*30th EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, 7-11 July 2003 ECA Vol. **27A**, P-4.64*

Toroidal interferometer/polarimeter density measurement system for long pulse operation on ITER

T. Kondoh[1], Y. Kawano[2], A. E. Costley[1], A. Malaquias[3], T. Sugie[1], C. Walker[4]

[1]*ITER International team, Naka Joint Work Site, Ibaraki, 311-0193, Japan*
[2]*Japan Atomic Energy Research Institute, Ibaraki, 311-0193, Japan*
[3]*Instituto Superior Tecnico, EURATOM/IST, CFN, Lisboa, Portugal*
[4]*ITER International team, Garching Joint Work Site, Garching, Germany*

1. Introduction

In order to measure line average electron density for long pulse operation on ITER, a CO_2 laser interferometer/polarimeter system has been selected [1]. High reliability is necessary because the measurements will be used as a reference signal for real time control of the density during long plasma pulses (> 600 s). In comparison with a conventional interferometer, a polarimeter is more reliable for long pulse operation since it does not depend on measuring the temporal history of the signal.

The design of the interferometer/polarimeter is improved from the previous design [1] which uses CO_2 (10.6 μm) and CO (5.3 μm) laser on the basis of experience gained with a similar system on JT-60U [2,3]. A dual CO_2 laser interferometer/polarimeter was chosen in order to improve reliability.

2. Dual CO_2 laser interferometer / polarimeter proposed for ITER

The CO_2 laser interferometer/polarimeter system has been developed in JT-60U for electron density measurement. The system has a toroidally tangential chord with a retroreflector, which has a similar geometry to the toroidal interferometer/polarimeter proposed for ITER. At first, the combination of CO_2 (10.6 μm) and IR-HeNe (3.39 μm) lasers was developed in JT-60U, because high resolution would be obtained by this arrangement. It operated successfully, however, its performance was unsatisfactory for stable measurement due to mirror damage, window coating, and mechanical vibrations/displacement because of short wavelength of the second laser. These conditions would be almost similar for CO_2 (10.6 μm) and CO (5.3 μm) combination. Therefore longer wavelength combination of dual CO_2 laser which has been developed for the JT-60U tokamak [2] was proposed for ITER.

Interferometry and polarimetry can be realized simultaneously using identical probing laser beams. The optical arrangement of the measurement system on a vibration isolation bench on JT-60U is shown in Fig. 1. For interferometry, an intermediate frequency (IF) of 2 MHz is chosen and is produced by two Acoustic Optic Modulators (AOMs) as frequency shifter of local oscillator (LO) beams. For polarimetry, a single polarization modulation unit (PEM: Photoelastic modulator) is used for probing the beams with different wavelengths. Each detector signal is processed by two lock-in amplifiers to provide the polarization component.

A proof-of-principle test of the dual CO_2 laser interferometer/polarimeter has been demonstrated and the system is operating routinely on JT-60U [4-6]. The signal measured with the polarimetry and the interferometry is used as reference for density feedback control. The line density resolution of the interferometry is ~0.5 x 10^{19} m^{-2} for a time resolution of 1 ms. The Faraday rotation was measured with a good angle resolution of ~0.01° with a temporal resolution of ~1 ms. A seven hours long continuous measurement was demonstrated with good stability and accuracy. Specifications obtained in JT-60U meet requirements on ITER (accuracy; 1%, and time resolution; 1 ms).

3. Wavelength selection

In JT-60U, the wavelength combination of 10.6 μm and 9.27 μm was chosen. Another candidate for wavelength combination for ITER is 12.1 μm ($^{14}C^{16}O_2$) /9.0 μm ($^{12}C^{18}O_2$) with isotope CO_2. The density resolution of a two wavelength interferometer is reduced by the factor $\alpha = 1/(1-\lambda_2/\lambda_1)$ relative to that of a single wavelength interferometer as shown in Fig. 2. Large wavelength ratio is therefore preferable for better resolution. Degradation in the resolution of the 12.1 μm /9.0 μm combination is only twice the 10.6 μm /5.3 μm combination. The degradation factor for polarimetry $\alpha = 1/(1-(\lambda_2/\lambda_1)^2)$ is also indicated in the figure. The combination of dual isotope CO_2 laser is preferable and high power (~10 W) sealed isotopic CO_2 lasers are commercially available for this purpose.

4. Design of lines of sight

Five tangential sight lines are planned near the midplane of ITER as shown in Figs. 3 and 4. The laser beams will be transmitted to the plasma through shielding labyrinths in an equatorial port and reflected by retroreflectors (~70 x 40 mm^2). The sites under investigation for the location of the retroreflectors are (i) behind the Blanket Shield Modules (BSMs) between the equatorial ports for channel 1 - 3, (ii) within the BSM in the diagnostic/remote handling port for channel 4, and (iii) within the BSM in the diagnostic port for channel 5. A schematic of the retroreflector placed behind the BSMs is shown in Fig. 5. The retroreflector will be mounted on the vacuum vessel and the laser beam will pass through grooves in the BSMs. Detail design of the retroreflectors is in progress.

The distance from the laser to the retroreflector is from 41 m (outer channel) to 50 m (inner channel). The position of the laser beams will be remotely controlled by steering mirrors outside the port plug because the vacuum vessel of ITER will move due to change in temperature during long plasma pulses. The optical alignment system, which was developed for divertor impurity monitor [4] using a CCD camera and a visible laser, can be applied to this system. The change of the optical axis will be detected with small pieces of diffuser (~ 3 x 3 mm^2) mounted at the side of the retroreflector. The diffusers are illuminated by a He-Ne laser through the optical axis of the CO_2 laser and monitored by the CCD camera. Displacement of the diffusers on the retroreflectors is used for feedback control of the optical axis.

Zinc selenide (ZnSe) is normally used as vacuum windows for CO_2 laser diagnostics. The Faraday rotation in the windows should be minimized by the following methods; (i) compensation with two-color polarimetry concept [3], (ii) setting direction of the windows to be parallel to the magnetic field, and/or (iii) using diamond windows. The Verdét constant of the diamond is ~1/17 smaller in comparison with that of the ZnSe. The diamond windows are attractive for the measurement because of small Faraday rotation, and high thermal conductivity. However, diamond windows are expensive and their use still under consideration. Detail discussion of the diamond windows is described in reference [5].

5. Summary and remaining issues

The toroidal interferometer/polarimeter has been designed based on the initial work [1] and is improved based on the recent progress on JT-60U in which good reliability was confirmed for both interferometry and polarimetry operation. The performance of the dual CO_2 laser meets requirements for ITER (accuracy; 1%, time resolution; 1 ms). Subjects for further work to be resolved are (i) detail design of retroreflectors, (ii) integration with other systems in the port plug of equatorial port, and (iii) decision on the window material.

Acknowledgement

This report was prepared as an account of work undertaken within the framework of ITER Transitional Arrangements (ITA). These are conducted by the Participants: Canada, China, the European Atomic Energy Community, Japan, Korea, the Russian Federation, and the United States of America, under the auspices of the International Atomic Energy Agency. The views and opinions expressed herein do not necessarily reflect those of the Participants to the ITA, the IAEA or any agency thereof. Dissemination of the information in this paper is governed by the applicable terms of the former ITER EDA Agreement.

[1] T. N. Carlstrom et al., "Baseline design of a multi-channel interferometer and polarimeter system for density measurements on ITER", in Diagnostics for Experimental Thermonuclear Fusion Reactors 2, Plenum Press, New York, 1998, p193.
[2] Y. Kawano et al., J. Plas. Fus. Res., **73** (1997) 870.
[3] Y. Kawano et al., Rev. Sci. Instrum. **72** (2001) 1068.
[4] T. Sugie, H. Ogawa et al., Rev. Sci. Instrum. **70** (1999) 351.
[5] Y. Kawano et al., in this conference (P-4.66).

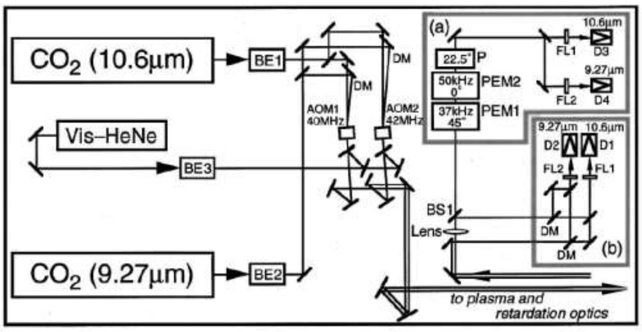

Fig. 1. Arrangement of the dual CO_2 laser interferometer / polarimeter on the optical bench of JT-60U.

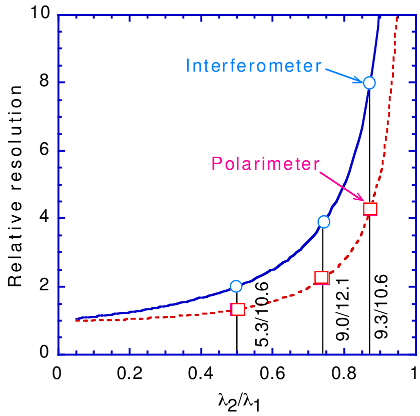

Fig. 2. Relative resolution for interferometry and polarimetry.

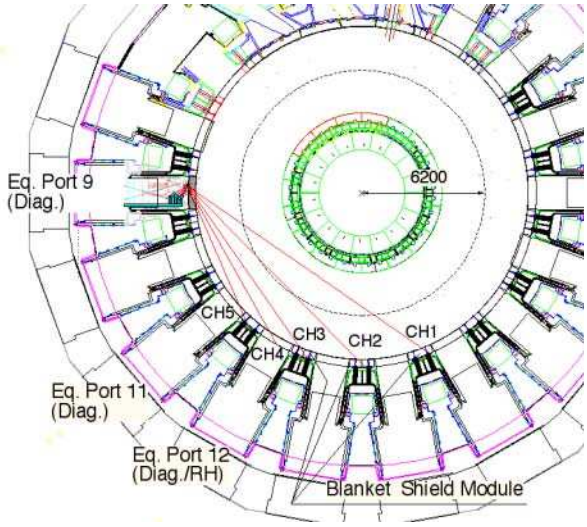

Fig. 3. Schematic plan view of lines of sight of the Interferometer/Polarimeter system on an equatorial port.

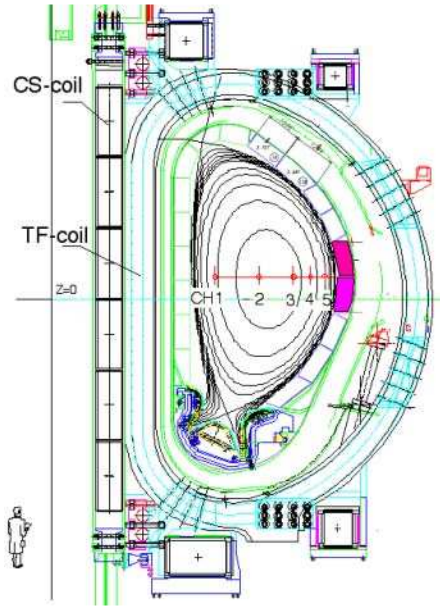

Fig. 4. Schematic sectional view of lines of sight.

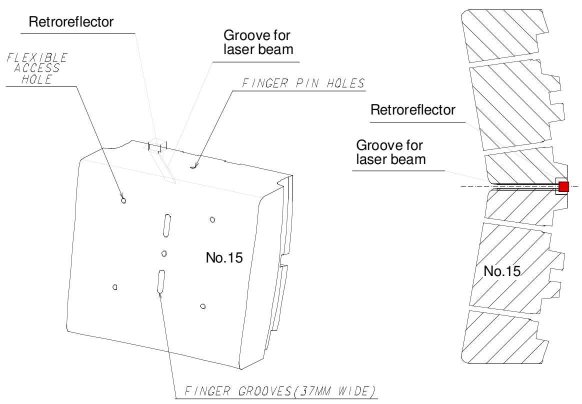

Fig. 5. Retroreflector placed behind the Blanket shield module.