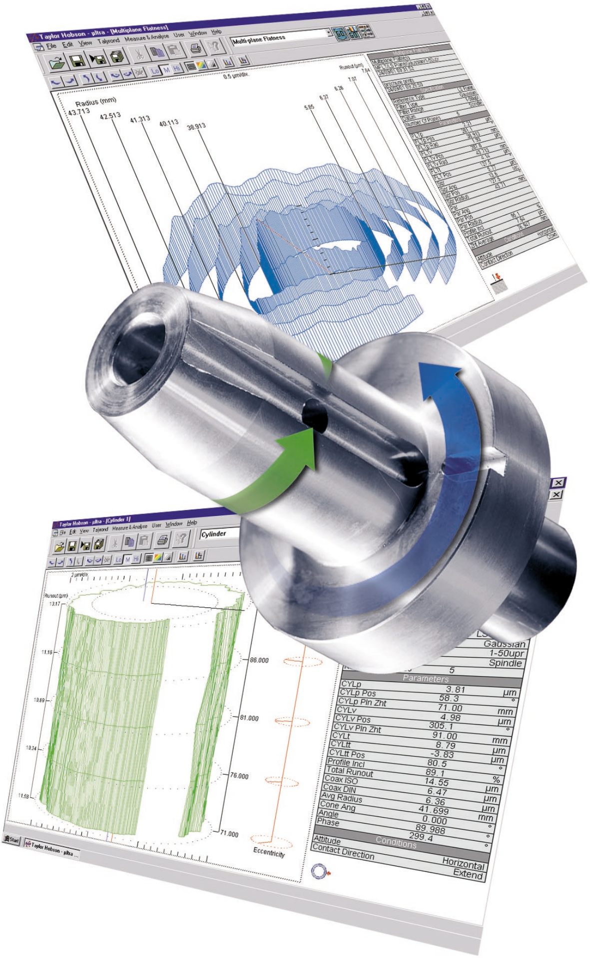
Taylor Hobson
PRECISION

A guide to the Measurement of Roundness



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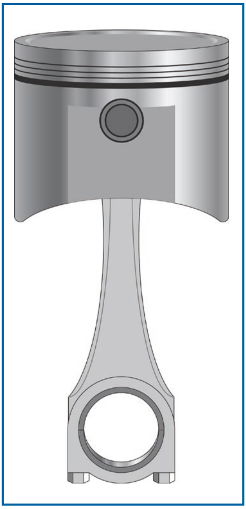
Introduction to roundness

Why roundness is important

It has been said that the greatest benefits to mankind were derived firstly from the invention of the alphabet and secondly from the invention of the wheel. Look around and consider how much your life depends on machines with rotating parts.

Controlling roundness improves performance



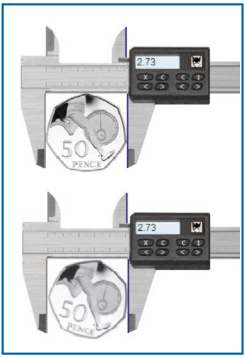
From power stations to power tools, from the smallest watch to the largest car, all contain round components.

In any manufacturing facility it will be seen that machines are producing round or cylindrical components. It is a function of engineering to determine and specify how round they must be; it is a function of metrology to verify if the specification has been met.

Roundness contributes to function and performance in many ways, not least of which is maintaining a lubricating film between mating components.

Although roundness and size both play a significant role in the way things fit together, roundness is evaluated independent of size and must therefore be measured in a different manner.

Diameter is not the same as roundness



Many people incorrectly believe that it is sufficient to measure the diameter of a workpiece in several places, with the difference in readings assumed to represent Out-of-Roundness of the component.

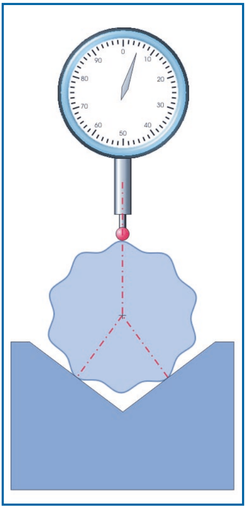
It is very easy to dispel that theory by measuring the diameter of a British fifty pence coin. The diameter reading of the coin is identical regardless of orientation yet the coin is very clearly not round!

How roundness is measured

Definition of roundness

A component is described as round if all points of a cross section are equidistant to a common center. Therefore, to measure roundness, rotation of the component is necessary coupled with the ability to measure change in radius.

Vee-block (3 point) method



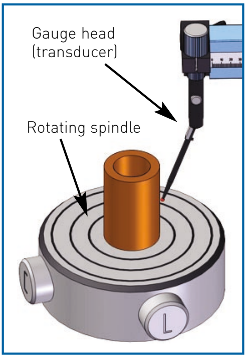
As with the component manufacturing process, it is the level of precision required that will determine the measuring method and equipment to be used.

In cases where roundness is not very critical, a simple technique is to place the part in a vee-block and rotate it in contact with a dial gauge. If the part is perfectly round the pointer of the gauge will not move.

As is apparent in this diagram, the 3 point method is greatly influenced by the spacing and "phase" of profile irregularities as well as the angle of the vee.

Thus the results obtained may not accurately reflect how the component will function nor will they provide information useful for correction of the machine tool that produced the component.

Rotational datum method



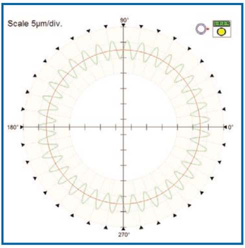
The component is rotated on a highly accurate spindle which provides a circular datum. The workpiece axis is aligned with the axis of the spindle by means of a centering and leveling table.

During rotation, a transducer measures radial variations of the component with respect to the spindle axis.

With adequate precison of the spindle and gauge head, the rotational datum method can be used for the most extreme roundness specifications and is suitable for both internal and external roundness measurements.

Putting a number to it

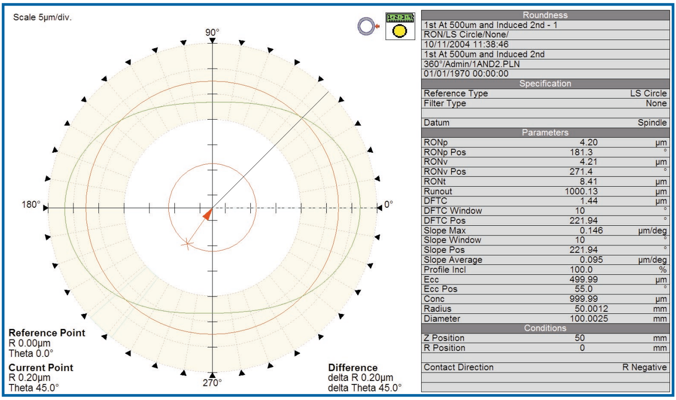
A picture of the results is not enough



It is convenient to represent the radial variations output from the gauge as a polar profile or graph. Roundness deviation can be determined by placing a template over the graph and visually centralizing the profile. Then the highest peak and deepest valley are identified and the distance between the two is measured. This method is dependent on operator skill and is prone to errors.

Modern instruments "Put a number to it!"

First we replace the old template with a computer generated "perfect circle". Since this circle is derived from the actual measured data it is possible to mathematically calculate departure of the measured profile from its reference circle. In this way we can numerically and reliably describe an Out-of-Round condition.



RONt, RONp and RONv

Parameter RONt (roundness total) is the most commonly used parameter. It is the maximum deviation inside and outside the reference circle, and is the sum of RONp (Roundness Peak) and RONv (Roundness Valley) which are companion parameters.

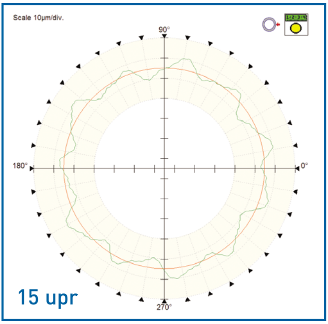
All roundness parameters are based on deviations from reference circles and the results will vary depending on the reference circle chosen. Refer to pages 5 - 6 for additional discussion on reference circles and their effect on parameter results.

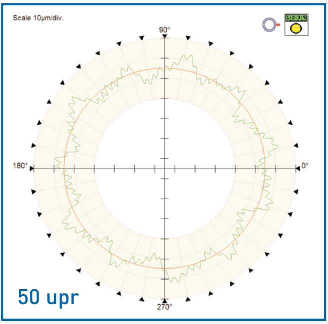
Filtering

Filters and their effects

Roundness measurements always contain imperfections at a number of different upr as shown in the examples below. Filters are used to isolate frequencies or ranges of upr to enable detailed examination of individual effects of machining defects and component function.

Filters can be arranged to remove all inormation above or below a certain frequency. Lowering the number of upr will filter the data more heavily. The choice of filter will depend on a variety of factors but many components will call for 1-50 upr. Internationally accepted filter cut-offs are 15 upr, 50 upr, 150 upr, 500 upr and 1500 upr (upr = undulations per revolution).





Some useful ISO references for roundness and geometry measuring:

ISO 1101:2004	**Geometrical Tolerancing -** Form, orientation, location and run-out
ISO 12180-1 & 2:2003	**Cylindricity -** Terms, definitions and parameters of cylindrical form
ISO 12181-1 & 2:2003	**Roundness -** Terms, definitions and parameters of roundness
ISO 12780-1 & 2:2003	**Straightness -** Terms, definitions and parameters of straightness
ISO 12781-1 & 2:2003	**Flatness -** Terms, definitions and parameters of flatness

UKAS TESTING 2624

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Roundness measuring solutions

The first successful roundness measuring instruments to use radial methods were invented by Taylor Hobson in 1951. We continue to lead the metrology industry with innovative solutions for a wide range of roundness, cylindricity and circular geometry applications.

Visit our website **www.taylor-hobson.com** for a thorough review of roundness instruments as well as comprehensive answers to "Frequently Asked Questions" about metrology.

Talyrond 100 series

Workshop roundness analysis

Roundness measuring instruments for the shop floor or metrolgy room. A diamond turned, ultra precision air bearing spindle and high resolution gauge head provide outstanding accuracy at an affordable price.

Talyrond 365 series

Automated performance, excellent value

A modular range of instruments with all the features you need to improve accuracy, repeatabilty and through-put including automatic centering and leveling, automatic measuring runs, automatic calibration and automatic follow mode for non-concentric features.

Talyrond 450

Large scale roundness for big components

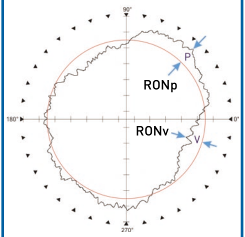
High precision roundness and geometry analysis for large, heavy or non-concentric parts such as cylinder heads and engine blocks. Handles large components (1,000mm height x 1,000kg load) with accuracy and efficiency.

How they are used in the analysis of

Least Squares Reference Circle (LSCI)

A line or figure is fitted to any data such that the sum of the squares of the departure of the data from that line or figure is a minimum. This is also the line that divides the profile into equal minimum areas. The LSCI is the most commonly used Reference Circle.

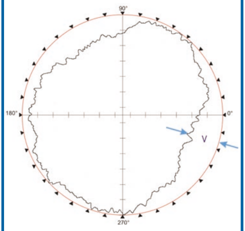
Out-of-Roundness is then expressed in terms of the maximum departure of the profile from the LSCI, i.e. the highest peak to the lowest valley.



RONt = distance P + V
Least Squares Circle (LSCI)

Minimum Circumscribed Circle (MCCI)

It is defined as the circle of minimum radius which will enclose the profile data. The Out-of-Roundness is then given as the maximum departure of the profile from this circle. Sometimes referred to as the Ring Gauge Reference Circle.



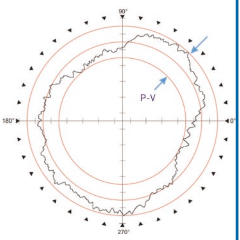
RONt = distance V
Minimum Circumscribed Circle (MCCI)

ce Circles

Peak to Valley out-of-roundness (RONt)

Minimum Zone Reference Circles (MZCI)

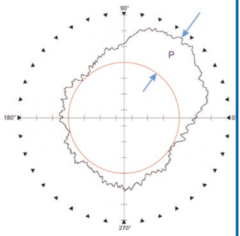
It is defined as two concentric circles positioned to enclose the measured profile such that their radial departure is a minimum. The Out-of-Roundness value is then given as the radial separation of the two circles.



RONt = distance P - V
Minimum Zone Circles (MZCI)

The Maximum Inscribed Circle (MICI)

It is defined as the circle of maximum radius which will be enclosed by the profile data. The Out-of-Roundness is then given as the maximum departure of the profile from this circle. Sometimes referred to as the Plug Gauge Reference Circle.



RONt = distance P
Maximum Inscribed Circle (MICI)

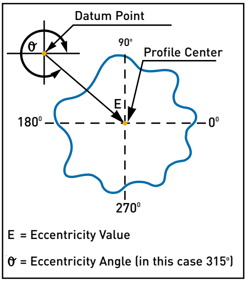
Note:
The designations LSCI, MZCI, MCCI and MICI apply to reference circles used for the analysis of roundness.

The equivalent designations for the analysis of cylindricity are LSCY, MZCY, MCCY and MICY.

Roundness Parameters

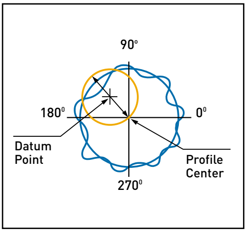
E = Eccentricity (ECC)*

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



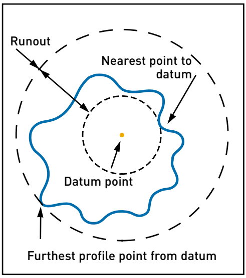
◎ = Concentricity (CONC)

This is similar to eccentricity but has only a magnitude and no direction. The concentricity is defined as the diameter of the 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.



↗ = Runout (Runout)

Sometimes referred to as TIR (Total Indicated Reading), Runout is defined as the radial difference between two concentric circles centered on the datum point and drawn such that one coincides with the nearest and the other coincides with the farthest point on the profile. Runout is a useful parameter in that it combines the effect of form error and concentricity to give a predicted performance when rotated about a datum.

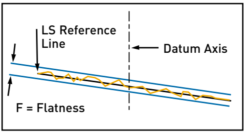


Note: ○ (RONt) is discussed in detail on pages 3 - 6

Associated Parameters

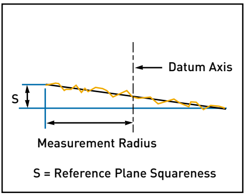
⏥ = Flatness (FLTt)

A reference plane is fitted and flatness calculated as the peak to valley departure from that plane. Either LS (least squares) or MZ (minimum zone) can be used.



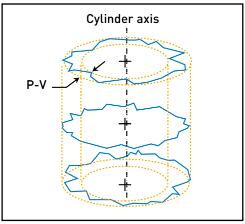
⊥ = Squareness (SQR)*

Having defined an axis, 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.



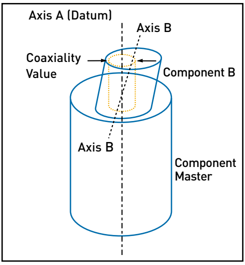
⌭ = Cylindricity (CYLt)

The minimum radial separation of two cylinders, coaxial with the fitted reference axis, which totally enclose the measured data. Either LSCY, MZCY, MICY (maximum inscribed) or MCCY (minimum circumscribed) cylinders can be used.



Ⓘ = Coaxiality (COAX ISO/DIN)

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



*Taylor Hobson µltra Roundness Software equivalent.

Harmonic content

Introduction to harmonic analysis

A basic understanding of harmonic content is essential in choosing the optimum analysis conditions, particularly in relation to the choice of filters. A fundamental understanding is also invaluable in terms of identifying the root cause of certain shapes in either the manufacture or the measurement of a workpiece. Harmonic analysis is, however, an advanced topic and will be discussed only at a qualitative level in this booklet.

Frequency = lobing = undulations per revolution (upr)

Looking at real life roundness graphs (see page 10) it is clear to the eye that information exists in the data at different “frequencies”. A classic example is ovality which indicates an irregularity that occurs two times in one complete revolution. The workpiece would be said to have two lobes or 2 upr (undulations per revolution).

An even or an odd number of lobes may be present on a component, with either condition contributing to problems of fit with mating components. High order lobing, often caused by chatter, vibration and processing marks, is generally more important to function than to fit of a component.

Methods of measurement and analysis

Rotational methods of measurement are effective for both odd and even lobing conditions as well as low and high upr (modern instruments can detect frequencies from 1 upr to more than 1,000 upr). Roundness data is especially suited to harmonic analysis because it is repetitive.

Starting with low upr and moving to higher upr enables many factors of Out-of-Roundness to be investigated. For example, instrument set-up, workpiece set-up, machine tool effects, process effects and material effects can be evaluated.

Primary Causes of Harmonic Content

Harmonic (upr)	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 of the work 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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