Control of a high-power cw CO_2 laser output beam properties by using an adaptive intracavity mirror

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ABSTRACT

Results of the experimental analysis concerning the output beam characteristics of the industrial cw CO_2 laser with an intracavity deformable mirror are presented. The mirror used is a bimorph piezoelectric adaptive mirror developed at Turn Ltd (Russia). The mirror shape is controlled by supplying the voltage to the mirror electrodes.

The performed analysis proves that the use of the deformable mirror with a variable radius of curvature in the laser cavity enables controlled and dynamic changes of the resonator properties that result in the modification and optimization of the laser output characteristics decisive for the laser material processing effects.

Keywords: adaptive mirror, laser resonator, output beam characteristics

1. INTRODUCTION

Optimization of the laser beam characteristics according to the requirements of the specific technological processes is a principal task in the industrial applications of a laser radiation. Improvements in the beam parameters and their control translate into better coupling of the laser beam energy to the workpiece and more efficient processing.

Temporal and spatial variations of the laser beam characteristics are often caused by different physical processes in the laser beam source like thermal, gas-dynamical or mechanical instabilities. In particular the power dependent effects like thermally induced distortions in the active medium or / and thermal deformation of the laser optics are often responsible for the power dependent behavior of a laser beam parameters which can influence the results and efficiency of the laser processing. The problem of the control and compensation of these effects is of a vital importance.

Some solutions to this task are offered by adaptive optic methods that are increasingly used in the modern laser technology for active compensation of some distortions in laser systems as well as for dynamic modulation and controlled adjustment of the laser radiation characteristics[1-3] in the processing zone.

An adaptive deformable mirror of a shape controlled by the voltage supplied to the mirrors electrodes was integrated into the optical cavity of the industrial high power transverse flow cw CO_2 laser. The possibility of the dynamic control of laser output beam properties by mean an adaptive intracavity mirror is a subject of the study. The laser output characteristics were analyzed versus the resonator configurations defined by the deformable mirror operational parameters.

2. PARAMETERS OF THE DEFORMABLE MIRROR

The deformable mirror used was developed and manufactured at Turn Ltd (Russia)[4-5]. The mirror called AT261/7 is a bimorph mirror with seven control channels. It is a molybdenum, water-cooled mirror with a high reflectivity coating for t[1]he wavelength of 10.6 μm. The diameter of the controlled part of the mirror reflective surface is 25mm. The mirror shape is controlled by supplying the voltage to the mirror electrodes from a range from U=–150V up to U=+250V. Control voltage to the deformable mirror is supplied from the electronic unit.

The basic characteristics of the mirror were tested in the interferometry measurements applying He-Ne laser, and CCD camera. The measurements prove that the surface of DM has a parabolic shape, especially in the central active part of the

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mirror, if the same voltage is supplied to all mirror actuators. The average value of the deformation sensitivity is estimated to be ~21.3ìm/kV. The radius of curvature of the deformable mirror can be adjusted approximately from R~+24m for U=-150V up to R~-16m for U=+250V. The measurements show hysteresis curve characterizing the deformation of the mirror surface depending on the sequence of voltage changes. An average value for the hysteresis width does not exceed ~14%.

3. LASER RESONATOR CONFIGURATION

The optical cavity of the cw CO_2 transverse flow laser under consideration is schematically shown in Fig.1.
In a standard configuration the laser cavity is a stable multi-pass resonator comprising two spherical mirrors (1,2) with radii of curvature $R_1=R_2=30$m and two flat mirrors *(*4,3) folding the inner beam path between the end cavity mirrors. Reflectivity of the ZnSe meniscus output coupler (2) is 50%. An effective diameter of the mirrors is 20mm and the resonator length measures 4.3m. The resonator is mounted inside the evacuated chamber sealed off by the antireflection-coated flat ZnSe output window (*5*).

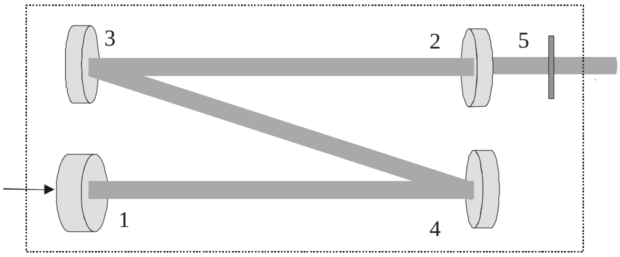

Fig.1 Scheme of the multipass cw CO_2 laser resonator

The output power from the laser with a standard resonator configuration, measured at nominal conditions of the laser operation, amounts to P=1.3kW. The output beam is characterized by the quality factor M^2 equal to 2.6.

The deformable mirror was implemented in the laser cavity in a place of a rear mirror (1). As the concave and convex curvature of the deformable mirrors can be achieved, the variety of concave-concave and convex-concave configurations of the stable cavity defined by the stability parameter $G=g_1g_2$ ranging from ~0.7 to ~1 can be realized.

4. RESONATOR WITH A VARIABLE FOCAL LENGTH MIRROR

4.1 Theoretical consideration

The principal properties of an optical resonator are recognised by the stability parameter and Fresnel number defined as $G=g_1g_2$ *where* $g_i=1-L/R_i$ and $N_f=d^2/4\lambda L$: L indicates the resonator length, R_i - curvature radii of the resonator mirrors, d is the mirrors diameter and λ - the wavelength of the laser radiation.

The stable resonator comprises a set of mirrors with radii of curvature satisfying the condition $0<g_1g_2<1$. Following the known formulae[6] for the Gaussian beam the basic parameters of the fundamental mode in a stable cavity can be calculated.

For the considered resonator with DM integrated to the system as the rear mirror the stability limit *(*G=1*)* is attained for the radius of curvature $R_1\cong-25.7$m ($1/R_I\cong-0.389m^{-1}$).
For the radius of curvature of the DM varying from +24m up to -30m the divergence of the theoretical TEM_{00} mode decreases from 1.35mrad to 0.995mrad. Approaching the stability limit, the divergence of the TEM_{00} beam increases again up to 1.53 mrad at R=-25.9m.

The laser beam quality related to the number of transverse modes oscillating in the real laser cavity can be approximately characterized by the factor (Q) defined as the ratio of the mirrors limiting aperture (d) and the maximum size of the fundamental mode (2ù) in the resonator. In Fig.2, the factors (Q), are plotted for the mirrors aperture of *d=2cm.* If the Q-factor decreases the

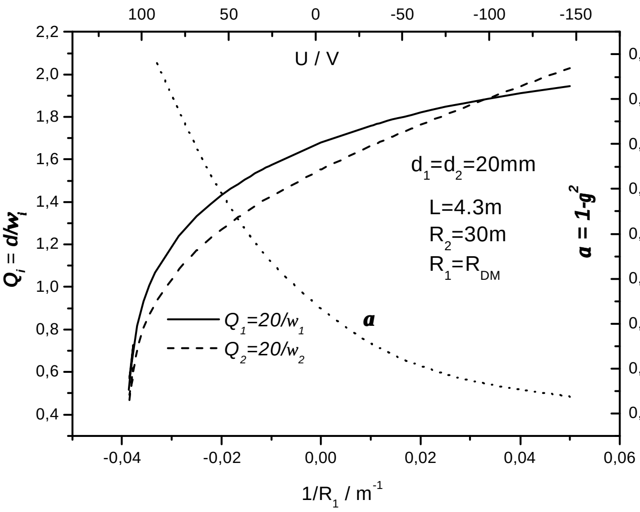

Fig.2 Fundamental mode properties vs curvature of a variable focal length mirror introduced to the resonator as a rear mirror

number or contribution of higher order modes to the beam decreases and the output beam of better quality can be expected. For 2ùi≈d - Q≈*1* then the TEM_{00} mode structure is strongly disturbed by the mirrors aperture.

It follows from the simple geometrical considerations that sensitivity of the resonator to the mirrors misalignment depends on the resonator length and the curvature of its mirror. For L and R_2 fixed, the misalignment sensitivity is defined by the changes of the back (DM) mirror curvature. The resonator becomes extremely sensitive when the DM curvature approaches the limit of stability.

Conclusions concerning the TEM_{00} properties in the resonator under consideration are supported by the diffraction type analysis implemented by means of a computer code based on the Fox and Li approach. In particular, calculations provide the modulus $|\gamma|$ of the eigenvalue that is related to the round trip intensity diffraction losses of the fundamental mode: $\alpha=1-|\gamma|^2$. The calculated loss factor α, correlated to the variations of the radius of the curvature of the DM in the resonator, is shown in Fig.2. The strong increase of the diffraction losses as DM curvature approaches the stability limit responds to the strong increase of the fundamental mode size in that region.

4.2 Experiments

In the experimental procedure the transverse intensity profiles of the beam in the near and far field zone, the divergence and waist size of the focused beam as well as the total laser power were measured versus the deformable mirror shape. The laser beam spatial profiles were measured versus the curvature of the deformable mirror by a means of a rotating pinhole type scanner[7]

According to the ISO standards[8] the beam quality factor M^2 and the corresponding waist size and the divergence angle were concluded from a hyperbolic fit to the beam diameters measured versus the distance from the focal plane of a focusing lens (f=190.5mm). The beam diameters at the measurement planes were calculated on the base of the second moments of the intensity beam distributions and compared to those following the power in the bucket definition.

The measurements show that the variations of the curvature radius controlled by the voltage at the mirror actuators result in the respective modifications of the beam intensity profiles. The characteristic examples of the measured laser beam intensity distributions are presented Fig.3.

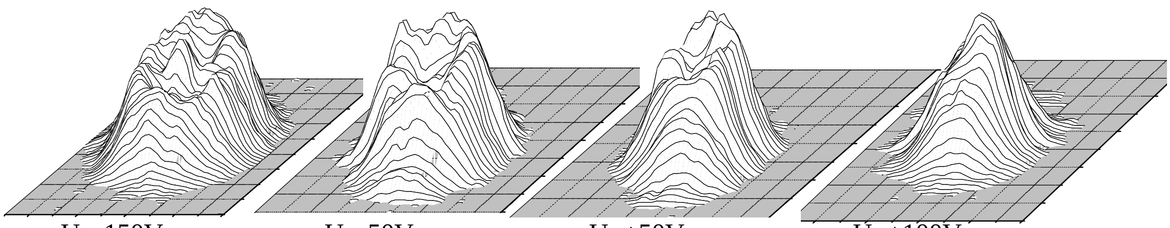

Fig.3 Three dimensional intensity distributions recorded for the different radii of curvature of the intracavity deformable mirror controlled by the voltage on the mirror actuators

The observed variations of the beam structure accompany to the respective changes of the output power as it is shown in Fig.4a. The maximum value of the output power P~1.5kW is measured when the curvature of the DM attains the minimum value for the concave surface. The output power decreases relatively slowly from the maximum value measured at U=-150V up to P=0 at U<+225V.

At U=-150V the recorded beam structure corresponds to the largest contribution of the higher order modes and the beam quality parameter is measured to be M^2~3. With the control voltage varying up to +100V the M^2 is reduced to ~1.8. It is accompanied by the 40% decrease of the output power.
Decreasing of the laser output power observed together with the improving of the far field characteristics is ascribed to the increase of the diffraction losses in the convex-concave cavities with *G*-parameter increasing up to stability limit

The focused beam size measured versus the DM curvature and the corresponding power density are given in Fig.4b.
The lower focused beam waist size and lower beam divergence are measured with increasing of the G-parameter. In particular, it follows from the measurements that for a convex-concave cavity nearly twofold increase of the power density in the processing region is recorded when the voltage of +50V is supplied to the deformable mirror actuators.

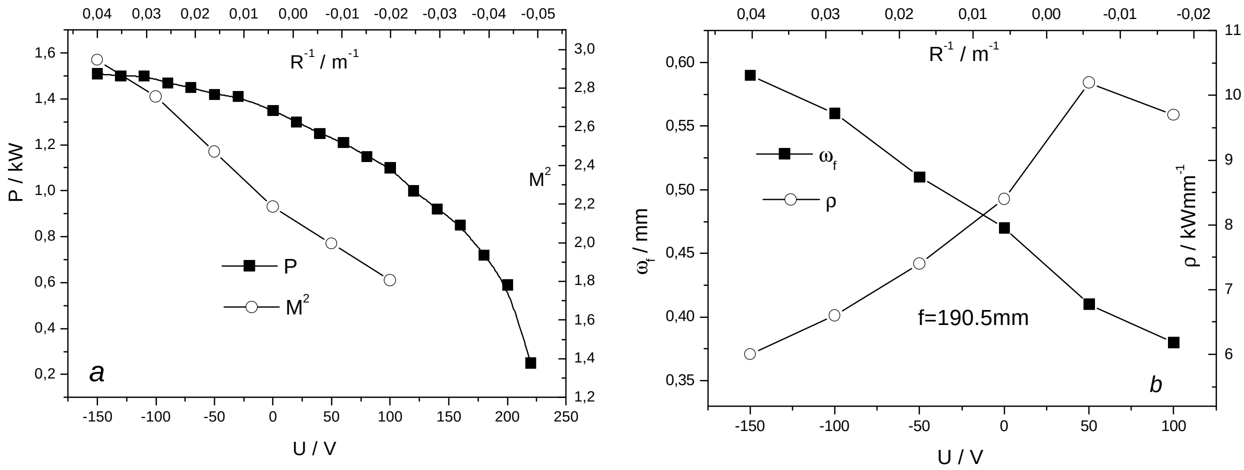

Fig.4 The output beam characteristics from the cw CO_2 industrial laser with an intracavity deformable mirror; (a) - the laser output power P and beam quality M^2 , (b) - the focused beam size w_f and the power density r measured versus the voltage controlling the curvature of the deformable mirror

5. CONCLUSIONS

The results of the experimental analysis concerning the output characteristics of the cw CO_2 laser with a bimorph mirror of a variable focal length are presented in the paper. The shape of the mirror was controlled by the voltage supplied to the mirrors actuators. The range in which the laser beam parameters can be varied by adjusting the voltage controlling curvature of the surface of the resonator mirror is concluded from the measurements.

The experimental tests confirm that the use of the controllable curvature mirror in the resonator of the lasers under consideration allows the dynamic changes in the resonator configuration and thus the dynamic and controlled modification of the lasers output characteristics including the laser power, mode structure and respective M^2 factor.

The performance of the laser system with an intracavity deformable mirror showed the possibility of the significant improving of the laser beam characteristics through the controlled adjusting of the resonator configuration.

6. ACKNOWLEDGEMENTS

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