The Complex Profilometric Measurement of Non-Closed Form Profiles of Machine Parts

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Abstract:. *Most methods of measurement used until now concern closed profiles. In practice, however, mating surfaces are frequently incomplete and their profiles determined in certain cross-sections are non-closed. For such profiles we need to use special instruments. Of particular interest are profilometric ones characterized by a wide measuring range. They can be applied to complex evaluation of the geometrical surface structure including form profiles, surface waviness and surface roughness. This group of measuring media is quite numerous but the Form Talysurf made by Taylor-Hobson is the most popular one. Previous models of this instrument need modernizing by coupling to a computer equipped with a special program PROFORM. The program enables us to perform a complex analysis of the geometrical state of the superficial layer including all types of surface irregularities. Additionally, the program makes it possible to determine the geometrical dimensions of the measured testpiece.*

Keywords: roughness, waviness, form, calibration.

1. Introduction

The introduction of profilometric instruments so called profilographers assures complex evaluation of the geometrical structure of surfaces of non-closed profiles with nominal forms of a circular sector or other curvilinear line in a cross-section. The world leading manufacturers of profilographers include Taylor-Hobson, Hommelwerke, and Perthen. IOS Kraków is the leader on the Polish market. The instruments are characterised by a wide measuring range of the pick-up, which enables evaluation of form profiles, surface waviness and surface roughness, as well as determination of dimensions of measured objects. The Form Talysurf made by Taylor-Hobson is an example of such an instrument and it is commonly applied in the precision (particularly bearing) industry [1].

The main units of the Form Talysurf profilographer are the measuring pick-up and the drive system assuring the movement of the former across the tested area. The measuring pick-up is equipped with a unit responsible for transmitting information about the studied area. The key element is a diamond needle with a given radius. It scans the surface profile and assures an appropriate measuring pressure. The pick-up is equipped with a laser interference converter whose principle of operation is shown in Fig. 1 [2].

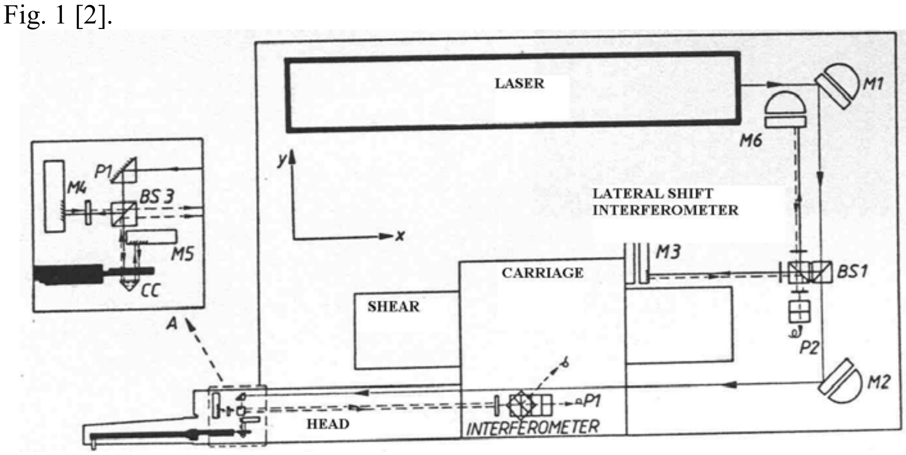

Fig. 1. Outline of the principle of operation of the measuring pick-up with an interference laser converter

Previous instruments equipped with a microcomputer measuring signal processing system operated by a special computer program could not perform the task of a complex measurement of the geometric surface structure in accordance with the recommended ISO standards and satisfying the requirements of the bearing industry.

The co-operation of research institutions in Kielce with the Polish bearing industry has resulted in the development of a new computerized measuring system. The system satisfies the ISO standards and the expectations of the bearing industry. It employs a modernized Form Talysurf coupled to a computer equipped with a PROFORM program.

2. PROFORM computer program

PROFORM is used for registering and analysing results of measurements of form profiles, surface waviness and surface roughness made with a FORM TALYSURF instrument. The PROFORM program enables:

- definition of the cutoff length and measuring length,
- selection of the measurement mode and parameters including the start level, method of starting a measurement (the 'start immediately' or 'wait' mode), method of ending a measurement (the 'manual', 'return', 'wait' or 'auto' mode),
- profile measurement,
- selection of the reference lines: no reference line, a straight line or a circle),
- selection of the type of the reference line: mean line, minimum zone line,
- definition of the nominal radius of a reference circle,
- profile filtration by means of digital filters satisfying the ISO standards (2RC, 2RC with phase correction, and Gauss and Fourier filters),
- analysis of a roughness profile on the basis of diagrams (roughness profile plot, plot of the distribution of the profile departure density, profile bearing ratio plot, discrete amplitude spectrum plot) and roughness profile parameters,
- analysis of a waviness profile on the basis of diagrams (waviness profile plot, discrete amplitude spectrum plot) and waviness profile parameters,
- analysis of a form profile on the basis of diagrams (form deviation profile plot, form profile plot) and form profile parameters,
- evaluation of the profile radius, angle between two straight lines, distance between two circle centres, etc.,
- selection of report profile parameters,
- manual or automatic selection of the plot scale,
- black or color printing of the measurement documentation on an ink or laser printer,
- saving selected measuring results on the computer disk,
- management of the measuring data base (copying, deleting measuring results, creating and removing directories),
- statistic analysis of the measuring results,
- calibration with a sphere standard.

The program can register up to 5,000 samples per measuring length, the sampling step being a multiplication of three quarters of the laser wavelength (approx. 0.48 μm).

3. System calibration

Before each calibration, it is necessary to define certain parameters such as stylus arm length, stylus tip radius, calibration range in degrees (depending on the stylus type) and calibration order (second or third) using the 'Options/Calibration Options' command. The values of the stylus arm length can be approximate. Calibration enables us to determine suitable correction coefficients and then transform the measured profile into the real one. The calibration range is expressed by the value of the central angle of the measured roundness profile of the sphere standard.

The calibration procedure can be chosen either by means of the Measurement/Calibration command or the Options/Calibration command. Using the first, we are able to make a calibration in the automatic mode. Command two is accessible after measuring the sphere standard or reading the results of the master measurement from the computer disk.

Calibration consists in analysing the results of the measurements of the sphere standard with a known radius. Its purpose is to define the correction characteristics eliminating the non-linearity of the stylus, and to determine the real profile on the basis of the measured one. The good understanding of the non-linearity correction requires analysing the mathematical model of a pick-up with a rotary arm. The considered pick-up system is presented in Fig. 2.

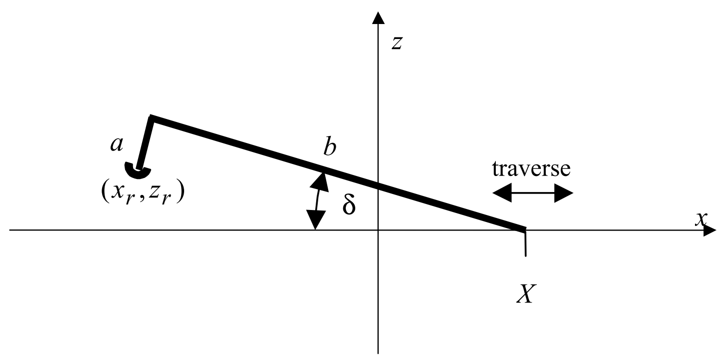

Fig. 2. The pick-up system with a rotary stylus arm

a and b are dimensions of the stylus arm, δ is an angle of displacement of the stylus arm from the horizontal position, and X is the co-ordinate of the stylus joint. Basing on the geometric relations, we have:

$$z_r = a\cos\delta + b\sin\delta \tag{1}$$

$$x_r = X - a\sin\delta - b\cos\delta \tag{2}$$

We assume that the dependence of the pick-up readings Z on the angle of rotation δ is linear. Thus

$$Z = Z_o + k\delta \tag{3}$$

where Z_o is the pick-up readings at the horizontal position of the stylus arm. Expanding the trigonometric functions into a Taylor series, and taking account of the first initial components of the expansion, we get:

$$\begin{aligned} z_r &= a_1 \cdot Z + a_2 \cdot Z^2 + ... + a_n \cdot Z^n \\ x_r &= X + b_1 \cdot Z + ... + b_n \cdot Z^n \end{aligned} \tag{4}$$

The number n is called the order of approximation, and the numbers $a_1,...,a_n.b_1,...,b_n$ are the correction coefficients.

4. Signal filter

When the pick-up moves horizontally, the changes in the deviation of the stylus caused by the irregularities of the measured surface are disturbed by undesirable stylus vibrations. This leads to a considerable increase in the surface roughness height parameters for pieces with R_a less than 0.1 µm. The character of the stylus vibrations can be identified by measuring a profile of the straightness standard. Figure 3 shows a spectrum of a signal obtained by measuring the standard profile with a speed of 0.5 mm/s. Two resonance frequencies corresponding to the wavelengths λ = 2.5 µm and λ = 5 µm are clearly visible. Similar results were recorded while measuring the sphere standard. To eliminate the components of a signal caused by stylus vibrations, a digital on-line filter operating in the measurement background was used. Obviously, the application of the filter eliminates also the roughness components with a length smaller than the filter cut-off length. Therefore, the filter should be a compromise between the necessity of disturbance elimination, on the one hand, and the need for evaluation of surface roughness in as wide a range as possible, on the other. Two filter designs with the boundary wavelength λ_s equal to 4 µm and 8 µm respectively were considered. The filters belong to a class of filters with finite time response having a suitably selected Blackman type window.

Appropriate window parameters had to be found to obtain as flat a characteristic as possible in the range of long wavelengths. This guarantees no distortion of the piece form profile. The characteristics of the implemented filters are shown in Fig. 3. We can see that the λ_s = 4 μm filter eliminates the vibrations caused by the resonance with a higher frequency, whereas the λ_s = 8 μm one eliminates vibrations caused by both resonances. It is the task of an operator to select the filter type.

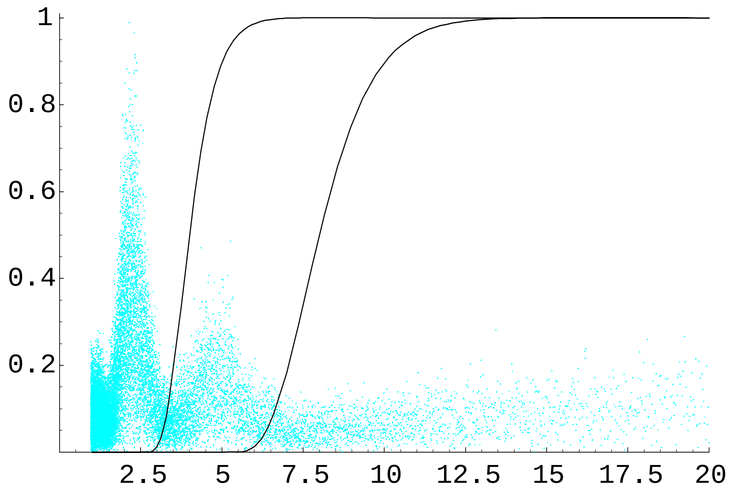

Fig. 3.Spectrum of the measured straightness standard profile and the characteristics of the available on-line filters

5. Conclusion

The paper has dealt with the concept of modernization of measuring instruments that enable complex evaluation of the geometric surface structure including the form profile, surface waviness and surface roughness. The modernization involves applying a computer-aided measurement system operating with the original computer program PROFORM. The PROFORM program makes it possible to perform a complete qualitative and quantitative analysis of all surface irregularities in accordance with the previous and latest Polish standards, which mirror the ISO standards, as well as the requirements of the bearing industry. The program applies filters which enable not only the evaluation of the measured profile of surface roughness and surface waviness but also the form profile. The developed computer-aided measurement system was used for the modernization of the Form Talysurf instrument. It has been successfully applied in the bearing industry, i.e. at NSK ISKRA, Kielce, Poland, ZVL Považka Bystrica and KINEX, Skalica, Slovakia. The proposed modernization of the Form Talysurf instrument including the PROFORM program was tested by representatives of the manufacturer, Taylor-Hobson, at NSK ISKRA S.A. in Kielce and the results were very satisfactory.

6. References

[1] Garatt J.D., A new stylus instrument with a wide dynamic range for use in surface metrology, Precision Engineering, July 1982, vol. 4, no. 3, pp. 145-151.

[2] J.Tomasik.: Aktualne kierunki badań przyrządów profilometrycznych Mechanik nr.9, Warszawa, 1989, s. 413-417.