MEASUREMENT OF IR-LASER BEAM PARAMETERS

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A modified method of replicas has been considered that unables one to estimate the dynamics of the parameters of IR laser beams. This method can be used for lasers operating in a periodic-pulse regime. The measurements of temporal dynamics of beam sizes, position of the beam center, and the beam divergence have been presented.

To measure the parameters of high-power IR laser beams, the methods based on heating of sensors upon exposure to the incident radiation are mainly used. For example, wire sensors inserted in the beam,[1] matrices of sensors with thermocouples,[2] thermal imaging methods of reconstruction of the radiation parameters from screen heating,[3] producing replicas (burns) on different materials (thermosensitive paper with color thresholds, paper impregnated by different compounds, magnetic types, and so on),[4,5] and others. The methods based on multielement receivers and thermal imaging systems are too complicated for practical implementation and expensive.

In the present paper, a modified method of replicas (simple and cheap) is proposed that can be used to estimate the dynamics of the parameters of IR lasers operating in a quasicontinuous (periodic-pulse) regime. The measurements of temporal dynamics of the beam sizes, position of the beam center, and the beam divergence are presented.

MEASUREMENT PROCEDURE

The modification of the method is that the registration material is moved during the time of generation through the beam cross section. Two variants of this system are shown in Figs. 1 and 2. Here, the motion is provided due to rotation of discs with the given number of revolutions and registration material is clumped on the disc surface. On the rotational axis there is a conical hole to fix the compasses used to draw a reference circle on the material surface. The coordinates of replica edges are measured relative to this reference circle. To adjust the velocity of rotation of discs, an optical, magnetic, or other sensor of the number of revolutions with a measuring device is mounted on each disc.

The Skanator–1 system (see Fig. 1) is capable of measuring the position of the beam center and the beam sizes simultaneously in two (vertical and horizontal) cross sections, if the beam is annular. In front of the discs, a metallic polished screen with two perpendicular slits is placed. The beam axis passes through the screen center. If the beam is circular or rectangular, measurements are performed in one cross section only with one disc and the screen with one slit. The radiation reflected from the screen surface is directed into an absorber (a trap). The radiation from each pulse passes through the slits and produces replicas on the registration material. Width of slits Δl, disc radius R, and the number of disc revolutions are adjusted from the conditions

$$V = (1.5 - 2)\,\Delta l\, f,\quad R \ge N\,(1.5 - 2)\,\Delta l,$$

$$n = 2\pi R / V, \tag{1}$$

where V is the disc rotation velocity, f is the pulses repetition frequency, $N = t \times f$ is the pulse number that are to be registered during the generation time t.

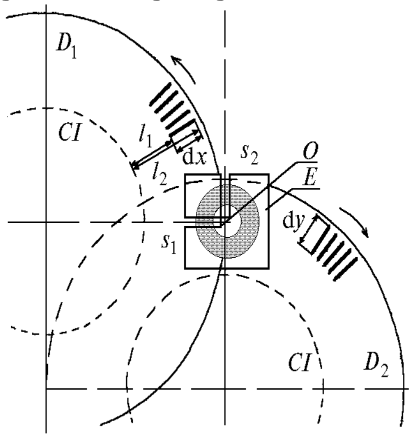

FIG. 1. Skanator–1 system for measuring the beam cross sizes in two directions (vertical and horizontal): D_1 and D_2 are the rotating discs, E is the screen with two perpendicular slits s_1 and s_2, O is the radiation beam axis, dx and dy are the sizes of beam along the x and y axes, CI is the reference circle.

Fulfillment of these conditions is required for separate registration of each pulse. In some cases it is necessary to consider the diffraction on the slit

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resulting in the increase of the replica width behind the slit by $\Delta l_d = \Delta l + 2.44\lambda L/\Delta l$, where L is the distance from the slit to the disc surface.

From narrow laser beams the direct registration is possible of each pulse without the screen.

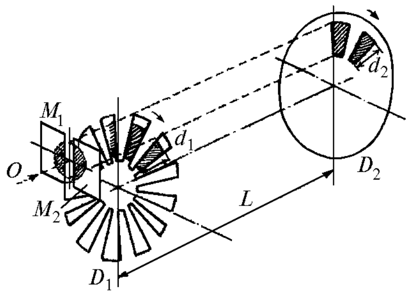

FIG. 2. Skanator–2 system for measuring the divergence and displacement of the laser beam by the method of two cross sections: D_1 and D_2 are the rotating discs, M_1 and M_2 are the mirrors forming the slit, L is the distance between the discs, d_1 and d_2 are the beam sizes, O is the beam axis.

In Fig. 2 the Skanator–2 system is shown for measuring the divergence and displacement of the laser beam by the method of two cross sections. The first disc represents a modulator and the second disc is solid. Some pulses of radiation that passed through the slit formed by two metallic mirrors (screens) produce the replicas of each pulse on the first or second disc. The modulator blade width is equal to the gap between the blades and must be several times larger than the slit width. The disc rotation velocity is adjusted so that during the time of blade or gap passage, several radiation pulses can pass. This is required for temporal averaging over this number of pulses.

In data processing, the upper and bottom edges of each replica were labeled at a selected level (visually at a calibration level) and radial distances were measured to the reference circle $l1_i$ and $l2_i$ on each disc. After that the sizes dx_i and dy_i and the center coordinates x_i and y_i were calculated for each pulse (i is the serial pulse number) and the displacements of the beam center Δx_i and Δy_i from its average position x_{av} and y_{av} were calculated by the formulas

$$d_i = l2_i - l1_i, \quad x_i = (l1_i + l2_i)/2,$$

$$\Delta x = x_i - x_{av}, \quad \Delta y = y_i - y_{av}. \tag{2}$$

Testing with a stable CO_2 laser has shown that the rms measurement error $\sigma(d) = 0.23$ mm and $\sigma(x_i) = 0.25$ mm for the average values $d_{av} = 61.4$ mm and $x_{av} = 89.2$ mm relative to the reference circle.

In the second modification, the total beam divergence Θ, the wavefront curvature radius F, and the displacement of beam propagation direction Δl through the slit, for example, due to thermal selfaction are estimated from the formulas

$$\Theta = \frac{d_1 - d_2}{L}, \; F = \frac{L\, d_2}{d_2 - d_1}, \; \Delta l = y_2 - y_1, \tag{3}$$

where d_1, d_2, y_1, and y_2 are the values averaged over the pulses registered on one blade or in one gap between the blades, and L is the distance between the discs.

MEASUREMENT RESULTS

The measurements were carried out under calm conditions on the path between the CO_2 laser and the optical system. The intensity distribution over the beam cross section was nearly uniform. The regime of generation was quasicontinuous (periodic-pulse).

In Fig. 3 the example is shown of measured beam sizes in the beam cross sections along the x and y axes. On the vertical axis, the beam sizes dx and dy are plotted normalized on the average sizes dx_{av} and dy_{av}. On the horizontal axis the serial number of pulse N_i is plotted normalized on the pulse number N.

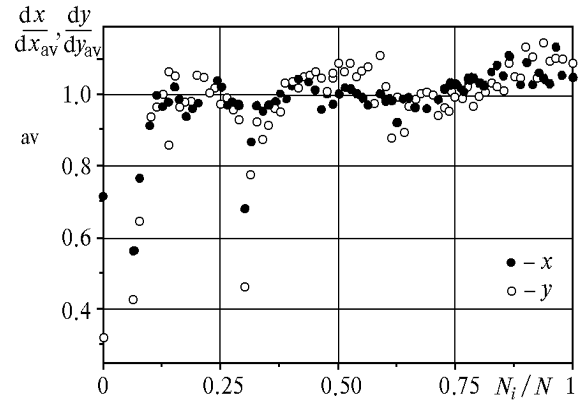

FIG. 3. Beam sizes in two cross sections normalized on their average values.

In Fig. 4 the displacements of the beam center Δx and Δy along the x and y axes are shown about the average position of the beam center.

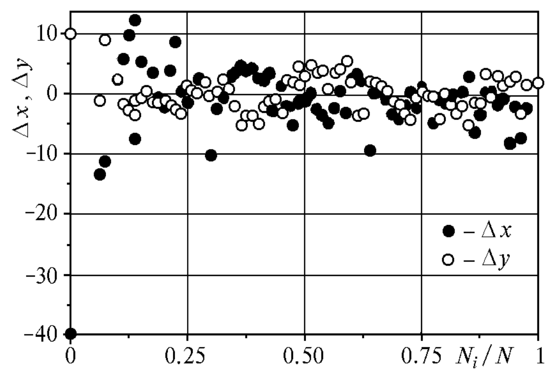

FIG. 4. Displacements of the beam center Δx and Δy about its average position.

From the measurements a number of characteristic features of the examined laser operation follow. The first feature is the unstable regime of laser generation after lasing of the first several pulses starting from (0.01 to ≈0.07) N_i/N. The second feature is the decreased beam sizes of the first pulses. The second breakdown of laser generation at $0.3N_i/N$ is not typical. It has been manifested in this concrete measurement and illustrates the potentialities of this method. Fairly large fluctuations (≈±10%) of the beam sizes and positions of its center were observed. The fluctuations of the beam sizes may be caused by two factors. The first factor is the energy variation from pulse to pulse, because the beam size was determined on the threshold level of the replica. The second factor is the real measurement of the beam size. Stable beam broadening upon fairly long exposure was observed in ≈ 0.8 s, which agrees with the measurements by other methods and is determined by the thermal selfaction.

Variations of the beam sizes at the distance L are shown in Fig. 5. Here, the points are for the beam sizes averaged over the series of pulses on discs d_1 and d_2. The solid curves are the approximations by the 4th order polynomials calculated by the least squares method

$$d_1 = 20.30 + 50.53t - 125.38t^2 + 130.39t^3 - 48.95t^4,$$

$$r = 0.893,$$

$$d_2 = 19.52 + 80.87t - 220.85t^2 + 260.85t^3 - 112.19t^4,$$

$$r = 0.945, \quad (4)$$

where r is the correlation coefficient.

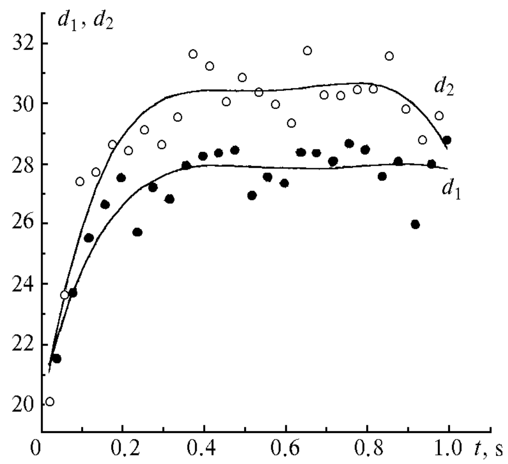

*FIG. 5. Beam sizes (*mm*) along the vertical axis measured on the first and second discs.*

With the help of Eq. (3) and approximation (4), the divergence Θ″ and the wavefront curvature radius F were calculated (Fig. 6). From the figure it can be seen that the focused beam ($F \le -200$ m, $\Theta \le -200''$) is first generated, which fast ($t \approx 0.04$ s) transforms into the collimated beam. At $t \ge 0.15$ s, the stationary regime of generation was established ($F \approx 86$ m, $\Theta \approx 700''$). This time behavior explains the decreased beam sizes for the first pulses (see Fig. 1) and instability of generation at the start due to fast variations of the effective focal distance of the laser resonator. Variations of F and Θ at the end of generation are caused, in general, by the approximation errors.

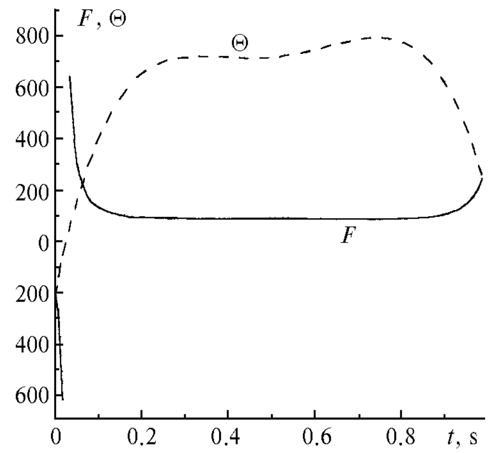

FIG. 6. Equivalent divergence Θ″ and wavefront curvature radius F (in m*) as functions of time.*

Thus, the obtained results have shown the applicability of employed systems, which do not require large expenditures, for estimation of the parameters of the IR lasers operating in the periodic-pulse regime.

REFERENCES

1. V.N. Sitnikov and L.K. Chistyakova, Atmos. Oceanic Opt. **7**, No. 5, 325–329 (1994).
2. G. Hird, *Measurement of Laser Parameters* (Mir, Moscow, 1970), 539 pp.
3. V.P. Aksenov, E.V. Zakharova, Yu.N. Isaev, et al., Atmos. Oceanic Opt. **9**, No. 10, 863–867 (1996).
4. B.M. Abakumov, I.A. Pan'shin, E.A. Podpalov, et al., *Registration of Optical Information on Thin Magnetic Tapes* (Atomizdat, Moscow, 1976), 150 pp.
5. L.A. Vasil'ev, Yu.B. Morozov, V.A. Pykhtin, et al., Kvant. Elekton. **5**, No. 1, 201–203 (1978).