γ

Conf-910968--5

GA–A20614

THE MULTIPULSE THOMSON SCATTERING DIAGNOSTIC ON THE DIII–D TOKAMAK

by

T.N. CARLSTROM, G.L. CAMPBELL, J.C. DeBOO, R.G. EVANKO, J. EVANS, C.M. GREENFIELD, J.S. HASKOVEC, C.L. HSIEH, E.L. McKEE, R.T. SNIDER, R.E. STOCKDALE, M.P. THOMAS, and P.K. TROST

SEPTEMBER 1991

GENERAL ATOMICS

DISCLAIMER

GA-A--20614

DE92 000262

THE MULTIPULSE THOMSON SCATTERING DIAGNOSTIC ON THE DIII–D TOKAMAK

by

T.N. CARLSTROM, G.L. CAMPBELL, J.C. DeBOO,
R.G. EVANKO, J. EVANS, C.M. GREENFIELD,
J.S. HASKOVEC, C.L. HSIEH, E.L. McKEE,
R.T. SNIDER, R.E. STOCKDALE, M.P. THOMAS,
and P.K. TROST

This is a preprint of a paper to be presented at the 14th IEEE Symposium on Fusion Engineering, September 30–October 3, 1991, San Diego, California, and to be printed in the *Proceedings.*

Work supported by
U.S. Department of Energy
Contract DE–AC03–89ER51114

GENERAL ATOMICS PROJECT 3466
SEPTEMBER 1991

GENERAL ATOMICS

THE MULTIPULSE THOMSON SCATTERING DIAGNOSTIC ON THE DIII–D TOKAMAK

T.N. Carlstrom, G.L. Campbell, J.C. DeBoo, R.G. Evanko, J. Evans, C.M. Greenfield, J.S. Haskovec, C.L. Hsieh, E.L. McKee, R.T. Snider, R.E. Stockdale, M.P. Thomas, and P.K. Trost

General Atomics
P.O. Box 85608, San Diego, California 92186-9784

Abstract: This paper describes the design and operation of a 40-spatial channel Thomson scattering system that uses multiple 20 Hz Nd:YAG lasers to measure the electron temperature and density profiles periodically throughout an entire plasma discharge. Interference filter polychromators disperse the scattered light which is detected by silicon avalanche photodiodes. The measurable temperature range is from 10 eV to 20 keV and the minimum detectable density is about 2×10^{18} m^{-3}. Laser control and data acquisition are performed in real-time by a VME-based microcomputer. Data analysis is performed by a MicroVAX 3400. Unique features of this system include "burst mode" operation, where multiple lasers are fired in rapid succession (< 10 kHz), real-time analysis capability, and laser beam quality and alignment monitoring during plasma operation. Results of component testing, calibration, and plasma operation are presented.

1. Introduction

Thomson scattering has long been a standard diagnostic for measuring the electron temperature and density in tokamaks. As fusion plasma machines become larger and more expensive to operate, and as temporal evolution of the plasma becomes important to the understanding of the physics of processes such as L–H transitions, edge localized modes (ELMs), beta limits, and disruptions, multipulse laser systems offer an attractive alternative to single pulse systems, both from the standpoint of the cost of repeating many discharges and studying events where shot-to-shot reproducibility is difficult. The use of a multipulse system eliminates the need to know *à priori* when the time of interest will occur during a plasma discharge and also permits measurements to be made during several different experiments in one shot, thereby increasing the productivity of the entire experimental program.

The design of the multipulse Thomson scattering system on the DIII–D tokamak was modeled after the multipulse system on ASDEX [1]. We use multiple 20-Hz Nd:YAG lasers instead of one high repetition laser however, which increases the complexity of control, calibration, and beam optics. Multiple lasers have the advantages of higher overall repetition rate, reliability, and "burst mode" capability where individual lasers are fired in rapid succession, limited only by the data acquisition rate. Unlike ASDEX, the lasers and detectors are located away from the tokamak, and are connected to it via a 30-meter feedback controlled beam path and 18-meter fiber optic bundles. A schematic of the overall layout is shown in Fig. 1.

Because of the importance of the edge plasma in the L-H transition, ELM behavior, and divertor physics, we designed a system to measure T_e from 10 eV to 20 keV, and n_e from 2×10^{18} to 2×10^{20} m^{-3}. Measurement precision is important when trying to compare subtle changes in the profiles from one laser pulse to the next. The system was optimized for high transmission and low noise in order to maximize the signal-to-noise ratio. Careful consideration is given to the background light measurement so that accurate error assessment can be made.

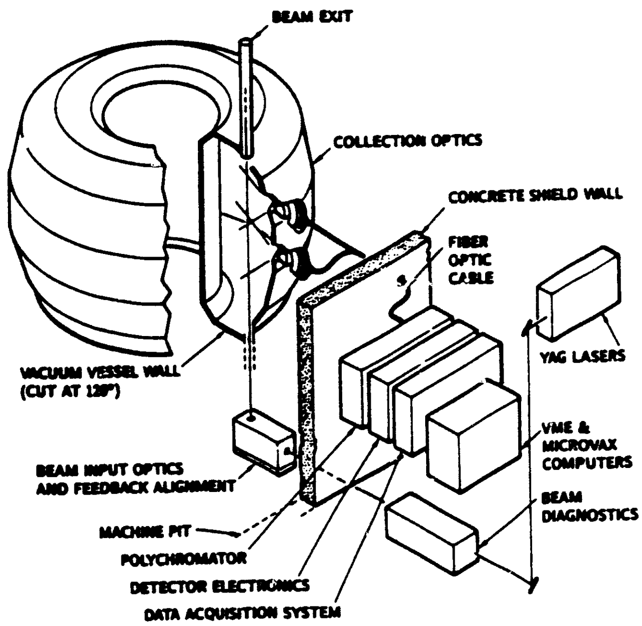

FIG. 1. Schematic of the multipulse Thomson scattering system showing the location of the laser beam path, the collection optics and fiber optic cables, and the remote detection and data acquisition system.

2. Design

Low divergence lasers are required to minimize the laser beam waist in the plasma. This maximizes the ratio of scattered laser signal to background light signal. We selected NY81C-20 Nd:YAG lasers made by Continuum. Each laser (two presently, eight in Sept. 1991) is a low divergence (< 500 mrad), 20 Hz, 1 J 10 nsec pulsed laser. The laser beams are packed closely together along a common beam path. A HeNe laser is made colinear with the Nd:YAG lasers and is used in a computer controlled feedback alignment system. The divergence of the lasers is monitored by a fast readout, 1-D reticon, situated at the focus of a sampled portion of the laser beam. This permits the identification of poor quality laser pulses which might affect the density measurement. In addition, the alignment between the collection optics and the laser beams is monitored by an array of optical fibers located at the image of the laser beam. A detector at each fiber measures the amount of scattered light and the relative position of each laser beam can be determined. This system identifies misaligned laser beams that can affect the density measurement Additional information on the laser system can be found in Ref. 2.

The scattered light is collected by an f/5 multi-element wide-angle collection lens which images the laser beam on an array of 40, 1.5×3.0 mm fiber optic bundles comprised of ~ 100, 212 μ diameter, low loss quartz fibers. Each fiber illuminates a seven-channel polychromator [3]. The transmission of the polychromator, fiber optic bundle, and a typical detector quantum efficiency is shown in Fig. 2. The 3 nm-wide filter at the laser wavelength is used for Rayleigh calibration.

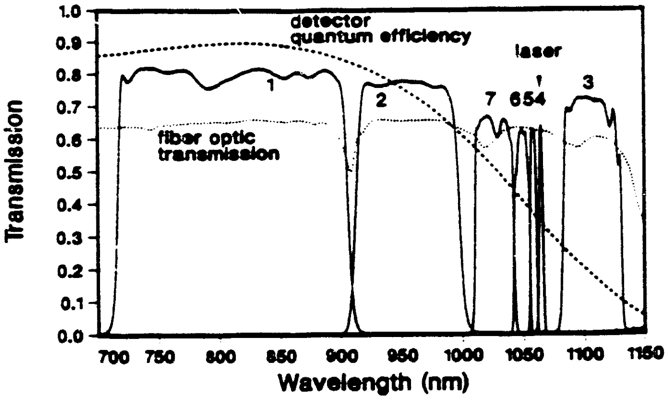

FIG. 2. Measured transmission curves (solid) for the polychromator. The curve numbers indicate the filter sequence in the polychromator. Also shown are the measured fiber optic transmission (dotted) and the estimated detector quantum efficiency (dashed).

The 2.3 mm diameter output image of the polychromator is directly coupled to large format (3 mm diameter), silicon avalanche photodiodes, (RCA C30956E). Each channel has an amplifier circuit [4] with two outputs: a direct-coupled output which is used for calibration and background light measurements and a high-pass output which contains the scattered laser pulse information while rejecting the lower frequency background light. Both the high-pass channel and the direct-coupled channel are digitized with LeCroy 4300B, fast-gated integrators.

The gain of the detector was measured to vary about 3% per degree C at 1060 nm. To minimize the thermal variation of the detector, the avalanche photodiode is placed in a separate chamber away from the circuit board, and the detector electronics assembly is arranged to sink heat to the water cooled polychromator frame structure.

A real-time, VME computer system [5] is used to operate the lasers and acquire the data. A block diagram of the system is shown in Fig. 3. The entire system is on a VMEbus operating at 16 MHz. All CPUs are Motorola 68030 with a 25 MHz clock rate. A Unix-based host communicates with the DIII–D computer center via DECnet. The target processors run the VMEexec real-time operating system. Two target processors are used, one for data acquisition and the other for laser and general diagnostic control. Additional processors can be added in the future to provide real-time data analysis. In addition, a MicroVAX 3400 is used for operator control, data archival and analysis, and an interface to additional CAMAC modules that do not require real-time interaction.

3. Calibration

We rely on an absolutely calibrated photodiode (EG&G Model 690) to measure the detector sensitivity (count/photon) in both the high-pass and direct-coupled channels by calibrating a 1060 nm light emitting diode (LED) (RCA C30116) operated in both pulsed and dc modes. Typical gain values for the high-pass and direct-coupled channels are 0.05 and 0.15 counts/photon, respectively. The difference in gain is purely a function of the electronics, and is therefore invariant with wavelength. The noise due to the electronic circuit is typically 5.0 and 3.5 counts for the high-pass and direct-coupled channels, respectively. The higher noise level in the high-pass channel is due

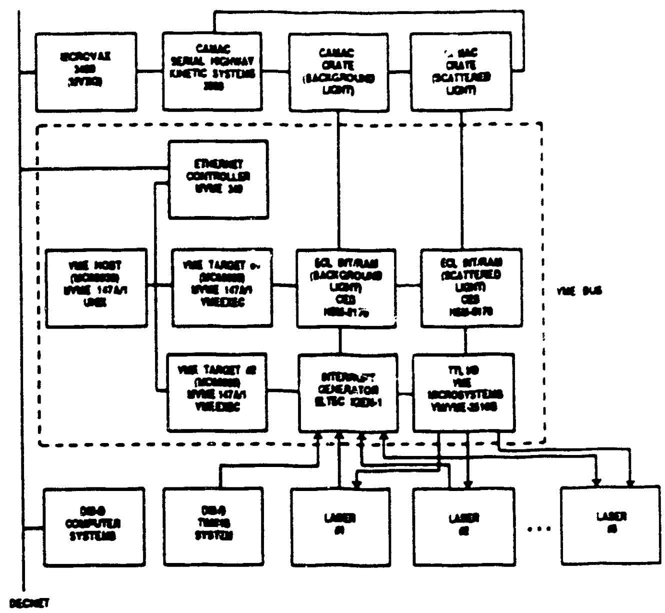

FIG. 3. Block diagram of the diagnostic control and data acquisition system.

in part to the fact that this channel subtracts two signals, and therefore the variance of each signal is added. By absolutely calibrating the silicon avalanche detectors, we can determine the ratio of the excess noise factor [6], which is an increase in the signal variance due to the avalanche process, to the quantum efficiency. Values of this ratio vary from 5 to 20 over the sample of 265 detectors measured. Measuring this ratio enables us to estimate the standard deviation of a signal by measuring only the signal level. Therefore, by measuring the background light in the direct-coupled channel, we can estimate the contribution the background light makes to the standard deviation of the scattered laser signal in the high-pass channel [7].

A dc light source is used to calibrate the wavelength and channel to channel response of the polychromators. To do this, the absolutely calibrated photodiode is used to calibrate a computer controlled CVI Digikrom 240 monochromator, which in turn, is used to measure the transmission and wavelength response of the polychromators. Since the ratio of the gain of the high-pass channel to direct-coupled channel is measured, this calibration can be used for the high-pass channel. The absolute sensitivity of the entire system is calibrated using Rayleigh scattered light from the DIII–D vessel.

4. Results

The data is analyzed immediately following a plasma discharge by using least squares fitting to the Thomson function derived by Selden [8]. The analysis time is minimized by using look-up tables to calculate fitted signal levels during successive iterations on T_e and n_e. The profile results of T_e and n_e for an entire discharge, typically 8000 fits, are avaliable to the user within a few minutes after a shot.

Figure 4 shows the viewing geometry, the laser beam path, and the viewing dump relative to the vacuum vessel. The location of the spatial channels are defined by the intersection of the laser path and the viewing angle. Also shown is a flux surface plot showing a typical plasma location.

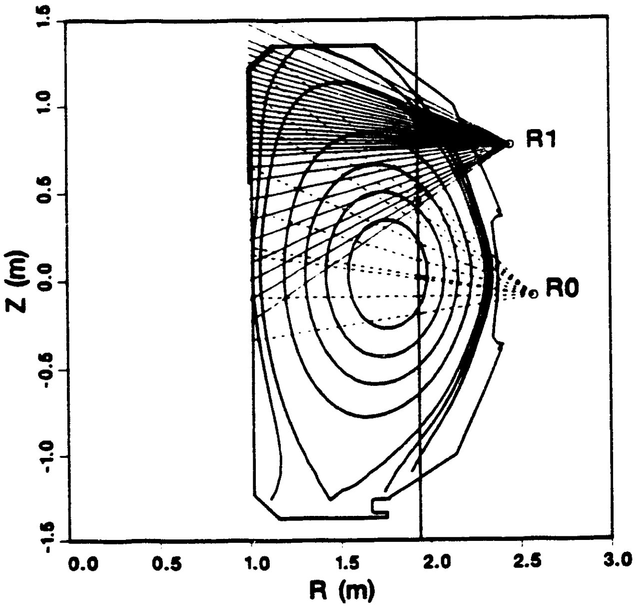

FIG. 4. Viewing geometry of the 40-channel, multipulse Thomson scattering diagnostic on the DIII-D tokamak.

Several different types of data display are available to the user. The time evolution of any spatial channel can be plotted along with other data from the DIII-D data acquisition system through use of the display code REVIEW. Another data display program, TSPLOT, allows the user to display T_e and n_e profiles at selected times, as well as contour plots and 3D plots as a function of time and space. A typical profile plot is shown in Fig. 5. The error bars represent one standard deviation, based on statistical noise from the electronics, photons, and the avalanche process in the detector. Figure 6 shows a contour plot of T_e and n_e for an entire plasma discharge. Although the plasma extends from $z = -90$ to $+90$ cm, measurements are only made from slightly below the midplane ($z = -20$) to the top of the vessel. Note the high density of spatial locations in the plasma edge region from $z = 75$ to 100 cm where the resolution is about 1.3 cm. This resolution is required to resolve the steep gradients produced in H-mode plasmas as shown in Fig. 5.

5. Summary

We have described the design and operation of a 40-spatial channel Thomson scattering system that uses multiple 20 Hz Nd:YAG lasers to measure the electron temperature and density profiles periodically throughout an entire plasma discharge. Interference filter polychromators disperse the scattered light which is detected by silicon avalanche photodiodes. The measurable temperature range is from 10 eV to 20 keV and the minimum detectable density is about 2×10^{18} m^{-3}. Laser control and data acquisition are performed in real-time by a VME-based microcomputer. Data analysis is performed by a MicroVAX 3400. Unique features of this system include "burst mode" capability where multiple lasers are fired in rapid succession (< 10 kHz), real-time analysis capability, and laser beam quality and alignment monitoring during plasma operation. The system has performed reliably as a standard diagnostic on the DIII-D tokamak that provides electron profile information routinely throughout the entire plasma discharge. Results are available within minutes after a shot and a variety of data display codes for the general DIII-D user have been developed. Careful attention has been given to minimizing and accurately determining errors so that detailed comparisons of profiles can be made.

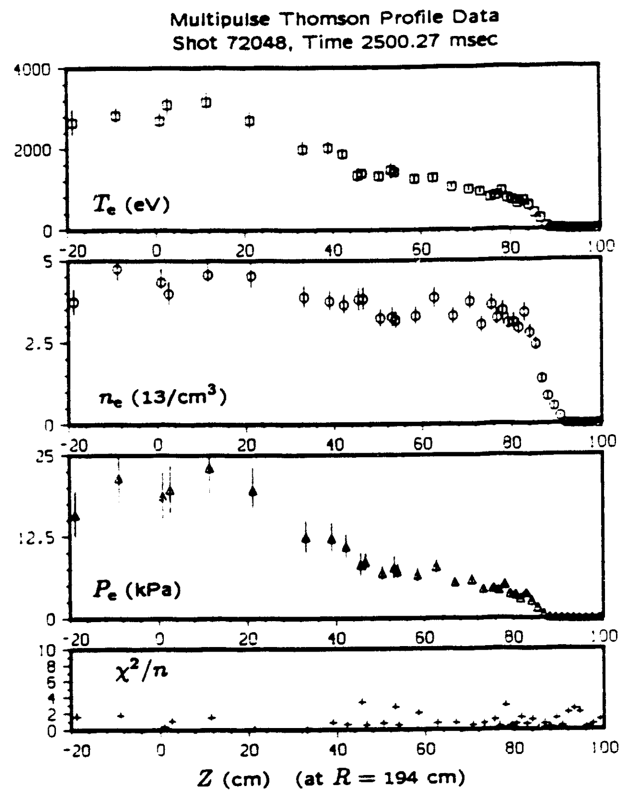

FIG. 5. Typical display of T_e, n_e, and P_e profiles during an H-mode discharge from TSPLOT. The error bars represent one standard deviation. Also shown is the reduced χ^2 for each spatial location.

6. Acknowledgment

This is a report of work sponsored by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

7. References

[1] H. Röhr, K.-H. Steuer, H. Murmann, D. Meisel, IPP report III/121 B, July 1987.

[2] P.K. Trost, T.N. Carlstrom, J.C. DeBoo, C.M. Greenfield, C.L. Hsieh, and R.T. Snider, Rev. Sci. Instrum. **61** 2864 (1990).

[3] T.N. Carlstrom, J.C. DeBoo, R. Evanko, C.M. Greenfield, C.L. Hsieh, R.T. Snider, and P.K. Trost, Rev. Sci. Instrum. **61** 2858 (1990).

[4] C.L. Hsieh, J. Haskovec, T.N. Carlstrom, J.C. DeBoo, C.M. Greenfield, R.T. Snider, and P.K. Trost, Rev. Sci. Instrum. **61** 2855 (1990).

[5] C.M. Greenfield, G.L. Campbell, T.N. Carlstrom, J.C. DeBoo, C.L. Hsieh, R.T. Snider, and P.K. Trost, Rev. Sci. Instrum. **61** 3286 (1990).

[6] P.P. Web, R.J. McIntyre, and J. Conradi, RCA Rev. **35** (1974) 234.

[7] C.L. Hsieh, J. Haskovec, T.N. Carlstrom, J.C. DeBoo, C.M. Greenfield, R.T. Snider, and P.K. Trost, General Atomics Report GA-A20094 (1990) Appendix A.

[8] A.C. Selden, Phys. Lett. A **79**, (1980) 6.

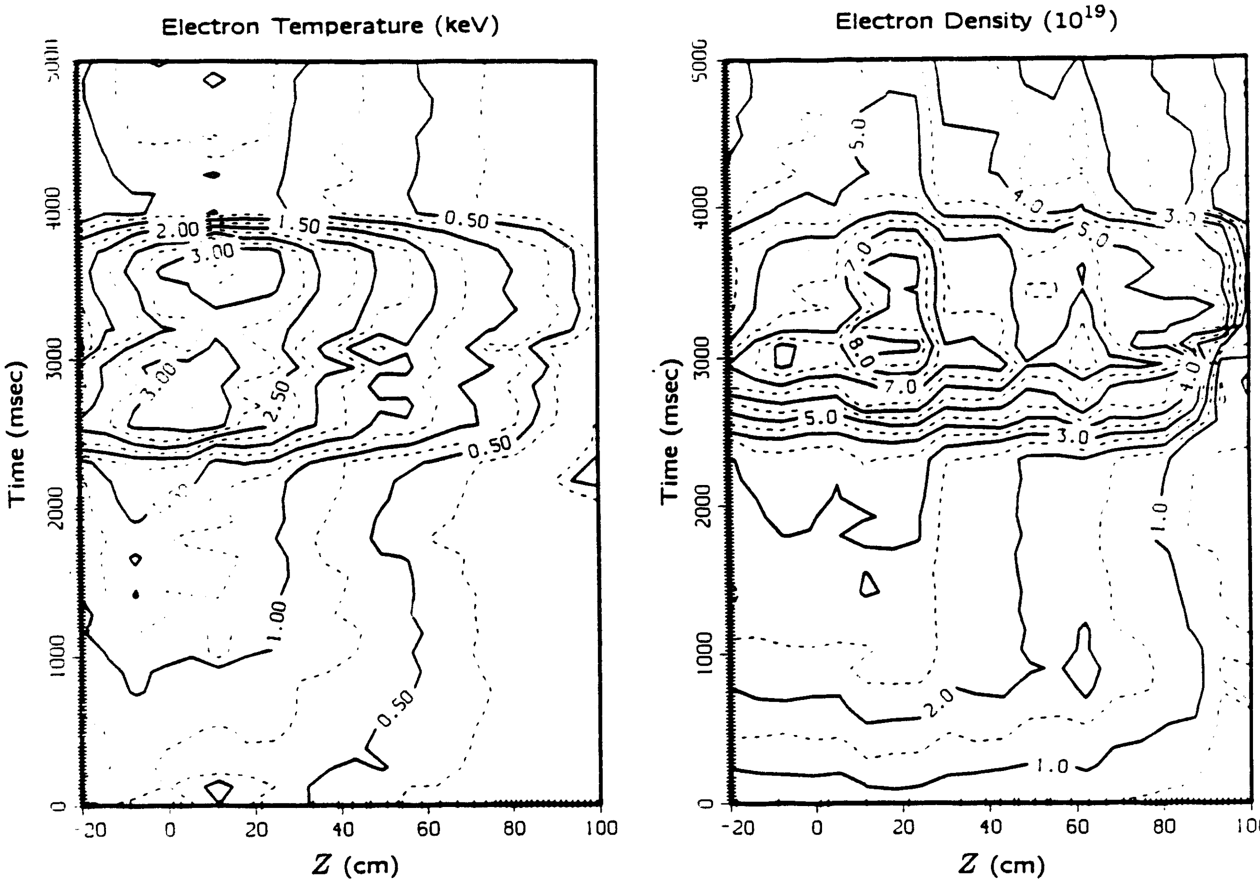

FIG. 6. Contour plots of T_e (in keV) and n_e (in 10^{19} m^{-3}) as a function of time and space from the display code TSPLOT for an entire plasma discharge. The H-modeperiod from 2400 to 3900 ms can be identified by the steep edge density gradient. The tick marks along the axes indicate actual times and locations where the measurement was made.

END

DATE FILMED

10/24/91

I