Method of computer controlled microlens processing and testing

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ABSTRACT

Computer controlled process of microlens manufacturing and testing is described. Lens surface figuring is made by high energy CO_2 laser beam scanning over surface. Testing procedure is realized in the same installation without removal of manufactured lens. Test uses low energy He-Ne laser beam scanning over entrance pupil of lens using the same scanning system as during manufacturing procedure. Testing method is based on principles of Hartmann test but do not used any diaphragm. The least squares method is used to determine coefficients of Zernike polynomial expansion, describing testing lens surface figuring errors.

Keywords: microlens, Hartmann test, Least Squares.

1. INTRODUCTION

Today nontraditional technologies of miniatural and microoptics manufacturing present on optical market a wide row of various optical elements. Diffractive optical elements, gradans, rasters, etc. are among them. But measuring of optical parameters of the elements remains to be difficult task. It restrict the possibility of manufacturing of the high accuracy elements wit h desired optical parameters.

Measuring of the parameters during process of optics manufacturing without removal of the element out of technological process and the ability to correct the processing parameters can give universal technology permitting to realize optical parameters feedback. It could give the possibility to make complicated aspherical elements.

Analysis of present-day technologies shows that laser technology of miniatural optics manufacturing developing by authors for some years is most acceptable from this point of view. In this case processing tools and materials keep away from glass substrate. Designed modes of laser etching keep the substrate optically transparent most part of processing time. It is principally important for the possibility of optical parameters measuring during the processing.

In the paper it is suggested the decision of the realization of automatic laser system for optical elements manufacturing with optical parameters feedback.

2. THE PRINCIPLES OF TESTING PROCEDURE

For manufactoring lens testing we use a technique based on well known Hartmann test, but use computer data processing and no Hartmann diaphragm. The idea of method is shown on fig.1. Processing lens **L** is figured by focused high energy laser (**HEL**) beam, which is focused by lens **FL**. The focused high energy laser beam is translated over lens surface by scanning mirror system **SM**. During testing procedure the auxiliary mirror **AM** is included in the beam path so the high energy processing beam is replaced by He-Ne laser testing beam moving at the same trajectory. At the plane, conjugated with the measuring plane, situated near lens focal plane, **CCD** matrix array is situated for register of focal spot movement during beam movement over the processed surface. Conjugation is made by auxiliary mirror **AM1** and relay lens **RL**.

Let us consider the principles of measure. The measuring beam passes through lens entrance pupil in the point with pupil coordinates x, y, and, refracted by lens, intersects the measuring plane in the point with the image coordinates $x' \; y'$ (see. Fig.2, Fig.3). The measuring plane is optical conjugated with CCD array, so we can read the real coordinates $x' \; y'$ in various beam position when measuring beam moves over pupil plane by scanning mirror rotation. If tested lens and all measuring scheme are ideal we can write an beam spot coordinates in measuring plane $x' \; y'$ as functions of pupil beam coordinates as following:

$$\begin{aligned} x_0' &= u_0(x, y) \\ y_0' &= v_0(x, y) \end{aligned} \qquad (1)$$

where u_0, v_0 - any unknown functions. We can determine values of this functions in the some set of pupil point having coordinates x_i , y_i using ray tracing procedure for number of rays forming measuring beam. In these points x_i , y_i measuring beam stays during measuring procedure. So we have:

$$
\begin{aligned}
x'_{0i} &= u_0(x_i, y_i) \\
y'_{0i} &= v_0(x_i, y_i)
\end{aligned}
\tag{2}
$$

where x'_i , y'_i - coordinates of beam spot in measuring plane for ideal system, corresponding pupil beam coordinates x' y'. Coordinates x'_i , y'_i are calculated as means of large number of rays. Our calculations shows that 100 rays more than enough to have a good accuracy.

The real situation differs from ideal at the first deformation of manufactured lens surface and at the second shift of measuring plane along axises x ,y, z at unknown values Dx, Dy, Dz.

For numerical description of surface deformation we use the well known Zernike polynomial expansion in form:

$$
d = \sum_k c_k P_k(x, y) \tag{3}
$$

where c_k - unknown coefficients of deformation, $P_k(x,y)$ - Zernike polynomials.

So using measuring procedure we have to determine unknown values of deformation coefficients c_k and measuring plane shifts Dx, Dy, Dz.

Using expansion of equations (1) in Teilor's seria we can write:

$$
\begin{aligned}
x' &= x'_0 + \Delta x' + \frac{\partial u(x, y)}{\partial z} + \sum_k \frac{\partial u(x, y)}{\partial c_k} \\
y' &= y'_0 + \Delta y' + \frac{\partial v(x, y)}{\partial z} + \sum_k \frac{\partial v(x, y)}{\partial c_k}
\end{aligned}
\tag{4}
$$

In equations (4) we neglect second and high order terms of Dx, Dy, Dz and c_k. Using equation (4) to foxed pupil points x', y', we obtain:

$$
\begin{aligned}
x'_i &= x'_{0i} + \Delta x' + \frac{\partial u(x_i, y_i)}{\partial z} + \sum_k \frac{\partial u(x_i, y_i)}{\partial c_k} \\
y'_i &= y'_{0i} + \Delta y' + \frac{\partial v(x_i, y_i)}{\partial z} + \sum_k \frac{\partial v(x_i, y_i)}{\partial c_k}
\end{aligned}
\tag{5}
$$

Equations (5) can be written in following form:

$$
\begin{aligned}
\sum_j a_{xij} x_j &= \Delta x'_j \\
\sum_j a_{yij} x_j &= \Delta y'_i
\end{aligned}
\tag{6}
$$

where $\Delta x'_i = x'_i - x'_{0i}$, $\Delta y'_i = y'_i - y'_{0i}$ - differences between measured and calculated for ideal system coordinates of beam spot in measuring plane, $x_0 = \Delta x'$, $x_1 = \Delta y'$, $x_2 = \Delta z$, $x_3 = c_0$, $x_4 = c_1$, etc. - unknown variables, containing measuring plane shifts and deformations Zernike coefficients, a_{xij} , a_{yij} - coefficients as follows:

$$a_{xi1} = \frac{\partial\, u(x_i, y_i)}{\partial\, x'} = 1, \quad a_{xi2} = \frac{\partial\, u(x_i, y_i)}{\partial\, y'} = 0,$$

$$a_{xi3} = \frac{\partial\, u(x_i, y_i)}{\partial\, z'}, \quad a_{xij4} = \frac{\partial\, u(x_i, y_i)}{\partial\, c_j}, \tag{7}$$

and so on.

Coefficients a_{xij} , a_{yij} as well as value of coordinates x'_{0i} , y'_{0i} must be preliminary calculated for specific manufactured lens data using ray tracing procedure as was above described.

So we have system of $m=2l$ linear equations with n unknowns x_l, where l - is number of measured beam position, $n=k+3$ and k is number of Zernike polynomials used to describe lens surface figuring errors.

Using matrix notation, we can write:

$$\mathbf{A}x = b, \tag{8}$$

where **A** - $m \times n$-matrix, containing coefficients a_{xij} , a_{yij}, b - vector containing deviations $\Delta x'_i = x'_i - x'_{0i}$, $\Delta y'_i = y'_i - y'_{0i}$ measured beam spot coordinates from precalculated for ideal lens, x - vector, containing unknown measuring plane shifts $\Delta x, \Delta y, \Delta z$ lens surface figuring errors Zernike coefficients c_k.

We can solve this system (8), using standard least squares method. If equations (4) as well as all measurements were exact, solution of system (8) give exact values of surface errors coefficients c_k. But due to neglecting of secondary and high order terms in equations (4) and measurements errors, solutions of system (8) is only first step of approximation.

Using values of Zernike coefficients of surface figuring errors for control of manufacturing process we can try to reduce these errors and then repeat measuring procedure. So we have the iterative process with interchanging procedures of surface processing and measuring with computer controlled feed back.

Convergence of this process depend on values of omitted secondary and high order terms in equations (4) as well as measuring and processing accuracy.

Our computer simulation of the process shows enough fast convergence .

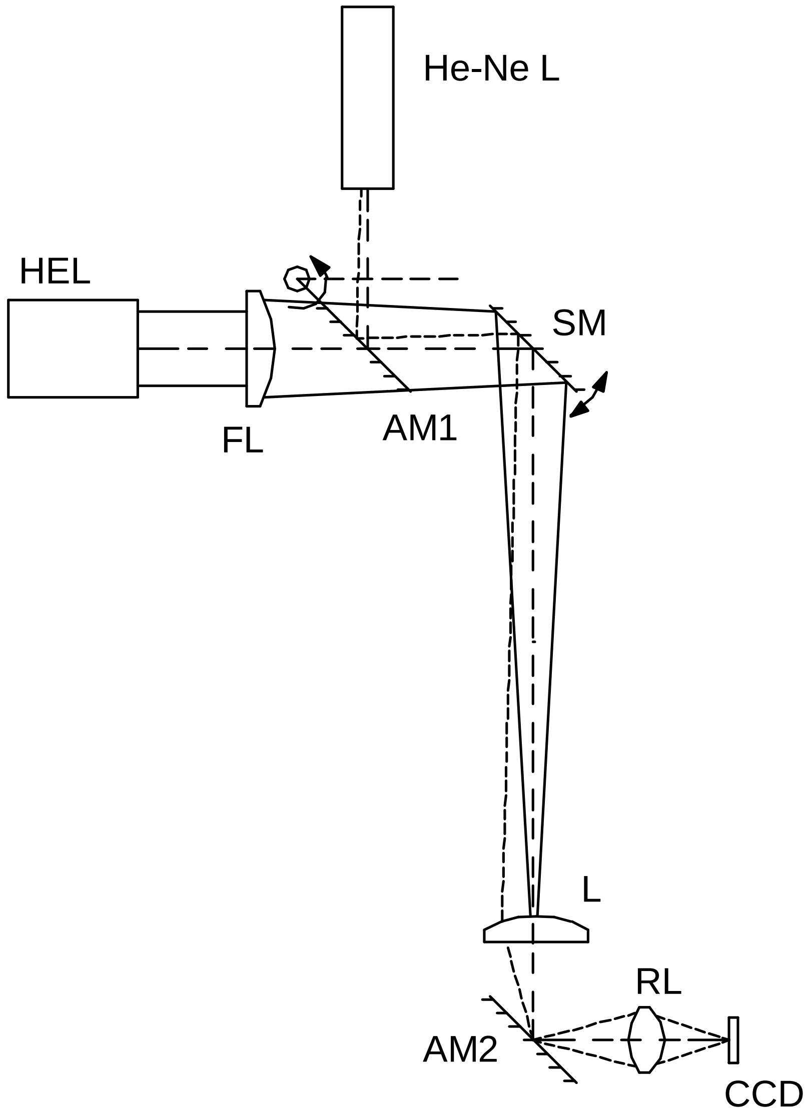

Fig.1 Layout of measuring scheme.

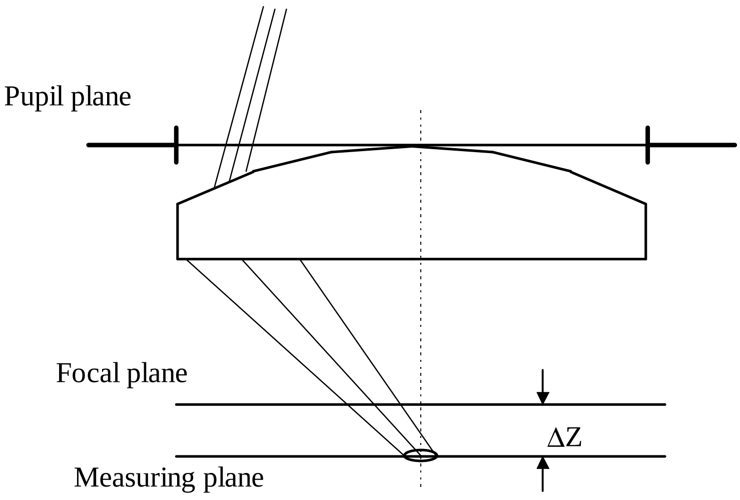

Fig.2 Scheme of passing measuring beam through tested lens.

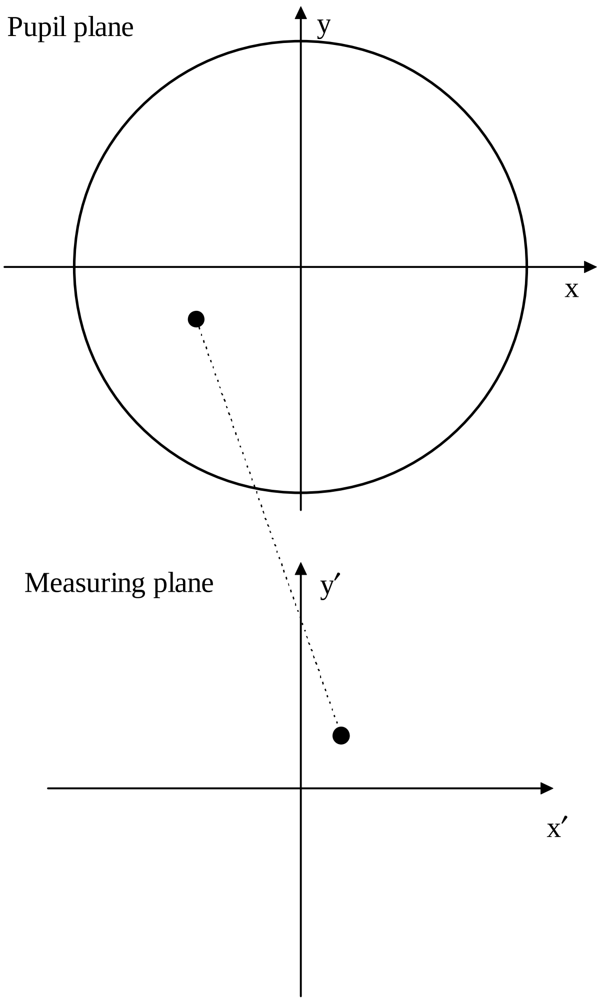

Fig 3. Beam coordinates in pupil and measuring plane.