Optica Applicata, Vol. XXI, No. 4, 1991

Computer simulation of monomode high power cw CO_2 laser with variable small signal gain

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The influence of a nonhomogeneous small signal gain on the cw CO_2 laser output is investigated. Simplified Gaussin variations of the small signal gain are considered. At certain resonator parameters, a maximum output power in the fundamental transverse mode can be obtained for laser operation providing a sharp gain variation with a pronounced maximum on the resonator axis.

1. Introduction

High-power CO_2 lasers are receiving and increasing industrial acceptance in many applications. The lasers can be made to operate in the fundamental transverse mode or other low order pure modes. There are several advantages of low order modes. The lower the mode, the smaller the spot produced at the focus of a given lens, the larger the depth of focus for a given spot size, and the easier it is to optically handle the beam. There is one disadvantage, the lower the mode is, the smaller the laser output power. Computer simulations are useful to maximize the power extraction in low order pure modes of cw CO_2 lasers. An optimum diameter of diaphragm adjacent to one mirror of the resonator can be found [1]. In addition to the proper choice of the resonator, the experimental data on laser active medium [2], [3] should be considered to get maximum output in a low order mode.

In the present work, the influence of a nonhomogeneous small signal gain on the near-field cw CO_2 laser output is investigated by computer simulation. Suitable small signal gain variation to get maximum output power in the fundamental transverse mode is given.

2. Computation model of the light field in a resonator

In a resonator with two mirrors M_1 and M_2 the field at one point of the mirror M_2 is computed according to the Huyghen principle as a superposition of waves originating from all points of the other mirror M_1 [4]. Beginning with an arbitrary complex amplitude distribution $E_1(x_1, y_1)$ on the plane p_1 of mirror M_1, field propagation through empty resonator is calculated by using the Kirchhoff–Fresnel integral. The resulting field distribution $E_2(x, y)$ on the plane p_2 of mirror M_2 is then

$$E_2(x,y) = \frac{ik}{2\pi L}\exp(-ikL)\int_{x_1}\int_{y_1}\exp\left[-\frac{ik}{2L}((x_1-x_2)^2+(y_1-y_2)^2)\right]E_1(x_1,y_1)dx_1dy_1 \quad (1)$$

where k is the magnitude of the wave vector, L is the distance between the planes p_1 and p_2.

Reflection of the light field from the mirror is described by a complex reflection coefficient $M(x, y)$ of absolute value determined by the mirror reflectivity R and phase determined by the distance $d(x, y)$ between the plane p_2 and the mirror surface [1]

$$M(x, y) = R^{1/2}\exp(-2ikd(x, y)). \tag{2}$$

The contribution of active laser medium is included by an amplification factor $A(x, y)$. In the thin sheet approximation, when the active medium of length l between the two planes is assumed to be concentrated in a small space adjacent to plane p_2, it is given by

$$A(x, y) = \exp(1/2g(x, y, I)l) \tag{3}$$

where I is the spatially dependent intensity of radiation and the gain factor $g(x, y, I)$ depends on the small signal gain g_0 and the saturation intensity I_s

$$g(x, y, I) = g_0(x, y)/(l + I(x, y)/I_s). \tag{4}$$

In a high power cw CO_2 laser [3], [4], there is a nonhomogeneous small signal gain $g_0(x, y)$ resulting from nonhomogeneous plasma excitation.

After one round trip the resulting field at mirror M_1 is calculated again and is compared with that of the previous round trip. This procedure is repeated until a stationary behaviour is obtained.

3. Numerical results

Small signal gain data on the gas flow direction depending on the partial pressures of the gas mixture, as given in paper [3] for a gas transport CO_2 laser, are introduced in computations as fitted Gaussian variations (Fig. 1) with the maximum on the resonator axis. The three curves in Fig. 1 denoted by 1, 2 and 3 correspond to partial pressures $p(CO_2)/p(N_2)$ equal to 1/2, 1/4 and 1/8, respectively. The same small signal

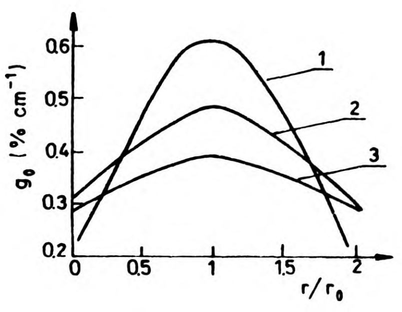
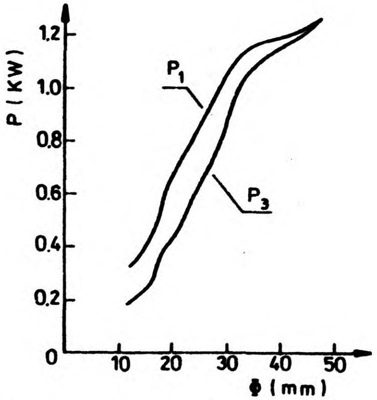


Fig. 1. Gaussian small signal gain variations along the gas flow directions [3] obtained by fitting experimental data corresponding to partial pressures $p(CO_2)/p(N_2)$ equal to 1/2 (curve 1), 1/4 (curve 2), and 1/8 (curve 3), respectively, with a maximum on the resonator axis

gain variation is considered on the electrical discharge direction. This two-dimensional variation is kept the same on the length of the active laser medium.

The following parameters of resonator are considered [5]: length of resonator $L = 3.8$ m, plane output mirror of 30 mm in diameter and 80% reflectivity, concave



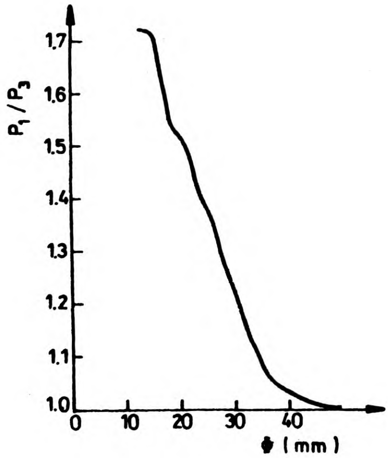


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Fig 2. Laser output power vs diaphragm diameter. P_1 and P_3 correspond to the small signal gain (curves 1 and 3 in Fig. 1, respectively)

Fig. 3. Ratio of laser output powers P_1/P_3 from Fig. 2 vs diaphragm diameter

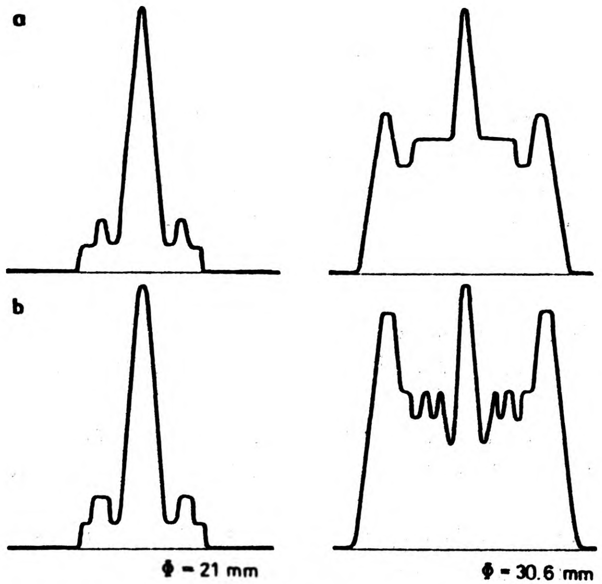

Fig. 4. Normalized near-field laser intensity distributions for small signal gain for curve 1 (a) and 3 (b) of Fig. 1 at two values of diaphragm diameter Φ. The central intensity on the resonator axis is used for normalization

end mirror of 55 mm diameter, 100% reflectivity and 10 m radius of curvature. The following data for the CO_2-plasma are assumed: saturation intensity $I_s = 158$ W/cm^2, length of active medium 4×60 cm. The maximum starting intensity was usually equal to 0.001 of the saturation intensity. A typical grid size of 51×51 was chosen.

Laser output power is almost the same for the three small signal gain variations but the laser intensity is more uniformly distributed on the near-field output spot in the case of small signal gain (curve 3 in Fig. 1).

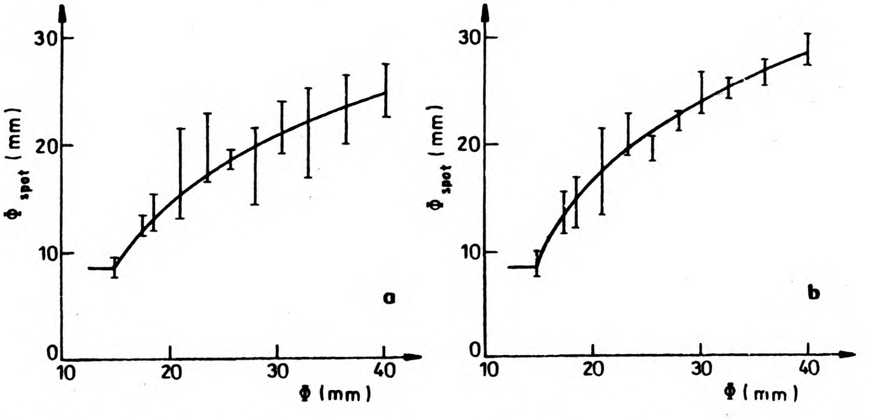

Fig. 5. Near-field laser spot diameter vs diameter of diaphragm adjacent to totally reflecting end mirror for small signal gain, curve 1 (a) and curve 3 (b)

A diaphragm was introduced in front of the totally reflecting end mirror. The laser output power has a strong dependence on its diameter as can be seen in Fig. 2. The fundamental transverse mode is obtained diaphragm of diameter less than 15 mm. In this mode, the laser output power is 1.7 times greater for small signal gain curve 1 than for curve 3, as can be better seen in Fig. 3. The near-field spot diameter in higher order modes is greater (Fig. 4) and chaotic fluctuations of laser output are smaller (Fig. 5) in the case of small signal gain curve 3 than those for the curve 1.

4. Conclusions

We investigated by computer simulation the influence of a nonhomogeneous small signal gain on the near-field CO_2 laser output. Simplified two-dimensional Gaussian variations of the small signal gain are considered.

In high order mode regime, a smooth small signal gain variation could be preferred because of a more uniform laser intensity distribution with smaller fluctuations.

The laser operation providing a sharp small signal gain variation with a pronounced maximum on the resonator axis could give considerably higher output power in the fundamental mode regime.

The fitted Gaussian small signal gain variations used in our computations can be replaced by the measured two-dimensional distributions of the small signal gain.

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Received July 25, 1991