# Good practice guide

## for surface parameter measurement strategies for form and diameter measurements for large bearings

# 1 Introduction

This good practice guide deals with surface parameter measurement strategies for form and diameter measurements on large bearings. The bearings are formed as large rings up to 3 m in diameter. The measurement strategy supplies sampling density distributions, filter types and filter settings for the measurement of bearing rings. Parameters for diameter, form and waviness are provided.

# 2 Surface parameters

The parameters that will be measured with this good practice guide are roundness, straightness and cylindricity as indicators for global form deviation, waviness as indicator for local form deviation, and diameter. Waviness is part of the form deviation according to definition of international standards for form [1-5]. Sometimes individual information of a range of certain wave numbers/frequencies is needed. Therefore, special nonstandard treatment of data sets like band-pass filtering [6] or spectral analysis of the form profile [7] has to be applied.

# 3 Measurement strategy

Techniques used most for precise diameter measurements of bearing rings are Abbe comparators and CMMs. Abbe comparators measure the two-point-diameter in a selected direction. As length standard precise scales or laser interferometers are used. A major uncertainty source is the search process for the largest chord. Two-point diameter measurements (LP, see appendix “Nomenclature” fur the explanation of standardized abbreviations and technical terms) in one or two orthogonal directions at one or more axial cut planes are recommended [8, 9].
The two-point diameter can also be measured with CMM, but they are more often applied to measure the mean diameter by probing a large number of points in a planar cut of the bearing ring or by probing the full cylinder. The mean diameter of all directions is identical to the Gaussian diameter. The difference between mean diameter and two-point diameter can be considered as not significant, when the difference of both is smaller than the measurement uncertainty. In many applications where precise rings with a roundness deviation much smaller than 1 µm are measured by a typical CMM with a measurement uncertainty of greater than 1 µm the difference may be neglected. However, there may be cases where the additional evaluation of two-point diameter values may be helpful. This is especially the case when e. g. gravitational deformations dominate the result.
For less precise measurements also laser trackers or calipers can be used.
If the diameter measuring instrument is an Abbe comparator, it is recommended to measure either several two-point diameters close to the nominal measurement direction with small variations in the selection of the polar angle and axial position of the diameter direction or to measure only a single two-point diameter and add roundness, straightness, and parallelism measurements to assess the variation of the diameter. The form and parallelism measurements deliver input for measurement uncertainty budget of the diameter [8].

In most cases form and waviness measurements are realized with dedicated form measurement instruments. These instruments are using high-precision spindles or rotary tables as roundness reference [10]. In many cases modern scanning-enabled coordinate measuring machines (CMMs) are used.
For all these measurement approaches rigidity is assumed. In case of less rigid bodies as large and comparatively thin bearing rings the circumference equivalent diameter can be calculated from the measured circumference of the ring by just dividing by $\pi$ as shown in equation (1) [11]. The circumference can be measured by CMM high data density probing of the bearing ring subsequent length integration of the probed trace.

$$d = \frac{L}{\pi} \tag{1}$$

$d$ Circumference equivalent diameter
$L$ Length of the envelope

The area equivalent diameter is a calculated parameter as well. Here the diameter is received by equation (2). The area equivalent diameter is defined within a cross-sectional area [11].

$$d = \sqrt{\frac{4A}{\pi}} \tag{2}$$

$A$ Area inside of the extracted envelope
$d$ Area equivalent diameter

The volume equivalent diameter is calculated according to equation (3) [11].

$$d = \sqrt{\frac{4V}{\pi \cdot h}} \tag{3}$$

$h$ Height of the cylinder
$V$ Volume defined by the complete extracted cylinder

The height of the cylinder is determined as the largest distance between two parallel levels vertical to the axis of the Gaussian cylinder and containing a complete cross-section of the geometrical element [11].
The bearings should be measured with tactile probing inside the inner cylinder for the roundness at three axial positions (central and near the faces), for the straightness in four lines from face to face and for the diameter at the central axial position [8].

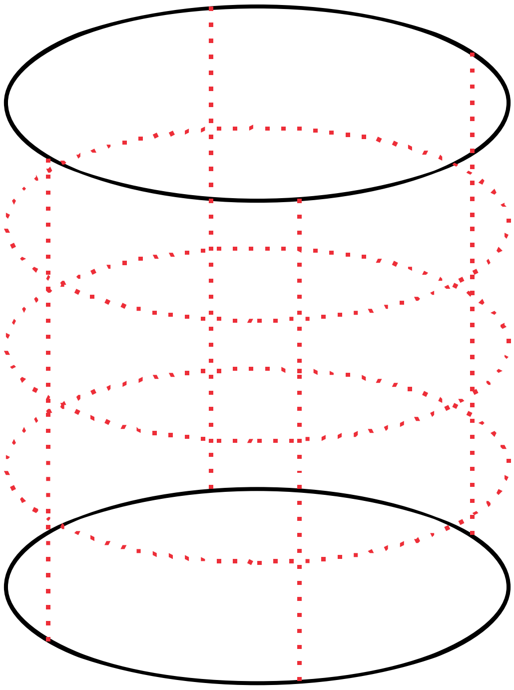

**Figure 1:** Minimum proposed measurement positions for form measurements of a cylindrical body shown as red dotted lines. The front faces are indicated by black lines.

In case of tactile probing the probe diameter should be selected corresponding to the recommendations in [12]. For most practical cases this means that probe diameters of 5 mm (for rings < 300 mm), 8 mm and 10 mm are reasonable. Before the measurements are carried out, the workpiece coordinate system has to be determined. The desired 0° position should be directed towards the positive x-direction of the CMM. If the bearing is measured several times, the polar 0° position is to be marked for the definition of the x-direction. The direction of the inner cylinder axis should be determined with two roundness profiles which are measured inside at two different levels. Their centres define the z-axis. It is recommended to determine the measuring surface with one or more probing points on the front face. The single point or the plane calculated from those points defines the z = 0 position.

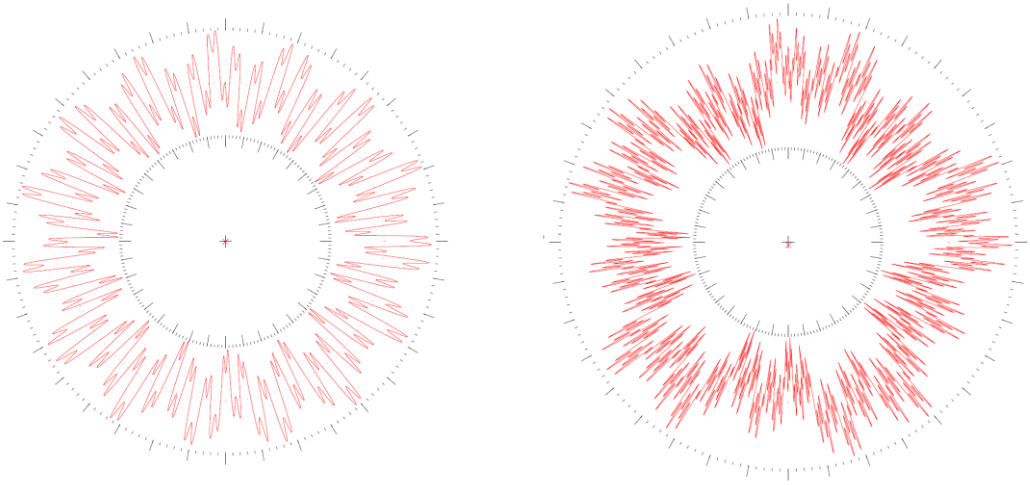

**Figure 2:** Form profile with waviness components. Left: Profile after applying a Gaussian band pass filter with 15 – 150 UPR, Right: unfiltered profile

The roundness is to be scanned with min. 7 x n data points per measurement profile at the central axial position and in two levels near the face surfaces, where n denotes the cut-off wave number in UPR of the applied Gaussian filter. A slightly larger number of measuring points may be used, when the instrument cannot be adjusted exactly to the default number. As a filter setting of 1-500 UPR is recommended. If the influences of short wavelengths (e. g. bearing noise) should be examined and the diameter of the workpiece is larger than 1 m, it is recommended to select 1-1500 UPR. For the example of d = 3.0 m this results in 10500 data points. Filtration must be applied according to [6]. A filter of the Gaussian type is recommended. In case waviness components have to be analysed an application specific band-pass filtering (an example is shown in Figure 2) has to be applied or even a Fourier spectrum of the form profile has directly to be analysed.

In case the CMM does not allow scanning, the number of achievable data points is limited by time and drift constraints to much lower numbers. It is recommended to acquire at least 120 data points in such a case. However, the requirements of [6] cannot be fulfilled.
The straightness of the four generatrices at 0°, 90°, 180° and 270° should be scanned with $L / \lambda * 7$ data points from face to face (excluding bevels or other non-functional end regions) with a Gaussian filter with a default cut-off filter wavelength of $\lambda$ = 0.8 mm where L denotes the measurement length. For an axial measurement length of 1 m this results in 8750 data points.
Furthermore, the parallelism of the lines at the axial cut planes 0°-180° and 90°-270° has to be evaluated.
In case the CMM does not allow scanning, it is recommended to acquire at least 30 data points.

For the measurements, the following additional parameters are recommended:

| | Diameter | Roundness | Straightness |
|---|---|---|---|
| Filter | - | Low pass filtering with 1-500 UPR or 1-1,500 UPR for surveying short wavelengths<br><br>Bandpass for the analysis of waviness | 0.8 mm |
| Calculation with | LSCI | MZCI | MZLI |
| Begin of measurement | 0° | 0°<br>At three different levels (central and near the faces) | 0°/180° and 90°/270°<br>z = near bottom face |
| End of measurement | 0° | 0° | z = near front face |

The roundness should be measured in a scanning modulus with ten repetitions in order that an average value can be evaluated. The diameter is to be measured at the central axial position, also with ten repetitions via single point probing. Straightness should also be measured with ten repetitions by scanning.

Identification of outliers is not standardised. It can sometimes be reasonable to detect them, if it is sure that the values are outliers.

## 4 Measurement uncertainty

The measurement uncertainty of form measurements can be estimated following the procedure of [13]. For most industrial cases the simplified and easier usable procedure in [14] will be sufficient.

For the estimation of the measurement uncertainty the method of virtual coordinate measurement machine (VCMM) and empirical data can be used. The standard measurement uncertainty should be multiplied by the coverage factor k = 2.0. This expanded measurement uncertainty is to be determined in accordance with the “Guide to the Expression of Uncertainty in Measurement (GUM)”. The value of the measurand then normally lies with a probability of 95 % within the attributed coverage interval.

## Nomenclature

LSCI: Least square circle (Gaussian reference circle), ISO 12181

MZCI: Minimum zone circles (circular Tchebychev zone), ISO 12181

MZLI: Minimum zone lines (straight Tchebychev zone), ISO 12780

LSPL: Least square plane (Gaussian plane), ISO 12781

Gaussian filter: Here Gaussian low-pass or band-pass filter, ISO 16610-21

GG: Least square or Gaussian diameter, ISO 14405

LP: Two-point diameter, ISO 14405

UPR: Undulations per revolution, ISO 12181

## References

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