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Technical note

In situ measurement of cylindricity—Problems and solutions☆

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ABSTRACT

The paper is a critical review of existing methods that permit in situ measurement of large external cylindrical surfaces. Large size cylindrical elements are used in many industries, e.g. papermaking, metallurgy or shipbuilding. Their diameter can sometimes reach even a few meters and they can be several meters long. Such elements should be characterized by high dimensional and form accuracy. Excessive loads or changes in temperature during use may result in their deformation. It is thus important for such elements to have their surface quality and form accuracy controlled not only during production but also during use. Measurement with conventional devices would involve transport, which may be impractical or impossible due to the large size and mass. That is why industries where such elements are produced or employed expect measurements to be performed in situ, for example, directly on a machine tool. Methods that can be used for this purpose are generally divided into three groups: V-block measurement, multi-probe measurement and measurements with Articulated Arm Coordinate Measuring Machines (AACMMs). This paper describes advantages and disadvantages of all the three groups of methods suggesting which one best meets the requirements of modern manufacturing processes and which are the most prospective.

1. Introduction

The parameters and recommendations for measurement of cylindricity are described in the standard ISO/DIS 12180-1, 2: 1999, Geometrical Product Specifications (GPS) – Cylindricity [1]. According to the standard, a deviation from cylindricity can be considered as three superposed deviations: a straightness deviation of the cylinder axis, a cylindricity deviation in a longitudinal section and a cylindricity deviation in a cross-section.

Fig. 1a–c shows cylindrical surfaces, each with a predominant deviation:

- A straightness deviation of the cylinder axis, occurring when the axis of a nominally cylindrical element is actually a 2D or 3D curve (Fig. 1a).
- A form deviation in a longitudinal section (also called a relative diameter change), occurring when the diameter of the cylindrical element is different in different cross-sections (Fig. 1b).
- A form deviation in a cross-section, which is, in fact, a roundness deviation; it occurs when there are irregularities of form in individual cross-sections of the workpiece; this deviation may be shifted in subsequent cross-sections linearly, angularly or otherwise (Fig. 1c).

A deviation from cylindricity is a three-dimensional form deviation; thus its accurate measurement may be relatively complex. For a long time, measurement of large size cylinders has only been approximate. Most commonly, the process involves measuring roundness deviations in different cross-sections, which can be achieved using various three-point methods. Measurement data, in such a case, is obtained, for instance, by means of three touch-probes [2] or three optical probes [3]. Circular cross-sections can also be measured by applying V-block systems [4,5], pneumatic systems [6] or coordinate measuring machines [7,8].

According to the standard ISO 12180, the results obtained from the assessment of selected roundness profiles cannot be considered sufficient to accurately determine a cylindricity deviation.

The literature on the subject of in situ measurement of cylindricity is limited. Most papers, e.g. Refs. [9,10], deal with the radial methods. In radial measurement, the axis of the analyzed element is the reference line. The radial methods can be divided into two main groups: those with a rotary probe, and those with a rotary table [11]. The accuracy of radial measurement in the case of cylindricity profiles is high. We obtain complete information on the analyzed surface [12]. However, radial measuring instruments

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☆ Fragments of the material were presented at the 19th IMEKO World Congress, September 2009, Lisbon.

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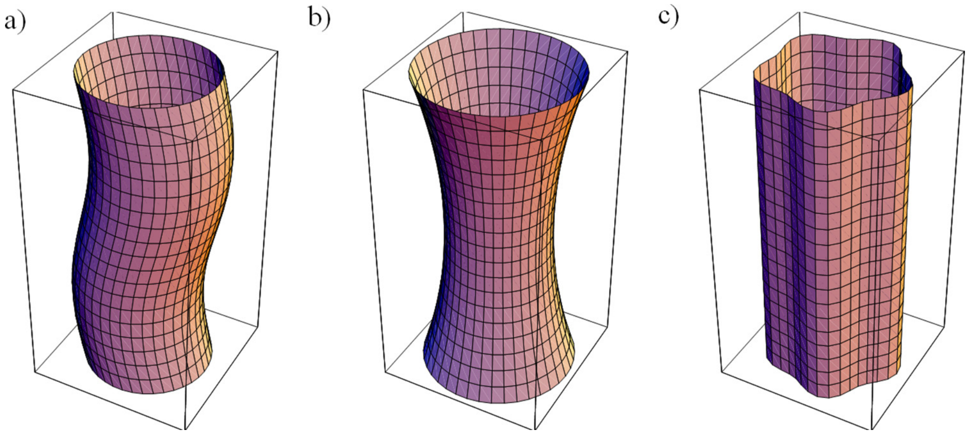

Fig. 1. Components of the cylindricity deviations: (a) a straightness deviation of the axis, (b) a form deviation in a longitudinal section, (c) a form deviation in a cross-section.

can only be used if the element is placed on the measuring table [13].

Large and heavy cylindrical elements are employed in numerous industries, for example, paper making, power generation and shipbuilding. Their high form and dimensional accuracy are essential [14–16]. Measurement is particularly vital if they suffer deformations due to certain operating conditions, e.g., high temperature or great external or internal loads [17–19]. As wear or other changes to the surface are undesirable, it is crucial that such elements be monitored for any deviations not only during production but also during use [20,21]. However, some elements cannot be measured accurately by existing measuring instruments because they are too large or too heavy – they cannot be placed on the measuring table of the instrument. Industries involved in the manufacturing or use of cylindrical elements expect that measurements of cylindricity profiles be taken directly on the machine tool or other devices used in production [2,22].

2. Methods for accurate in situ measurement of cylindricity

Sources of information concerning in situ measurements of cylindricity are relatively scarce. The methods described in the specialized literature generally fall into three groups: multi-probe measurement, V-block measurement and measurements with Articulated Arm Coordinate Measuring Machines (AACMMs).

2.1. The multi-probe method

Multi-probe measurements, which are usually based on the error separation technique (EST), require applying a system of probes. Some of the elements of the machine tool on which the workpiece is placed are used as the elements of the measuring system; for example, the guideways of the machine tool are used as the guideways of the measuring probes, etc. The most popular procedure for cylindricity measurement involves assessing roundness profiles in subsequent cross-sections and the straightness of the generatrix. Roundness is generally determined with a three-point method using three measuring probes located in one plane at clearly defined angles. A schematic diagram of a classical three-point measuring system is shown in Fig. 2.

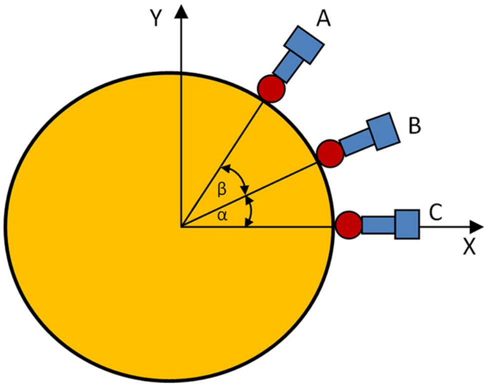

Fig. 2. Measurement of roundness profiles with three probes: A, B and C (three-point method) [22].

In a three-point method, three measuring probes denoted as A, B and C (Fig. 2), are fixed around the workpiece to simultaneously detect roundness deviations and two-dimensional components of spindle errors, by scanning the surface while the workpiece is rotating. The effect of the spindle error is canceled in the differential output of the probes and the correct roundness profile can be evaluated from the differential data, for instance, by integration or the Discrete Fourier Transform method.

Straightness is generally measured using the sequential two-point method (see Fig. 3) with a system of two probes, A and B. Knowing the distance between the probes, *D*, and the displacement of the probe system, *L*, we can calculate and remove the influence of the Z directional error, which was presented in detail in Ref. [23].

In Ref. [23], Nyberg proposes a method for in situ cylindricity measurement, which combines the concepts of two- and three-point measurements. He uses a system of four measuring probes mounted on the tool carriage of a turning machine (see Fig. 4). In Nyberg's method, signals from probes A, B and C (three-point method) are used to calculate out-of-roundness, whereas signals from probes B and D (two-point method) are employed to determine out-of-straightness. As can be seen, the signal from probe B is used twice. This method was successfully verified experimentally on a measuring device that was designed and constructed according to the assumptions of Nyberg's concept.

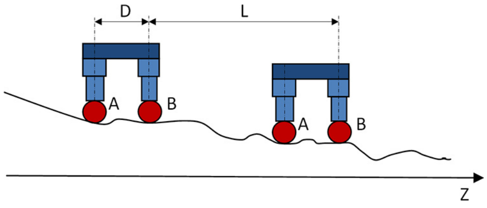

Fig. 3. Straightness measurement by the sequential two-point method [22].