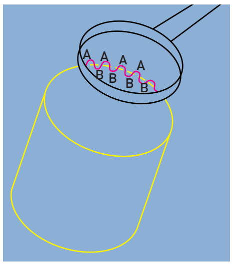
The Measurement of Roundness

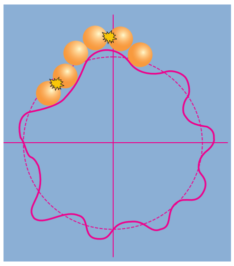
METROLOGY

A component is described as round if all points of a cross section are equidistant from a common center. Therefore, out-of-roundness or roundness error can be measured by evaluating changes in radius on a component relative to a true or perfect circle. The first successful roundness measuring instruments using radial methods were invented and developed by Taylor Hobson in 1951.



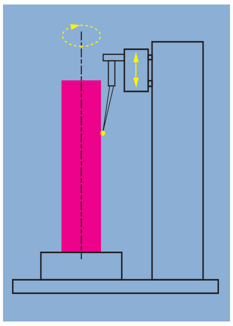
Why measure roundness?

A component may appear round to the eye and may even have an apparently constant diameter when measured with a vernier or micrometer, but is it round?



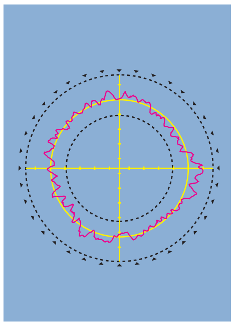
Out-of-roundness affects performance

The bearing shown here could have a race that is not truly circular. This would probably function for a short time but the undulations about this bearing race would cause vibration. This would result in premature wear and cause the race to perform less efficiently than intended.



The measurement of roundness

Measuring roundness requires rotation coupled with the ability to measure change in radius. The accepted method is to compare the profile of a component under test to a circular datum, i.e., a highly accurate spindle. After aligning the axis of the component with the axis of the spindle by means of a centering and leveling table, a gauge (transducer) is used to measure radial variations of the component with respect to the spindle axis.

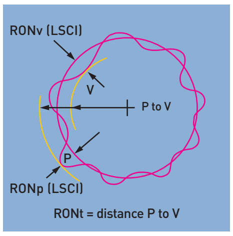


Evaluating the results

Out-of-roundness is expressed as the difference bertween the greatest and least distance of the profile from a center. To assist in the measurement of this distance, a reference circle (or pair of circles) is superimposed on the profile. Visually this helps to identify the maximum peak and valley and it also, since the reference circle is mathematically defined, allows reliable calculations of departure from true circularity to be performed.

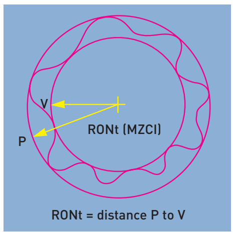
Reference Circles

How they are used in the analysis of peak to valley out of roundness (RONt)



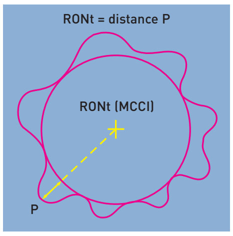
Least Squares Reference Circle (LSCI)

A circle is fitted to the data such that the sum of the squares of the departures of the data from that circle is a minimum. Out-of-roundness is expressed in terms of the maximum departure of the profile from the LSCI (the highest peak to the lowest valley).



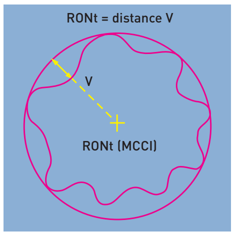
Minimum Zone Reference Circles (MZCI)

Defined as two concentric circles positioned to enclose the measured profile such that their radial departure is a minimum. The roundness value is then given as the radial separation.



Maximum Inscribed Circle (MICI)

Defined as the circle of maximum radius which will be enclosed by the profile data. Out-of-roundness is then given as the maximum departure (or peak) of the profile from the circle. Sometimes referred to as the Plug Gauge Reference Circle.



Minimum Circumscribed Circle (MCCI)

Defined as the circle of minimum radius which will enclose the profile data. The out-of-roundness is then given as the maximum departure (or valley) of the profile from this circle. Sometimes referred to as the Ring Gauge Reference Circle.

Note: The designations **LSCI, MZCI, MCCI** and **MICI** apply to reference circles used for the analysis of roundness.
The equivalent designations for the analysis of cylindricity are **LSCY, MZCY, MCCY** and **MICY**.

Additional references for roundness and geometry measuring:

ISO 12180:2003	Geometrical product specifications (GPS) - Cylindricity
ISO 12780:2003	Geometrical product specifications (GPS) - Straightness
ISO 12181:2003	Geometrical product specifications (GPS) - Roundness
ISO 12781:2003	Geometrical product specifications (GPS) - Flatness

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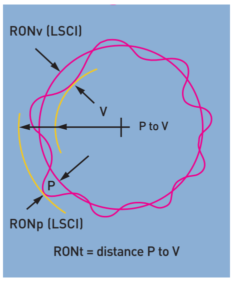
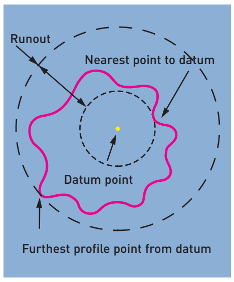
Roundness Parameters



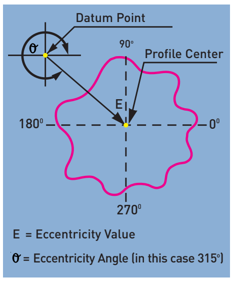
= Roundness (RONt)

Parameter RONt (roundness total) is important in that it puts a number to the departure of a profile from a perfect circular form. By mathematically assessing the relationship of the measured profile to a reference circle, an out-of round condition can be reliably calculated and numerically described. RONp (roundness peak) and RONv (roundness valley) are companion parameters to RONt.



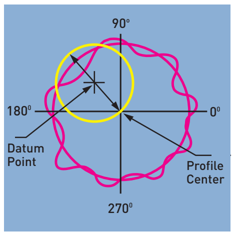
= Runout (Runout)

Sometimes referred to as TIR (Total Indicated Reading), runout is the radial difference between two concentric circles centered on the datum point and drawn such that one coincides with the nearest profile point to the datum and the other coincides with the farthest point on the profile. It combines the effects of form error and concentricity and attempts to predict the behavior of a profile.



E = Eccentricity (ECC)

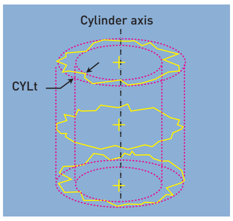
This is the term used to describe the position of the center of a profile relative to a datum point. It is a vector quantity in that it has both magnitude and direction. The magnitude of the eccentricity is expressed simply as the distance between the profile center and the datum point. The direction is expressed as an angle from the datum point.



= Concentricity (CONC)

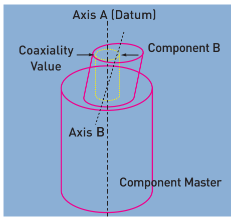
This is similar to eccentricity except that it has only a magnitude and no direction. Concentricity is defined as the diameter of a circle described by the profile center when rotated about the datum point. It can be seen that the concentricity value is twice the magnitude of the eccentricity value.

Associated Parameters



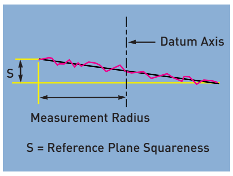
= Cylindricity (CYLt)

Minimum radial separation of two cylinders, coaxial with the fitted reference axis, which totally enclose the measured data. Either LS, MZ, MC or MI cylinders can be used.



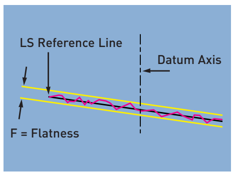
= Coaxiality (Coax)

The diameter of a cylinder that is coaxial with the datum axis and which will just enclose the axis of the cylinder referred for coaxiality evaluation.



⊥ = Squareness (Sqr)

The squareness value is the minimum axial separation of two parallel planes normal to the reference axis and which totally enclose the reference plane. Either LS or MZ can be used.



= Flatness (FLTt)

A reference plane is fitted and the flatness is calculated as the peak to valley departure from the plane. Either LS or MZ can be used.

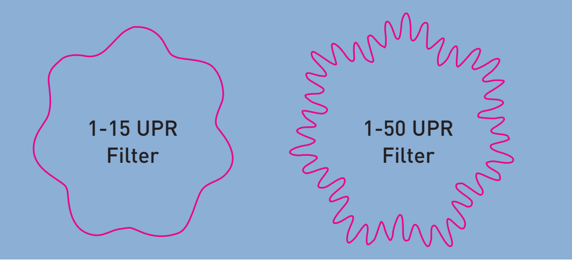
Roundness filters and their effect on measurement results

Roundness filters attenuate any undulations per revolution above the selected number, allowing the true component form to be seen.

Lowering the number of upr will filter the data more heavily, thus reducing the peak to valley displayed. The choice of filter will depend on a variety of factors but many components call for 1-50 upr (undulations per revolution).

Current instruments offer the choice of 2CR or Gaussian filter as well as non-standard filter selections.

The effect of filtering undulations per revolution (upr)



Harmonic Analysis - undulations per revolution (upr)

Roundness data is well suited to harmonic analysis because it is repetitive and the Fourier coefficients of the series use this repetition to good effect. Starting with the low upr and moving to higher upr enables many factors of out-of-roundness to be investigated; for example, instrument set-up, work-piece set-up, machine tool effects, process effects and material effects.

Harmonic	Source or possible cause
0	corresponds to the radius of the component
1	represents eccentricity, i.e., instrument set-up (centering)
2	ovality of the workpiece or instrument set-up (tilting)
3 - 5	distortion caused by clamping or manufacturing forces
6 - 20	chatter caused by lack of rigidity of the machine tool
20 - 100	process effects, tool marks, etc.
100 and up	material effects

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