Curvature sensor for a laser beam wavefront control

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ABSTRACT

Results of the experimental tests concerning the wavefront sensor designed for control of the laser beam transformed by the deformable multichannel bimorph mirror are presented in the paper. The sensor developed on the base of the curvature sensing method consists of the vibrating mirror of a membrane type and a multi-element detector for the beam intensity measurements. The characteristics of the sensor are analysed versus the controlled deformation introduced to the tested beam by a deformable mirror. The measurements prove that the curvature signal measured by the detector is proportional to the local distortions of the wavefront of the laser beam.

Keywords: adaptive optics, curvature sensing

1. INTRODUCTION

In the modern laser technology the adaptive optics [1-3] methods are often applied for the dynamic control of the laser beam characteristics decisive for the technological processes. The mirrors of controllable, flexible surfaces integrated into a laser optical system enable compensation of the different type of inner and outer perturbations that can influence the laser beam characteristics and thus the results of the laser material processing.

A key component of any adaptive system is a wavefront sensor that should measure any changes in the optical wavefront. The sensor coupled with a wavefront corrector in a closed loop can be applied for adaptive compensation of the laser beam distortions. The pinhole-type sensors[4] are usually applied with one-channel deformable mirrors for correction of the low order aberrations. They are not effective for systems with multichannel mirrors designed for correction of the higher order aberrations.

Roddier[5-6] who first proposed the curvature sensing method showed that the local curvature of the wavefront can be controlled by the measurements of the intensity at two corresponding points of the pre- and post-focal planes of the distorted wavefront brought to a focus.

The results of the experimental tests concerning the wavefront sensor based on the curvature sensing method are presented in the paper. The sensor has been developed for control of the laser beam transformed by the deformable multichannel bimorph mirror[7-8] of a reflective surface controlled by the voltage supplied to the mirrors actuators.

2. EXPERIMENT

The scheme of the experimental setup is presented in Fig. 1. The collimated tested beam of a He-Ne laser is reflected from the deformable mirror (1) of a surface controlled by the voltage supplied to the mirror actuators. The wavefront of the reflected beam is modified according to the mirror deformations. The detector (5) measures the intensity in the beam reflected from the vibrating mirror (2) and transformed by the lens (4).

As the curvature sensing method requires the near simultaneous (at least within a few ms) measurements of the beam intensity at two equal distances before and after focus, the oscillating mirror of membrane type has been designed.

The oscillating membrane coupled with the focusing lens (4) allows a quick switching of the measurement plane on the detector (5) between the intra and extra focal planes of the beam transformed by the focusing lens.

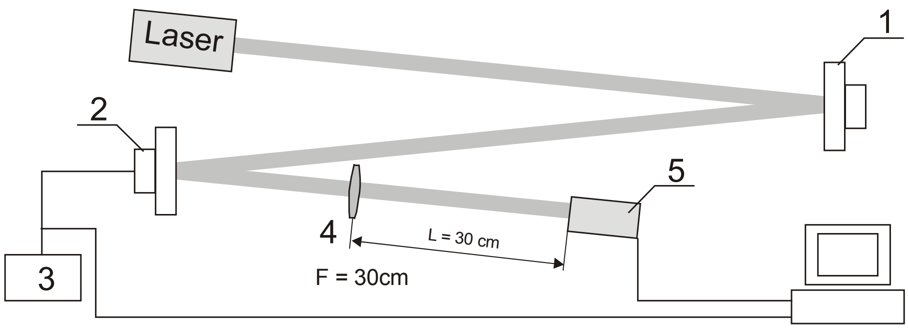

Fig. 1. Experimental setup: 1 – 7-channel bimorph mirror (AT 261/7 TURN Ltd.), 2 – membrane mirror, 3 –generator of an electric signal, 4 – focusing lens, 5 – detector

The membrane mirror is a 0.2 mm thick nitro-cellulose gold-coated foil attached to the small acoustic cavity which when driven by a loudspeaker, causes the membrane to switch between positive and negative curvatures. The total membrane diameter is 40 mm. The used optical diameter of the membrane is 15 mm. In the experiment the membrane oscillates with a frequency of 10 Hz.

The optical quality of the membrane mirror was tested in the interferometry measurements applying He-Ne laser and CCD camera. The high contrast and circular symmetry of the interferometry fringes indicate a good optical quality and an axial symmetry of the extreme profiles of the oscillating mirror. The curvature radius of the membrane mirror, measured by using pinhole method[4], oscillates between $R \approx 0.66$ m and $R \approx -0.75$ m with a period of 5 ms. Fig. 2. shows the time dependence of the membrane mirror curvature radius on the voltage signal from the generator. For a lens with a focal length of F=30cm the membrane mirror oscillations cause the switching of the measurement plane position from –5 cm up to +5 cm with reference to the focal plane.

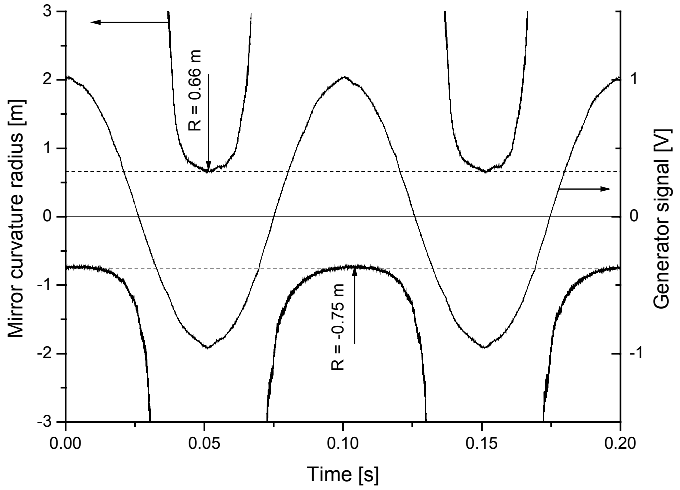

Fig. 2. Time dependence of the curvature of the membrane mirror.

The detector designed for the intensity measurements in the tested laser beam consists of seven optical fibers coupled to seven photo detectors. They are connected with a computer through the amplifier of gain 50. The location of the measurement channels in the detector corresponds to the location of the respective channels in the bimorph mirror – Fig. 3. Diameter of the detector array fits to the beam diameter in the measurement plane.

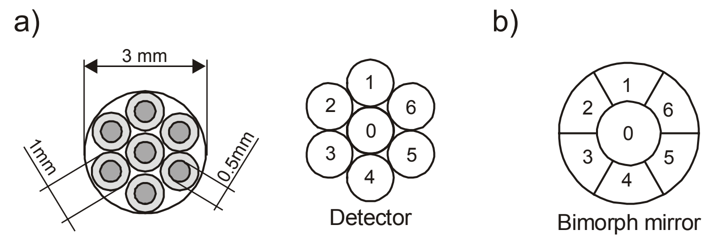

Fig. 3. The scheme of the detector system: cross section view of the detector – (a), adaptive mirror channels distribution - (b)

The signal measured by the detector is analysed versus the membrane mirror characteristics and the deformation level in the laser beam controlled by the voltage supplied to the deformable mirror.

The computer program for data acquisition records the radiation intensity distribution in the intra- and extra- focal planes and calculates the curvature signal S(r) defined as [5–6]

$$S(r) = \frac{I_1(\vec{r}) - I_2(\vec{r})}{I_1(\vec{r}) + I_2(\vec{r})}$$

where: $I_1(r)$ – radiation intensity in the intrafocal plane, $I_2(r)$ – corresponding radiation intensity in the extrafocal plane,

3. RESULTS

The bimorph mirror is deformed by applying the set of seven control voltages from the range of –150 V up to 250 V to the mirror actuators. The mirror deformation characteristics described by the average dependence of the mirror surface deflection on the applied voltage, measured by the interferometry methods are given in Fig. 4.

The convex profiles of the deformable mirror surface are obtained when the same positive voltages are applied to all mirror actuators. The concave profiles of the mirror surface are obtained for negative voltages. Depending on the voltage, the deformable mirror has a parabolic shape with the radius of curvature changing from R=+24 m up to R= -16 m.

Fig. 5 shows the measurement results of the sensor signal S(r) related to the changes in the wavefront curvature in the tested He-Ne laser beam.

Changes in the wavefront curvature following the changes of the deformable mirror shape result in the respective changes of the curvature signal S(r). The small modulation in the S(r) value (< 15 %) measured for $U \neq 0$ can be ascribed to the slightly different sensitivity of the deformable mirror channels to the control voltage.

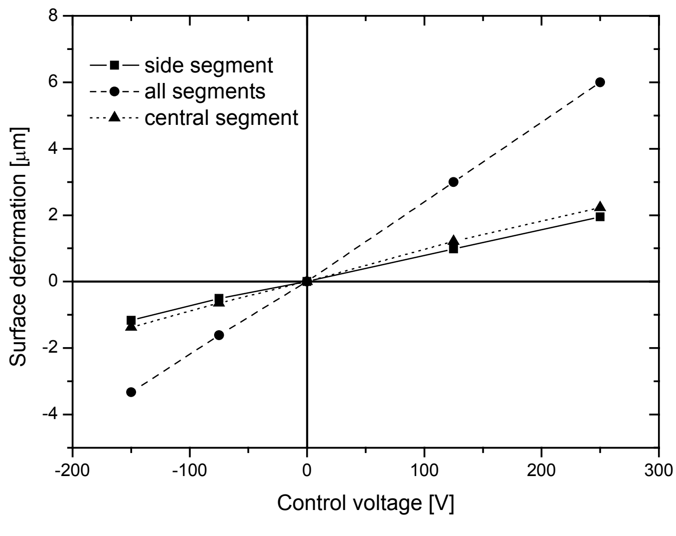

Fig. 4. The mirror deformation characteristics describing the average dependence of the mirror surface deflection on the applied voltage

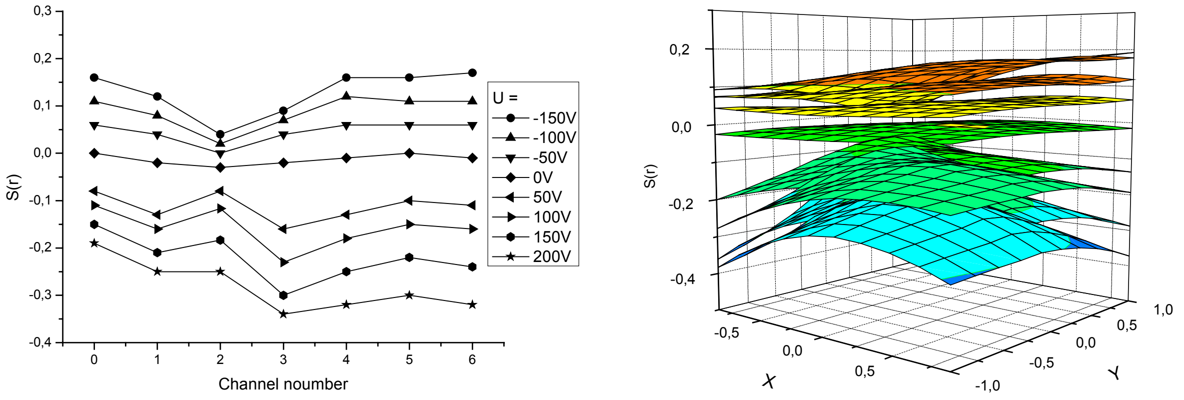

Fig. 5. S(r) signal distribution measured for spherical deformations of the adaptive mirror

Applying control voltages to the side adaptive mirror segments, the aspherical surface profiles are obtained. The example of the deformed mirror surface measured for the case when the voltage U_1= +250 V is applied to the single side segment is shown in Fig. 6. The profiles of the deformed mirror surface recorded for the other side segments are similar. The deformation center is relocated according to the active channel position.

Results of measurements of the sensor signal S(r) obtained for two selected side channels are presented in Fig. 7. Measurements prove that the spatial distribution of S(r) corresponds to the mirror surface profile. Results given in Fig. 8 show the linear dependence of the sensor signal S(r) on the wavefront distortions measured by the local curvature of the deformable mirror. It means that developed curvature sensor coupled with the adaptive mirror can be applied for the on-line correction of the laser beam distortions.

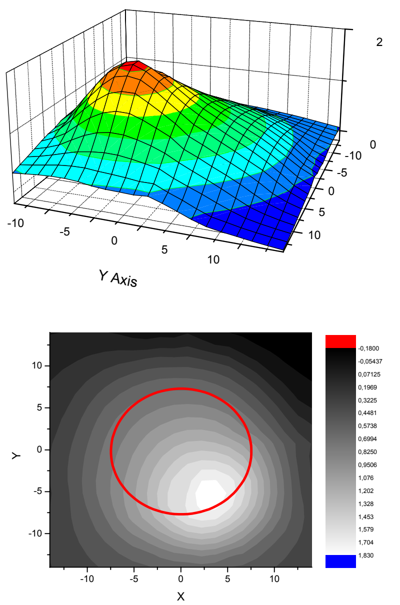

Fig. 6. Profile of the deformable mirror surface when the voltage U=+250 V is applied to the segment 1. The circle corresponds to the 15 mm diameter of the HeNe laser beam

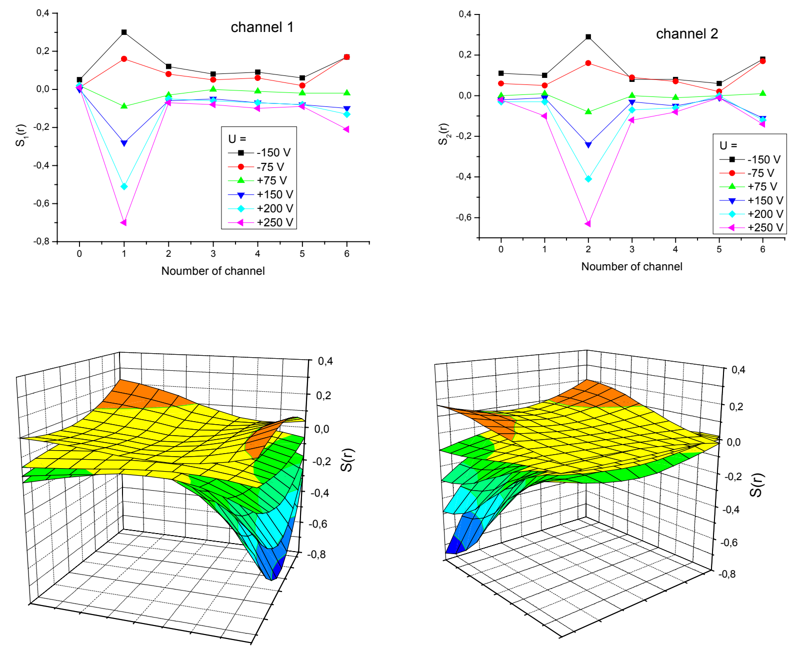

Fig. 7. S(r) distribution corresponding to the deformation of the mirror surface generated by the side channel 1 (a) and 2 (b) of the 7- bimorph mirror

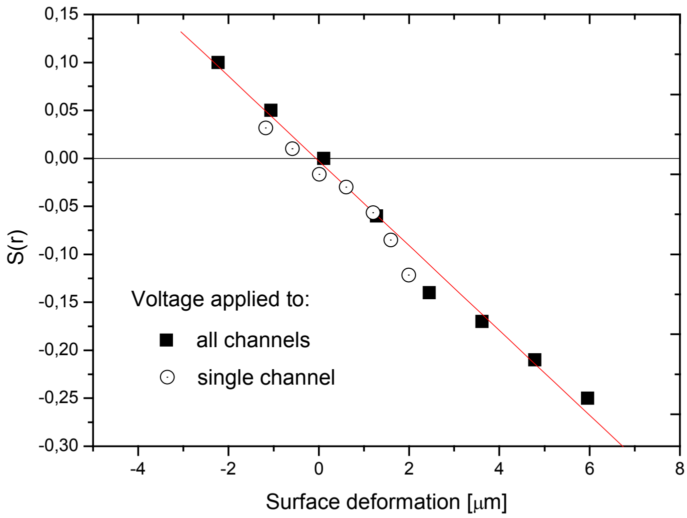

Fig. 8. Sensor signal S(r) versus the mirror surface deformation

4. SUMMARY

In this work, the wavefront curvature sensor designed for control of the laser beam wavefront distortions is presented. The sensor is tested in a system with a 7-channel bimorph mirror introducing controlled deformation to the wavefront of the HeNe laser beam. The measurements confirm that the signal, measured by the detector is proportional to the local distortions of the wavefront. The results prove that this type of sensor can be used for the control of the wavefront distortions in the laser beam.

The possibilities of applying the sensor in a feedback loop with a bimorph mirror for correction of the low order beam aberrations are in the course of investigations.

5. ACKNOWLEDGEMENTS

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