J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 419–422

Thomson Scattering System for Steady State LHD Plasma

NARIHARA Kazumichi*, HAYASHI Hiroshi, YAMADA Ichihiro and YAMAUCHI Kenji
National Institute for Fusion Science, Toki 592-5292, Japan

(Received: 19 January 2000 / Accepted: 13 April 2000)

Abstract

We examine the problems that will arise when the present LHD Thomson scattering system operates for a long pulse plasma and consider countermeasures against them. The viewing window poses most severe problems. For an expected heat flux from the plasma of 10kW/m^2, the present system withstands the operation of up to 10 minutes duration, which can be extended to infinity by placing a water cooled sapphire plate coated with a low-pass-filter in front of the view window. As a whole, the system will operate without an interruption at least 16 hours with modest modifications.

Keywords:

steady state plasma, LHD, Thomson scattering

1. Introduction

Even if a steady state plasma is realized in LHD, continuous or repetitive plasma diagnostics are still necessary to check if the plasma is truly in a steady state, and sometimes to feedback control the plasma state. For electron temperature (Te) and density (ne) measurement, repetitive Thomson scattering is most suitable because it gives reliable Te and ne in a wide range of plasma parameters. The Thomson scattering system (TS) currently operating on LHD has already demonstrated its ability to take data for a long pulse plasma persisting up to 72 s. In below, we study the problems with which we will confront when the operation time is prolonged up to hours and consider countermeasures against them.

2. Description of LHD Thomson Scattering System

The features of the LHD TS are: (1) its oblique back scattering configuration, which enables us to measure whole profiles of Te and ne along a major radius on the mid plane; (2) its large solid angle of light collecting optics, which enables us to take high quality data even with a small laser energy, which, in turn, permits high repetition operation. The detail designconsiderations of the TS is given in [1], and the construction and the performance of a prototype

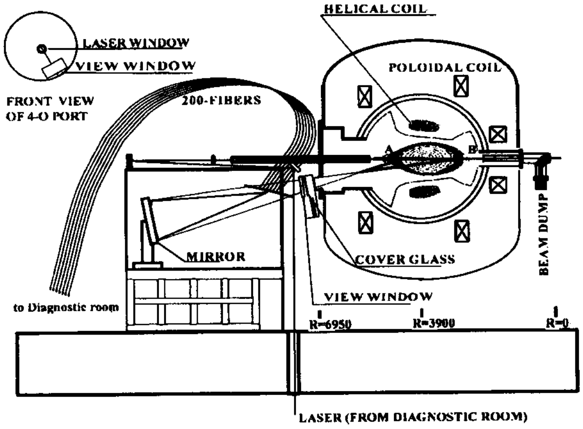

Fig. 1 Scattering configuration of the LHD Thomson scattering system.

---

*Corresponding author's e-mail: narihara@nifs.ac.jp installed on the Compact Helical System (CHS) is described in [2]. Figure 1 shows the scattering configuration.

The laser beam (pulse energy 0.55 J, repetition rate 50 Hz), transported ~50 m from the diagnostic room and aligned so as to run along a major radius on the mid plane, first passes through a focusing lens of $f = 7$ m, enters the LHD vacuum chamber through a laser window set at the center of 4-O port, runs through plasma region and finally is dumped in a beam dump made of carbon block backed by a 3 mm thick SUS 304 plate. The beam diameters at the entrance window and at the beam dump are 10 mm and 6 mm, respectively. A viewing window (fused quartz) of 0.65 × 0.4 m^2 area and 0.05 m width is set on 4-O port, the center of which being separated 0.75 m from the laser beam. The light backward scattered is collected by a mosaic mirror of 1.5 × 1.8 m^2 area and focused onto the end faces of 200 arrayed optical fibers of 2 mm in diameter. For the standard LHD operation the plasma region is covered by the view scope extended by 105–120 fibers. The thus collected light is transported 45 m by the optical fiber to the diagnostic room and then spectral analyzed by 5-filter polychromators. The electric outputs from the polychromators (up to 1000 channels) are converted to digital data by FASTBUS ADCs (1881M Lecroy). The digital data are transferred to two 1 MB fast ECL memories on VME in a flip-flop mode. When the first memory becomes full, then the data flow is switched to the second memory and the data in the first are transferred to a 64 MB memory installed on VME. This process is repeated for two memories alternatively, enabling continuous data acquisition with acquisition rate of up to 10 MB/s. Although, the total data size is limited by the memory size in the VME, this is easily increased substantially.

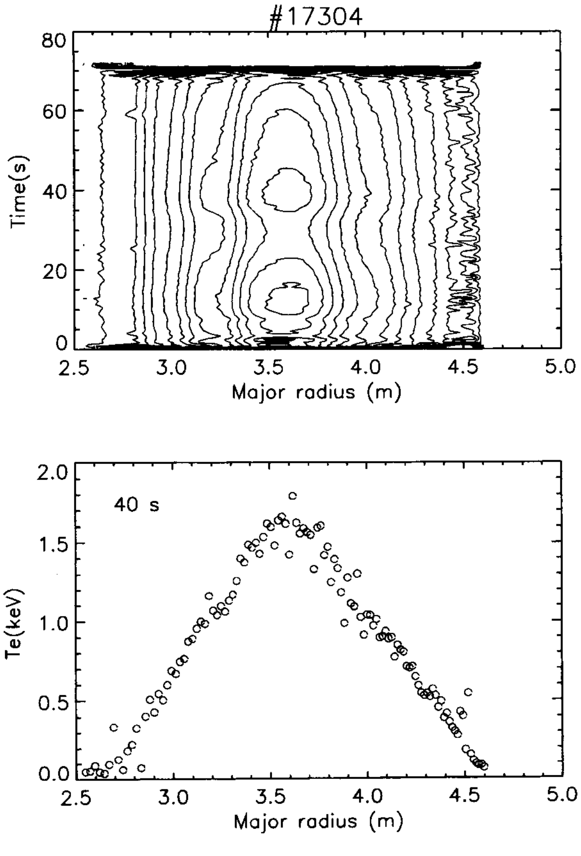

Fig. 2 An example of the evolution of Te profile of the plasma that persisted for 72 sec.

This TS has already operated for long pulse discharge persisting up to 72 s. An example of the contour plot of *Te* of a long-lived plasma is shown in Fig.2. The central density is around 2 × $10^{19}/m^3$. The slow variation of *Te* was caused by a unregulated gas puffing.

3. Problems Arising in the Steady State Operation

(i) Laser: Nd:YAG laser (Continuum NY81-50: 50 Hz rep. rate, 0.55 J/ 10 ns pulse width, 0.6 mr pointing stability) can operate continuously until the life time of flash lamps (50 million shots = 11.5 days) expires.

(ii) Laser beam transport system This is composed of 6 steering mirrors, one focusing lens. These are placed in atmosphere without any particular cooling system. Our concern is if a small fraction of laser power is deposited on the substrate of the mirror or lens, thereby introducing thermal distortion to the mirrors or lens. We have already transported laser beams for more than 10 minutes without any noticeable growing degradation in the transported beam quality.

(iii) Laser entrance window is a both side AR coated fused silica window of 3" in diameter and 0.5" in thickness. The laser power density at the window is $0.55/\pi(0.5)^2 = 0.7$ J/cm^2, which is much less than the specified damage threshold of 10 J/cm^2. High transmittance (>0.975) of the window implies that no heat will be accumulated in the substrate even for long time laser injection.

(iv) Beam dump: The currently used beam dump is a carbon block backed by a 3 mm thick SUS304 plate. After ~10000 plasma shots including several long pulse discharges persisting for > 60 s, we observed that there formed a burnout hole in the beam dump. We speculate that the laser sputtering process was accelerated by the raised temperature of the carbon and SUS304. We are planning to use a water cooled beam dump made of molybdenum, which has high heat conductivity and high melting point.

(v)View Window: The heat flux from the steady state LHD plasma is supposed to be around 10 kW/m^2. If the view window made of fused quartz is exposed to this heat flux, soft x-ray quanta and neutral particles, the dominant careers of the heat, are deposited in the very thin surface layer (a few microns), thereby introducing very high thermal stress particularly at the startup phase of plasma. In order to prevent the fracture of the window due to this thermal stress added to the mechanical stress caused by vacuum pressure, we set a cover glass (12 mm thick fused quartz) in front of the view window as shown in Fig. 3. The cover glass is first heated up to a temperature T_{glass} while emitting radiation $F(T_{glass}) = \varepsilon(\lambda)B(\lambda, T_{glass})\mathrm{d}\lambda$ from both sides, which, in turn heats the viewing window. Here, $B(\lambda, T) = 2\pi c^2 h/\lambda^5/(e^{hc/\lambda kT}-1)$ is the Planck function and $\varepsilon(\lambda) = \alpha(\lambda) = 1-\tau(\lambda)$, where $\varepsilon(\lambda)$ is emissivity, $\alpha(\lambda)$ absorptivity and $\tau(\lambda)$ transmittivity, respectively. Solving the energy transport equation using $\tau(\lambda)$ for quartz shown in Fig. 5, we obtained the time evolutions of the volume averaged temperatures of the cover glass and the temperature distribution of the view window (T_{win}) as shown in Fig. 4. After 1000 s from the start of plasma discharge, T_{glass} almost reaches an equilibrium temperature of 277 °C. The temperature at the surface facing to the cover glass T_{win} (0) increases with much longer time scale. This temperature inevitably introduces a high temperature gradient at the window's periphery, where it tightly touches to LHD flange kept at the room temperature (25 °C). If we make a moderate assumption that T_{win} up to 65 °C is permissible, then the current TS system endures 600 sec operation without modifying the view window.

For operation longer than 600 sec, we need to block the radiation from the cover glass to the view window. An easily conceivable way to block the radiation is to place a sapphire plate, which has high thermal conductivity (0.36 J/sec-cm-°C at 25 °C) and high optical transmittance in visible-near infrared region, between the cover glass and the view window. On a water-cooled frame at 25 °C, 24 sapphire plates of 0.1 × 0.1 m^2 in area and 5 mm in thickness are patched to form a 0.4 × 0.6 m^2 mosaic plate. The opening percentage of 80% seems to be easily realized. A numerical calculation shows that the sapphire plate with the periphery temperature fixed and exposed to the steady state radiation from the cover glass has the temperature distribution with the peak value at the center 40 °C higher than the periphery. The radiation power emitted by the sapphire plates at this temperature is negligibly small. Unfortunately, the pass band of sapphire is wider than that of quartz as shown in Fig. 5, implying that some portion (30%) of the radiation from the cover glass can not be blocked. Hence, the safe operation time is prolonged only about 3 times. Much longer operation time will be achieved by coating the sapphire plates with a thin film filter whose bandwidth is narrower than that of the fused quartz but is wide enough for Thomson scattered light. For example, a low-pass filter with the cutoff wavelength at 2.5 μm,

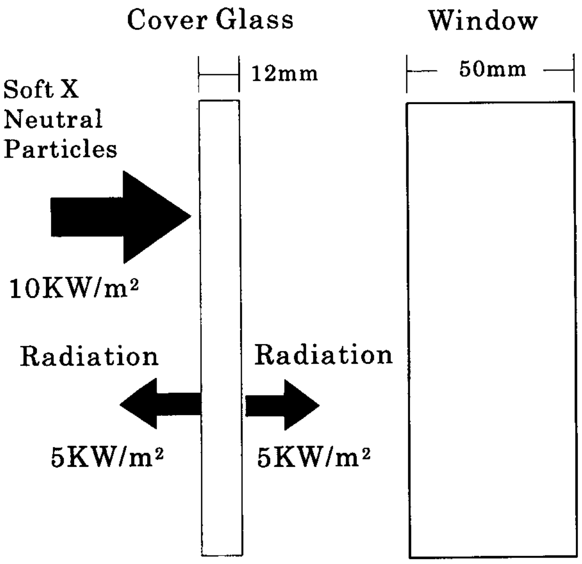

Fig. 3 Side view of the viewing window.

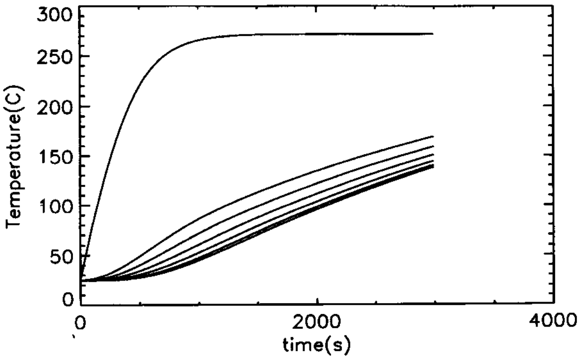

Fig. 4 Evolutions of the temperatures of the cover glass and the viewing port without the cooled sapphire plate.

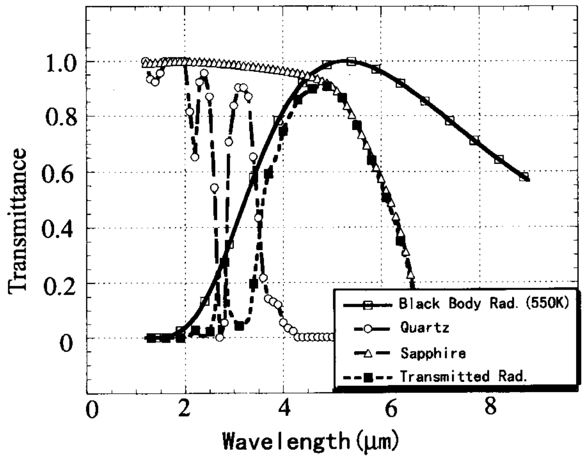

Fig. 5 Transmittances of fused quartz and sapphire as functions of wavelength. Spectra of black body radiation from the cover glass and the radiation that pass through the sappier plate are also shown.

which is easily fabricated, almost block the radiation from the cover glass.

The temperature coefficient of refractive index of 13×10^{-6}/°C makes the sapphire plates focusing lenses, but they are too weak to degrade the image quality of the laser beam.

The cover glass, being faced with the plasma, is darkened gradually and then backups are indispensable for periodic replacement in vacuum. Therefore, a scheme to cool the cover glass made of sapphire directly is very expensive.

For the same reasoning, replacing the view window with the cooled sapphire plate will do well. However, it will be much difficult technically.

(vi) Data acquisition/processing: A sequence of processes involving data acquisition, data storage in a memory, data transfer to a computer and calculation without an interruption during a long pulse plasma discharge is our concern. If the deduced data is used for feedback control of the plasma state, a real time data processing with a minimum delay is required. The present TS system can be modified so as to afford a real time data processing by implementing multi processors into the VME frame. Here, we only examine the feasibility of continuous data acquisition for a long pulse plasma discharge. The most time consuming process in the present data acquisition scheme is the data transfer from the 64 Mb memory to the memory on a PC and subsequent creation of a data file which is stored in a disk. It takes 1 sec for 1 MB data. The data birthrate for the single laser plus 8 backgrounds mode, that is currently used, is 1.6 MB/s, which is too high to be stored in the disk continuously. If we reduce the number of backgrounds to 2, the birthrate is reduced to 0.53 MB/s, which permits a continuous data acquisition by transferring data in the 64 MB memory as soon as the data size reaches 1 MB. Accordingly, a 1 MB data file is being created sequentially every 1.9 s, until a hard disk of, say, 100 GB, which is available at a reasonable cost, become full in 53 hours. For continuous Te deduction from these data files, four task sharing PCs (Pentium II/ Intel) are necessary.

4. Discussions

Up to this, we considered the problems that disable the operation of the TS. Here, we discuss a problem that is related to degradation of the data quality. Impurity particles from plasma pile up on the surface of the cover glass forming a thin layer of film, which distorts the spectrum of the Thomson scattered light, introducing systematic errors in Te. For exposure to ~10000 shots of average 2 sec duration plasmas, no appreciable change in the transmittance of the cover glass was observed. Then, the data quality is preserved at least for 20000 sec (5.5 hours). The operation time thus limited is prolonged by replacing the cover glass with a backup in vacuum. We have another two backup cover glasses housed beneath (Fig. 1). Another method is to correct the spectrum of Thomson scattered light with the transmittance obtained by measuring the spectrum of the blackbody radiation from a heater set inside of the vacuum through the cover glass plus the sapphire plate plus the view window. This method, however, inevitably introduces interruptions of the measurement. Alternative method is to occasionally clean the cover glass by using laser blow off method [3], which also requires some interruption of the measurement.

5. Conclusions

From the above considerations, it seems quite feasible to operate the present 50 Hz repetition rate Thomson scattering system for at least 16 hours with modest modifications.

References

[1] K. Narihara *et al.*, Fusion Eng. Des. **34-35**, 67 (1997).

[2] K. Narihara *et al.*, Rev. Sci. Instrum. **66**, 4607 (1995).

[3] K. Narihara *et al.*, Rev. Sci. Instrum. **63**, 3527 (1992).