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ALTERNATIVE EVALUATION METHODS FOR ROUNDNESS MEASUREMENTS

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ABSTRACT

Requirements to roundness tolerances are a part of the geometrical product specifications. However, the definition for the roundness tolerance according to ISO 1101 considering radial deviations only is not sufficient to assure the functionality of many products. In addition, the form of roundness deviations along the circumference plays a significant rule for rotating machine components. Especially periodic deviations cause vibrations that lead to noise and wear. 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. Often, only one amplitude of the spectrum is significantly larger than the others are and effects functionality. In this case, an algorithm that detects the largest amplitude enables an easier tolerance definition.

Index Terms - 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. Examples are bearings and shaft-hub connections for gearboxes. Therefore, requirements to roundness are usual in geometrical product specifications. However, the common known radial definition for roundness according to ISO 1101 [1] is not sufficient to assure the functionality of many products. In addition, the form of roundness deviations along the circumference plays a significant rule for rotating machine components (Figure 1). Especially periodic deviations cause vibrations that lead to noise and wear.

2. EQUIPMENT FOR ROUNDNESS MEASUREMET IN INDUSTRIAL PRODUCTION

The so-called form testers are the typical instruments for measuring roundness in production. They use a tactile or optical one-dimensional sensor and the part is aligned mechanically with tilting and moving functions on the rotary table. Coordinate Measuring Machines (CMMs) measure from with or without rotary table. They are equipped with a three dimensional sensor system and do mathematical part alignment based on measured elements on the part or on rotary table (Figure 2) [2].

To avoid mechanical filter effects an appropriated probe sphere diameter must be selected depending on length and height of the expected waviness and surface's shape according to VDI/VDE 2617-2.2 or VDI/VDE 2631-3 [3, 4].

CMMs with a measuring probing system record data for roundness evaluation normally in scanning mode. The received data are usually uneven sampled. The not evenly spaced points affect the behavior of the Fourier analysis and require interpolation for reconstruction of the point pattern to receive evenly spaced points [5]. Furthermore, it is usual on CMMs to measure circles with an overlap. This overlap also effects the Fourier analysis and must be removed before data processing.

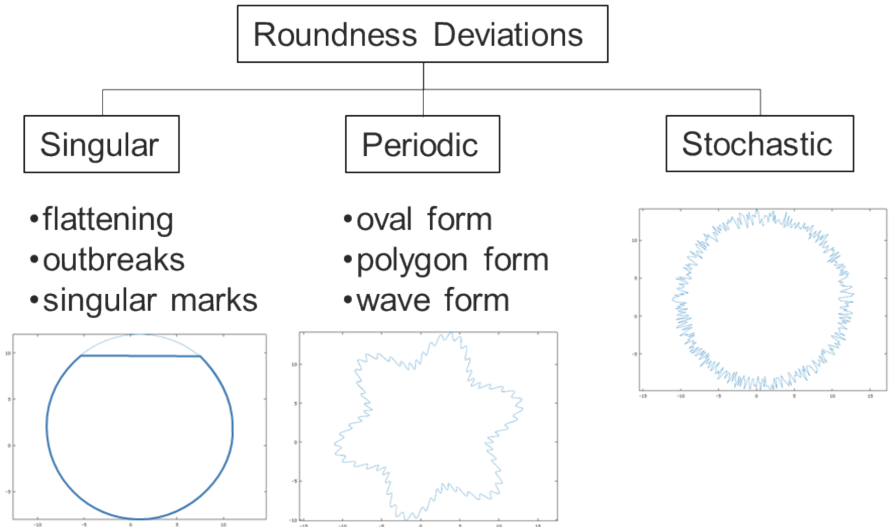


Figure 1: Types of roundness deviations

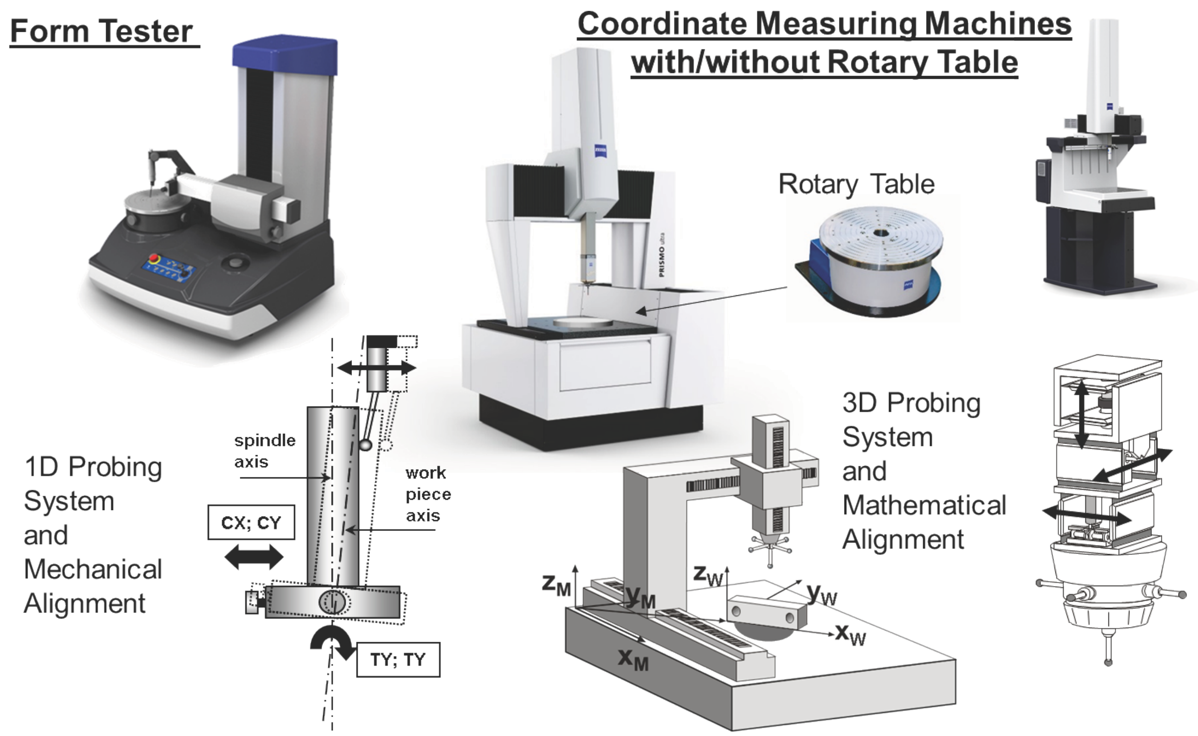


Figure 2: Equipment for roundness measurement: Form Tester and Coordinate Measuring Machines (CMMs)

3. ROUNDNESS TOLERANCE ACCORDING TO ISO

Roundness is a according to ISO 12181-1 [6] a property of a circle. This circle is defined in a roundness plane. 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 [1], in the considered cross-section, is limited by two concentric circles with a difference in radii of the zone's size. The tolerance requirement is fulfilled if the profile fits into the zone.

The described roundness tolerance definition according to ISO 1101 [1] is not sufficient for many applications because this tolerance considers only the size of the radial deviation. The corresponding standards [6, 7] for measurement define parameters for the measurement procedure and the evaluation like probe diameter, filter and number of points to achieve comparable results.

4. FOURIER ANALYSIS FOR AMPLTUDE SPECTRUM AND ITS TOLRANCES

Many applications require also information about the 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.

Figure 3 shows roundness evaluation and the amplitude spectrum of an artificial roundness profile representing two chatter marks patterns (profile with waviness of amplitude 2 with 6 UPR and 0.5 with 60 UPR; UPR = Undulation Per Revolution).

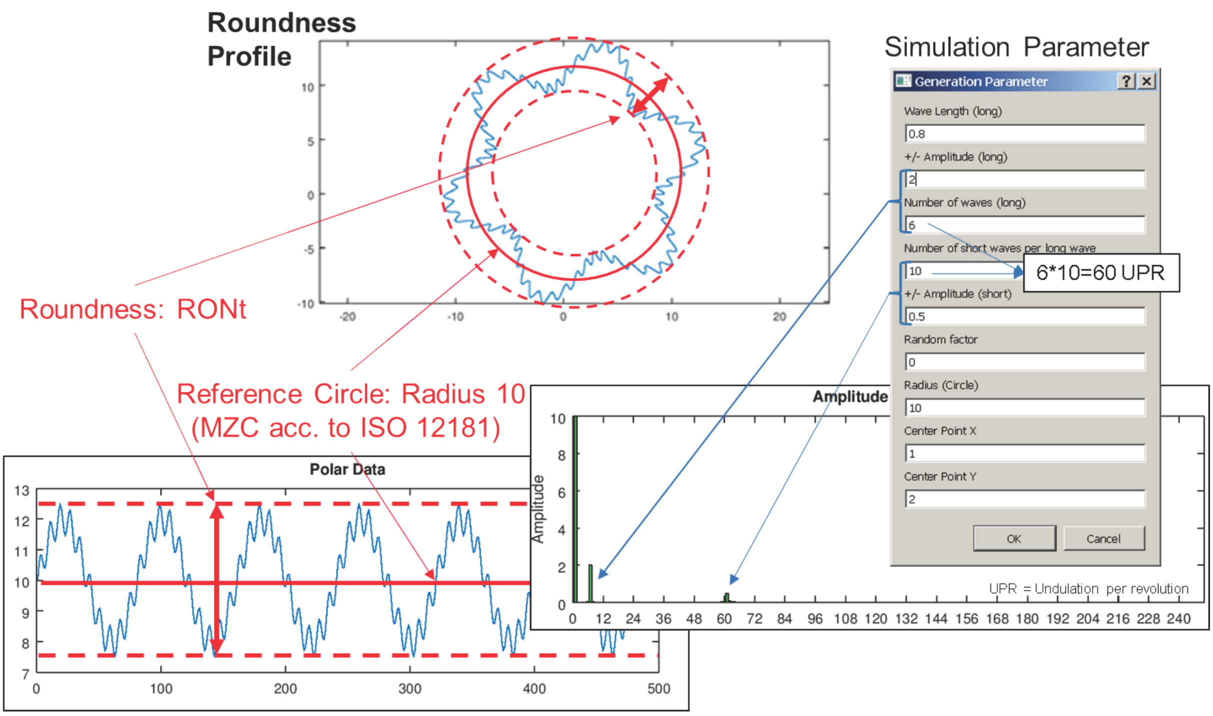


Figure 3: Analysis of circumferential lines of circles: roundness and amplitude spectrum

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. Figure 4 shows different amplitude dependent tolerance definitions for the spectrum using piecewise limits and a mathematical equation.

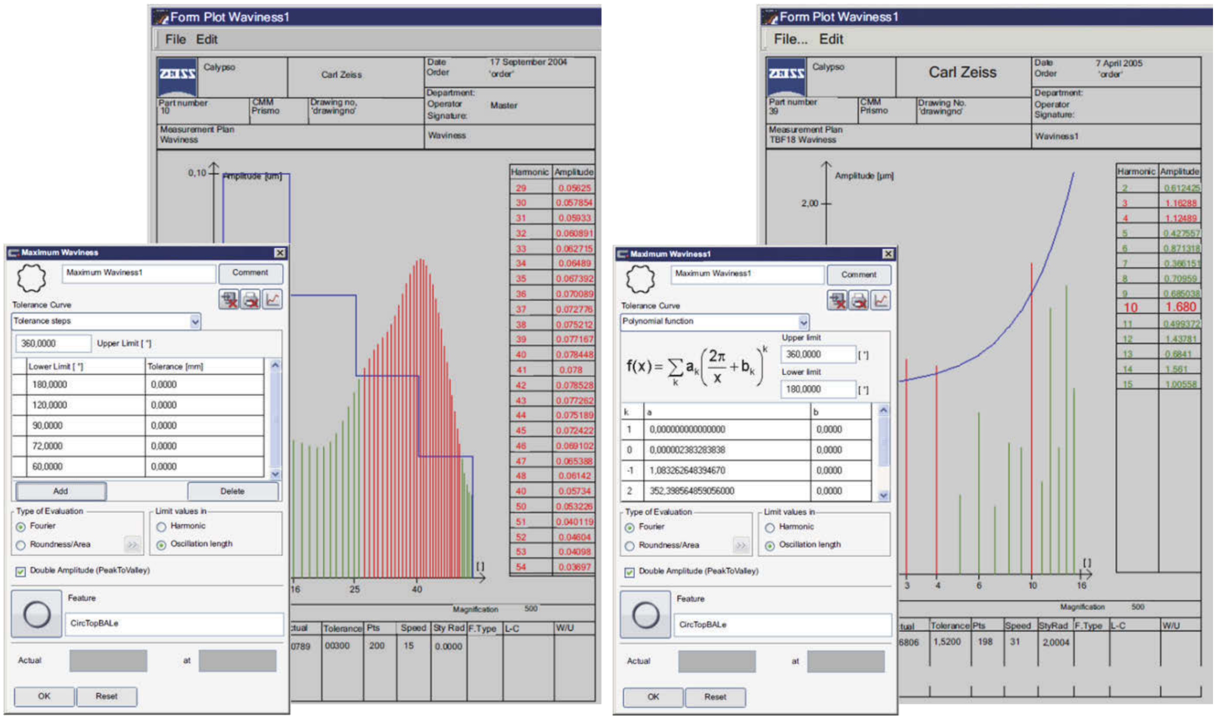


Figure 4: Tolerances for amplitude spectrums: tolerance steps and tolerance polynomial equation [8]

5. 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. Therefore, a different approach derived from an established evaluation for surface texture measurement [9] defines a so-called "Dominant Roundness Waviness" [10]. 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 [11].

Figure 5 shows the profile data from Figure 3 evaluated according to MBN 10 455 [11]. The corresponding amplitude spectrum shows the peak to valley amplitude instead of +/- amplitude in Figure 3. Due to its size, the waviness with 6 UPR dominates the spectrums. This value defines the parameter RONWDn. Three parameters describe the amplitude of the dominant roundness waviness, derived from the zero band pass filtered raw profile with a cut-off frequency of 6 UPR: mean height = RONWDc, total height = RONWDt and maximum height = RONWDmax. In case of this artificial profile, all values are equal.

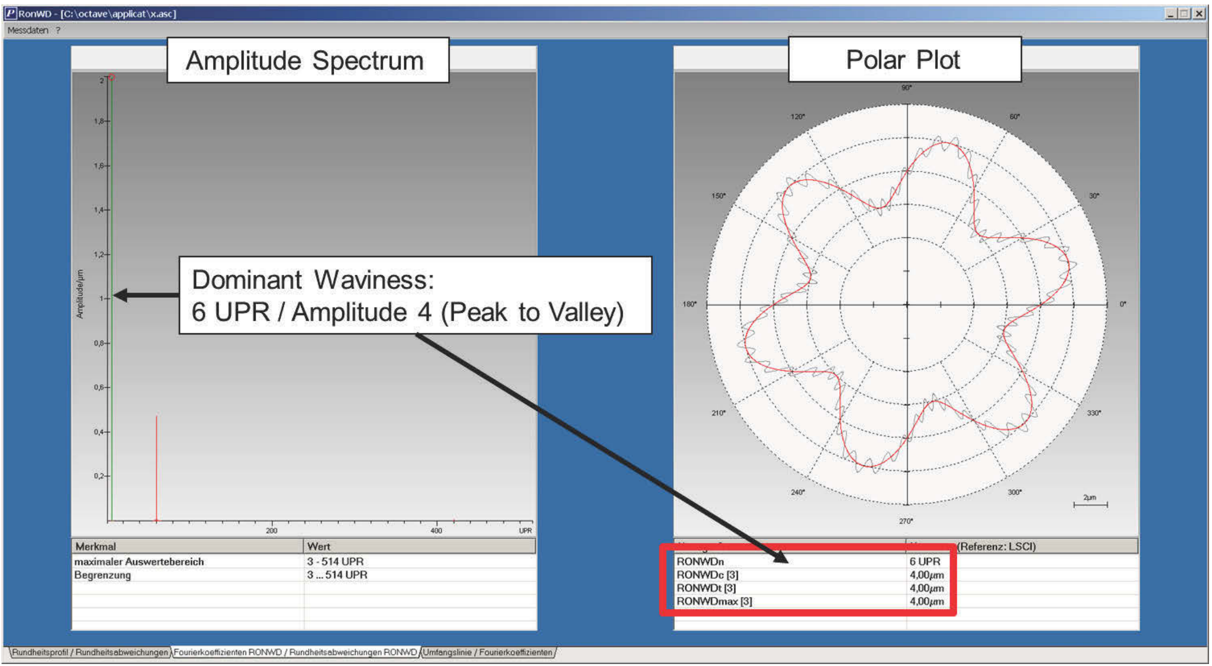


Figure 5: Dominant roundness waviness evaluation of profile data from Figure 3

6. RESULTS FROM MEASUREMENT OF A MULTI WAVE STANDARD ON CMMS

A multi-wave standard is cylindrical body with a well-defined superposition of sinusoidal form deviations of different amplitudes and wavelengths (Figure 6). 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 [12].

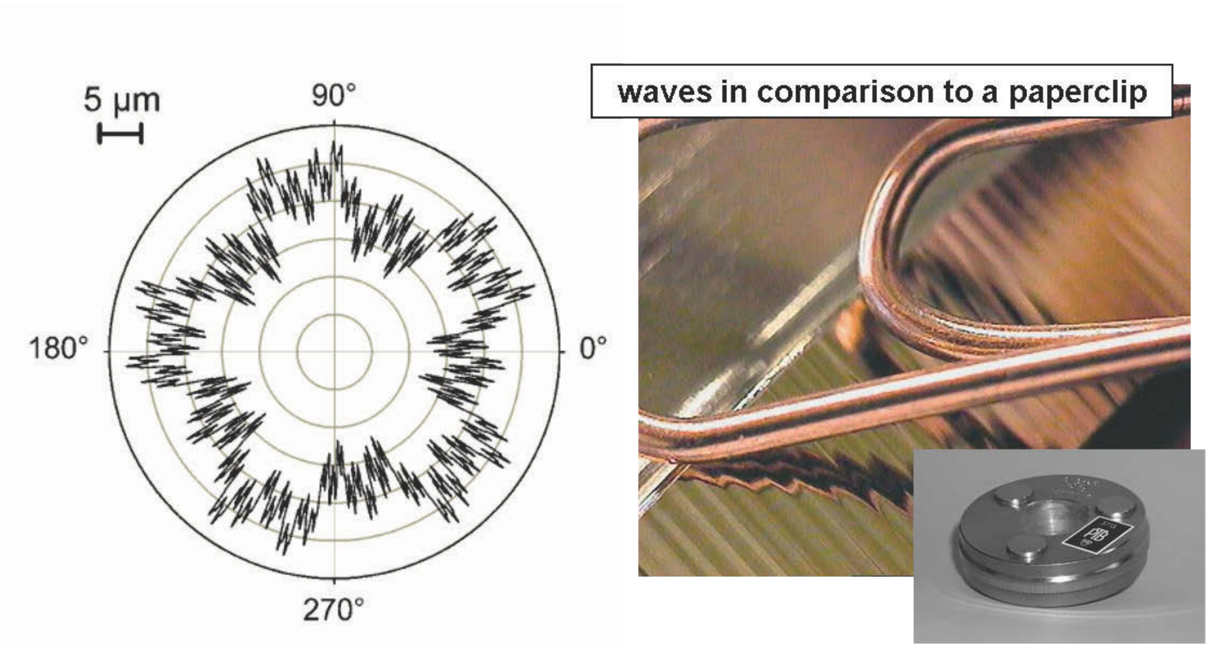


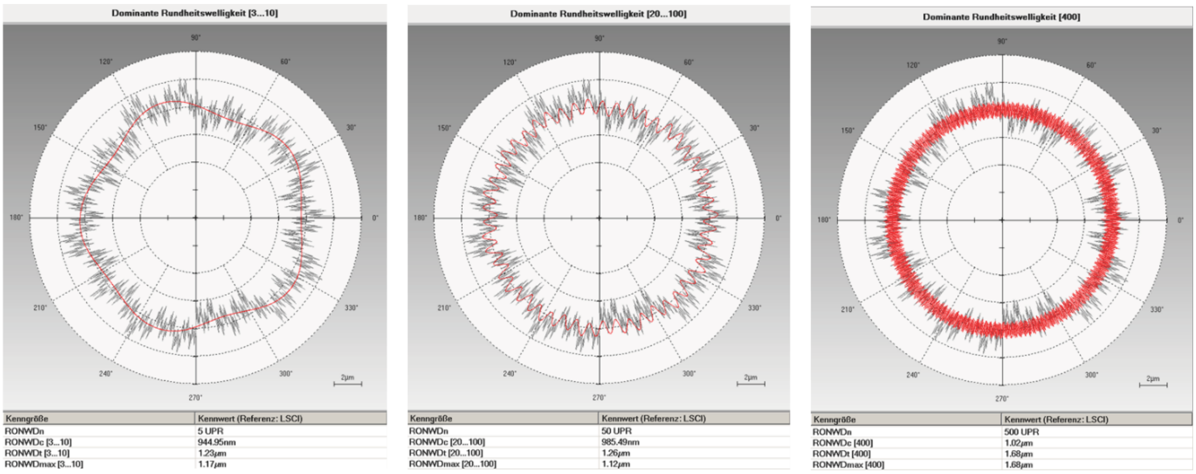
Figure 6: Multi wave standard with large roundness deviation RONt=20 micrometer [12]

These standards were used to present the abilities of modern coordinate measuring machines to perform roundness measurements like form testing machines [13, 14, 15].

The use of the multi-wave standard to evaluate dominant roundness waviness requires the limitation of validity range of the evaluation because the amplitudes of the different sinusoidal form deviations have usually almost the same size. An evaluation without limitation of validity range would not deliver any dominant roundness. The validity range must be defined that only one sinusoidal form deviations appears within the range.

Figure 7 show results for three different validity ranges from a measurement of a multi-wave standard (diameter 200mm; five different sinusoidal form deviations with a nominal peak to valley amplitude of 1 micrometer and 5, 15, 50, 150, 500 UPR) on a CMM with rotary table. The recorded data from the CMM were interpolated to receive 3600 evenly spaced points also considering the overlap of measurement data. The same probe sphere diameter of 1.3mm as during calibration is used. These parameters are sufficient to record the roundness deviation down to the shortest wavelength of 500 UPR without mechanical filter effect according to VDI 2617-2.2 and VDI 2631-3 [3, 4].

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 micrometer). Based on recent experiences with form measurements on CMMs [16] it can be expected that also for 500 UPR a results within the uncertainty range on a dedicated CMM for form measurement is achievable.



Validity Range 3...10 UPR:
Mean Height of Dominant Waviness 0,945 at 5 UPR (Calibration: 1,02 at 5 UPR) => Deviation 0,075

Validity Range 20...100 UPR:
Mean Height of Dominant Waviness 0,985 at 50 UPR (Calibration: 0,964 at 50 UPR) => Deviation 0,021

Validity Range from 400 UPR:
Mean Height of Dominant Waviness 1,02 at 500 UPR (Calibration 0,874 at: 500 UPR) => Deviation 0,146

Figure 7: Dominant roundness waviness result from measurement of a multi wave standard on a CMM (all size values micrometer)

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. An alternative called dominant roundness waviness is described. It is useful in case only one amplitude of the spectrum is significantly larger than the others are and effects functionality. A tolerance definition for such dominant roundness waviness is simpler because it can be defined by tolerance limits for dedicated parameters. Measurement results form a coordinate measuring machine for dominant roundness waviness on at multi-wave standard show the ability of these machines to perform roundness measurements.

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