THE DIMENSIONAL CONTROL OF OBJECT ON A POSITION OF INFLEXION POINTS OF THE DIFFRACTION PATTERN

Associate professor Ivanov A.N.

ABSTRACT

The method of an estimation of the object size on a points of inflection position a principal maxima of a diffraction pattern is offered. It is shown, that the method has high sensitivity to a size change of objects and allows to carry out measuring with a error up to 0.1 microns.

Index Terms – diffraction measurement, inflection point, diffraction pattern

1. INTRODUCTION

For the precise measurement of low-sized products the diffraction method of measurings is sometimes used. In devices, which realizing the method, checked object is illuminated a coherent radiation of the laser and a diffraction pattern of Fraunhofer is formed in long-range area. Advantages of such devices are the relative simplicity of a construction, low requirements to optics, magnification of sensitivity at the control of low-sized objects.

For definition of object size on a diffraction pattern of Fraunhofer it is necessary to determine coordinates of minimums from a distribution function of intensity. Then to calculate the coefficient linking these coordinates with the size of object. The error analysis of the diffraction methods of measurings has shown, that a dominant error in them is the error of definition of coordinates of minimums - sensitivity of a signal $d\,I(x)/d\,x$ their neighbourhood is close to 0, that gives in the considerable broadening of minimum [1,2].

On the basis of a procedure offered in article, the expression (1) linking a difference of intensity on the adjacent pixels of the CCD-sensor in a neighbourhood of a minimum of a diffraction pattern with parameters of a measuring circuit has been received

$$\Delta I \approx \frac{2\,d^2\,a^2\,I_0}{N^2\,\lambda^2\,f^2}, \qquad (1)$$

where N - the number of a minimum, d - the size of pixel, a - the size of object, f - a focal distance of the objective. His analysis has shown, that in most cases it is impossible to determine coordinate of a minimum precisely - error makes ± 2÷3 pixel.

2. THE ANALYSIS OF THE DIFFRACTION PATTERN

It is definable coordinates of points of a diffraction pattern from object in the shape of the slit in which sensitivity of the receiver attains the peak value. Intensity distribution in it is described by expression

$$I(U) = \sin(U)^2 / U^2, \qquad (2)$$

where $U = k\,a\,x/2\,f$, $k = 2\pi/\lambda$ - a wave number. It is definable coordinates of a point in which the module of the first derivative function (2) possesses the peak value $|\,d\,I(U)/d\,U\,| = \max$.

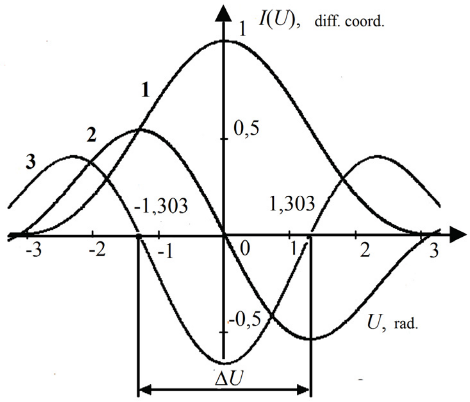

Fig.1. Principal maxima of a diffraction pattern and its derivatives

The analysis of a derivative has shown, that points with coordinates $U_2 = 1.303$ and $U_1 = -1.303$ have the peak sensitivity $I'(U) = 0.54$. These points correspond to inflection points of a main maximum the diffraction patterns (fig. 1). The difference of intensities on adjacent pixels of receiver in their neighborhoods is discrabed by expression

$$\Delta I \approx \frac{2.2\,d\,a\,I_0}{\lambda\,f}. \qquad (3)$$

Comparison (1) and (3) show, that at use of inflection points a difference of a signal on adjacent pixels increases by two orders. It secures detection of these points with a limiting error ±1 pixel.

Also dependence of sensitivity of inflection points position on the size of object have been explored, it increases with object downsizing (fig. 2).

If to measure a difference of the linear coordinates of inflection points $\Delta x = x_2 - x_1$ it will be interlinked with a priori known of (2) difference of angular coordinates of these points $\Delta U = U_2 - U_1 = 2.606$ simple dependence $\Delta U = k\,a\,\Delta x / 2f$. From here it is possible to determine the size of object a

$$a = 2\Delta U\, f / k\,\Delta x = 5.212\, f / k\,\Delta x . \qquad (4)$$

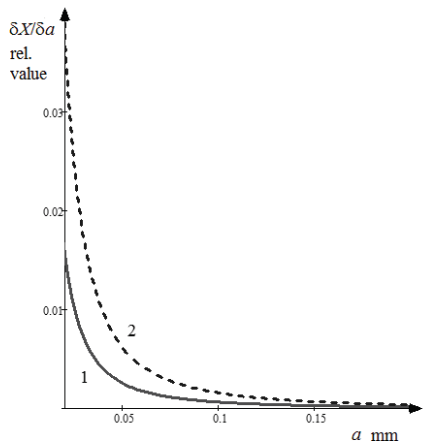

Fig. 2. Dependence of sensitivity of a position of inflection points (the graph 1) and minimums of 1-st order (the graph 2) from the size of object at f = 25 mm and λ = 0.63 µm

3. EXPERIMENTAL RESEARCH

For the offered algorithm verification the experimental setup (fig. 3), consisting of laser LGN-5, the spectral slit with a step of opening 1 microns, the objective with a focal distance f = 25 mm and CCD with the resolution 792×576 pixels has been maked.

During experiment we registered diffraction pattern from the slit which width changed over the range from 40 up to 70 µm with a step 2 microns. From the registered image the main maximum is extracted. It is filtered by low-frequency filter of the Gauss.

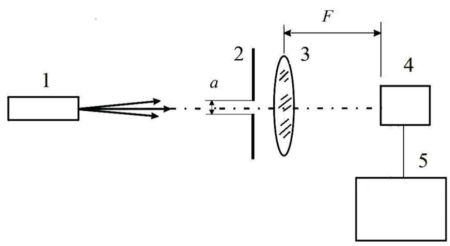

Fig. 3. Experimental setup: 1 – the laser, 2 – the slit, 3 – the objective, 4 – the CCD, 5 – the frame grabber

Main maximum was numerically differentiated with the help of an interpolation formula of Newton (fig. 4).

$$I_i' \approx \left(\left(I_{i+1}-I_i\right)-\left(I_{i+1}-I_i\right)^2/2+\left(I_{i+1}-I_i\right)^3/3\right)/h ,$$

where I - the number of the CCD pixel, I_i - signal intensity in i-th pixel, h - a step of change of values (h = 1 pixel)

Coordinates of extremes of the received function correspond to coordinates of inflection points.

For definition of extremes position of a derivative with subpixel precision the method of approximation of the first derivative in of its extremes neighbourhood by a method of least squares has been used, that allowed to determine its position with a limiting error 1/5 pixel. In the capacity of the fitted function the derivative from the function describing of intensity in a diffraction pattern has been taken. Further difference Δx was determined and on expression (4) the width of the slit was computed.

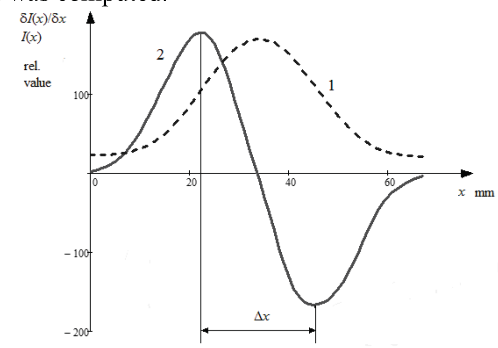

Fig. 4. Obtained section of a principal maxima (function 1) and its first derivative (function 2) for a slit in width 70 µm

Table 1. Result of measuring of slit width

Slit width, µm	40	42	44	46	48	50	52	54
Measurment error, µm	0.3	0.3	0.4	0.1	0.3	0.2	0.2	0.4
Slit width, µm	56	58	60	62	64	66	68	70
Measurment error, µm	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2

In table 1 results of measuring of width of the slit are given. The measurement error of slit width has made 0.3-1 % depending on value of the checked size.

4. CONCLUSION

The method of measuring of the sizes of objects on inflection points position of diffraction pattern which have high sensitivity is offered. Simple transformations of an initial measuring signal allow robust and with good precision to determine their coordinates.

Dependence between coordinates of inflection points and the size of checked object is exposed and the experimental researches which have confirmed correctness of theoretical calculations are lead. It is shown, that the method is convenient for the check of low-size objects when the main maximum of a diffraction pattern is placed on CCD-sensor only.

5. REFERENCE

[1] V. N. Nazarov, A. N. Ivanov "Using the moiré effect to increase the accuracy of diffraction method for monitoring the geometrical parameters and the spatial position of objects," J. Opt. Technol. 76 (1), 2009, p. 39-42;

[2] V. N. Nazarov, A. E. Linkov "Diffraction methods for monitoring the geometrical parameters and spatial position of objects," J. Opt. Technol. 69 (2), 2002, p. 97-101.