Test of a periodic multipass-intracavity laser system for the TEXTOR multiposition Thomson scattering diagnostics

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(Presented on 21 June 2000)

A multipass intracavity laser probing system operating in a burst mode has been tested for the Torus Experiment for Technology Oriented Research Thomson scattering diagnostics. The parameters tested were the probing pulse energy and power as well as pulse repetition frequency. The system is to be applied for the dynamic study of fast plasma phenomena (e.g., transport barrier formation and filaments) requiring both high time and spatial resolutions of the electron temperature measurements. [DOI: 10.1063/1.1319370]

I. INTRODUCTION

The resonator cavity of the multipass intracavity laser probing system[1,2] is formed by a 100% rear mirror (1) and multipass system (MPS), which forces the laser beam to scan a probing volume many times and then turns it back to the laser rod (Fig. 1). The system provides a significant gain in probing energy and low radiation losses in the cavity. This high efficiency of the pumping-to-probing energy conversion allows the system to operate in a burst mode providing many pulses during one flash lamp discharge. The system appeared to be an efficient tool in small tokamak experiments,[3] nevertheless, the feasibility of the approach to larger devices required a special study.

II. SYSTEM DESIGN

A model of the multipass intracavity probing system was built in geometry suitable for the Torus Experiment for Technology Oriented Research (TEXTOR) tokamak. The laser head with a 19×200 mm ruby was placed on a distance of 24 m from the MPS center. Four flat mirrors relayed the beam to the MPS with ~5% reflection losses. About 8% of the beam energy was split in the vicinity of the ruby rod to measure the direct and returned energies. An objective (2) consisting of positive ($F=245$ mm) and negative ($F=-120$ mm) lenses compensated a wave front distortion of the laser beam to minimize its divergence. Lens (7) of focal length $F=2490$ mm focused the direct beam in the MPS center. The MPS spherical mirrors ($R=2000$ mm) were positioned at about 4 m from each other. The resonator cavity was passively Q switched by tinted glasses doped with CdSe.

III. SYSTEM TEST

The parameters tested were the probing pulse energy and power as well as pulse repetition frequency. The pulse energy and repetition frequency were controlled with initial absorber transmission and pumping rate. With a denser absorber, the pulse probing energy and power rise, but the repetition frequency goes down. In the test, the laser pulse energy inside the ruby rod was limited to 10–15 J to prevent possible damage from the pulse train of several hundreds of Joules. There was no damage observed in the rod and their coated faces, giving a minimum damage threshold of ⩾5 J/cm^2.

The multipass intracavity system requires special care for the beam divergence because it affects essentially the number of passes, light losses in the cavity and, as a whole, the system performance. Transverse optical irregularity of a

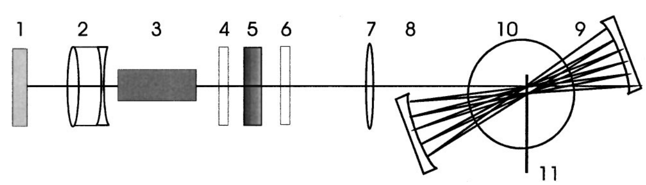

FIG. 1. Multipass intracavity laser system: (1) rear mirror, (2) objective, (3) laser rod, (4,6) glass plates, (5) Q switch, (7) focusing lens, (8,9) spherical mirrors of the multipass system, (10) plasma volume, (11) observation axis.

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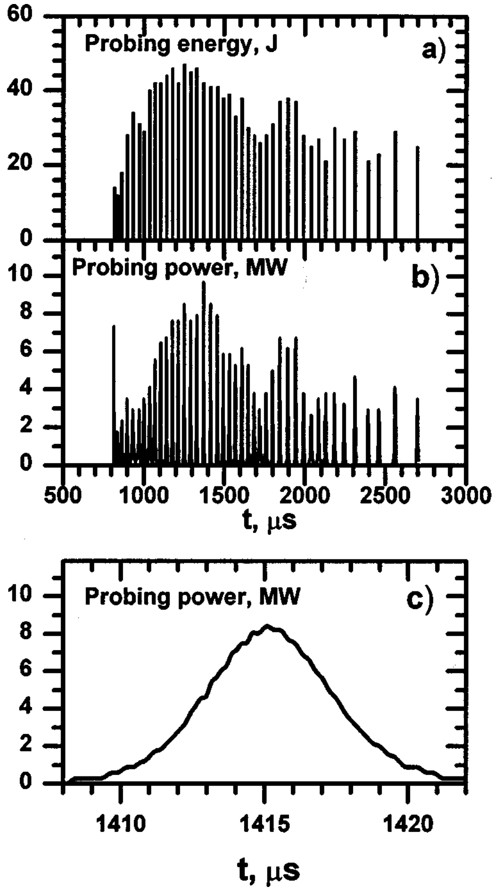

FIG. 2. Probing pulse energy (a), power (b), and shape (c) with 94% absorber. The total probing energy is 1370 J.

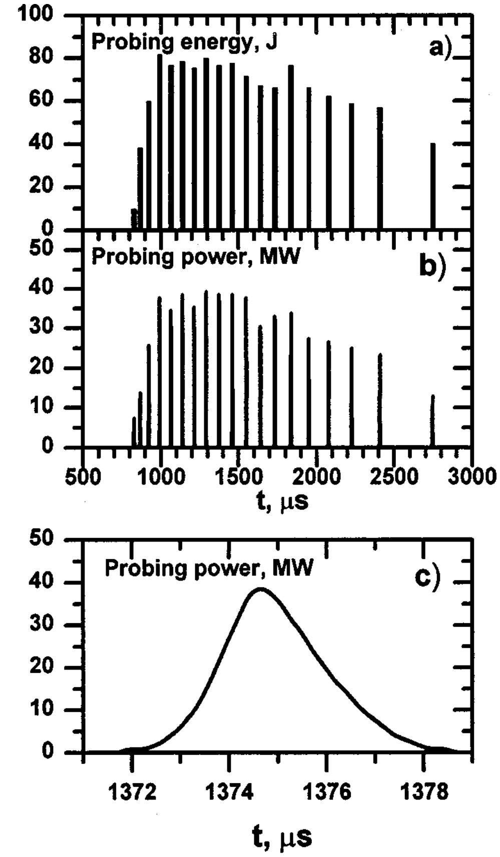

FIG. 3. Probing pulse energy (a), power (b), and shape (c) with 86% absorber. The total probing energy is 1210 J.

ruby rod is most responsible for poor beam divergence. The objective (2) allowed a partial compensation of the irregularity. At the optimal lens distance, the beam divergence was reduced by five times against the objective-free cavity. As a result, the full width half maximum (FWHM) of the beam angular pattern reached a low of 0.5 mrad.

Intracavity probing also requires exact adjustment of the position of the focusing lens and spherical mirrors. The accuracy of the mirror distance required by the resonator stability conditions[4] is about 10^{-3}. An incorrect MPS configuration changes the beam mode and can result in a recession of the beam waist along the system; even in its focus on the mirrors. Alignment flaws also deteriorate the spatial resolution of the measurements and increase the stray light level and light losses in the system. The optimal distance between the mirrors was found to be 3963 mm. At the optimal system configuration, 89% of the direct energy was returned to the laser rod. Taking into account the 10% reflection losses in the optical relay system, this means almost no loss in the multipass system.

Examples of laser oscillation in the 14-pass system are shown in Figs. 2 and 3. More than 40 laser pulses at 25 kHz repetition frequency and with 1370 J total probing energy were produced with a 94% saturable absorber. A 86% absorber provided 20 pulses at 10 kHz frequency with 1210 J total probing energy. For both absorbers, the pulse probing energy is quite high, whereas the probing power is several times less than in conventional systems with an active *Q* switch. Note that a repetitively *Q*-switched three-stage ruby laser based on the conventional approach yields only 1.6 J and 16 MW per pulse at ~10 kHz pulse frequency.[5]

One of the reasons for low power is a slow bleaching of the saturable absorber, which retards the laser pulse formation. With an active *Q* switch, a shorter pulse will result in a higher probing power.

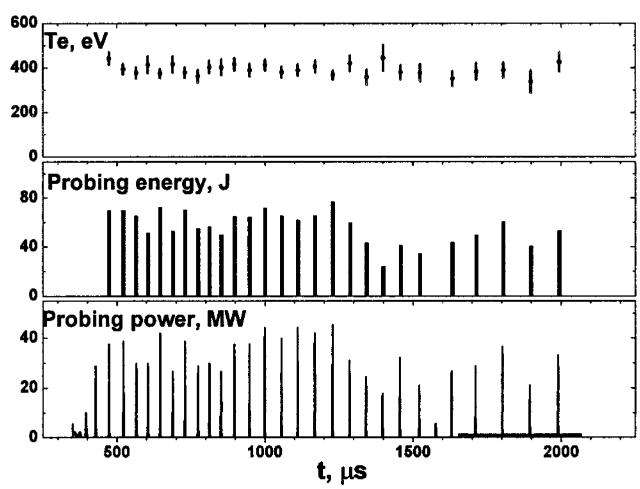

FIG. 4. Multipass intracavity system in the FT-2 tokamak: electron temperature, probing energy, probing power.

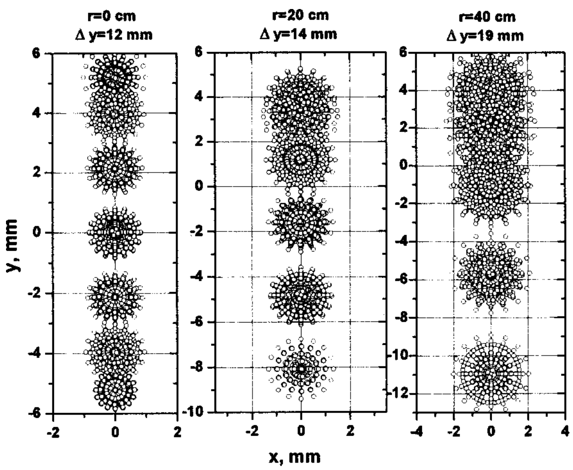

FIG. 5. Cross sections of the beam fan in the 14-pass system at $r=0$, 20, and 40 cm.

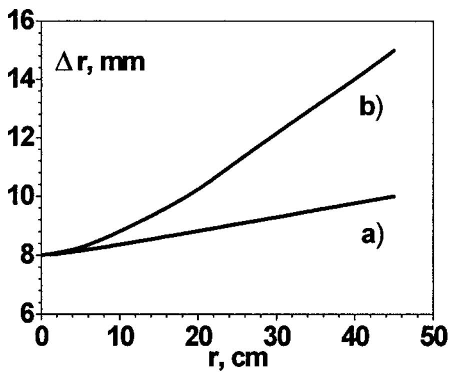

FIG. 6. Radial spatial resolutions of the conventional (a) and 14-pass intracavity (b) systems in the TEXTOR.

In spite of low probing power, the large number of incident and therefore scattered photons provide perfect temperature evolution measurements. An example of the measurements in the FT-2 tokamak is shown in Fig. 4. The ratio of scattered-to-plasma background light at 700 MW probing power was found to be ~25 in the TEXTOR multiposition Thomson scattering (TS) system.[6] Despite a 20-fold decrease of this ratio in the intracavity system, 2×10^4 photoelectrons will be recorded, resulting in a statistical error of 1% for the temperature measurement in each laser pulse. However, the high plasma light level, especially H_α, for a 3 μs integration interval might lead to saturation of the detector.

A special problem of the work was to preserve as much as possible a high spatial resolution of the TEXTOR multiposition TS,[6] which is 8 mm at FWHM in the vertical direction. The new system holds the transverse resolution. The FWHM of the probing beam was found to be 1 mm in the plasma center (beam waist) and 3.5 mm at the edge (40 cm away). The longitudinal resolution is deteriorated because of the beam expansion. Figure 5 shows the beam fan cross sections calculated in geometrical optics approximation. The laser beam was represented by 625 rays launched from the ruby rod within a full angle of 1 mrad. The calculated patterns agree perfectly with the observed beam positions.

Figure 6 gives a comparison of the radial resolutions calculated for the existing and multipass intracavity systems at the TEXTOR scattering geometry assuming circular magnetic surfaces in plasma. One can see that the new system preserves the radial resolution in the plasma core. In spite of worse resolution at the edge caused by a large angle between observation axes and magnetic surfaces, the system maintains a high radial resolution sufficient for most tokamak experiments.

A higher spatial resolution required for the filament study is provided by a double pass system consisting of a single spherical mirror (9), which directs the laser beam back into the laser rod. If correctly designed, it entirely preserves the spatial resolution of the conventional single pass system and yields 300 J of the total probing energy in the burst.

IV. CONCLUSION

A multipass intracavity system designed for TEXTOR TS diagnostics has been tested in a model experiment. The system has shown high performance in burst mode operation, giving a probing energy >1000 J at a pulse repetition rate of >10 kHz. These new capabilities allow the application of TS diagnostics to study the dynamic of fast plasma phenomena (e.g., transport barrier formation and filaments) both at high time and spatial resolutions. Future efforts will be spent on a decrease of the pulse width using an active Q switch, which also enables it to get a preprogrammed burst of pulses.

ACKNOWLEDGMENT

The work was partially supported by the Russian Foundation for Basic Researches, Grant No. 00-02-16927.

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