In-vessel Optic System Design of FIR Interferometer/Polarimeter System for KSTAR

Y U Nam¹ and J W Juhn²
¹ National Fusion Research Institute, 113 Gwahangno, Daejeon, 305-333, Korea
² Seoul National University, 599 Gwanak-ro, Seoul, 151-742, Korea

E-mail: yunam@nfri.re.kr

Abstract. An FIR interferometer/polarimeter system will be constructed in the Korea Superconducting Tokamak Advanced Research (KSTAR) device for electron density profile measurements. Due to the complex inner-wall geometry and long diagnostics ports, a specially designed in-vessel optic system is necessary to ensure a sufficient number of beam lines for inversion of the density profile. A single channel on the vertical center line and seven channels on the tangential plane will be placed using corner-cube reflectors mounted on the vacuum vessel. To avoid interferences with in-vessel structures such as neutral beam protection tiles and diagnostics systems, the positions of these beam lines are designed carefully using an in-vessel beam positioning module placed inside a narrow diagnostics port. Since these in-vessel optic components must be mounted on the vacuum vessel, a vibration compensation system needs to be integrated on the module. Designs of the corner-cube reflectors and the beam positioning modules have been performed for these purposes. A prototype corner-cube reflector will be installed on KSTAR before the 2010 campaign and vibration compensation performance and surface degradation due to plasma will be tested.

1. Introduction
First commissioning operation of Korea Superconducting Tokamak Advanced Research (KSTAR) device was successfully completed last year. During the commission phase, line-integrated electron densities were measured by a 280 GHz millimeter-wave interferometer system [1]. The maximum line-density was about \(5 \times 10^{19} \text{ m}^{-2}\) which corresponds to 24 fringes with a probing frequency of 280 GHz. The fringe jump effect was compensated with help of a multi-fringe counting circuit and a correction algorithm [2]. For the main operation phase in which a line-density of over \(10^{20} \text{ m}^{-2}\) is expected, however, these correction techniques will no longer be valid. A 118.8 \(\mu\text{m}\) far-infra red (FIR) interferometer/polarimeter system with a triple FIR laser pumped by a CO\(_2\) laser has now been developed for these purposes [3]. It contains a single vertical channel for density feedback control and a total of seven channels of tangential lines for density profile reconstruction. As a superconducting tokamak with a large cryostat, KSTAR has complex inner-wall geometry and long diagnostics ports. A specially designed in-vessel optic system is necessary to ensure a sufficient number of beam lines for inversion of the density profile. The beam line configuration has been optimized and a prototype design of the in-vessel optic systems including vibration compensating in-vessel corner-cube reflectors and an in-vessel beam positioning module using a cassette system have been performed.
2. In-vessel vibration compensating corner-cube reflector

Heterodyne interferometry is the most reliable diagnostic for electron density measurements. Since it measures phase and not amplitude, it is very insensitive to amplitude modification from power attenuation or electronic noise. However, mechanical vibration can affect the measurement data, especially for a short probing wavelength system. Although two-color interferometry is typically used for vibration compensation, severe vibration could be damped by a mechanical technique [4].

The mechanical vibration during plasma operation mainly comes from the vacuum chamber itself. The best solution is to dismount all optical components from the chamber. Unfortunately, this is not possible on a superconducting tokamak with large cryostat such as KSTAR. A straight beam line through the vacuum chamber is not available. At least one mirror must be mounted on the chamber wall. Since a typical plain mirror can deflect the beam path significantly by small angle tilting due to vibration, a corner-cube reflector (CCR) has been adopted for the in-vessel reflecting mirror. A reflected beam on a CCR always is parallel to the incident beam regardless of the angle of the reflector. A CCR is especially good for plasma measurements since the beam itself is refracted during passage through the plasma due to electron density gradients. Figure 1 shows a simulation result of the beam refraction effect on KSTAR. The peak electron density is set to $10^{20}$ m$^{-3}$ and a parabolic density profile is assumed. The maximum deflection length on a reflection mirror is below 10 mm, and the maximum refraction angle is below 4 mrad. However, this small refraction angle makes a large deflection for a detector which is 17 m away from the reflection mirror. It can be seen in Figure 1(c) that the refraction angle and the deflection length on a detector can be significantly suppressed by using a CCR as a reflecting mirror.

Although a CCR is insensitive to angle tilting as shown previously, position shift along the beam direction can affect the measurement data. This shift directly affects the beam path length, and results in phase variation. The problem is that the in-vessel environment is significantly unfavorable for vibration damping. Inside the tokamak there is a high vacuum and a high magnetic field. During plasma operation, there are high heat flux and high neutron bombardment on the vessel wall. Typical
vibration damping techniques use springs, rubber, and pneumatic pressure. Rubber cannot be used inside the vessel and pneumatic methods are difficult to employ. The only solution is to use a simple spring made from a non-magnetic material such as brass. A conceptual design of an in-vessel vibration compensating CCR is presented in figure 2. A prototype corner-cube reflector will be installed in KSTAR before the 2010 campaign and the vibration compensation performance and surface degradation due to plasma will be tested.

3. Beam distribution/positioning module
For a profile reconstruction with line-integrated data, a sufficient number of measurement channels should be ensured. The required number of channels had been calculated using an improved Abel inversion method. The optimized number is seven in the case of KSTAR [5]. Due to the complex inner-wall geometry and long diagnostics ports, designing beam-lines for a total of seven channels is not easy. The positions of these beam lines are designed carefully using an in-vessel beam positioning module placed inside a narrow diagnostics port using a diagnostics cassette to avoid interferences with in-vessel structures such as neutral beam protection tiles and diagnostics systems. Since the optical components in the positioning module cannot be mounted on the vessel wall, the module is supported by a vibration compensation stand placed outside of the vacuum vessel. A beam line configuration and the beam positioning module are presented in figure 3. Positioning of the beam lines was limited by the neutral beam protection armor and the diagnostics cassette. To ensure the beam paths within the narrow diagnostics cassette and to minimize the size of the holes in the armor, the beam lines are stacked in two columns using two plane mirrors. These beams are arranged on the vibration compensation stand and are transmitted to the beam distribution module placed downstairs.

Figure 2. Conceptual design of an in-vessel vibration compensating CCR.

Figure 3. (a) Beam line configuration and (b) beam positioning module.
A triple FIR laser system will be placed in the diagnostics room to allow routine maintenance of the laser system. A probing beam and a reference beam are transmitted to the beam distribution module. The beam distribution module is mounted on the same vibration compensation stage as the beam positioning module. Before the beams are split for the probing and the reference detectors, the beam transmission lines do not need to be protected from vibration since the vibration effect is compensated by a phase comparison circuit. A schematic diagram of the beam distribution system is presented in figure 4. One of the important points for designing a beam distribution system is the cross-talk of the backward beam. As it can be seen on figure 4, the main portion of the channel 6 backward beam power is transmitted to the channel 6 detector, however, some portion of beam power can be transmitted to channel 7, channel 4, or even channel 2. Using low transmittance beam splitters is one of the solutions. When the channel 6 backward beam is transmitted to its own detector, only two reflection processes are need. When the channel 6 beam is transmitted to the channel 7 detector, it requires two transmission processes. Therefore, the cross-talk of a backward beam can be reduced using a low transmittance splitter. In the case of 50:50 splitter, the power ratio between its own detector and nearest detector is 4:1. In case of 30:70 splitter and 10:90 splitter, this ratio is reduced to 11:1 and 100:1. A low transmittance splitter also is good for beam power distribution between channels in a cascade type distribution system such as figure 4.

4. Conclusion and future work
The design of the in-vessel optic system of the FIR interferometer/polarimeter system for KSTAR has been performed. In spite of the complex in-vessel geometry on KSTAR, a sufficient number of beam lines for a profile reconstruction can be ensured using a beam positioning module. All in-vessel optics has been designed with consideration of protection from mechanical vibration. A prototype corner-cube reflector will be installed on KSTAR before the 2010 campaign and the vibration compensation performance and surface degradation due to the plasma will be tested. Based upon these results, a single-channel vertical FIR interferometer system will be installed for the 2011 campaign. Finally, a multi-channel tangential FIR interferometer/polarimeter system will be installed for the 2012 campaign.

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