New trends in design of instruments for measurements of roundness and cylindricity

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Abstract

The paper deals with modern systems for roundness and cylindricity measurements. It gives the classification of methods for roundness and cylindricity measurement and it describes more precisely the radial method. Fundamental part of the paper is presentation of measuring abilities of Talyrond 365. In the summary a brief comparison between of and new systems for cylindricity measurements are given.

KEYWORDS: **roundness**, **cylindricity**, **measurement**, **radial method**

Introduction

Shafts and cylinders constitute very large and important group of machine elements [1, 2]. They are crucial components of such parts as rolling bearings, machine tool spindles, engine pistons etc. [3, 4]. Form errors of cylindrical parts can influence durability of mechanical devices very significantly. This is the reason why the problem of correct measurements of roundness and cylindricity is the matter of great importance in the field of metrology of geometrical quantities [5–7].

Roundness measurements can be applied to control the quality of cylindrical parts, if it is assumed that straightness deviation of their axes or generatrices are relatively low in comparison to a roundness deviation of a given cross-section of the element. Roundness measurements are also sufficient when it is assumed that roundness profiles in all cross-sections of the shaft are very similar. Otherwise, cylindricity measurements should be conducted to identify form errors of an investigated element. Roundness measurements are easier to conduct and to analyze because it is a two-dimensional metrological problem, whereas cylindricity deviations have to be analyzed in a three dimensions [8].

According to the standard ISO/DIS 12180-1 [9] a total cylindricity deviation can be regarded as a sum of three components:

- a straightness deviation of a cylinder axis,
- a straightness deviation of a cylinder generatrix,
- and a roundness deviation in a given cross-section of the cylinder.

A diagram given in fig. 1 shows a classification of methods applied to measure roundness and cylindricity deviations.

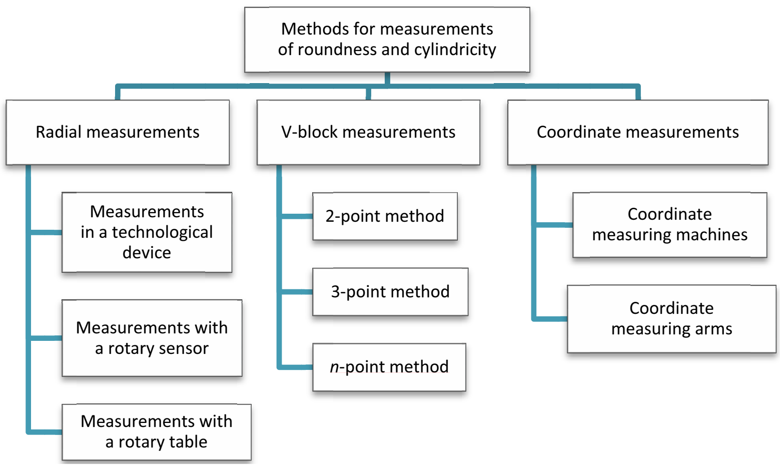

Fig.1. *Basic classification of methods applied to measure roundness and cylindricity deviations*

To comment a diagram shown in Fig. 1 it should be noted that there is a slight difference between an application of above mentioned methods to measure roundness and cylindricity. For example, measurements in technological devices are usually conducted to find only rough approximation of roundness or cylindricity deviations. However, there are works that describe how to increase a measurement accuracy of this method, but it is limited to roundness measurements.

There is also a difference between state-of-the-art in the field of an application of V-block methods to measurements of form deviations. In the case of roundness measurements, the V-block method is more common and in the case of cylindricity measurements this method has not been practically used in industry; it is still investigated by scientists under laboratory conditions.

It should be underlined that there is also a difference between ranges of application of coordinate measuring machines and coordinate measuring arms. Despite very dynamic development of measuring arms their accuracy is still relatively low in comparison to CMMs, whose maximum permissible error can reach values lower than 1 micrometer.

Mesurements of form deviations by the radial method

In hitherto practice the most common methods applied to measure roundness and cylindricity are radial methods (sometimes they are called also non-reference methods). Radial devices can be divided into two main groups:

- the ones with a rotary sensor,
- and the ones with a rotary table.

A diagrams and examples of radial measuring instruments are shown in fig. 2.

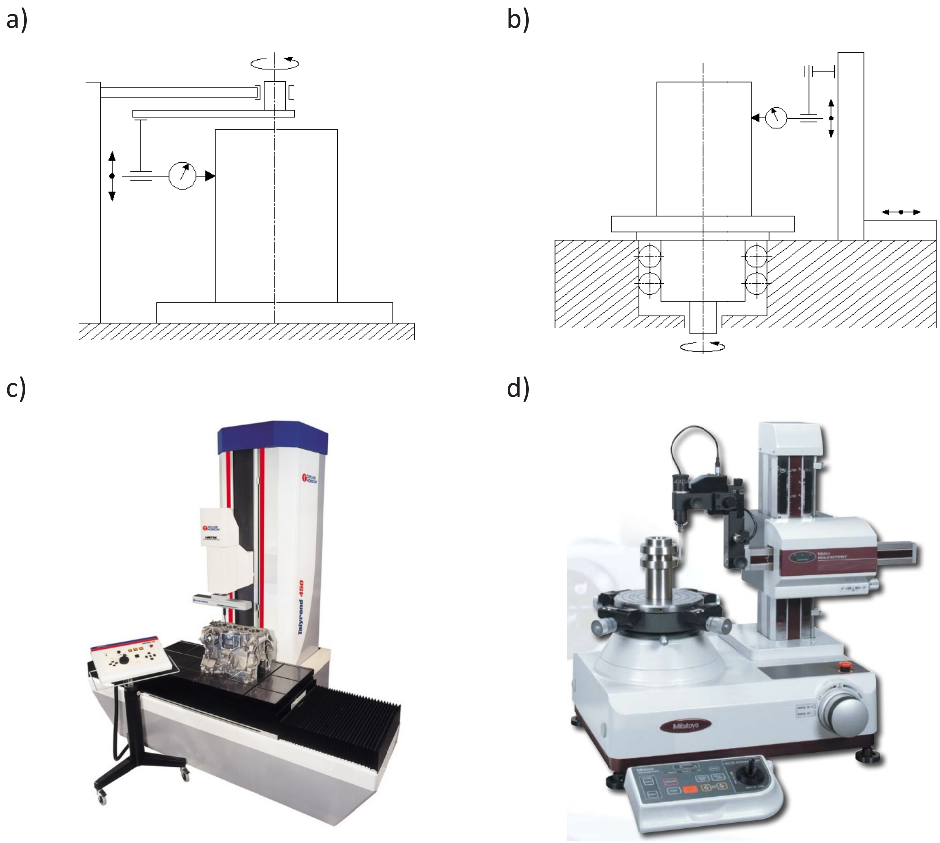

Fig. 2. *Types of radial instruments and their examples: a) an instrument with a rotary sensor, b) an instrument with a rotary table, c) an example of the instrument with a rotary sensor – Talyrond 450 by Taylor Hobson, d) an example of the instrument with a rotary table – Roundtest RA 1500 by Mitutoyo*

The most important advantage of radial methods is their high accuracy (reaching 0,1 µm). Unfortunately, these methods have also a severe drawback – in most cases they can be applied only to measure small elements. Moreover, before the measurement measured elements should be accurately centered and leveled on a measuring table. This is the reason why radial methods are dedicated mainly to conduct measurements under laboratory conditions.

Characteristics of a modern instrument for cylindricity measurements (Talyrond 365 by Taylor Hobson)

An example of modern instrument dedicated to measurements of cylindricity deviations by the radial method is Talyrond 365 by Taylor Hobson, shown in fig. 3.

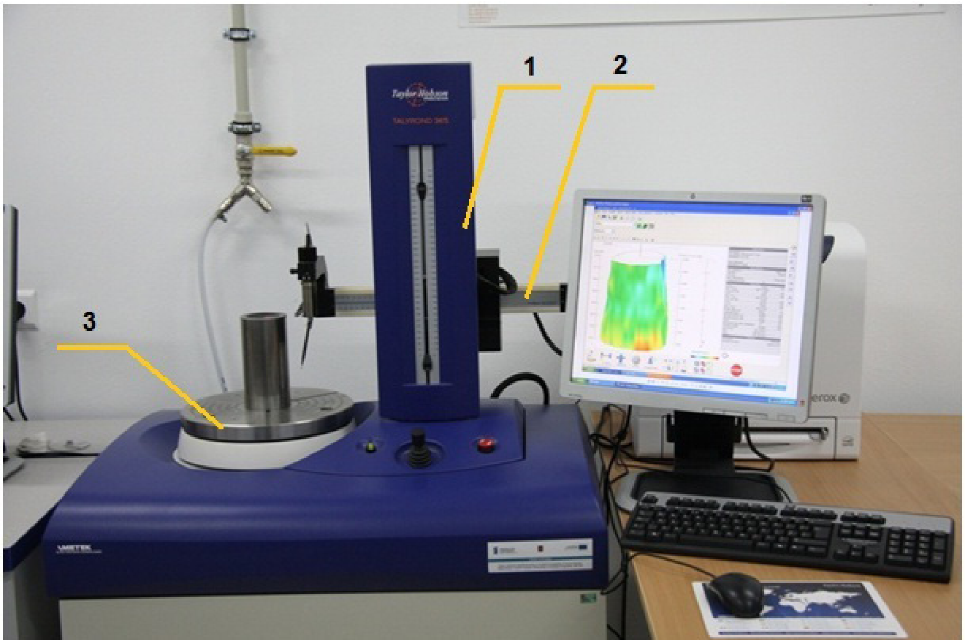

Fig. 3. *A special-purpose system for roundness and cylindricity emasurements by the radial method Talyrond 365 by Taylor Hobson and its fundamental components: 1 – column, 2 – horizontal arm, 3 – rotary table*

Talyrond 365 belongs to the largest group of radial instruments – the instruments with a rotary table. In its design following components can be distinguished: a column, a horizontal arm and a rotary table (see fig. 2).

The column is made of cast iron, and a its maximum straightness deviation is equal to 0,3 µm. A maximum deviation of the column axis from the rotary table axis equals 0,3 µm, too. A maximum number of sampling points during the movement of the sensor along the column is 200 000 points.

The horizontal arm is made of composite material based on ceramic. The range of the horizontal displacement of the sensor is 200 mm, and the straightness deviation of the movement of the sensor along the whole measurement range in the horizontal direction is 0,25 µm. The maximum number of sampling points during the displacement of the sensor along the whole arm is 200 000 points.

The table is placed on aerostatic bearings, which assures reaching high accuracy and high stability of the measuring system. The table can rotate in both directions with five measuring speeds: 0,6; 1; 2; 6 i 10 rev/min. The maximum number of sampling points along measured circle is 18 000 points.

Talyrond 365 is equipped with an inductive sensor, whose range is ±1 µm and its minimum resolution is 0,012 µm. The configuration of the measuring tip can be changed according to measurement type to be conducted. In the case of roundness and cylindricity deviations the stylus is vertical and when measurements of flatness or straightness of the face of the cylinder are to be carried out then the stylus is horizontal.

Basic technical specifications of Talyrond 365 referring to its dimensions and measuring capacity are following:

- instrument dimensions: height 870 mm, depth 705 mm, width 1460 mm,
- weight: 276 kg,
- maximum diameter of the workpiece: 350 mm,
- maximum height of the workpiece: 300 mm,
- maximum weight of the workpiece: 75 kg (during automated centering and levelling).

Characteristics of *μltra* software package

Talyrond 365 is a fully computerized instrument and a software that allows users to conduct measurements and to analyze them is a package *μltra* by Taylor Hobson. The software permits carrying out a procedure of automated centering and levelling of the workpiece on the measuring table. Thanks to this automated procedure, measurement time is reduced. Another characteristic feature of the software is its ability to perform mapping of cylindrical surface, which in association to the system Talymap enables conducting full qualitative and quantitative evaluation of the whole surface of the workpiece.

In the upper part of the main window of the software there is a roll-up menu containing basic programme functions that allow:

- operations on files,
- measurement results display,
- modifications of programme settings,
- conducting measurements and their analysis,
- presentation of results,
- user data modification,
- personalization of the layout.

In the lower part of the main window there is a set of icons describing clearly current configuration and a position of the measuring tip, current position of the measuring table, etc. Another set of icons is used to move measuring tip and the table to a desired position. In the lower part of the main window there is also STOP button that permits quick switching off the instrument (for example in the case of a collision of a measuring tip and a measured surface).

The range of applications of Talyrond 365 equipped with *µltra* software is very wide. It includes measurements of such parameters as:

- roundness,
- cylindricity,
- straightness (of the face and of the generatrix)
- radial and axial run-out,
- flatness of the face,
- perpendicularity of the face and the generatrix,
- parallelism of generatrices,
- harmonic analysis of profiles.

Fig 4 shows a protocol of a roundness deviation measurement of an analyzed element. It can be noticed that the software allows clear graphical representation of the profile on the background of a reference feature [10]. The protocol contains also numerical values of selected parameters, filter type, harmonic components range etc.

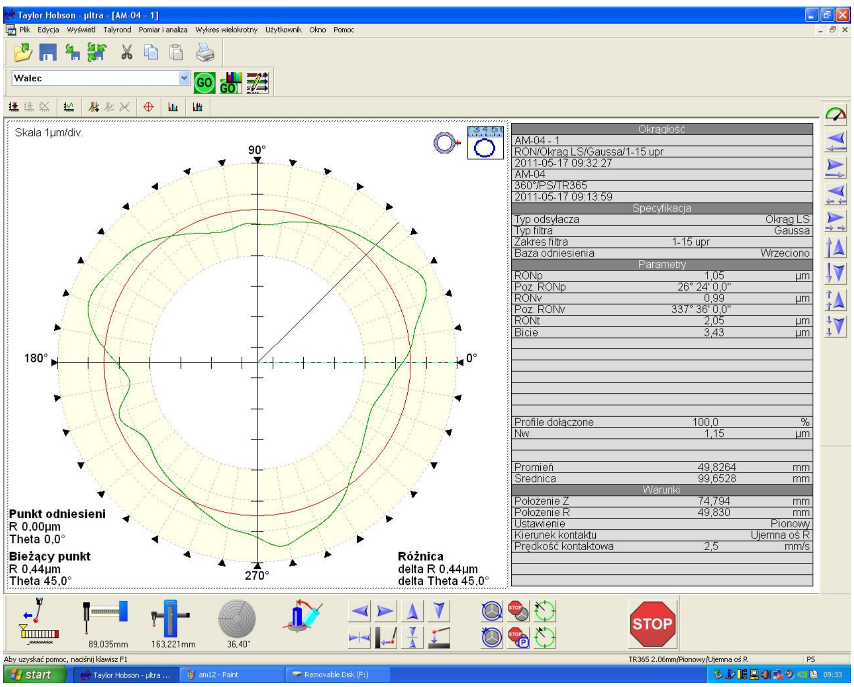

Fig. 4. *A protocol from a roundness measurement*

Measured profiles can be also analyzed with the use of Fourier transform (i.e. an analysis of harmonic components of the profile) [11].

The software permits numerical as well as graphical representation of dominant harmonic components (with the use of bar charts), which is shown in fig. 5.

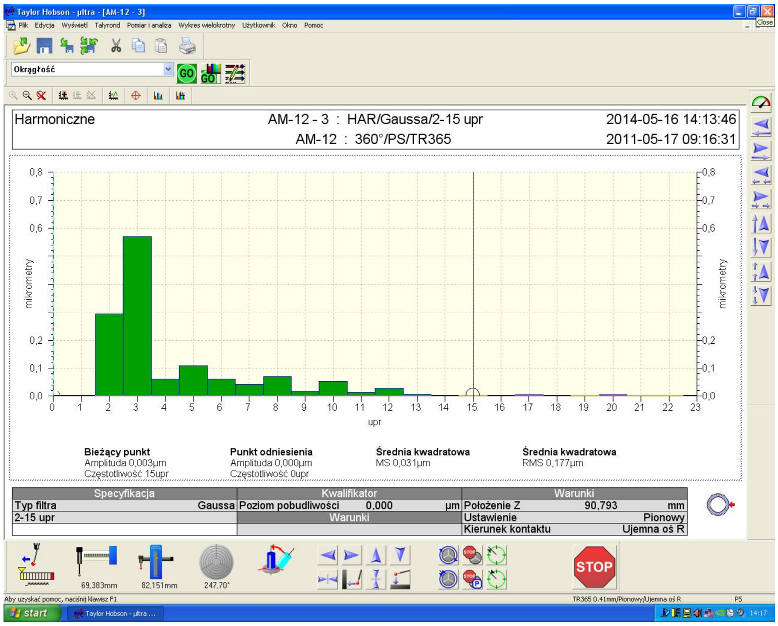

Fig. 5. *Graphical representation of dominant harmonic components of an analyzed roundness profile*

In the case of cylindricity measurement the software allows full visualization of an analyzed surface. It is for example possible to rotate the view, to incline it, to analyze deviations of a selected point. The software provides also complete data referring to cylindricity deviations, run-out, measurement parameter etc.

An example of a protocol from a cylindricity measurement is shown in fig. 6.

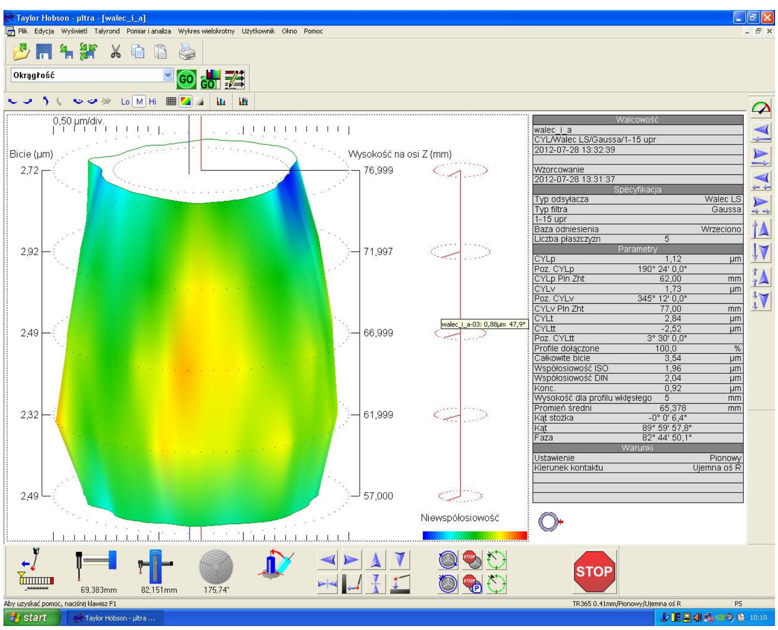

Fig. 6. *A protocol from a measurement of cylindricity deviations*

Talyrond 365 equipped with *μltra* software can also measure straightness deviations (of the cylinder face or its generatrix). Another interesting feature of the software is its ability to measure flatness deviations of the face of analyzed cylinder. In such measurements the stylus should be oriented horizontally. During the flatness measurement the tip moves from the center of the face toward its edge and the cylinder rotates. The composition of the move of the tip and the cylinder results in scanning the face of the cylinder along the spiral trace.

An example of a protocol from measurement of the flatness of the face is shown in fig. 7.

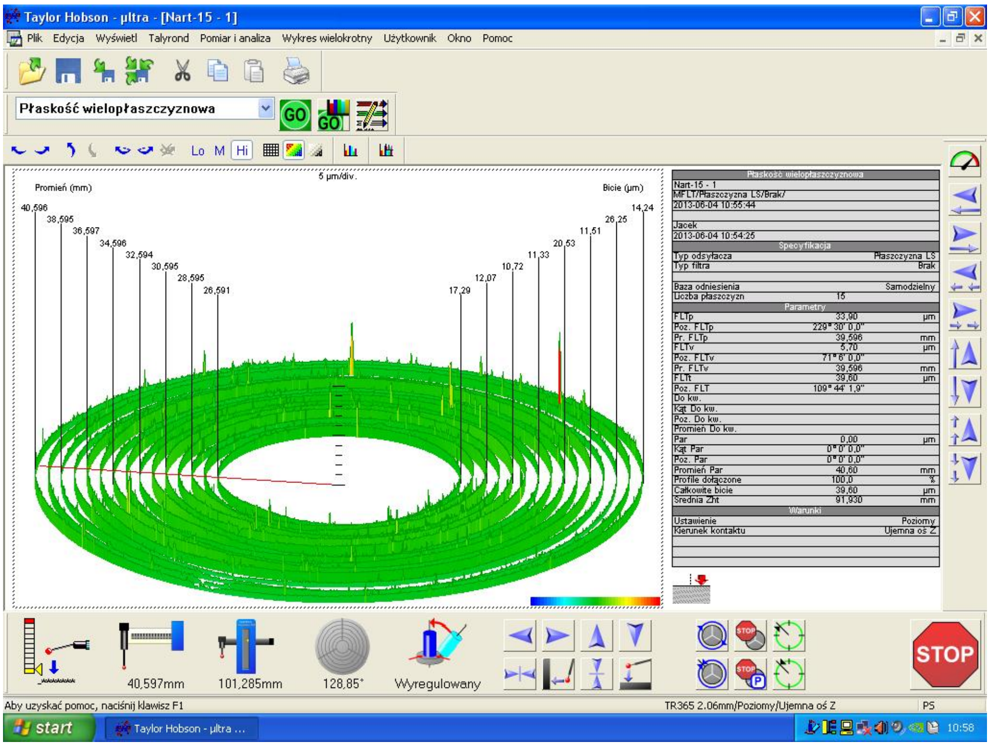

Fig. 7. *A protocol from a measurement of the flatness of the cylinder face*

Summary

Correct measurements of form deviations of cylindrical machine parts is the matter of great importance in modern manufacturing technology. The most common and advanced systems for cylindricity measurements are the ones that apply the radial method. In the past such systems were dedicated only to measurements of roundness or cylindricity. Moreover, radial measurements were quite difficult and time-consuming due to the necessity of accurate centering of the workpiece on the measuring table. Thanks to applying computers radial systems have become much more user-friendly. A good example of a user-friendly system is Talyrond 365 by Taylor Hobson. The instrument enables conducting a computer-aided procedure of centering. Therefore measurements are easier to perform and less time-consuming. Moreover, the instrument can measure not only roundness and cylindricity but also straightness, flatness of the face or radial and axial run-out. There are also works that describe an application of this instrument to measurements of roughness [12]. It shows that modern radial systems have become much more universal than they were in the past and they offer number of applications, enabling accurate measurements of different characteristic features of cylindrical elements.

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