OPTICAL SYSTEM FOR MEASUREMENT OF SURFACE FORM AND ROUGHNESS

Cz. Łukianowicz, T. Karpiński
Department of Mechanical Engineering, Technical University of Koszalin
PL – 75-620 Koszalin, Poland

Abstract: An optical system designed for measurement of surface form and roughness is the subject of this paper. The system's operation is based on the light scattering from surface irregularities. This system can be used for controlling the rough surfaces of objects under static conditions and while their movement. Measurement of form and surface waviness requires steady-rate displacement of the measuring setup with respect to the object. The principle of the system's operation and experimental results obtained from various machined rough surfaces are presented.
Keywords: optical measurement, measurement of surface roughness.

1 INTRODUCTION

An increased demand for automatic systems controlling the surface roughness and form, especially in finishing operations, has been observed in many production plants. They comprise contact, electrical, pneumatic and optic systems described in works, including [1], [2] and [3]. These systems used for active measurement of surface roughness and form should be low sensitive to vibration, dustiness and other factors troubling measurement. Furthermore, they should guarantee measurement in a short time. Methods based on scattering of light from rough surfaces have a great chance of practical application [4]. One of them is presented in Refs [5], [6]. In this paper an optical measurement setup designed for roughness evaluation and measurement of form and waviness deviations by this method are discussed. Experimental results obtained from measurement of selected surfaces are presented as well.

2 EVALUATION OF SURFACE ROUGHNESS

The measurement setup works on the principle that a laser beam reflected from a rough surface becomes scattered. The larger surface micro-regularities the wider angles of light scattered from the object surface. Surface roughness is estimated through measuring the angular distribution of scattered light. In this method the rough surface is considered as a set of micro specular reflectors. Due to such simplification it is possible to show that the angular distribution of scattered light from rough surface corresponds with the angular distribution of irregularity inclination. What is more, the system allows for determination of the slope profile parameters [7], the variance of angular distribution of scattered light intensity [5], [6], [7] and other characteristic parameters of measured distribution. A diagram explaining the principle of operation of the system is shown in Fig. 1.

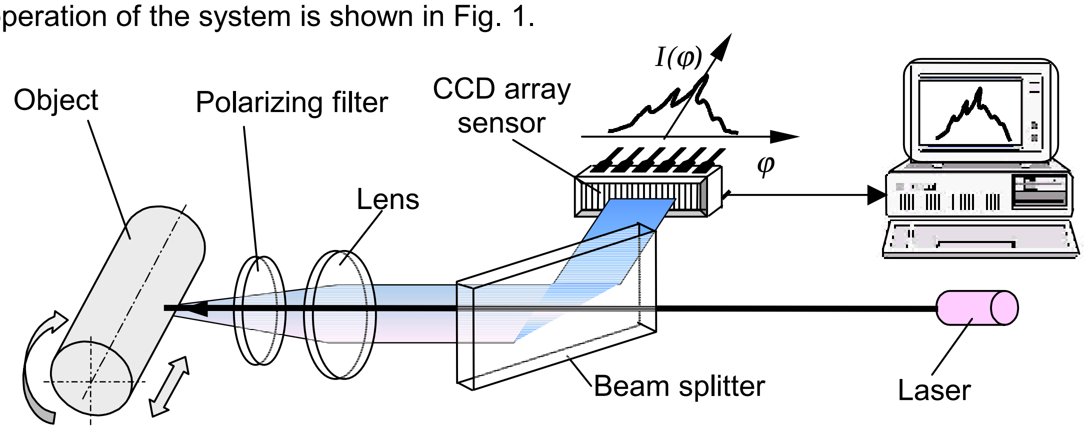

Fig. 1. Diagram explaining the principle of operation of the system designed for evaluation of machined surface irregularities.

A laser beam running through a beam-splitter, optical lens and a polarizing filter is projected onto the object surface. The light reflected from the object surface runs again through the polarizing filter and optical lens. Then the beam splitter directs the light to a CCD array sensor. This CCD array sensor, owing to a special driver, is linked with a microcomputer. Consequently, the values angular distribution of the light scattered $I(\varphi)$ are stored in the microcomputer. The program developed on the basis of these values presents a graphical visualization of this distribution and determines respective parameters of surface roughness. The view of the measurement setup is presented in Fig. 2.

The instrument can measure motionless or moving surfaces. Motion of surfaces makes averaging the measuring signals as a function of time. The variance of angular distribution of scattered light intensity, marked by S_N, is proportional to the root mean square slope of the profile Δq expressed by the following equation:

$$\Delta q = \sqrt{\frac{1}{l}\int_0^l \left(\frac{dy}{dx}\right)^2 dx} \ , \tag{1}$$

where l denotes the elementary segment of surface profile, whereas the dy to dx ratio is a derivative of surface profile. The variance of angular distribution of scattered light intensity S_N is determined on the basis of light intensity measured by the CCD array sensor. The following equations are used for this purpose:

$$S_N = C\sum_{i=n}^{i=-n}\left(i-\bar{i}\right)^2 p_i \ , \tag{2}$$

at the same time

$$\bar{i} = C\sum_{i=n}^{i=-n} i\ p_i \ , \tag{3}$$

while

$$p_i = \frac{I_i}{I_t} \ , \tag{4}$$

and

$$I_t = \sum_{i=n}^{i=-n} I_i \ , \tag{5}$$

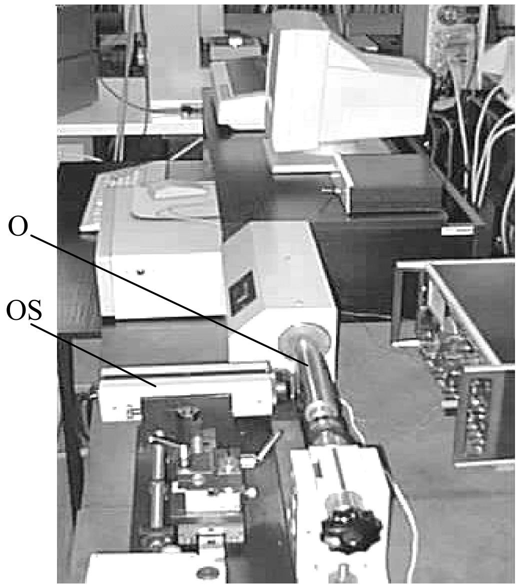

Fig. 2. View of the measurement setup. O – measured object; OS – optical system.

where: C – constant, i – number of a consecutive element of scattering indicatrix (CCD array sensor), $2n$ – total numbers of CCD array sensor elements, $\bar{i}$ – expected value of an angular distribution of scattered light intensity, equivalent to the mean scattering angle, p_i – standard rate of light intensity of i element of CCD array sensor, I_i – light intensity of i element of scattering indicatrix (total intensity of scattered light measured by CCD array sensor). The constant C is selected in this way that S_N comes within the scope from 0 to 100. The value of Δq parameter is estimated on the basis of the measured value S_N. Other parameters of the surface roughness, including R_a, could be also estimated for a given machining operation.

3 EVALUATION OF FORM AND WAVINESS

Form and waviness of a surface is measured while an object moves under an optical system with a constant speed. Measuring the parameter $\bar{i}$ determined by Equation (3), proportional to the average, local scattering angle $\overline{\varphi}$ one can compute the derivative of surface form and waviness profile $y'(x)$. The height of form and waviness profile $y(x)$ is determined by integrating the derivative:

$$y(x) = \int_0^x y'(x)\,dx = \int_0^x \tan\left[\frac{\overline{\varphi}(x)}{2}\right] dx \ . \tag{6}$$

The system makes it possible to determine the surface form and waviness in a selected section for either flat or rotary surfaces. The idea of form and waviness measuring in simplified representation is illustrated in Fig. 3. It consists in measurement of an average, local scattering angle in consecutive points of a surface. Then a derivative of a profile and – in accordance with Equation (6) – a surface profile are determined. Such measurement is an indirect measurement because all values on the ordinate at individual points of the profile are related to the starting point, which value on the ordinate is unknown.

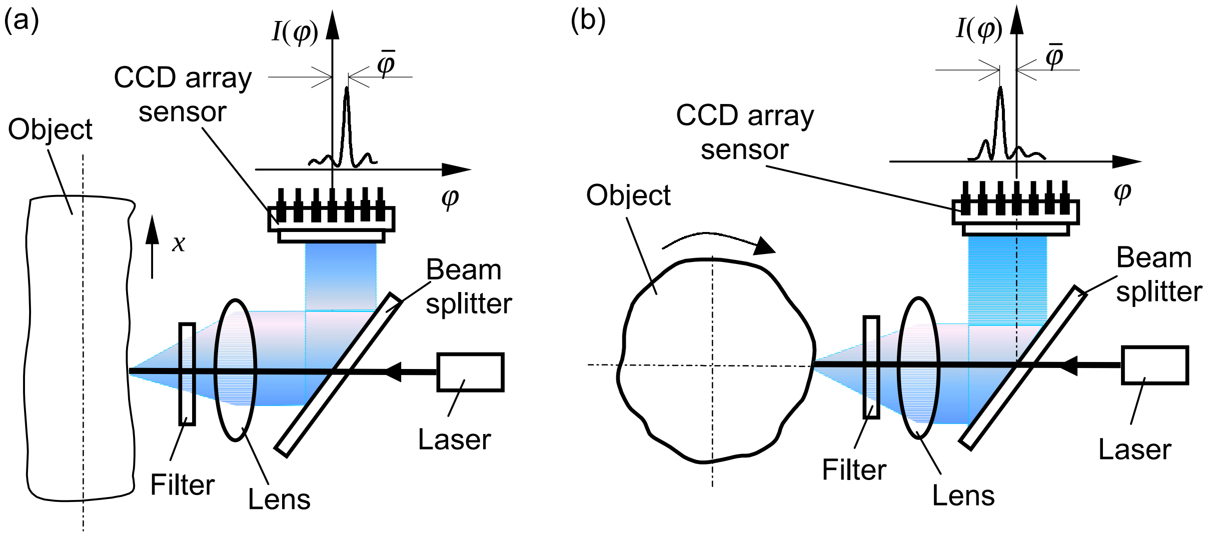

Fig. 3. Diagram displaying the method of surface form and waviness determination: (a) while measurement of cylinder straightness, (b) while measurement of roundness.

4 EXPERIMENTAL RESULTS

The system was developed for experimental investigations focused on evaluation of the surface roughness, form and waviness. These investigations were carried out on flat and

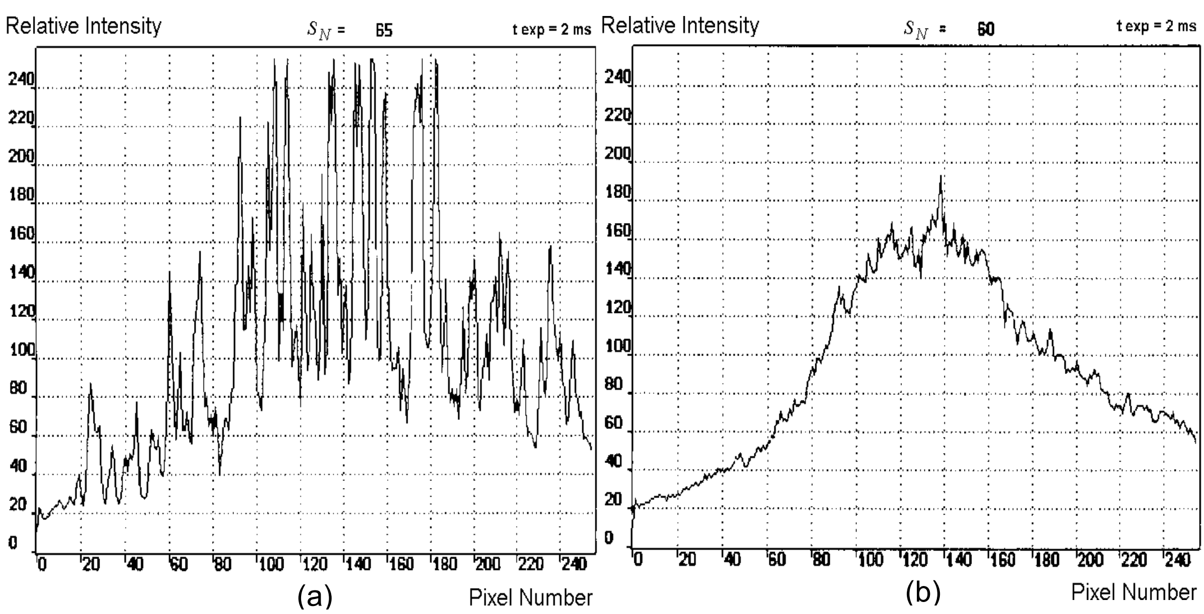

Fig. 4. Angular distributions of scattered light obtained during the measurement of cylindrical surface roughness: (a) under static conditions, (b) during rotary motion.

cylindrical surfaces. The surfaces were made of 45 steel, cast iron, PA6N aluminum alloy, brass and glass.

Investigations comprised ground-finished, machined, polished and lapped surfaces. Evaluation of cylindrical surface roughness was carried out under statistic conditions and during rotary motion of the object. The experimental results were compared with results obtained with the aid of contact instruments. Sample results obtained from assessment of surface roughness of a steel shaft are presented in Fig. 4. Results of roundness measurement for the same shaft are shown in Fig. 5.

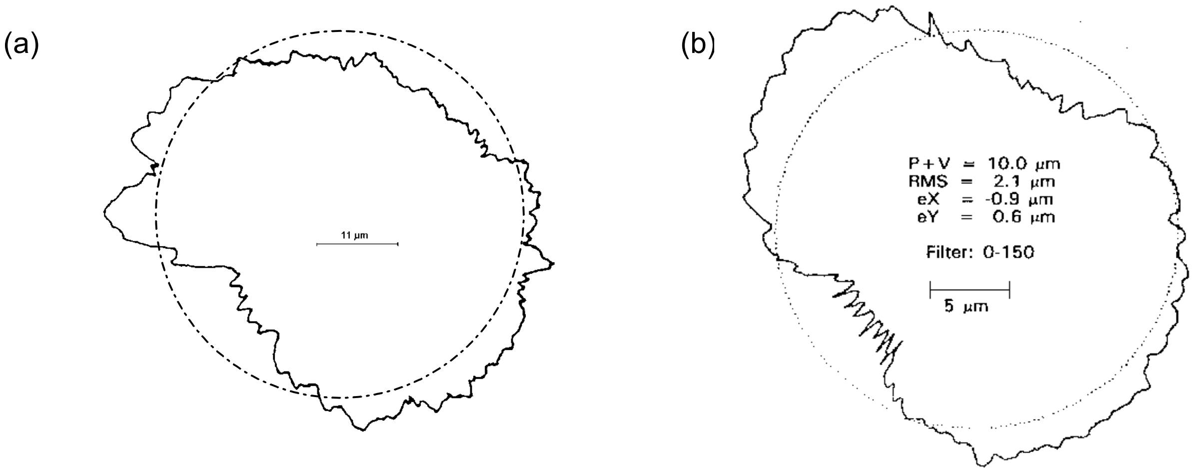

Fig. 5. Experimental results of shaft-roundness evaluation: (a) diagram obtained by optical method, (b) diagram obtained by contact method.

5 CONCLUSIONS

The investigations revealed that the presented optical system is suitable for evaluation of the surface roughness, form and waviness. The range of the surface-roughness evaluation, for an R_a parameter is from 0.01 µm to 1 µm. Measurement of the surface waviness and form can be carried out within the scope from 2 µm to 500 µm.

REFERENCES

[1] T. R. Thomas (ed.), *Rough Surfaces*. Longman, London and New York, 1983.

[2] D. J. Whitehouse, *Handbook of Surface Metrology*, Institute of Physics Publishing Ltd., Bristol, England, 1994.

[3] S. Adamczak, *Odniesieniowe metody pomiaru zarysów okrągłości części maszyn*, Politechnika Świętokrzyska, Kielce, 1998. (in Polish).

[4] J. M. Bennett, L. Mattsson, *Introduction to Surface Roughness and Scattering*, Optical Society of America, Washington, D. C., 1989.

[5] R. Brodmann, G. Thurn, Roughness measurement of ground, turned and shot-peened surfaces by the light scattering method, *Wear*, **109** (3) (1986) 1-13.

[6] C. Lukianowicz, Optical instrument for evaluation of rough machined surfaces by angular distribution of scattered light, in: M. Pluta, M. Szyjer (ed.) *Proceedings of the International Conference "Diffractometry & Scatterometry"* (Warsaw, 24-28. May 1993), *Proceedings SPIE*, **1991**, IAO Warsaw, Poland, 1994, p. 168-174

[7] M. Allgäuer, R. Brodmann, Vergleichende Untersuchung der Mikrotopographie von Sinusprofilen mit Hilfe der mechanischen und optischen Profilometrie sowie der Streulichtmethode. *Feingerätetechnik*, nr 1/1988, 9-12.

AUTHORS: Department of Mechanical Engineering, Technical University of Koszalin, ul. Raclawicka 15-17, PL - 75-620 Koszalin, Poland, Phone 48-094-3478368, Fax 48-094-3426753, E-mail: kipkarpt@lew.tu.koszalin.pl