Experimental tests of an intracavity deformable mirror designed for a cw CO_2 laser

M. Sawczak, G. Rabczuk
Polish Academy of Science, IF-FM, Fiszera 14, PL-80-952, Gdańsk
Phone: +4858 3411271, Fax: +4858 3416144, e-mail: bacus@imp.gda.pl

ABSTRACT

The experimental preliminary results concerning the operation conditions of a cw CO_2 laser with a variable focus, concave mirror are presented in the paper. The mirror is introduced as a rear mirror into a stable cavity of the laser. The contour of the mirror is changed by adjusting the pressure of the cooling medium. The laser output properties are investigated versus the parameters describing the deformable mirror shape.

Keywords: adaptive optic, beam forming, laser resonators

1. INTRODUCTION

The temporal and spatial characteristics of a laser radiation are decisive for the technological. processes of the laser – material interactions. The active control and adaptation of the laser beam structure to the specific processes requirements is a subject of a vital importance. Some solutions to the problem are offered by adaptive optic methods which allow not only for the compensation of different type of inner and outer cavity perturbation but also for shaping the beam characteristics, accordingly to the users requirements, by introducing the mirrors of controllable flexible surfaces to the laser optical system [1, 2].

In order to investigate the possibility of the dynamic control of the laser cavity configuration for the compensation of the long-term, thermal distortions, a system of a variable focus, concave mirror was designed, on the basis of the method presented in [3, 4]. The system allows for dynamic changes of the cavity mirror curvature and thus for the controllable changes of the resonator parameters and output beam characteristics.

The deformable mirror was positively tested under condition of the transverse flow high power cw CO_2 laser[5]. The rear, a high reflectivity mirror of the stable plano-concave cavity was replaced by a deformable mirror. The shape of the mirror was controlled by the pressure of the cooling medium.

In the experimental tests the laser output characteristics were measured and discussed versus the mirror shape.

2. EXPERIMENTAL RESULTS AND DISCUSSION

2.1. Design properties of a variable focal length mirror

The design of a deformable mirror is illustrated in Fig. 1 The mirror surface is a steel plate which is coated by a gold layer for a high reflectivity at 10.6 μm. Thickness of the plate is 2mm and its diameter is 80mm The plate is mounted to the special metal holder. The applied solution for mounting limits the deformation of the mirror only to the concave contours but it allows for minimization of the mechanical stresses which can influence considerably the accuracy of the mirror contour. Taking into account the way of mounting , the plate can be considered as a freely supported.

The curvature radius of the tested deformable mirror at different pressures is determined by applying the shear interferometry method The results are plotted in Fig.2, together with the theoretical values found by the solution of the differential equation for deformation of a simply supported circular plate, subjected to a rotationally symmetric and uniformly distributed load.[6]

At a given, constant pressure of the cooling medium the contour ω (r) of the deformed plate surface can be described by equation;

$$\omega(r)=\frac{pr_0^{4}}{64D}\left[2\eta-1-2\eta\frac{r^{2}}{r_0^{2}}+\frac{r^{4}}{r_0^{4}}\right]\text{with } D=\frac{Eh^{3}}{12(1-\nu^{2})}\text{ and } \eta=\frac{3+\nu}{1+\nu}$$

where h and r_0 are the thickness and the radius of the plate, E – denotes the Young's modulus of elasticity and ν is the Poisson's ratio. Assuming only the parabolic deformation of the mirror surface, the changes of the contour curvature versus pressure is approximately described by equation;

$$\frac{1}{R}=-4\psi\frac{pr_0^{2}}{Eh^{3}}\eta$$

where ψ is a constant following the dependence of parameter D on ν, and for typical value of ν=0,3 - ψ =0.17

The term proportional to r^4 represents the spherical aberration which should be held below $\lambda/10$ for most laser applications. This requirement imposes the limit for the usable optical aperture[3] of the mirror deformed by the pressure loading.

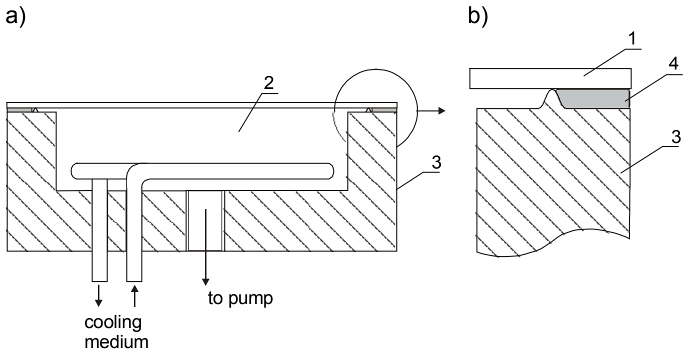


Fig. 1. Scheme of a variable focus, concave mirror: 1 – steel plate, 2 – chamber with a liquid , 3 – metal holder, 4 – silicone seal

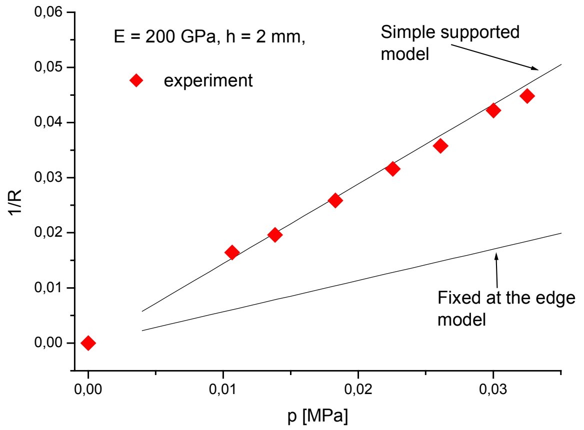


Fig. 2. The dependence of the curvature radius on the pressure of the cooling medium

As it follows from the data gathered in Fig.2, the experimental estimation of the mirror curvature are in a good agreement with the results following the theoretical model.

According to the measurements the curvature of the investigated deformable mirror can be adjusted in the range from 0 to 0.05m^{-1} if the pressure is varied between 0 and 0.032MPa, relatively to the atmospheric pressure.

The mirror surface shape was tested using Michelson interferometer in which one of the mirrors was replaced by a tested deformable mirror. The iterferograms of the initial shape (flat) of the deformable mirrors and the concave one corresponding to the radius curvature of about 30m are presented on Fig.3. The analysis of the interferograms shows that in the applied range of pressure changes, all the shapes can be regarded as a rotationally symmetrical.

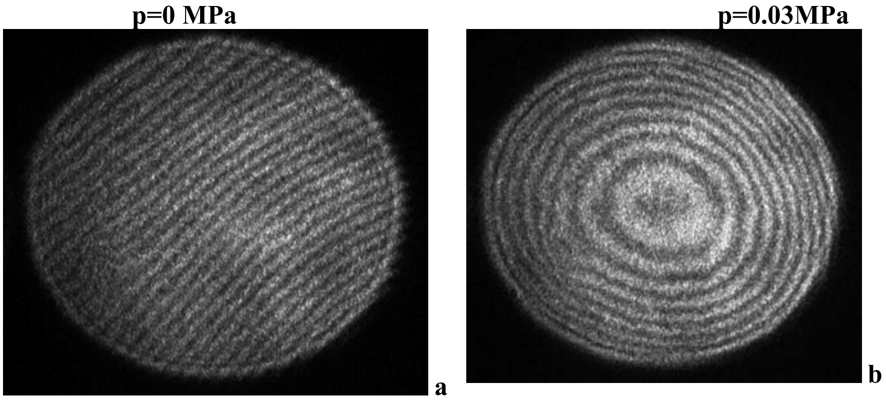


Fig. 3. The interferogram of the reflective surface of the deformable mirror; initial shape (a) , the surface with a radius curvature about 30m (b)

2.2. Mirror tests in laser resonator

The designed, deformable mirror was examined in conditions of the cw CO_2 laser operation. The experimental setup is shown in Fig.4

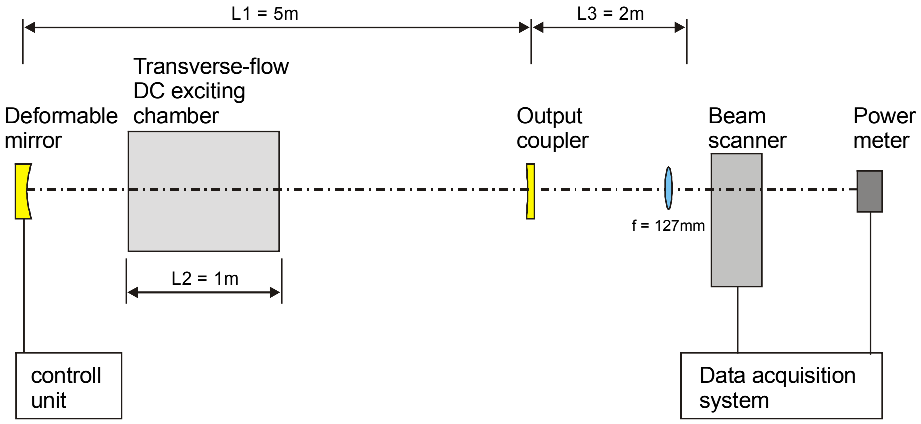


Fig. 4 The experimental setup for the deformable mirror tests

For the experimental purposes the stable resonator of a transverse flow DC excited laser was mounted outside the laser vacuum chamber. The rear, high reflectivity concave mirror of the stable cavity was replaced by the deformable mirror. ZnSe meniscus output coupler with an inner radius of curvature 15m, and transmission T=50%.was mounted at the distance of 5m the from the back mirror. The effective diameters of the cavity mirrors are limited by the diaphragms of 2cm in dia. The active medium length was 1m. The laser, in the above configuration system, but equipped with a conventional laser mirrors was working at the output power up to 600W.

The intensity distributions of the beam emitted from the laser supplied with the deformable mirrors were measured by means of the laser mechanical scanner [7] of a rotating pinhole type. Simultaneously, the laser power was recorded by the infrared detector. The beam characteristics were measured in a focal region of a ZnSe lens with a focal length of 127mm.

At the first step of the testing procedure the laser output characteristics were compared for the conventional resonator and for that one with a deformable mirror. The results are summarized on Fig . 5

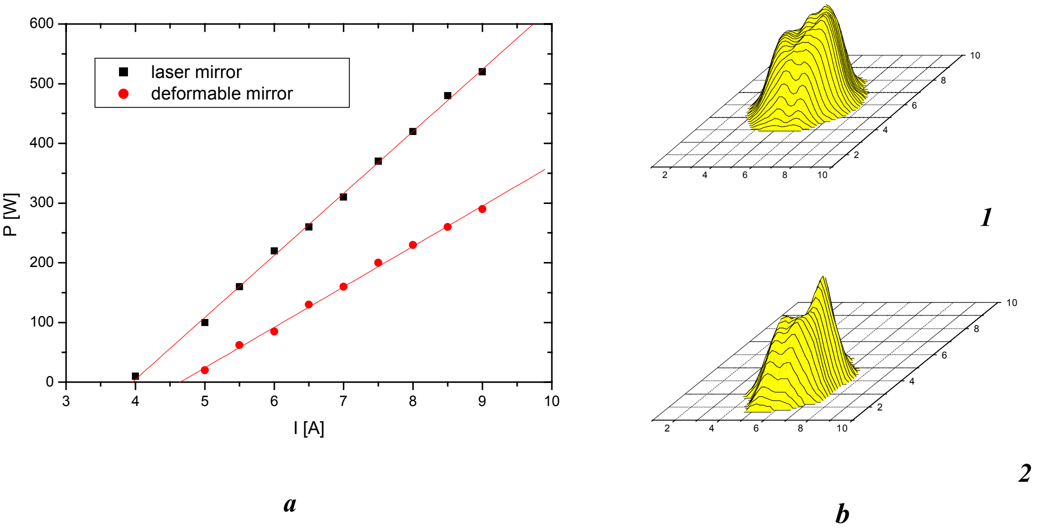


Fig.5 Comparison of the output laser characteristics measured for the laser with the back mirror of curvature radius 30 m and with the deformable mirror of the same curvature (a), the beam intensity distributions recorded for the conventional (1) and for the deformable (2) mirror, measured at the same distance from the focal plane of a focusing lens

The lower output power, measured for the deformable mirror result from the higher absorption losses due to the lower quality of the mirror reflective surface, prepared in the laboratory conditions. The difference in the *P(I)* curves slopes, indicate the slight difference in the mirrors curvature. It can be explained by the thermal effects caused by the power absorption on the mirror surface. This conclusion is supported by the results given in Fig 5b where the field distributions recorded for both investigated cavities are compared. The measured beams profiles are very similar but the differences in their transverse size is noticeable.

Fig. 6 shows the dependence of the laser output power on the pressure in a chamber of a deformable mirror. The changes of the beam dimensions, corresponding to the various changes of pressure and thus to the different values of the mirror curvature radii are presented in Fig. 7.

The gradual increase of the output power from the laser is observed with an increase of the pressure. It means that the output power is reduced when the radius of curvature of the deformable mirror is increased. This effect can be explained by the increasing of the diffraction losses versus the radius of curvature. The high overall intrinsic losses in the system, including the increasing diffraction losses, are not balanced by the simultaneous increase of the modal volume and thus the reducing of the output power is observed.

The results given on Fig 7 confirm expectations concerning the dependence of the beam diameter in the near and far field region versus the changes of the resonator parameters. Due to the larger size of the intracavity beam, connected to the larger radii of curvature, the smaller beam size is recorded in the focal region of a focusing lens.

Fig. 8 shows the examples of the intensity spatial distributions recorded for three different values of pressure. Although the mirror radius changes are relatively small in the investigated range, we can detect some differences in the beam profiles versus the pressure applied to the deformable mirror. It also can be related to the differences in the diffraction losses describing the modes contents in the beam and thus its spatial profile and propagation properties.

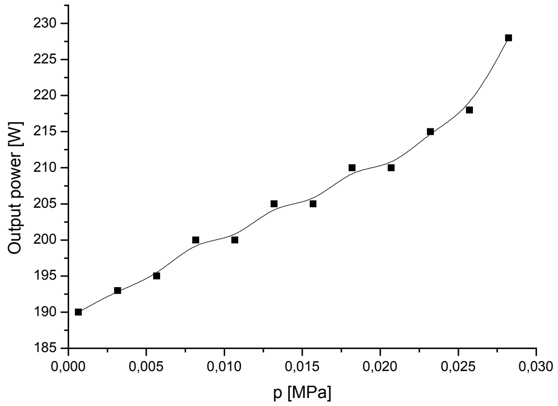


Fig. 6. Laser output power versus pressure of cooling medium corresponding to different mirror curvatures.

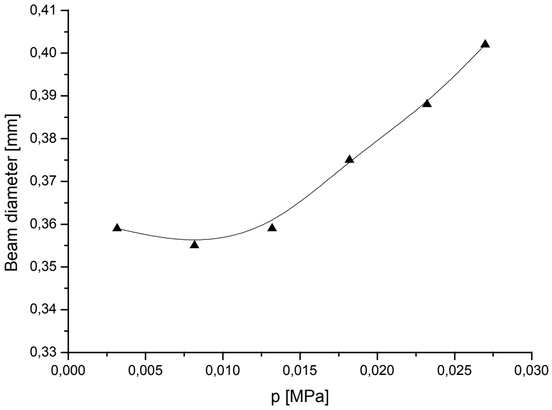
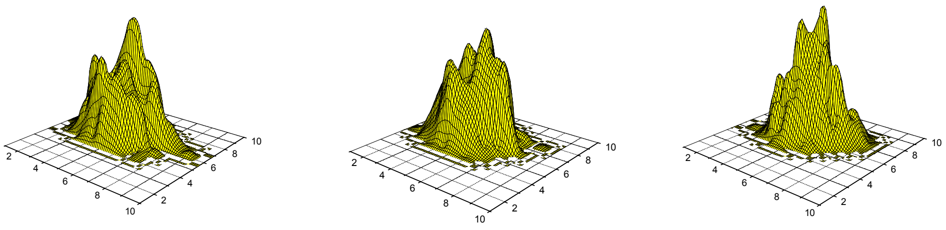


Fig 7. Beam diameter measured near focus plane for different mirror curvatures.



p = 0.03 MPa

p = 0.02 MPa

p = 0 MPa

Fig. 8. The laser beam profiles recorded in the far field (f = 127mm), for different values of the control pressure.

3. CONCLUSIONS

The aim of the performed analysis was to test the possibilities of shaping the beam characteristics by introducing the mirror of a controllable flexible surface to the laser optical system.

Tests of a designed deformable mirror with curvature controlled by hydrostatic pressure shows that the mirror contour is spherical and the mirror can serve as a laser resonator mirror. The curvature radius can be adjusted in the range of ∞ to 20 m depending on the applied pressure.

The mirror was positively tested in the high power cw CO_2 laser system. Experiments show possibilities of controlling the output power and the output beam properties by the dynamical adjusting the shape of the intracavity mirror. The beam intensity distribution and the beam quality measured for tested deformable mirror are comparable to those obtained for the standard laser mirror of corresponding curvature.

Experiments concerning the optimization of the deformable mirror system, in particular those concerning the efficient and correct control of the mirror shape as well as those aiming at the broadening of the range of the available curvatures, are being undertaken and will be reported later.

4. ACKNOWLEDGEMENTS

Work was supported by the KBN through the Project PB 1495/T11/2002/22
The authors gratefully acknowledge the technical assistance of M. Piskulski.

5. REFERENCES

1. A.V. Kudryashov, H. Weber, *Laser Resonators Novel Design and Development III*, SPIE, Bellingham, Washington, 1999
2. H. J. Obramski, R,. Mastle at all, “Optical measurement and control components for highly dynamic beam guiding and forming of CO_2 laser beams”, Laser Opto, **32** (4), 36-42 (2000)
3. Keming Du, P. Loosen, H. Kochmann, “Properties of a high-power CO_2-laser with an adaptive mirror”, Optics Communications **106,** 269-277 (1994)
4. V.V Apollonov, G. V. Vdovin at all, “Active correction of a thermal lens of a solid-state laser., I. A metal mirror with controlled curvature of the central region of the reflecting surface”, Quantum Electronics (in Russian) ,**18**, (1), 128-130, (1991)
5. P. Kukiełło, G. Rabczuk, “High power cw CO_2 transverse flow laser with a stable multipass cavity. Comparative study”, Laser and Particle Beams **10**, no. 4, 865-870, (1992)
6. R. Szilard, *Theory and Analysis of Plates, Classical and Numerical Methods,* Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1974
7. G. Rabczuk , M. Sawczak, G. Śliwiński , “ Diagnostic instrument for measurements of a high power CO_2 laser beam”, *Laser Technology VI: Progress in Lasers,* Editors: W. L. Woliński, Z. Jankiewicz, Proceedings of , vol 4237,212-217 ,(2000)