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125 years of innovation

Cylindricity

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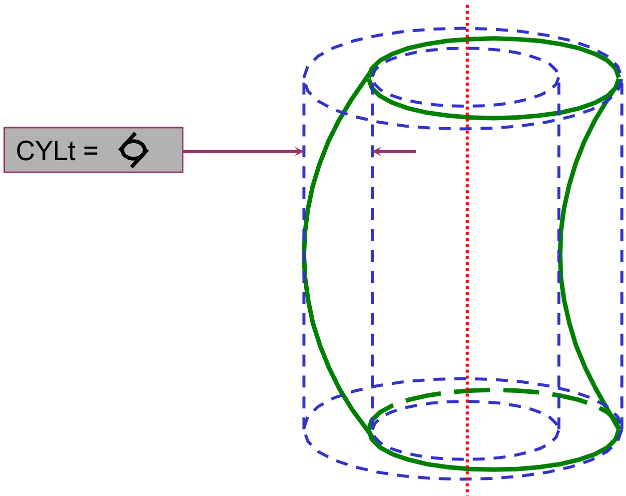
Cylindricity Contents

Cylindricity Introduction

What is Cylindricity?



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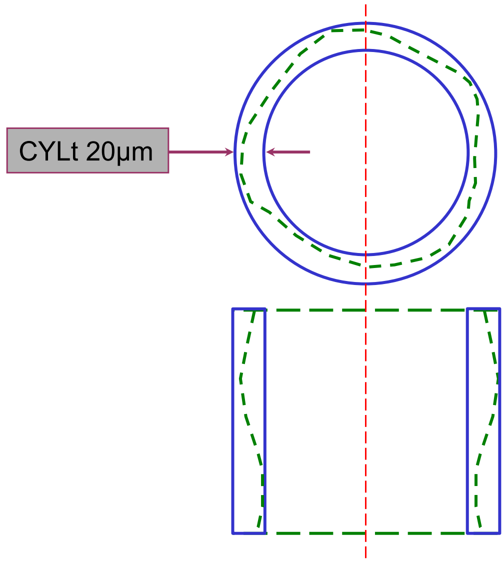
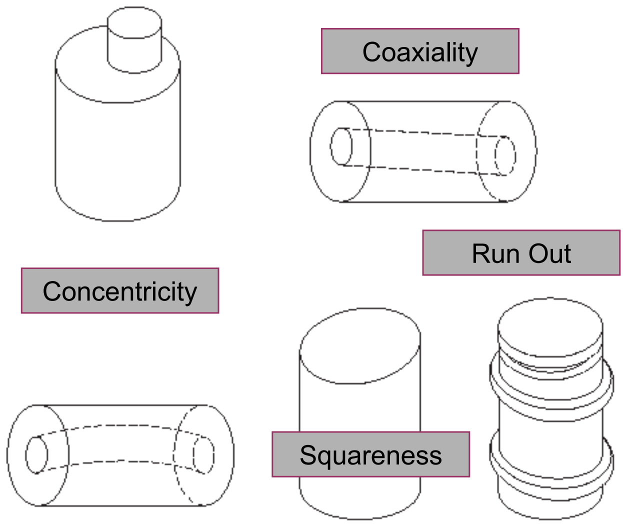
The radial seperation of two co-axial cylinders fitted to the total surface under test such that their radial difference is at a minimum

Cylindricity Tolerance



Definition of a cylindricity tolerance-The surface of the component is required to lie between two co-axial cylindrical surfaces having a radial separation of the specified tolerance.

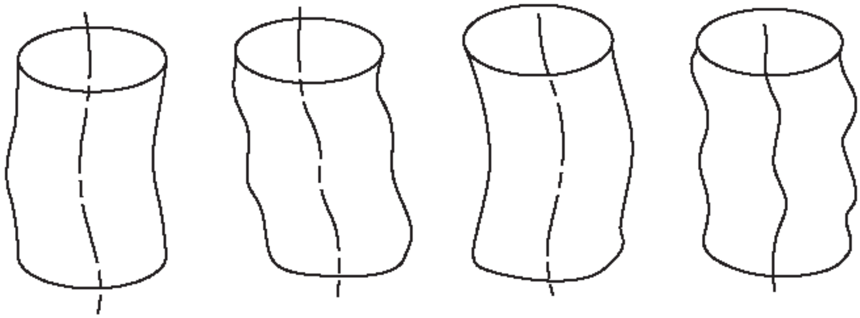
Errors of Geometry



The above slide shows some very typical errors of form that can be checked when performing a cylindricity measurement.

Including concentricity, co-axiality, squareness and run-out.

Cylinder Shapes



Axis Deviations

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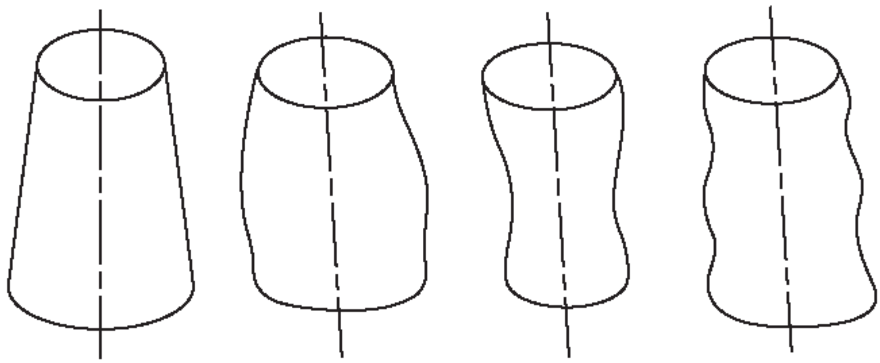
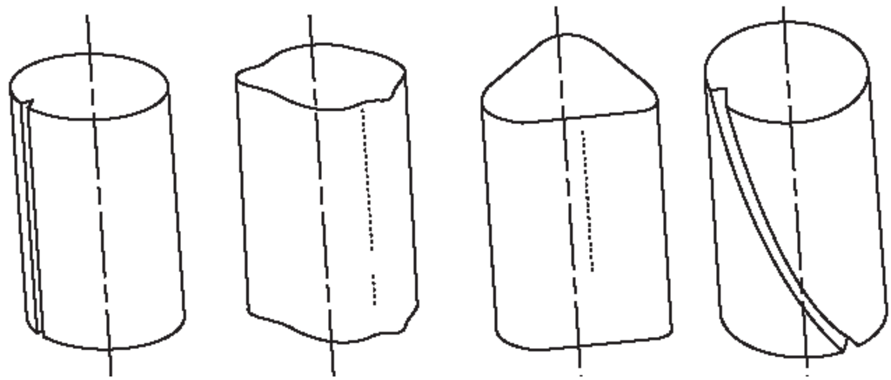
The Following slides illustrate some of the shapes that are associated with a cylindrical profile.

Cylinder Shapes



Radial (Generatrix) Deviations

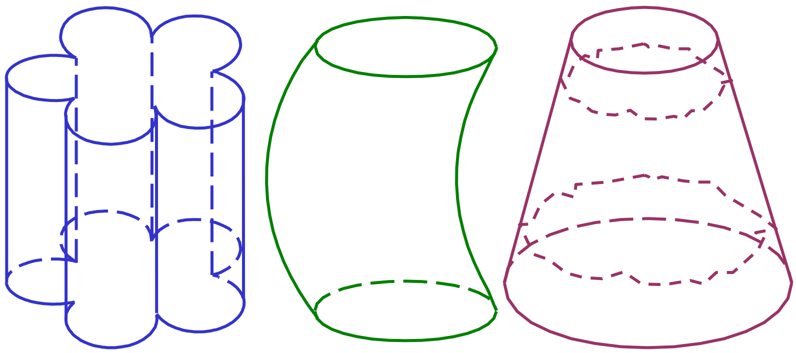
Cylinder Shapes



Cross Section Deviations

Cylindricity Analysis - 3D Form Measurement

Basic Types of Deviations



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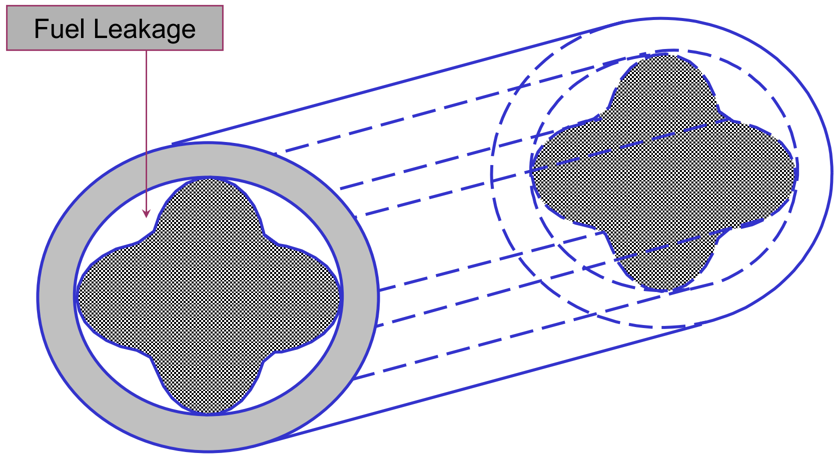
Cylindricity is a 3 dimensional analysis of form: it attempts to combine the characteristics of axial form, radial form and overall shape by the use of best fit cylinders.

Combined Deviations

Axis Deviations + Radial Deviations + Cross Section Deviations

Here we can see the affects of combining the radial, axial and cross section errors.

Component Mating



Where a male to female fit is required the measurement of cylindricity is needed

The ability to mate two components that function together as one is essential when producing components such as fuel injection systems and valve pumps.

Why Measure Cylindricity?

Improved Component Mating

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Cylindricity values are becoming more important in the measurement of components particularly as an aid to improve the efficiency and cost effectiveness of systems.

Again of particular note is automotive fuel injection, where the need for greater economy is demanding greater precision in components.

Why Measure Cylindricity?

Improved Efficiency and Performance

The above example shows the cylindricity of a roller used in a photo copier machine.

The form of the roller will effect the ability of the machine to effectively feed the paper through the copier.

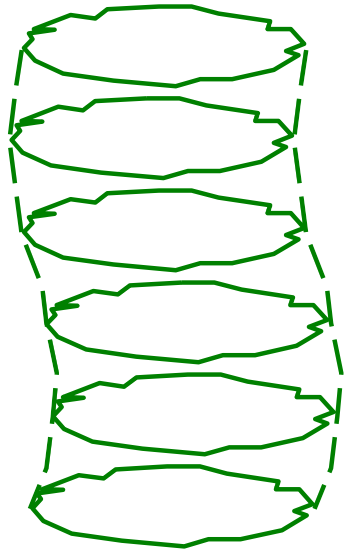
Instrument Requirements

The Ability to Measure...

• Radial Form

• Axial Form

• Dimensional Uniformity



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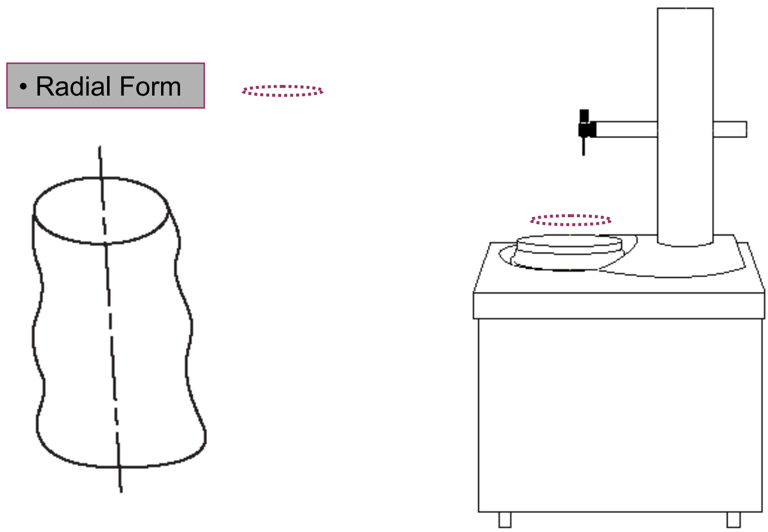
To measure cylindricity we require the ability to measure radial form (roundness), axial form (vertical straightness) and dimensional uniformity (parallelism)

To enable us to measure cylindricity we must be aware of the contribution of errors from our instrument.

Radial and axial errors are often known but we must be able to assess parallelism of the spindle and column axes

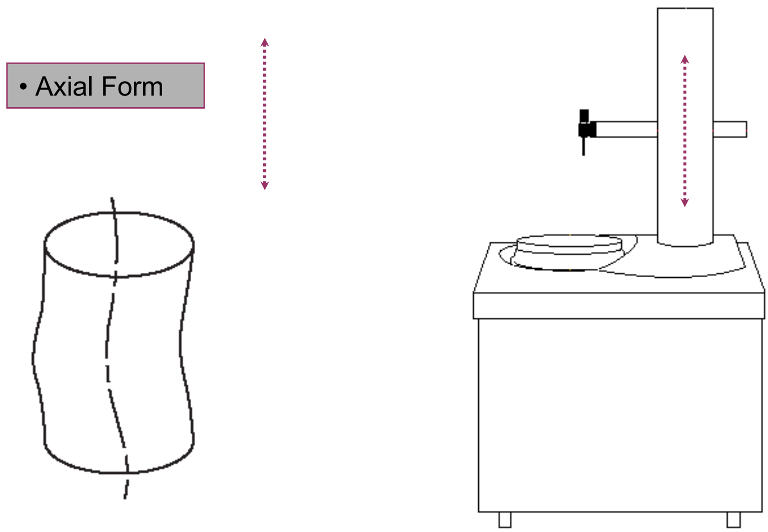
The Ability to Measure...



To measure cylindricity as with roundness we must be able to measure radial deviations from a known datum

In this case we are using a spindle of high accuracy and measuring the deviations from the fixed axis of this spindle.

The Ability to Measure...



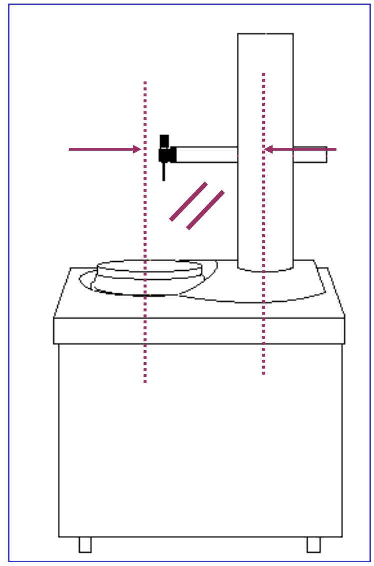
In order to create a cylinder from a series of roundness planes we must have the ability to relate each plane vertically

This is achieved by a straightness datum that is set parallel to the spindle axis as discussed

The Ability to Measure...

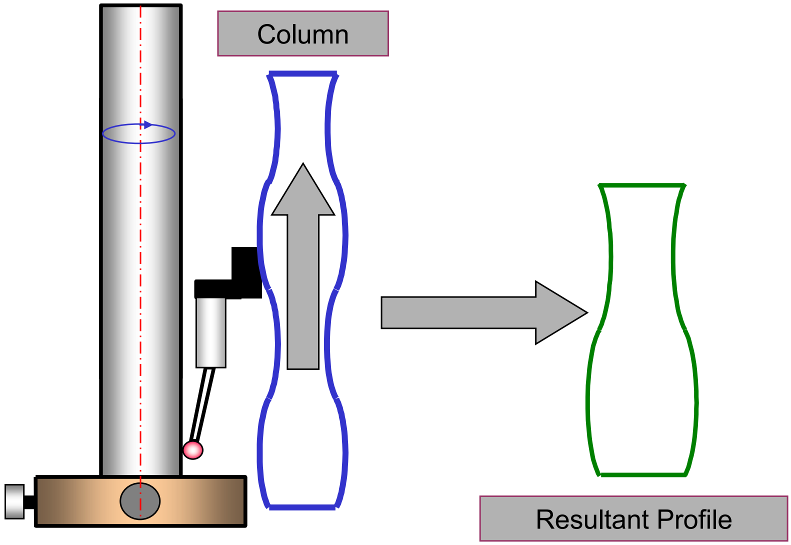
• Position

• Column Axis Set Parallel to Spindle Axis



To enable the production of a cylinder it should be possible to measure not only radial error but also dimensions in both the radial and vertical directions

Column Form



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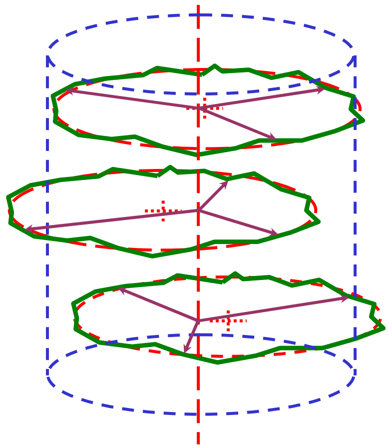
An important part of any cylindricity measuring instrument is the parallelism of the column to the spindle.

The column form must also be true or the situation shown here may occur, where a perfect component may appear to be distorted.

Reference Cylinders

Least Squares (LS)

Cylinder Axis



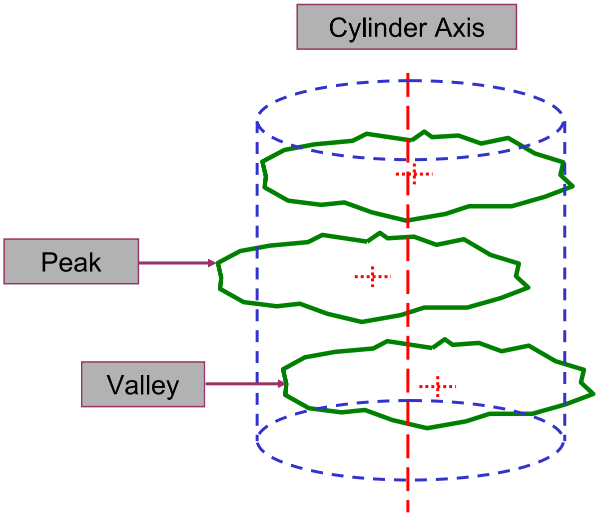
Average Radial Departure of all the Measured Data from the Least Squares Axis

The least squares cylinder is constructed from two or more roundness planes measured at different heights. A best fit line is fitted through the centres of the measured roundness planes, this line is called the least squares axis.

The least squares cylinder is constructed from the average radial departure of all the measured data from the least squares axis.

It should be noted that eccentricity errors from the LSC axis are left in the calculation of these departures.

Least Squares (LS)



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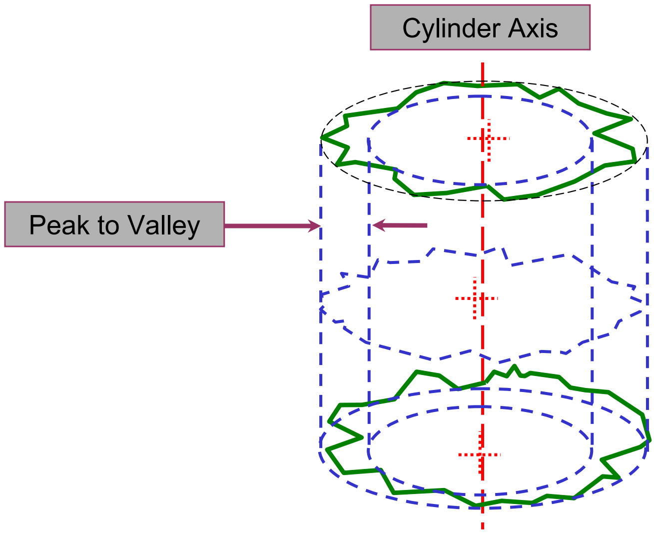
In the case of the least squares cylinder , the cylindricity value is given as the sum of the maximum and minimum departure from the reference cylinder- the cylinder peak to valley.

The MI and MC values are given as the maximum departure from the reference cylinder.

The MZ cylinder values are given as the radial difference between the two reference cylinders.

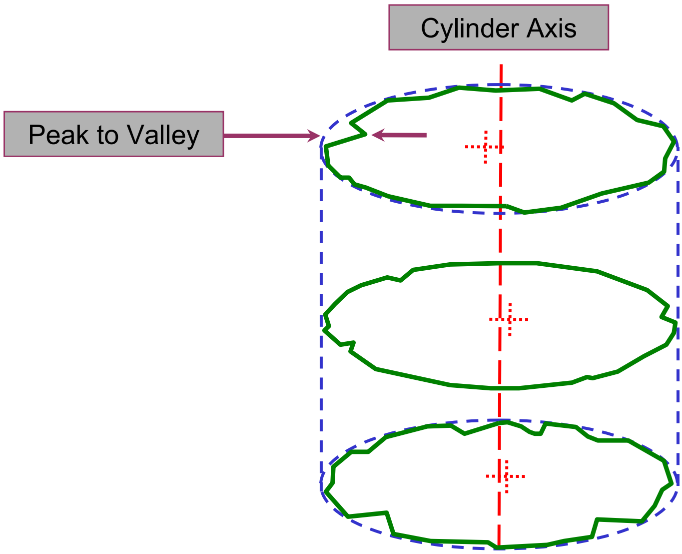
Minimum Zone (MZ)



The minimum zone cylinder can be described as the total separation of 2 concentric cylinders which totally enclose the data and are kept to a minimum separation.

Typical applications for a minimum zone cylinder would be for functional fits.

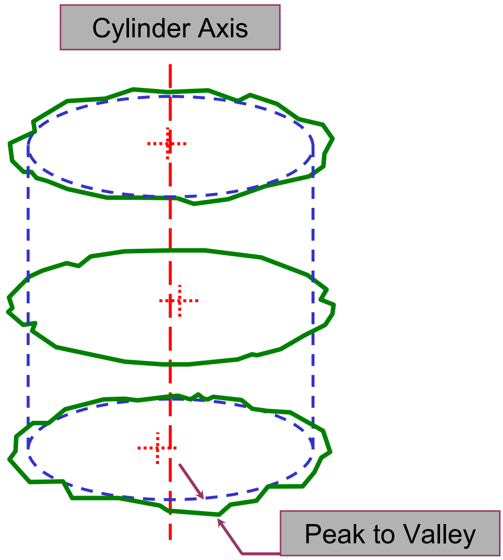
Minimum Circumscribed (MC)



The minimum circumscribed cylinder is a cylinder of minimum radius that totally encloses the data .

A typical use for this cylinder would be for items such as plug gauges where the outside diameter of the surface is important.

Maximum Inscribed (MI)



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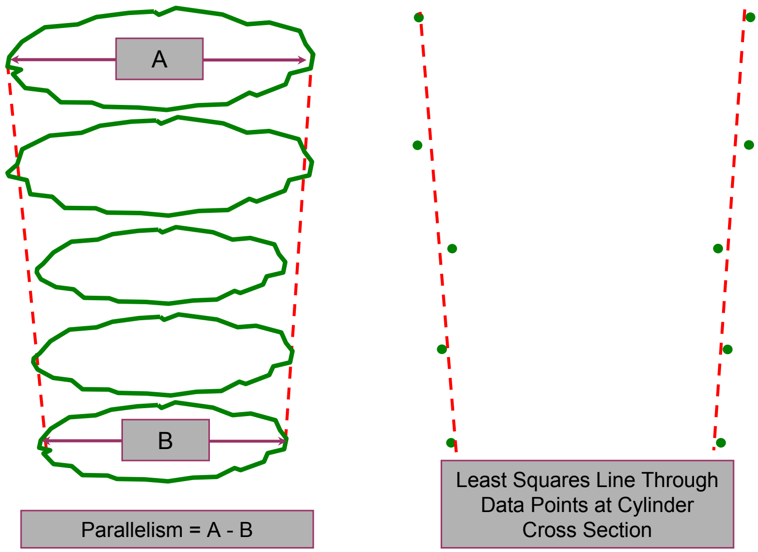
The maximum Inscribed cylinder is the largest cylinder that is enclosed by the data.

This would be used for the female mating part of an assembly or a ring gauge.

Cylindricity Parameters

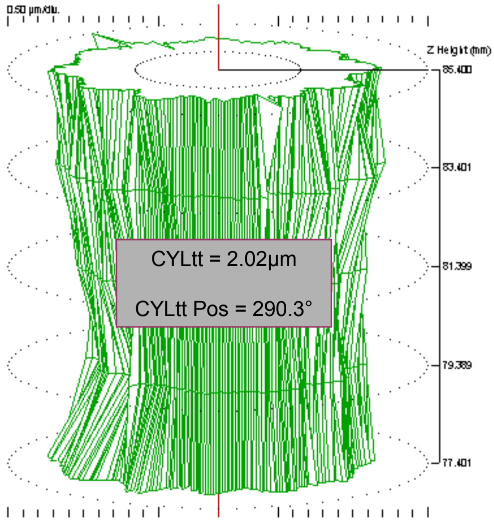
Parallelism

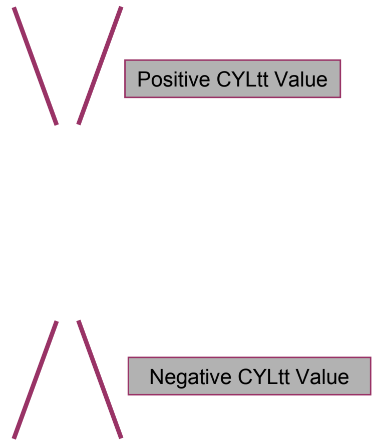


Cylinder parallelism is a measurement of the taper of the cylinder and is given as the parallelism of two least squares lines constructed through the vertical sides of the profile.

Usually the maximum value is denoted.

Parallelism

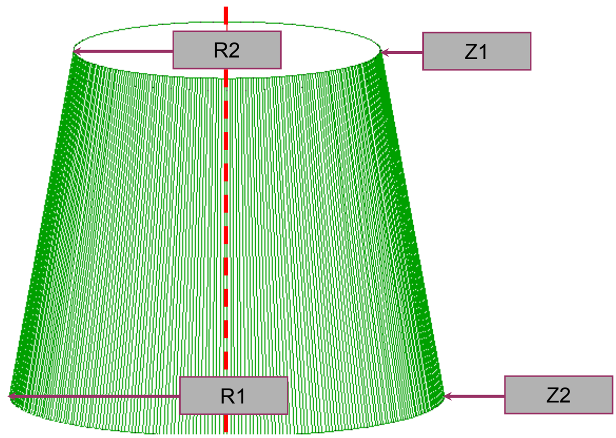


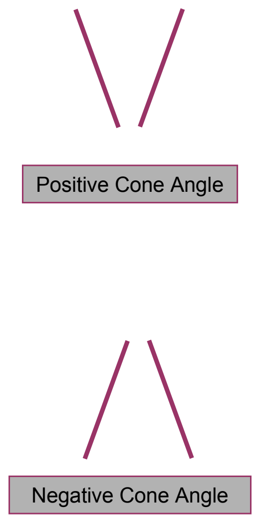


The above slide shows an example of a Least Squares cylindricity result with a computed parallelism (CYLtt) value.

The normal convention for a negative and positive taper is also shown.

Cone Angle



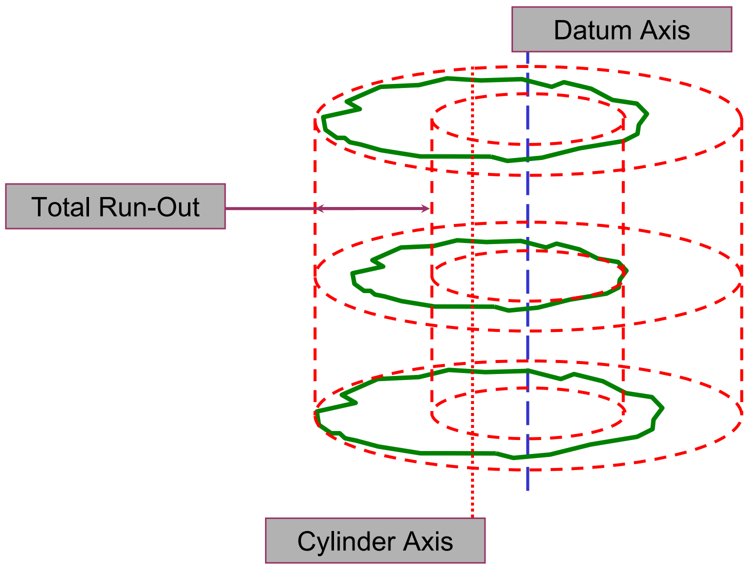


$$\text{Cone Angle} = 2 \times \text{Arc Tan} \frac{(R_1 - R_2)}{(Z_1 - Z_2)}$$

The cone angle value is calculated by taking the upper and lower roundness planes of a cylindricity analysis. A least squares circle is fitted to each plane and the cone angle is calculated from the radial difference of the two circles over the Z height separation, as shown in the formula above. Where R= Radius and Z= Z height separation.

Any roundness planes used in the cylindricity analysis, which are between the upper and lower planes, will not affect the cone angle result, as they are not used in the calculation.

Total Run-Out



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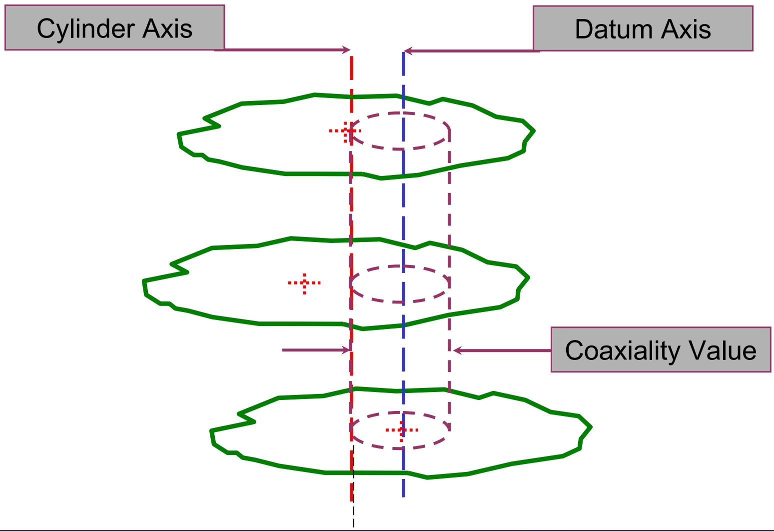
Total run-out is described as the radial departure of 2 concentric cylinders, centered on a datum axis, which totally enclose the cylinder under test.

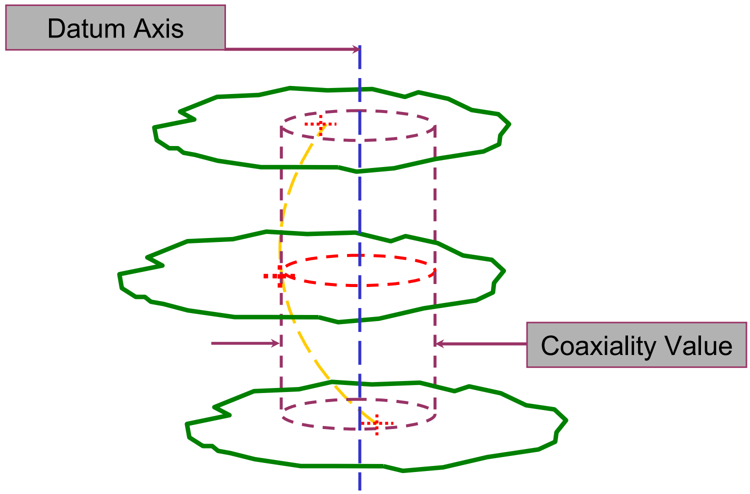
This is also known as total indicator reading.

Coaxiality (ISO)



ISO co-axiality is defined as the diameter of a cylinder of a defined length, with its axis co-axial to the datum axis that will totally enclose the axis under evaluation.

Coaxiality (DIN)

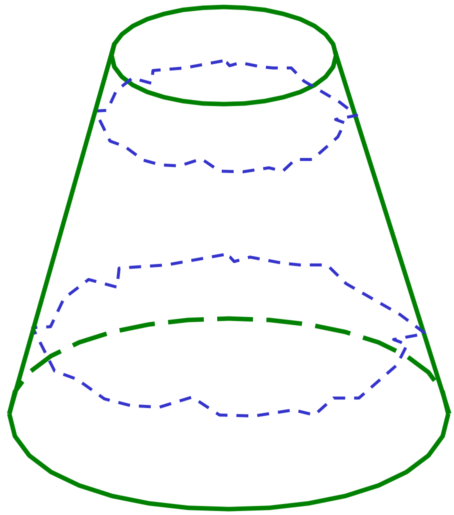


Co-axiality is the relationship of one axis to another.

Co-axiality DIN is defined by a diameter of a cylinder, of defined length, with its axis co-axial to the datum axis that will totally enclose the centroids of the planes forming the cylinder axis under evaluation.

Measurement Techniques & Methods

Cylinder Construction



Cylindricity Only Requires Two Planes

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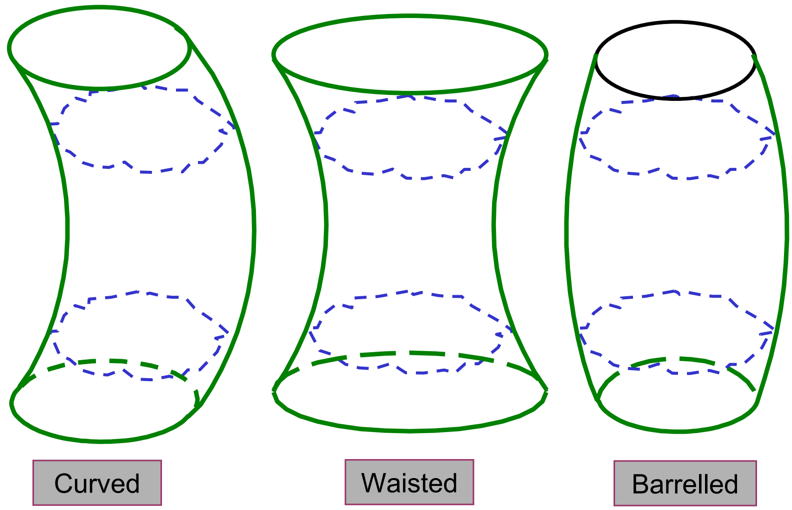
Two planes is the minimum requirement to construct a cylinder.

On a cone such as this it is possible to detect the taper.

Cylinder Construction

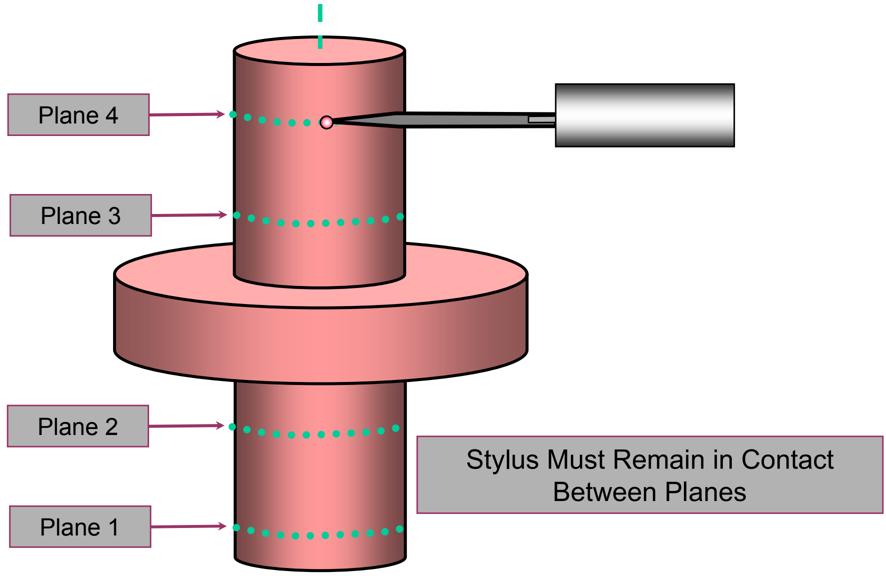
Two Planes Will Not Show the True Shape



However as can be seen here the analyst must be wary of using two planes only.

In each situation here the presumption could be made that the cylinder has a straight profile.

Cylinder Construction



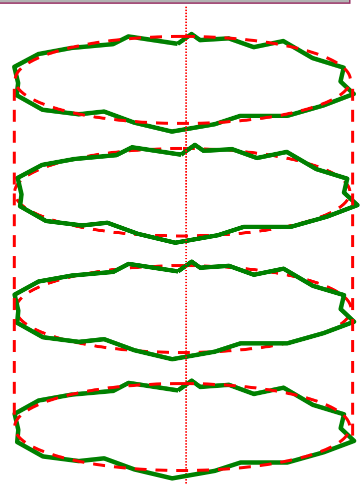
If the only means of measuring radial departure is by use of the pick-up then the stylus or measuring head of the instrument must remain in contact with the component in order not to lose the datum.

To overcome this problem we can incorporate a grating within the gauge arm in order to re-attain the datum on movement.

The user must be aware that he is now attaining accuracy from the resolution of the grating and not the pick-up.

Circumferential Method

High Density of Data Points Around the Circumference



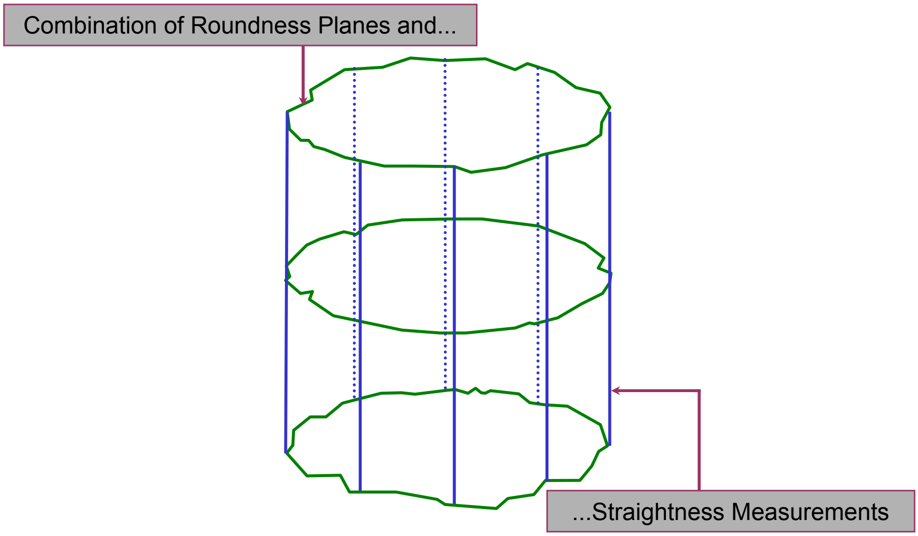
Good for Circumferential Harmonic Analysis

There are a number of ways of measuring cylindricity the method discussed so far is by use of a number of roundness planes that have a relationship in terms of angle, relative radius and height.

When these planes are joined together they make up the complete cylindrical analysis.

The main characteristic of the Circumferential Section Method is a high density of points along the circumference relative to the density of points along the generatrix(see following pages). This gives the method the ability to assess very much higher circumferential harmonic information in comparison to generatrix harmonic information. Hence this method is recommended if circumferential information is of interest.

Birdcage Method



An alternative method to the circumferential technique is the bird cage measurement.

This involves taking axial measurements along the generatrix of the cylinder within the measurement domain and then taking a number of roundness planes having assigned a top and bottom plane that cover the measurement domain.

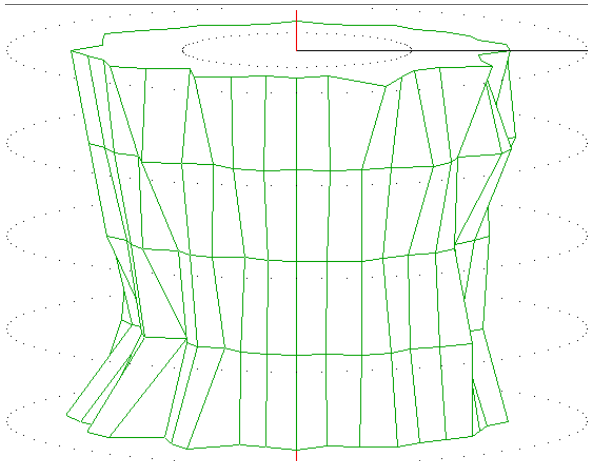
Obviously the advantage of this method is the operator or inspector gets more information on the shape of the cylinder.

However this type of measurement has some limitations, it takes slightly longer than the circumferential method due to the number of straightness tracks required.

The instrument not only also needs to record the angular position of each straightness track, but more importantly the spindle of the measuring instrument needs to be programmable for absolute position to make this measurement automated.

Cylinders that have many interruptions can make this sort of measurement more difficult.

Wirecage View



Used for Displaying Circumferential Method of Measurement

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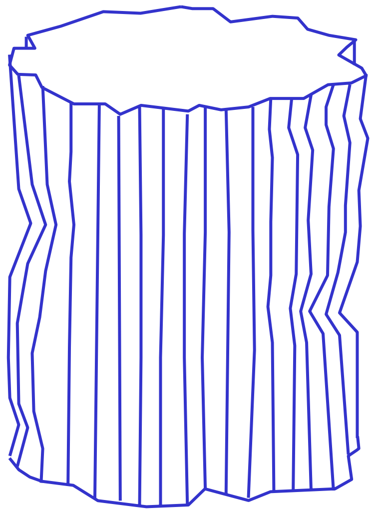
The bird cage method of measurement should not be mixed up with a wirecage view of a cylinder, the wirecage view is just a means of displaying the circumferential method of measurement.

No straightness tracks have been made on the cylinder but each data point at the same angular position on each plane have been joined, this is for display purposes only.

Care should also be taken when viewing this type of display because points are joined even if there are interruptions on the surface.

Generatrix Method

Computed from a Series of Axial Straightness Tracks



The Generatrix method of cylindricity measurement involves a series of straightness tracks taken in a vertical direction along the axis of the cylinder. These straightness tracks are measured at given angles and are then joined to make a cylinder. This method should include a high degree of data along these straightness tracks but not so much data along the circumferential tracks.

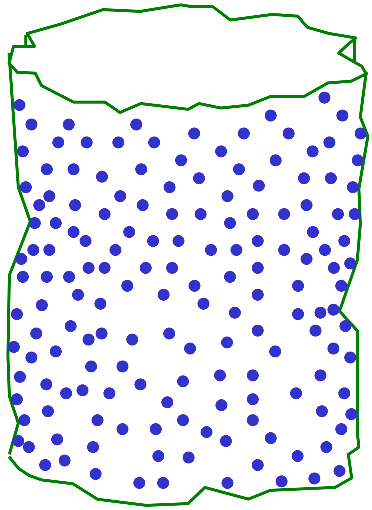
If roundness is of prime importance then the generatrix method of measurement is not recommended because of the limited amount of data in the circumferential direction.

For the generatrix method a minimum of 16 tracks of equal angular spacing is recommended to form the cylinder using a 0.8mm filter for cylinder heights of less than 240mm. This sort of measurement will involve a longer measurement time than the circumferential method.

For the generatrix method there should also be 7 points per cut off, therefore if the cut off is 0.8mm then you need 0.11mm spacing between points. So for a 110mm length cylinder you need 1000 points, if the cylinder is 220mm in length you need 2000 points and so on.

Points Method

Probed Random Points Used to Construct a Cylinder



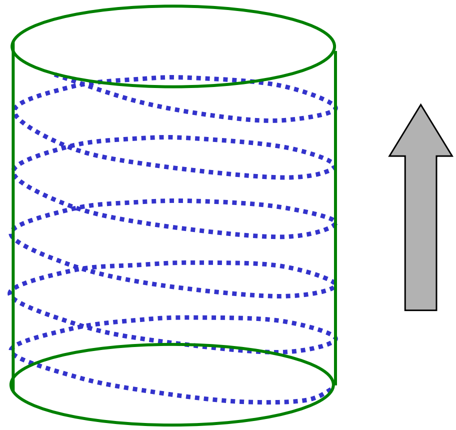
The points method of measurement consists of taking a large number of probed points taken at random or patterned in order to construct a complete cylinder.

The density of points for this type of cylinder is limited and consequently restricts the ability to study the harmonic content of the component.

This method also has problems when filtering, it is therefore not a recommended method of cylindricity measurement unless only approximations of cylindricity measurements are required.

Helical (Spiral) Method

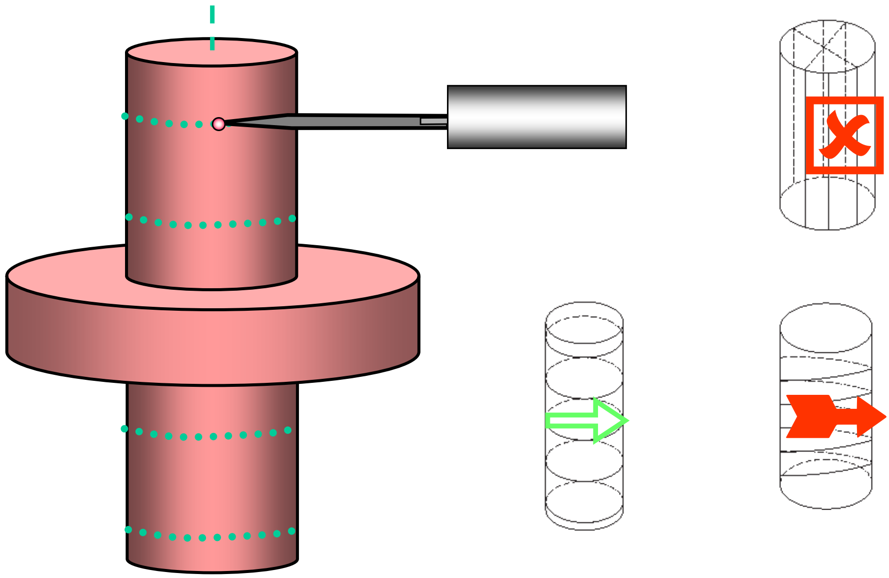
Requires Simultaneous Movement of the Column & Spindle



The helical method of measurement involves taking a track around the cylinder with a helical motion.

This method would require movement of the Z and X axis at the same time along with spindle movement.

Advantages of the Circumferential Method

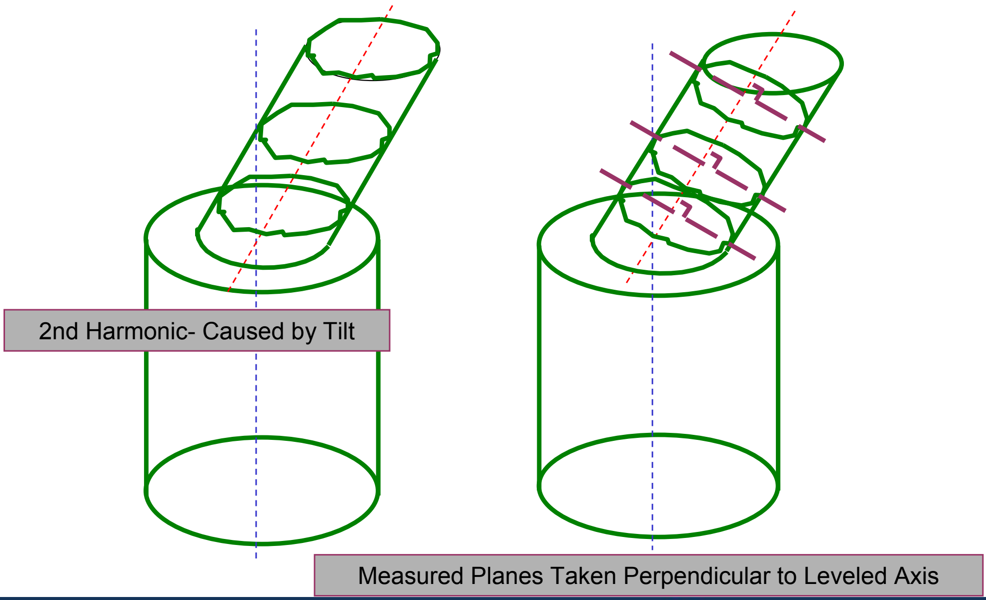


One of the main limitations of the generatrix method and the birdcage method is the inability to measure surfaces with the type of interruption shown above.

Straightness tracks can be made on interrupted surfaces with holes but it is usually not possible or unusual for a instrument to have the ability to measure over shoulders.

Measurement Errors & Effects

Tilt Correction



As discussed earlier if a cylinder is measured tilted it will produce an ovality, to remove this it should be centered and levelled.

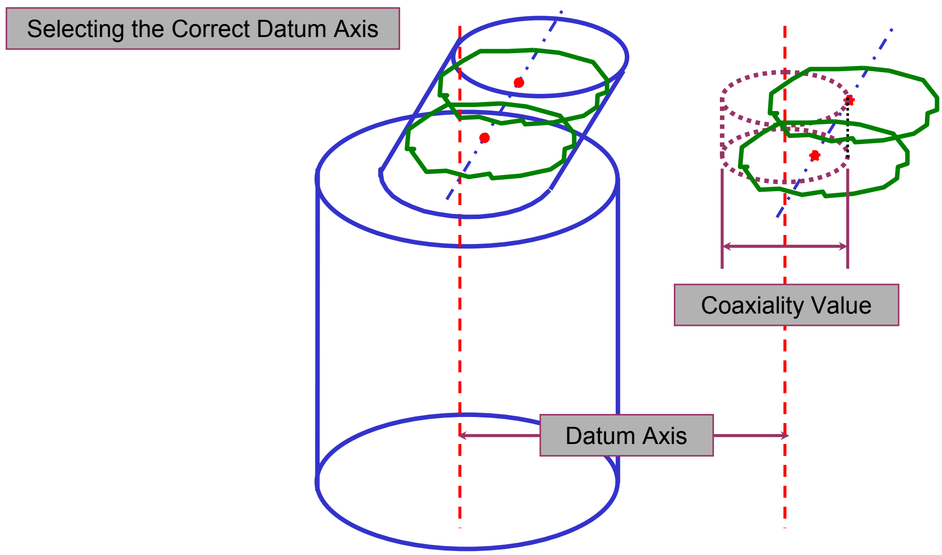
However as in the case above this is not always possible, the upper cylinder of this component cannot be levelled as it will cause the lower cylinder to be tilted.

By calculating the relationship of both cylinder axes the ovality effect can be calculated and removed.

However this technique is slightly flawed, this is because the removal of the ovality effect will also remove ovality that may exist in the part.

A bigger flaw is that the actual measurement track of the stylus was taken perpendicular to the levelled axis, the diagram above is not correct because it indicates that the measurement track was perpendicular to the upper cylinder axis.

Coaxiality Errors



When measuring a component for co-axiality it is important that the inspector understands the nature of the component and how is it to be used.

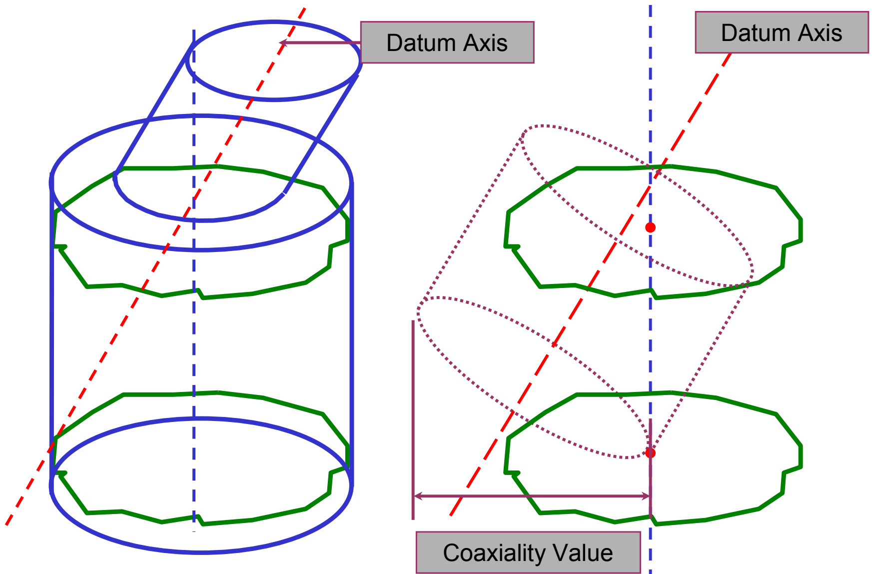
If we look at the above component we can see that an axis has been constructed through the larger diameter cylinder of the component.

This axis is projected and used as the datum.

Two roundness planes are now measured on the smaller cylinder and a new axis calculated, co-axiality of these two axes can now be assessed.

If we imagine the small cylinder axis (length based on the upper and lower roundness measurement planes) rotating around the datum axis a new cylinder will be traced, the diameter of this cylinder will be the co-axiality value.

Coaxiality Errors



However what value of co-axiality would be obtained if we made the small cylinder the datum and calculated co-axiality again.

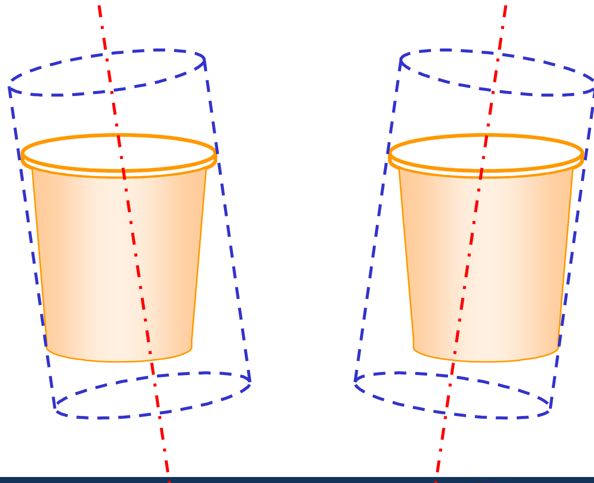
This time the large cylinder axis would rotate about the projected datum axis and trace a considerably larger diameter cylinder.

Try to imagine placing the the larger cylinder into a lathe chuck, when the lathe spindle is rotated the small cylinder will move and describe a small cone. If the small cylinder is placed in the lathe chuck, when the spindle is rotated the large cylinder will trace a bigger cone.

Because of these differences it is important that the inspector understands the nature of how the component is to be used, this is usually established by naming the datum on the component drawing.

Instability of the MC Cylinder

Minimum of 3 Points of Contact on Reference Cylinder

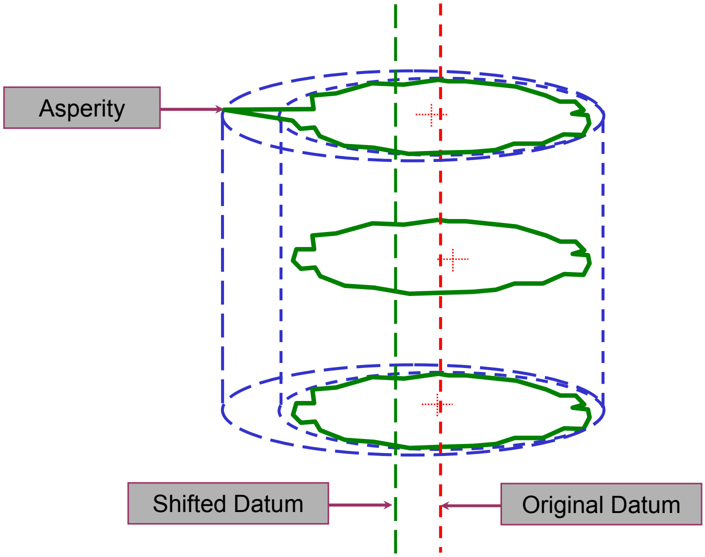


Care must be taken when analysing using a MI or MC cylinder on a taper surface .

The reference cylinder is constructed and must touch the profile in at least 3 positions this could result in the situation shown here.

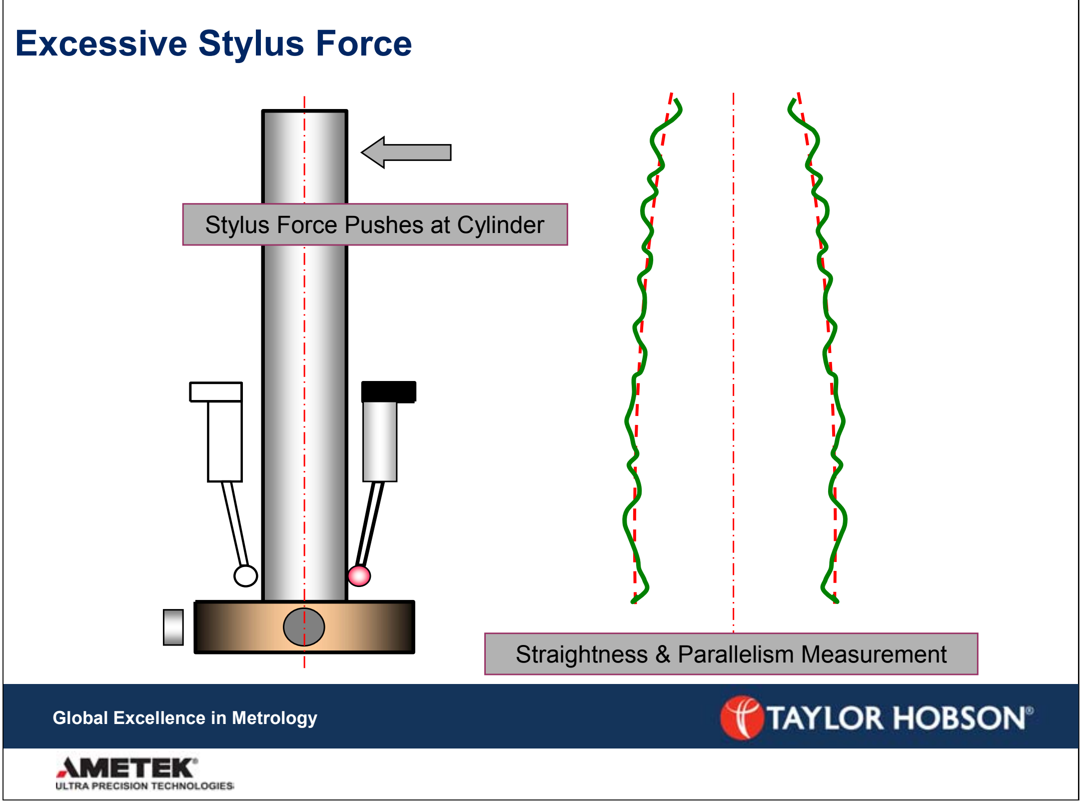
Because of this instability there may not be a unique position for which to construct the cylinder.

Asperity Effects



The MIC, MCC axes are very sensitive to asperities are where possible should not be used for datum axes.

The LSC axis however is insensitive to asperities and is a better alternative as a datum axis.

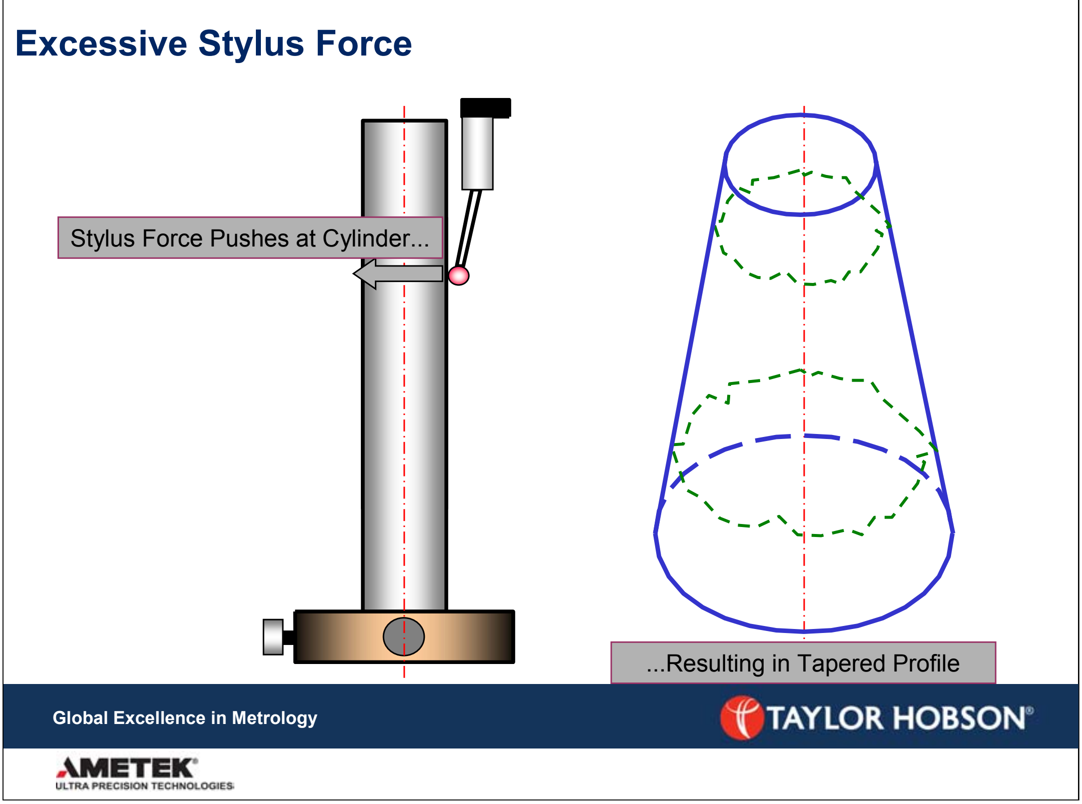


For both straightness measurement and cylindricity measurement too great a stylus force will cause a pushing of the component.

In the case above too much stylus force has caused the part to be pushed over, this pushing will be greater as the stylus moves up the part.

In other words the further up the cylinder the less resistance to the stylus force.

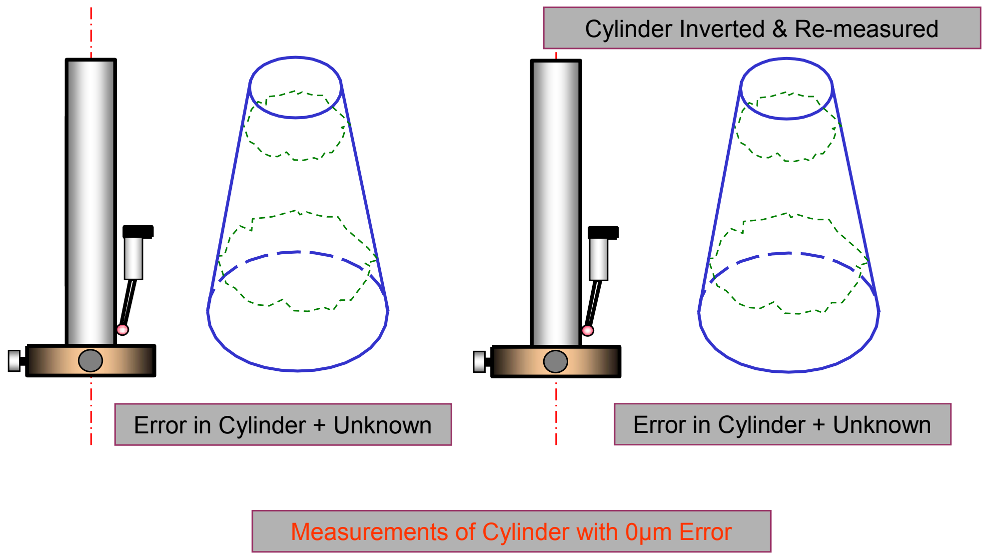
This effect will cause a non-linear straightness error to the final result.



If there is too high a stylus force when measuring cylindricity then the effect is to push the top of the cylinder.

The result will be a cylinder with a taper as shown in the diagram.

Excessive Stylus Force

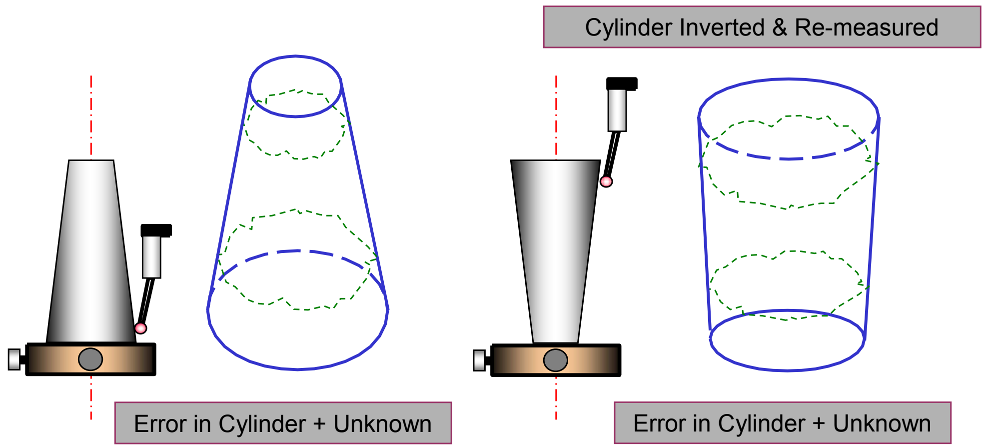


It is possible to demonstrate the effect of too much stylus force by measuring a precision cylinder of known error with the force control turned to maximum.

If there is zero error in the cylinder then all of the error will be coming from the stylus pressure (presuming a perfect column to spindle alignment).

If we invert the cylinder we should get the same answer.

Excessive Stylus Force



It is possible to put a number to the stylus force error or find out the error in the cylinder. In the case above there is an error in the cylinder and an error due to stylus force.

If the cylinder is measured and subsequently inverted and measured again then errors in the cylinder will change sign and errors from stylus force will remain constant.

So it can be stated:

$$\text{Cylinder parallelism error} = \frac{\text{measurement 1 - measurement 2}}{2}$$

For example if the error in the cylinder parallelism is 1µm and the stylus force error is 0.5µm

Therefore measurement 1 = -1.5µm (negative taper)

measurement 2 = +0.5µm (positive taper)

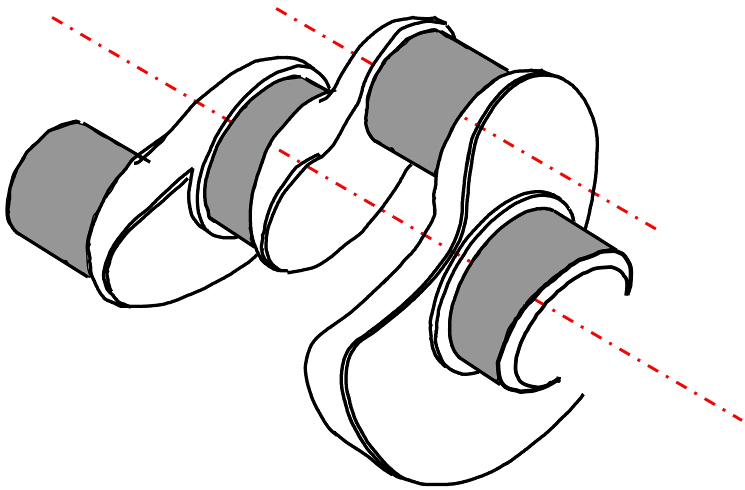
$$\text{Using the formula above Cylinder parallelism} = \frac{-1.5 - (+0.5)}{2} = -1\mu m$$

If we add the two measurements together and divide by two we can get the stylus force error.

It should be noted this is not an exact formula as there are other factors to take into consideration, however it is a useful technique.

Straightness to a Cylinder Axis

Parallelism Measurement of Non Coaxial Axes



Crankshaft - Pins to Mains Parallelism

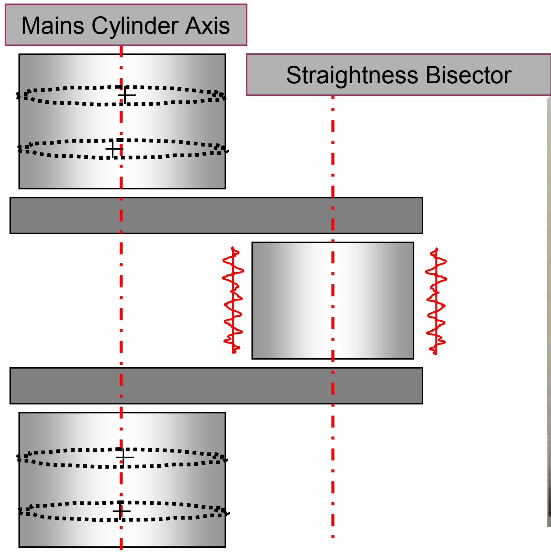
On some types of component it may be necessary to measure to see if two non co-axial axes are parallel.

To explain this lets look at the drawing above, this shows part of a crankshaft.

On this crankshaft it is important that the axes of the bearings are parallel to the axis of the pins, incorrect parallelism will produce unnecessary stress on the crankshaft when in use.

It is difficult to measure and construct both of the axes by roundness measurement, this is because the physical distance between the two axes is too great.

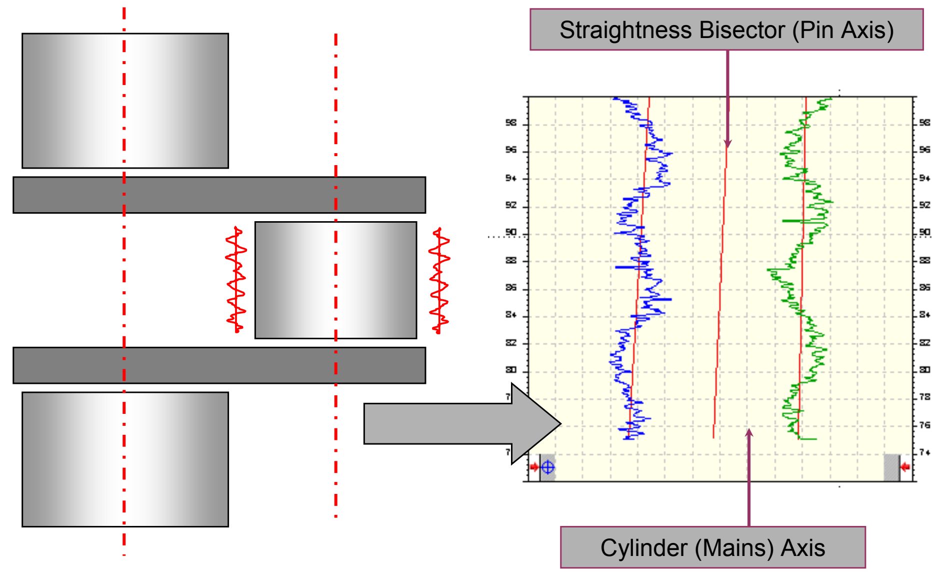
Parallelism Measurement of Non Coaxial Axes



An alternative method of measurement is to measure a number of roundness planes on each bearing and construct an axis based on the analysis.

A straightness measurement can now be made on both sides of the pin, the bisector of these measurements can be assessed for their parallelism to the previuosly defined datum axis through the bearings.

Parallelism Measurement of Non Coaxial Axes



The overall result will tell the inspector that the pins are parallel to the bearings.

Summary

- Cylindricity is a 3 dimensional analysis of form: it attempts to combine the characteristics of axial form, radial form and overall shape by the use of best fit cylinders.
- Cylindricity values are becoming more important in the measurement of components particularly as an aid to improve the efficiency and cost effectiveness of systems.
- To measure cylindricity we require the ability to measure radial form (roundness), axial form (vertical straightness) and dimensional uniformity (parallelism)
- The high accuracy spindle / the straightness datum being set parallel to the column allow us to offer this 3 dimensional analysis of form.
- Reference cylinders are available to allow us to analyse the cylindricity parameter- the LS cylinder being the most widely used and most stable for datums.
- There are a number of ways of measuring cylindricity the method used by Taylor Hobson uses of a number of roundness planes that have a relationship in terms of angle, relative radius and height. When these planes are joined together they make up the complete cylindrical analysis.

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