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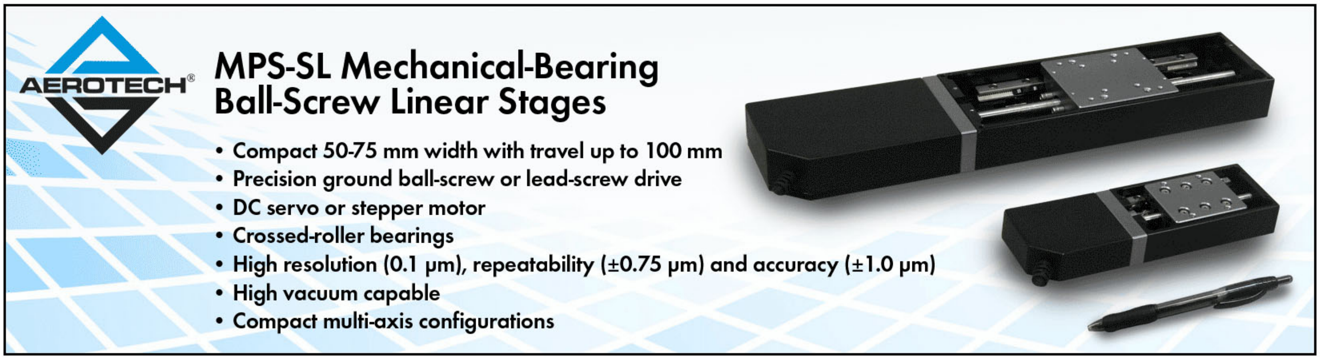

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Active control of laser beam direction for LHD YAG Thomson scattering

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(Presented on 21 June 2000)

We have developed a YAG Thomson scattering (TS) system for the measurements of electron temperature and density profiles on the large helical device (LHD). The LHD-TS has four YAG lasers, and flexible operational modes are possible by using them. For example, (1) high-energy mode: The pulse energy can be increased up to four times by firing the four lasers simultaneously. In this mode, the data quality can be improved for low-density plasmas. (2) High repetition mode: When firing the lasers at intervals of 5 ms, the lasers work as a 200 Hz laser. The laser beams are guided to the LHD by seven steering mirrors. The first mirror is real-time feedback controlled for precise beam transport. The beam pointing stability is improved successfully from 200 μrad to below 4 μrad with the feedback-control system. We describe the details of the laser system for the LHD-TS. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1321750]

I. INTRODUCTION

We have constructed the large helical device (LHD) YAG Thomson scattering (TS) system (LHD-TS) for the measurements of electron temperature and density profiles of LHD plasmas.[1] An overview of the LHD-TS is described in other papers.[2,3] The LHD-TS works well during the second and third LHD experimental cycles, and numerous data have been obtained. The LHD-TS has four YAG lasers, and flexible multibeam operations are possible according to various experimental conditions and research objects. Furthermore, we have developed a feedback beam control system for accurate beam transport. In this article, we describe the laser system of the LHD-TS, with emphasis on the feedback-control system and multibeam operations.

II. OVERVIEW OF THE LHD-TS LASER SYSTEM

A schematic diagram of the LHD-TS laser system is shown in Fig. 1. We have four YAG lasers (Continuum NY81-50) of which the pulse energy and repetition frequency are 0.5 J and 50 Hz, respectively. The lasers are located in the underground diagnostic room where no restriction against radiation hazard is applied. The beam path length from the diagnostic room to the LHD laser entrance window is about 40 m. The beam path is completely covered with aluminum tubes for reducing perturbations due to the environmental variations, and for safety. The laser beams are guided with seven steering mirrors. At several positions of the mirrors, we can observe the beam position through position-sensitive detectors (PSDs) and/or charge-coupled-device (CCD) cameras. The fourth to seventh mirrors are located in restriction areas where no one can enter during the plasma experimental hours. Then, these mirrors can be remote controlled from the diagnostic room. The laser beams are focused at the LHD plasma center, and finally, absorbed with a carbon beam dump. An oblique backward scattering configuration is adopted in the LHD-TS. The scattering angle is 166° at the center of the LHD plasmas. Thomson scattered lights are collected with a large 1.8×1.5 m spherical mirror, transmitted by 200 optical fibers, and finally, analyzed with five-channel polychromators.[2,3]

III. BEAM FEEDBACK CONTROL SYSTEM

In the Thomson scattering system, accurate beam transport is required. Since the LHD building is well air conditioned, the disalignment of the steering mirrors due to the temperature variations is very small. In addition, the time scale is long, roughly speaking, a few days or a week. Then, these mirrors are aligned by using a stable, reference HeNe laser beam every other week. On the other hand, the beam-pointing stability of each laser is not good enough. The pointing stability quoted in the catalog is 400 μrad, and then the beams fluctuate about 16 mm at the position of the LHD laser entrance window after traveling 40 m. The actual measured pointing stability is about 200 μrad. However, the fluctuation is even too large to make accurate Thomson scattering measurements. Therefore, we have developed a real-time feedback-control system for reducing the beam fluctuation. Fortunately, the shot-by-shot variation is small, typically, less than one tenth of the measured values. Therefore, the direction of the next pulse may be predicted from that of the previous pulse. In this control system, the first steering mirror is feedback controlled by referring the position information observed with a PSD (Hamamatsu HK-500), as shown in Fig. 2. The PSD is located at just behind of the fourth steering mirror of which transmissivity is less than 0.5%. The transmitted beam image is reduced with a convex lens, and further diminished by ND filters. The effective area of the PSD is 20 mm×20 mm square, and four electrodes are attached at the four sides. The beam center positions X and Y are obtained by $X=L(X1-X2)/SUM$ and $Y=L(Y1-Y2)/SUM$, where L is the length of the PSD, $X1$, $X2$, $Y1$, and $Y2$ are the charges picked from the four electrodes, and $SUM=X1+X2+Y1+Y2$. The calculations are made with

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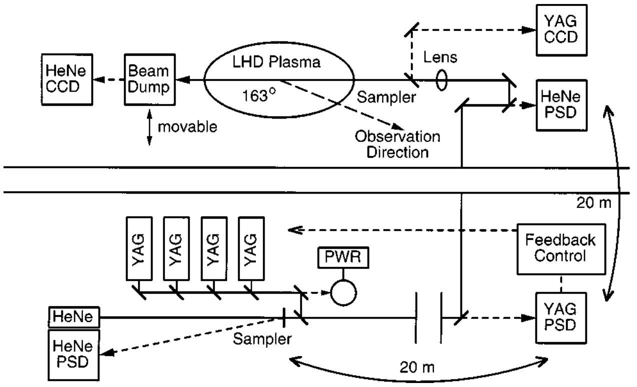

FIG. 1. Overview of the laser system of the LHD Thomson scattering.

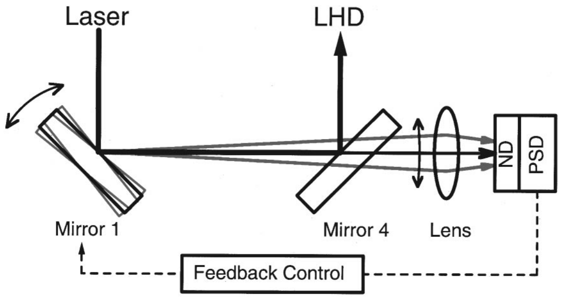

FIG. 2. Scheme of the active feedback-control system.

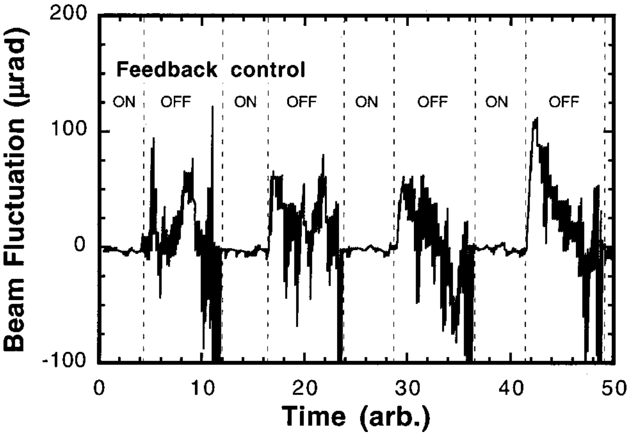

FIG. 3. Beam fluctuation measured with a position-sensitive detector. The feedback system reduces the beam fluctuation efficiently.

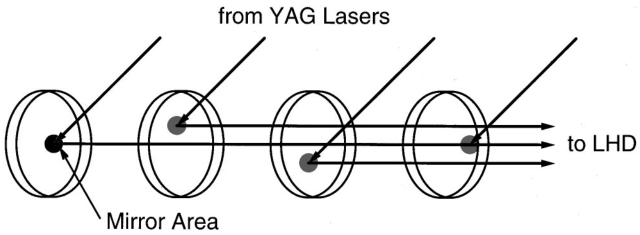

FIG. 4. Scheme of the beam packing mirror.

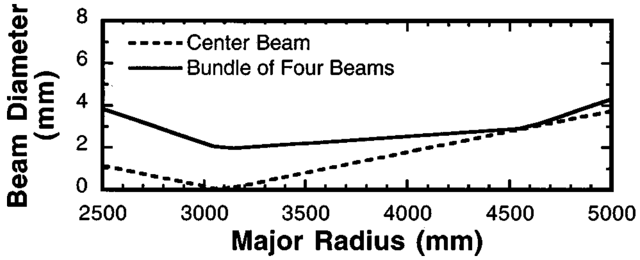

FIG. 5. Beam diameter for bundle of four laser beams (solid line) and the center beam (broken line).

analog computers. The PSD unit can distinguish two laser pulses if the temporal interval between the pulses is longer than 10 μs. Even in multibeam operations described later, all beams are observed with the PSD. The position information

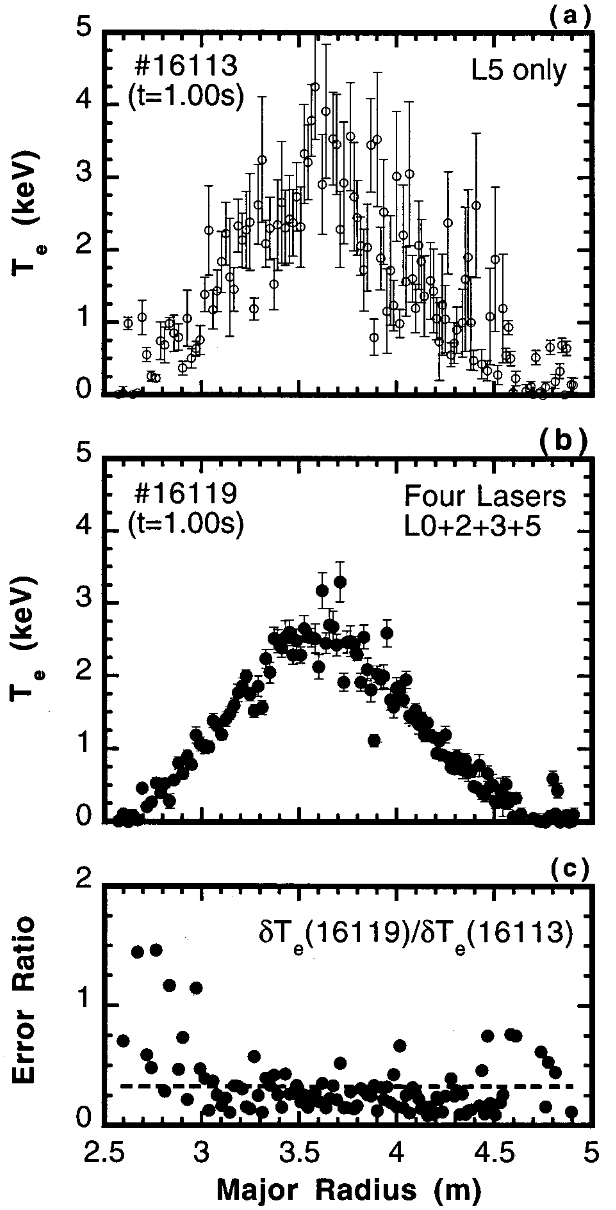

FIG. 6. Electron temperature profiles measured with a single laser (a) and four lasers (b). The center electron densities were about 6×10^{12} cm^{-3} for both shots. The ratios between experimental errors for these two profiles are also plotted in (c). By adding pulse energies with the four lasers, the data quality can be improved significantly for low-density plasmas.

for each beam is distributed to the corresponding feedback system by an analog switching circuit following the fire trigger signal. The feedback-controlled first steering mirror is mounted on a precision gimbal mirror mount (Newport 605-4) equipped with ultraresolution electrostrictive actuators (Newport AD-30). The resolution and motion speed of the linear actuator are 0.04 μm and 400 μ/s, respectively. These correspond to the angular resolution of 0.8 μrad and speed of 8 mrad/s, respectively, when the 605-4 mirror mount is used. Figure 3 shows the beam fluctuation measured with the PSD. The feedback control is applied at the periods indicated by ''ON.'' The beam fluctuation is almost completely eliminated during the periods. The residual small fluctuation is due to electrical backgrounds. Hence, we can say that the pointing stability has been suppressed down to less than 4 μrad, which is good enough for the requirements. This feedback control system has been verified to work well even in the multibeam experiments when the pulse intervals are longer than 15 μs.

IV. MULTIBEAM OPERATION

We have four YAG lasers whose repetition time and pulse energy are 20 ms and 0.5 J, respectively. By setting the fire sequence, several operational modes are possible. For example, the lasers can be used as a high-power laser with the pulse energy of 2 J, keeping the repetition frequence of 50 Hz when firing the four lasers simultaneously. In this operation, the signal-to-background ratio is expected to be increased, resulting in improved data quality. If the four lasers fire at intervals of 5 ms, the lasers work as a high-repetition 200 Hz laser. This operation is suitable for observing fast phenomena. It is noted that we have already carried out the measurements with up to four lasers, and full multibeam operation will begin in the near future.

For such multibeam operations, we have designed beam packing mirrors,[2,3] similar to those developed by the DIII-TS group.[4] By using the mirrors, up to seven beams can be packed. The multibeam operations with five YAG lasers were carried out successfully in the CHS-TS,[5] which is the prototype of the LHD-TS. A dielectric 14×20 mm^2 elliptic mirror is formed on an AR-coated glass substrate with a diameter of 80 mm. The position of the mirror area is different for each laser to allow upstream laser beams to pass through, as shown in Fig. 4. It is noted that the feedback control is applied to the beam packing mirrors. Before entering LHD plasmas, the laser beams are focused with a convex lens whose focal length is 6 m. The parameters of the lens and beam path for each laser are optimized to minimize the diameter of the bundle beam inside LHD plasmas. Figure 5 shows the estimated beam size inside LHD plasmas. The diameters of the bundle beam (solid line) are smaller than 4 mm, typically, 3 mm.

Figure 6 shows the comparison between the electron temperature profiles measured with a single laser (a) and four lasers (b). The four lasers are fired almost simultaneously (10 ns interval). The two profiles were obtained under similar plasma conditions, and the central electron densities were about 6×10^{12} cm^{-3} for both shots. Clearly, the data quality is improved in high-power operations for such low-density plasma discharges. The ratios of the experimental uncertainties are also plotted in Fig. 6(c). In this example, the errors are reduced to about one third by increasing the total pulse energy by four times. This method is very useful for observing low-density, but physically important, plasmas such as edge plasmas and high-temperature ECH plasmas in LHD.

V. CONCLUSION

We have developed the LHD-TS for the measurements of electron temperature and density profiles of LHD plasmas. In the LHD-TS, accurate beam control has been achieved with the newly developed active feedback-control system. Furthermore, multibeam operations have been successfully applied in the LHD plasma experiments. In the near future, lasers with higher pulse energy will be introduced for further improvement of data quality. In addition, the number of lasers will be added for increasing the repetition rate.

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