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Roundness measurement and its different evaluation methods

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Abstract

Between 50 to 60% of tasks in manufacturing metrology are measures of circles and cylinders. The requirements for a cylinder can be form (roundness), size (diameter) and location (position of the cylinder in a defined datum system). All these tolerances are described in geometrical product specifications (GPS) standards. But, the definitions for the form (roundness) tolerance according to ISO 1101 - considering radial deviations only - is not sufficient to assure the functionality of many products. The specific form of roundness deviations along the circumference plays also a significant role for rotating machine components. The Fourier analysis and the corresponding amplitude spectrum deliver information about the properties of the form derived from the magnitude of the different harmonics. This information presents a series of results depending on the harmonics. Therefore, a dedicated tolerance definition in most cases in from of a mathematical equation is used. The currently used tolerance definitions are not standardized and difficult to understand for a standard user. Often, only one amplitude of the spectrum is significantly larger than the others are and affects functionality. In this case, an algorithm that detects the largest amplitude enables an easier tolerance definition and an understandable measurement result.

Key words: Roundness, Filter, Fourier analysis

1. Introduction

Requirements to roundness tolerances play an important role in mechanical production because cylindrical parts are often used for mechanical transfer of energy (e.g. bearings and shaft-hub connections for gearboxes). The measurement of internal and external cylinders accounts for 50% to 60% of the measurement tasks in manufacturing metrology [8]. Together with size (diameter) and location, the requirements of roundness is described in geometrical product specifications (GPS). However, the common known radial definition for roundness according to ISO 1101 as value is not sufficient to assure the functionality of many products. The form of the deviations along the circumference plays a significant role for rotating machine components. Especially periodic deviations related to defined rotational speed cause vibrations that lead to noise and wear.

2. Roundness measurement in industrial production

There are two different systems for the roundness measurement in the industrial production: the form testers and the coordinate measuring machines (CMMs). The first one are the typical instruments for measuring roundness in production and they are dedicated for this measurement task. They use a tactile or optical one-dimensional sensor and the workpiece is aligned mechanically with tilting and moving functions on the rotary table. The CMMs are universal systems for the GPS measurement. In this specific measurement task, CMMs are able to measure form with or without rotary table. The first solution is called "three-axis measurement" and the second is called "four-axis measurement". They are equipped with a three dimensional sensor system and do a mathematical workpiece alignment based on measured elements on the workpiece or on rotary table (Figure 1) [6]. Additional information about the comparison between form tester and CMMs are part of the introduction of the German guideline VDI/VDE 2617 part 2.2.

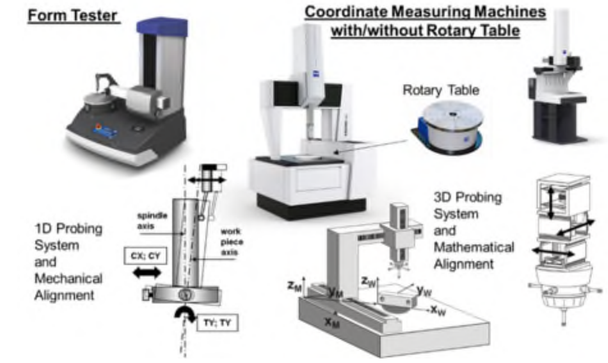

Figure 1. Equipment for roundness measurement

3. Roundness tolerance according to ISO

Roundness is according to ISO 12181-1 a property of a circle. This circle is defined in a roundness plane. According to the standard the roundness plane has to be perpendicular to the least square cylinder axis (Figure 2). The intersection of the real surface and the roundness plane determines the circumferential line, which is called roundness profile if it is modified by a filter. The tolerance zone for roundness according to ISO 1101, in the considered cross-section, is limited by two coplanar concentric circles with a difference in radii of the tolerance's size. The GPS tolerance requirement is fulfilled if the profile fits into the zone.

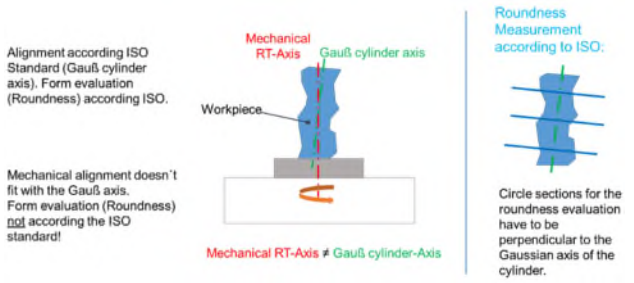

Figure 2. Roundness evaluation according to ISO

4. Fourier analysis for amplitude spectrum and its tolerances

Many applications require also information about the specific form of the roundness deviation along the circumference. A typical reason for roundness deviations are so called chatter marks. They arise, for example, due to lack of manufacturing machine's stiffness. The chatter marks form a regular circulating pattern on the surface. These marks may cause vibrations and noise if they are on the surface of a rotating shaft. The Fourier analysis and the derived amplitude spectrum, also called power spectrum, deliver information about the properties of the form derived from the amplitudes of the shape. The amplitude spectrum shows amplitude's size for the different harmonics. Therefore, a tolerance definition for the amplitude spectrum needs to consider the dependency of amplitudes on the harmonics.

5. The dominant roundness waviness

The interpretation of the amplitude spectrum and the definition of an appropriated tolerance for the spectrum are complex and difficult to understand for normal user. Therefore, a different approach derived from an established evaluation for surface texture measurement [7] defines a so-called "Dominant Roundness Waviness" [2]. It is applicable in case only one amplitude of the spectrum is significantly larger than the others are and effects functionality.

This single value is easy to understand and can be connected to a simple tolerance limit. The measurement procedures and evaluation parameters are defined in a company standard [5]. Three parameters describe the amplitude of the dominant roundness waviness: mean height = RONWDc, total height = RONWDt and maximum height = RONWDmax.

6. Measurement results of a multi wve standard on CMMs

A multi-wave standard is cylindrical body with a well-defined superposition of sinusoidal form deviations of different amplitudes and wavelengths. The signal characteristics of multi-wave standards' profile make it possible to evaluate the signal transmission chain of measuring instruments for form measurements in a highly stable manner. These standards were used to present the abilities of modern CMMs to perform roundness measurements like form testing machines [1, 4]. Figure 3 shows results for three different validity ranges of dominant roundness from a measurement of a multi-wave standard on a CMM with rotary table. The results for 5 and 50 UPR show a very good conformability with the calibration results within in the uncertainty of the calibration. For 150 UPR the deviation exceeds the uncertainty of the calibration (0.08 µm). Based on recent experiences with form measurements on CMMs [Jus 15] it can be expected that also for 500 UPR a results within the uncertainty range on a dedicated CMM for form measurement is achievable.

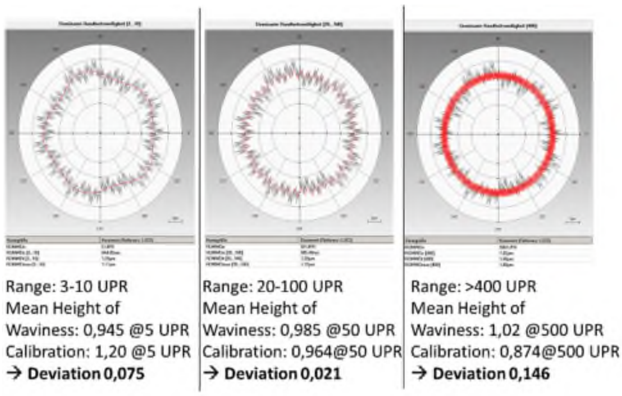

Figure 3. Dominant roundness waviness result from measurement of a multi wave standard on a CMM (all size values and deviations are in micrometer [µm])

7. Summary

Derived from the different type of roundness deviations the paper presents the ISO definition for roundness tolerance and different tolerance definitions for the amplitude spectrum. The definitions for the spectrum are complex and not easy to apply. There is an alternative for the roundness waviness evaluation. The dominant waviness evaluation is useful in case only one amplitude of the spectrum is significantly larger than the others are and effects the functionality of the workpiece. A tolerance definition for such dominant roundness waviness is simpler because it can be defined by tolerance limits for dedicated parameters.

Aknowlegdement

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