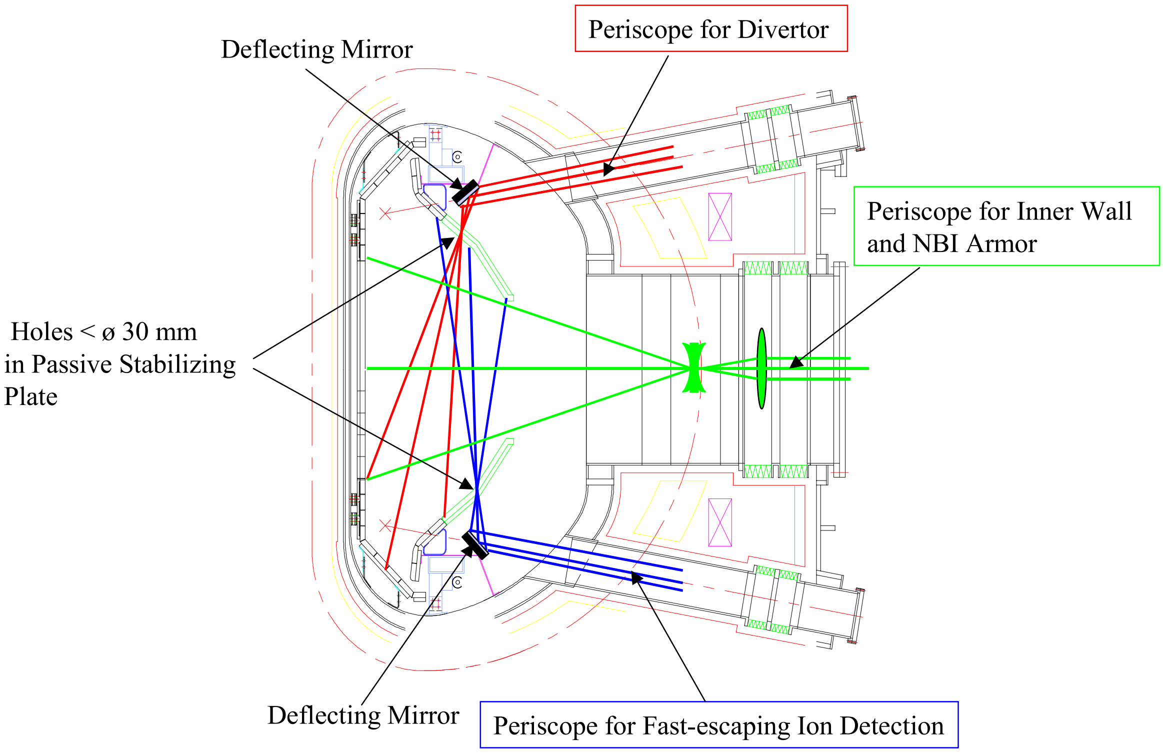


FIG. 3. Layout of the KSTAR periscope installation.

[1] G. S. Lee, et al., Fusion Engineering and Design **46** (1999) 405.

[2] The KSTAR Team, Nuclear Fusion **40** (2000) 575.

[3] S. G. Lee, et al., Fusion Technology **33** (1996) 861.

[4] S. M. Hwang, et al., Transactions of Fusion Technology **35** (1999) 99.

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