Stanisław ADAMCZAK, Dariusz JANECKI, Jacek ŚWIDERSKI
POLITECHNIKA ŚWIĘTOKRZYSKA, WYDZIAŁ MECHATRONIKI I BUDOWY MASZYN

Combined roundness and straightness measurement applied to the assessment of cylindricity profiles of machine parts

Prof. dr hab. inż. Stanisław ADAMCZAK

Jest Dziekanem Wydziału Mechatroniki i Budowy Maszyn Politechniki Świętokrzyskiej oraz kierownikiem Katedry Technologii Mechanicznej i Metrologii na tym wydziale. Jego zainteresowania naukowe obejmują podstawy metrologii i metrologię wielkości geometrycznych. Jest członkiem wielu organizacji i stowarzyszeń naukowych, m.in. Komitetu Metrologii i Aparatury Naukowej PAN oraz prezesem Sekcji Metrologii SIMP. W kwietniu 2008 r. wybrany na Rektora Politechniki Świętokrzyskiej.

e-mail: adamczak@tu.kielce.pl

Dr hab. inż. Dariusz JANECKI

Studia wyższe na Wydziale Elektroniki Politechniki Warszawskiej ukończył w 1981, a w 1996 obronił tam pracę doktorską. W 1996 obronił pracę habilitacyjną w Instytucie Podstawowych Problemów Techniki PAN. Obecnie pracuje na stanowisku profesora w Politechnice Świętokrzyskiej i jest kierownikiem Zakładu Informatyki i Sterowania. Zainteresowania naukowe obejmują teorię sterowania ze szczególnym uwzględnieniem metod identyfikacji i sterowania adaptacyjnego oraz matematyczne podstawy metrologii powierzchni.

e-mail: djanecki@tu.kielce.pl

Abstract

The traditional methods used for the measurement of cylindricity do not always provide us with complete qualitative and quantitative data about the whole surface of an object, particularly in the case of local difficult-to-detect irregularities. The combined method involves measuring roundness profiles in several transverse sections as well as straightness profiles in several longitudinal sections. In conventional instruments, the measuring sensor moves along the object axis, so straightness profiles of the generatrices of the cylindrical surface are seldom measured. The combined measurement is possible thanks to a specially developed measuring system basing on a new mathematical model and calculation procedures.

Keywords: combined method, cylindricity measurement, straightness measurement, roundness measurement.

Kombinowana metoda pomiarów okrągłości i prostoliniowości do oceny zarysów walcowości części maszyn

Streszczenie

Dotychczas stosowane metody pomiaru walcowości nie zawsze podawały pełną informację jakościowa i ilościową o całej badanej powierzchni, zwłaszcza gdy pojawiają się znaczne lokalne nierówności, niekiedy trudne do wykrycia. Metodą, która może być wykorzystana do tego typu ocen jest kombinowany sposób, umożliwiający pomiar zarysów okrągłości w kilku przekrojach poprzecznych przedmiotu, a następnie pomiar zarysów prostoliniowości w kilku przekrojach wzdłużnych. Dotychczas stosowano głównie przyrządy, które umożliwiają kontrolowany przesuw czujnika pomiarowego wzdłuż osi sprawdzanego przedmiotu. Natomiast pomiar prostoliniowości tworzących powierzchnię walcową był stosowany sporadycznie. W związku z tym opracowano układ pomiarowy, który umożliwiałby pomiar wyżej opisaną metoda kombinowaną. Dla tej metody rozbudowano model matematyczny, który stał się podstawą opracowania procedur pomiarowych umożliwiających zbudowanie programu komputerowego.

Słowa kluczowe: metoda kombinowana, pomiar walcowości, pomiar prostoliniowości, pomiar okrągłości.

Mgr inż. Jacek ŚWIDERSKI

Jest pracownikiem Laboratorium Komputerowych Pomiarów Wielkości Geometrycznych w Katedrze Technologii Mechanicznej i Metrologii Politechniki Świętokrzyskiej w Kielcach. W swoich pracach zajmuje się zagadnieniami pomiarów wielkości geometrycznych, a w szczególności pomiarami zarysów okrągłości i walcowości. Jest współautorem 2 prac prezentowanych na konferencjach międzynarodowych.

e-mail: swiderski@tu.kielce.pl

1. Introduction

The assessment of surface geometry of products is an important problem in basic experimental research as well as in practical measurements because form deviations may affect the dynamics of elements in contact. In the engineering industry, the main aim is to minimize form errors of cylindrical surfaces. It is significant both in the case of rotary drive elements such as rolling and sliding bearings or machine-tool spindles as well as in the case of non-rotary elements moving linearly, for instance, an engine piston.

The accuracy of cylindrical elements have usually been assessed basing on the roundness deviations measured in several cross-sections. Since the operation of elements in contact can be affected by deviations from cylindricity, it is necessary to assess the analyzed element by means of parameters that refer to the whole surface. Specialized measurement systems need to be applied so that high accuracy is assured and boundary values of cylindricity deviations are satisfied.

2. State of the art

The sources relating to the measurements of form profiles of rotary surfaces are relatively limited. They are concerned mainly with the methods of measurement of changes in the radius, which do not provide complete information about the analyzed surface. The research on the subject is being conducted mainly outside Poland by centres cooperating directly with the leading manufacturers and standards institutions [1, 2, 3, 4, 5]. The Polish research centres dealing with the problem include the Warsaw University of Technology [6, 7] and Kielce University of Technology [8, 9, 10, 11]. All the studies have focused on developing computer-based systems for measuring cylindricity by means of several parameters. It has been reported recently, however, that the systems do not enable complete visualization of the measured profiles and the values of the parameters are sometimes unreliable. The problem was pointed out in the latest standard documents - ISO [12, 13]. It is recommended that the proposed method, called the bird's cage method, be applied in the research project. To apply the method it is necessary to analyze the problem theoretically and experimentally. The authors of the project recognized the problem, too, as their cooperation with a number of manufacturers of cylindrical products concerns the theoretical and practical implementation aspects of the reference and non-reference methods of roundness measurement (e.g. research projects No 7T07D04008 and 7T07D00617 financed by the State Committee for Scientific Research) and cylindricity measurement (statutory research projects). Of importance is also the cooperation with companies specializing in the modernization of equipment for measuring and assessing cylindricity profiles.

3. Principles of measurement of cylindricity profiles

In industrial practice, cylindricity profiles are measured with the radial – non-reference – methods. They are assessed basing on the results of roundness profiles. As the object axis constitutes the measurement basis, it is necessary to apply instruments with a rotary spindle or table. The measurement accuracy of traditional instruments is less than 0.1 μm, and the measurement process involves labour-intensive activities related to the centering and alignment of the element measured. Today, non-reference instruments are frequently incorporated in computer-based systems for processing measurement signals, which facilitate the object positioning on the measuring table and considerably improve the measurement accuracy to 0.03 μm. Non-reference instruments with a vertically adjustable sensor are reported to be particularly useful. Still, the assessment of cylindricity is labour-intensive, as it involves performing complex calculations of the particular roundness profiles. Moreover, it is not possible to represent the cylindricity profile graphically.

Under industrial conditions, cylindricity is assessed by measuring three particular cases - barrel shape, saddle shape, and conicity; the results, however, are frequently unsatisfactory. Now computer-based facilities are commonly applied to measure cylindricity profiles. The measurement is performed basing on a selected parameter. Roundness profiles are measured in n-cross-sections to the object axis (see Fig.1), and the analyzed surface can be represented graphically in any plane section.

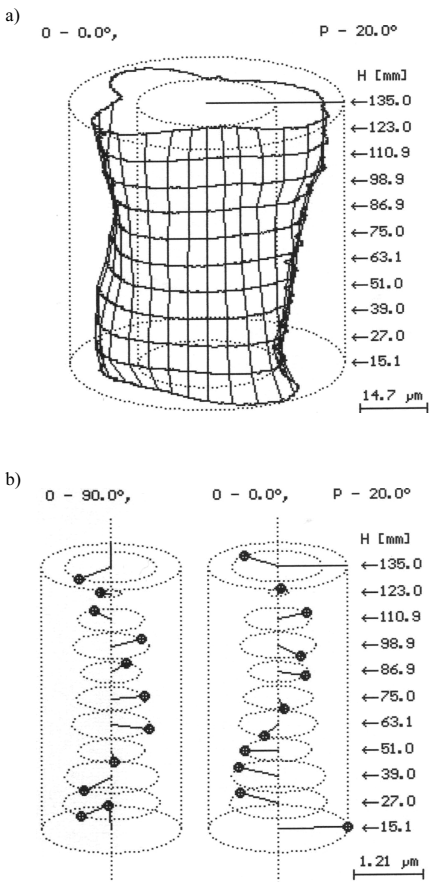

Fig. 1. Graphical representation of the measurement results obtained with the cross-section method: a) cylindricity profile; b) central line of the cylinder

Rys. 1. Graficzne przedstawienie wyników pomiaru walcowości metodą przekrojów poprzecznych: a) zarys walcowości; b) linia środkowa walca

The computer software is also suitable for assessing cylindical surfaces basing on the straightness profiles measured in *n*-cross-sections transverse to the object axis.

The other methods recommended for cylindricity measurements such as those performed in relation to the object helix or at n-points around the object surface are not popular with manufacturers. The experiments described in Ref. [14] (Research Project No T07D00617 financed by the State Committee for Scientific Research) involved comparing cylindricity profiles obtained by means of the non-reference (radial) method with those obtained by applying the reference (three-point) method. The qualitative and quantitative data were not complete, especially in the case of local difficult-to-detect irregularities (see Fig. 2).

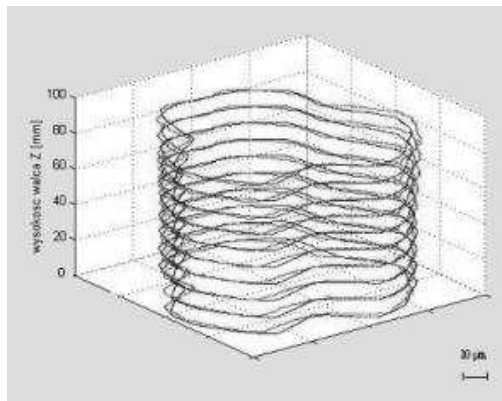

Fig. 2. Comparing the cylindricity profiles obtained in the non-reference (radial) measurement with those obtained in the reference (three-point) measurement

Rys. 2. Porównanie zarysów walcowości uzyskanych metodą bezodniesieniową (promieniową) i odniesieniową (trójpunktową)

Manufacturers of machine components which are cylindrical in shape (the bearing and automotive industries) expect researchers to develop a new measurement method so that a cylindrical surface can be graphically represented in as complete a way as possible and assessed reliably by means of the predetermined parameters.

4. The principle of measurement with the combined method

According to the project authors, the combined or bird's cage method is suitable for this type of assessment. When an object is placed on the measuring table, first its roundness profiles are measured in several cross-sections in planes perpendicular to the object axis, then the object straightness profiles are assessed in several cross-sections in the plane going through the object axis. Traditionally, cylindricity has been assessed with instruments that enable a controlled shift of the sensor along the object axis. The straightness of the generatrices of the cylindrical surface to be assessed has been measured occasionally, and this is due to the fact that most of the instruments employed for the purpose are not able to precisely control the rotary motion of the object. It is necessary to develop measuring systems in which the sensor rotations and shift along the object axis are controlled by the computer. A measurement performed with such a system will enable complete visualization of the whole surface. Developing the computer software requires formulating a mathematical model and preparing appropriate calculation procedures. These will constitute the theoretical and experimental basis of the non-reference (radial) measurement of cylindricity profiles for the new method of combined straightness and roundness measurement. Solving these problems is essential to meet the requirements of industry, especially those relating to the manufacture of cylindrical components used in mechanical devices that guarantee

the correct functioning of machines, e.g. bearings, motor engines, drive systems).

5. Problem solving

A mathematical model has to be formulated for the new method. It is necessary to combine the measured profiles of roundness and straightness into one profile of cylindricity. Accidental errors resulting from the occurrence of measurement noise or instrument defects have to be taken into account. One of the achievements in the problem solving process was the development of a special method for profile filtration. It is known that a measured profile consists of form components (cylindrivity) as well as waviness components. Therefore, the filtration algorithm needs to be a two-dimensional algorithm so that filtration is performed both around the circumference and along the axis of the cylinder. To assess the cylindricity deviation, it is essential to formulate the relationships and algorithms for determining the associated and derivative elements (associated cylinder–derivative axis). Two types of associated elements will be analyzed: the least squares and the minimum zone. The authors aim to formulate the theoretical basis of the assumed parameters and methods of profile filtration. The specially constructed computer-based facility equipped with a traditional instrument for measuring cylindricity profiles is suitable for experimental verification of the theoretical considerations and computer simulations. The object rotation will be controlled with the computer. The information about the recorded surface irregularities will be obtained by means of a high-resolution inductive sensor system. The computer-based measurement system will be tested statistically. Special computer programs will be used for assessing the measuring capacity and accuracy of the system. Measurement results will be compared with those obtained with traditional methods. The experiments will also involve applying modern measuring systems for cylindricity profiles equipped with high class instruments such as Taylor-Hobson Talyrond 200 and Talycenta operated with the CYFORM program (see Fig. 3).

Fig. 3. Taylor-Hobson Talycenta incorporated in the developed computer-based measurement system.
Rys. 3. Przyrząd Talycenta (producent - firma Taylor-Hobson, Wielka Brytania) umieszczony w skomputeryzowanym systemie pomiarowym

The statistical analysis will be conducted by applying specially developed software. It will be possible to determine the accuracy of the new measurement system and the degree of coincidence between the profiles.

6. Conclusion

The construction of the computer-based testing facility discussed in the paper is a measurable and well documented scientific achievement on a national scale. The computer software developed for the facility, the assumed methodology and procedures will constitute the basis for future measurement systems of this type. They will be able to provide complete qualitative and quantitative data concerning cylindricity profiles being analyzed. The next stage of research is to develop the methodology for testing the systems to be implemented. Of particular importance is the visual and parameter-based comparison of form profiles obtained with different instruments. The main aim is to implement the research results, particularly, the measurement methodology, procedures and computer software, in companies manufacturing rolling bearings and other components with rotary surfaces. Measurements of form profiles based on selected parameters will be characterized by higher accuracy. It will also be possible to visualize a profile by rotating and tilting the image.

The paper was presented at the 3rd International Conference on "Metrology in Manufacturing Technologies" at Białystok University of Technology in September 2007

7. References

[1] Osanna P. H. et al: Cylindricity – a well known problem and solution, International Journal of Machine Tools and Manufacture, vol. 32, No 1/2, Elsevier 1992, pp. 91-97.
[2] Dawson D. J. W.: Cylindricity and its measurement, International Journal of Machine Tools and Manufacture, vol. 32, No 1/2, Elsevier 1992, pp. 247-253.
[3] Starcevic G., Osanna P.H; Umrüstung eines Rundheitsmeßgeräts. E&I, 113. Jg. (1996) H. 4, pp. 293-295.
[4] Weckenmann A., Eitzert H.; Ein Gerät für Koordinatenmessung und Formprüfung?, 5 Internationales DAAAM Symposium, Maribor, pp. 487-488.
[5] Gao W. et al: Precision measurement of cylinder straightness using a scanning multi-probe system, Precision Engineering, vol 26., Elsevier, 2002, pp. 279-288.
[6] Żebrowska-Łucyk S.: Cyfrowe metody pomiaru odchyłki walcowości. Model matematyczny, oprogramowanie, wyniki badań. Konferencja „Metrologia Wspomagana Komputerowo", Zegrze k/Warszawy, 1993, vol.2/B, pp. 269-276
[7] Żebrowska-Łucyk S,: Bezodniesieniowa metoda badania makrogeometrii powierzchni elementów obrotowych. Prace naukowe: Mechanika, Oficyna Wydawnicza Politechniki Warszawskiej, 2001
[8] Adamczak, S., Janecki, D.: Komputeryzacja oceny zarysów walcowości części maszyn. Konferencja „Metrologia w Technikach Wytwarzania", Zeszyty Naukowe Politechniki Świętokrzyskiej, Mechanika nr 63, Kielce 1997, pp. 195-202
[9] Janecki D., Adamczak S.: Modernization of automated form measuring instruments, E&I 116. 1999, H.4, Springer Verlag, pp. 244-248
[10] Adamczak S., Janecki D.: Reference measurement of cylindrity profiles of machine parts. Postępy Technologii Maszyn, vol. 25, nr 3/2001, pp. 7-18
[11] Adamczak S., Janecki D.: Modernizacja przyrządów do oceny struktury geometrycznej powierzchni. Cz. 2. Pomiary zarysów walcowości. Mechanik, nr 7/2001, pp. 495-499
[12] Norma ISO/DIS 12180-1. Geometrical Product Specifications (GPS) - Cylindricity - Part 1. Vocabulary
[13] Norma ISO/DIS 12180-2. Geometrical Product Cylindricity - Part. 2. Specification operators
[14] Projekt badawczy KBN nr T07D00617: Teoretyczno-eksperymentalne podstawy referencech pomiarów zarysów walcowości części maszyn. Politechnika Świętokrzyska, Kielce 2003

Artykuł recenzowany