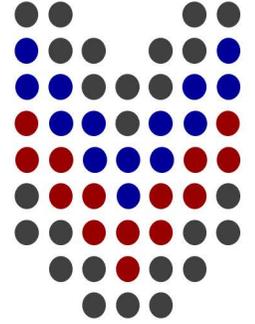


[ ME 472 ]

# Engineering Metrology & Quality Control



[ CHAPTER 4 ]

## Measurement of Geometric Tolerances



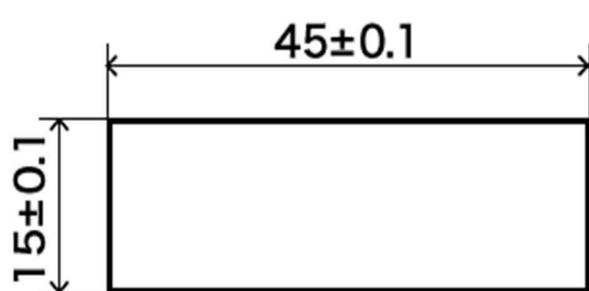
**Assoc. Prof. Dr. A. Tolga BOZDANA**  
**Mechanical Engineering Department**

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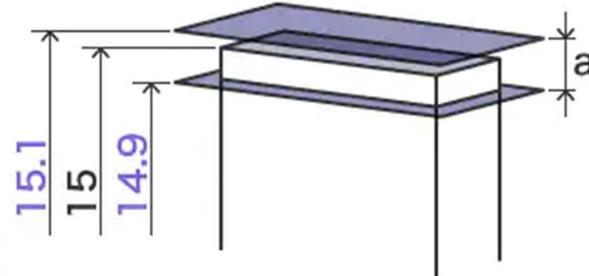


## Geometric Dimensioning & Tolerancing (GD&T)

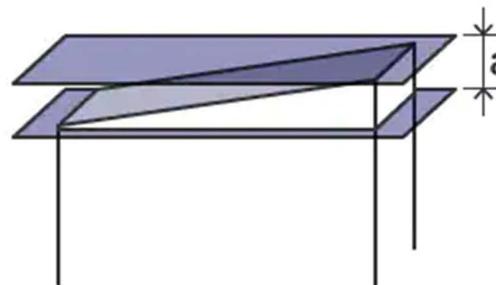
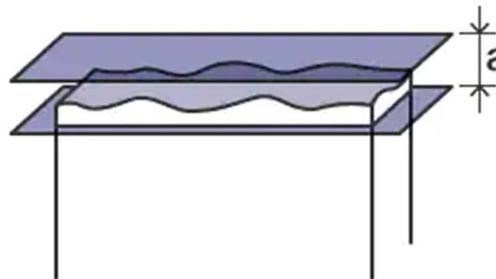
- It refers to **Geometrical Product Specifications** (i.e. shape, size, and positional relationship of product) and **Geometrical Tolerances** (i.e. the allowable errors for form and position in addition to size).
- **Size Tolerancing** together with **Geometric Tolerancing** would enable **accurate representation of the design**.



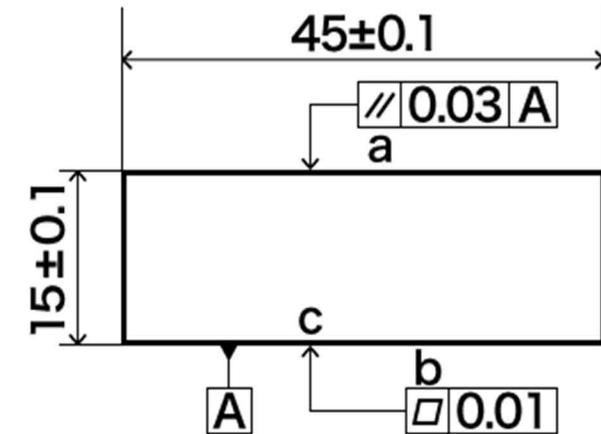
Design with Size Tolerancing



Dimensional Representation of Design  
(a = tolerance zone)



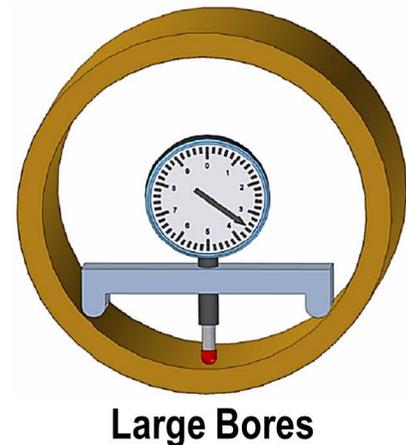
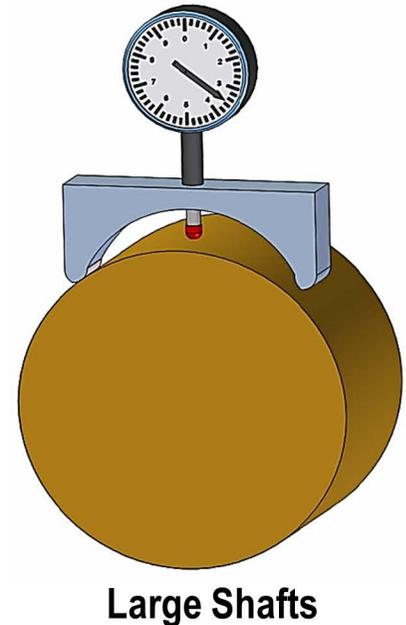
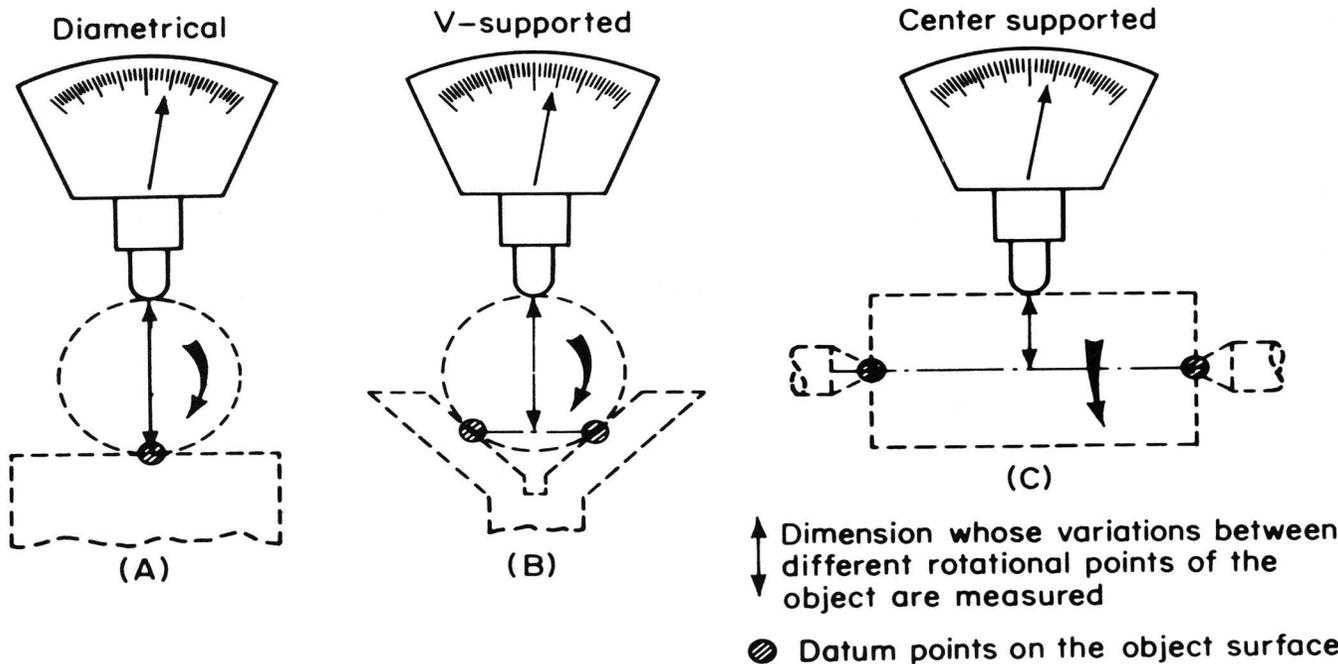
Non-conforming or defective parts  
(The fault lies with the designer,  
not with the manufacturer)



Revised Design with GD&T  
a = tolerance for parallelism  
b = tolerance for flatness  
c = reference plane

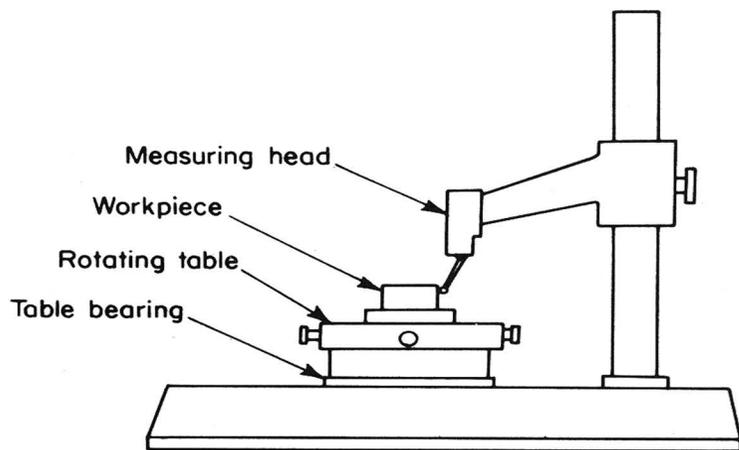
### Roundness (Circularity) Measurement using Intrinsic Datum

- The conventional method using **points on the part surface for reference**.
- Roundness profile is obtained from a desired cross-section of the part.
- The deviations along cross-section are sensed by means of **dial gauge**.
- The part can be rotated on a flat surface (**Fig. A**), on a V-block (**Fig. B**), or between two supports (**Fig. C**).
- Fixtures are available for measuring roundness on large shafts & bores.

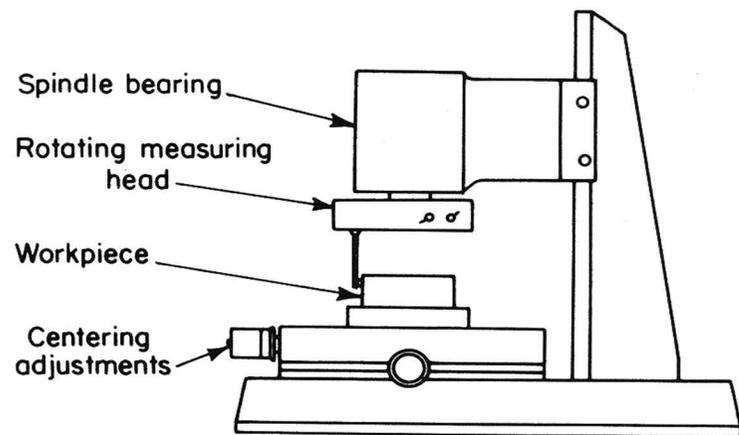
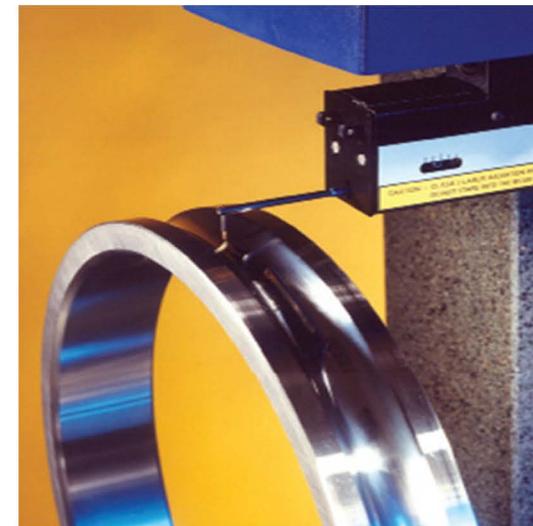


## Roundness (Circularity) Measurement using Extrinsic Datum

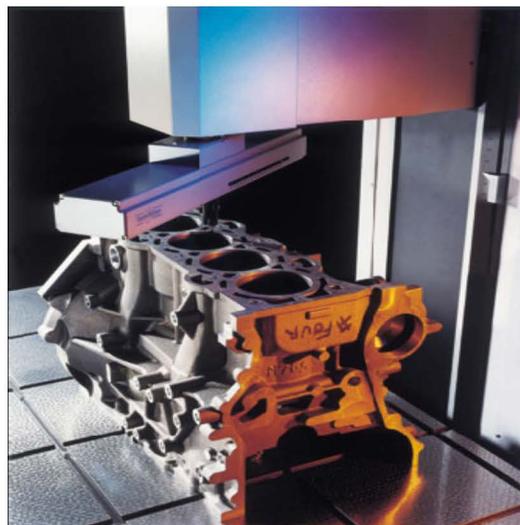
➤ Measurements are taken based on **an external reference** of known precision.



Instrument with rotating workpiece table:  
sensing head stationary

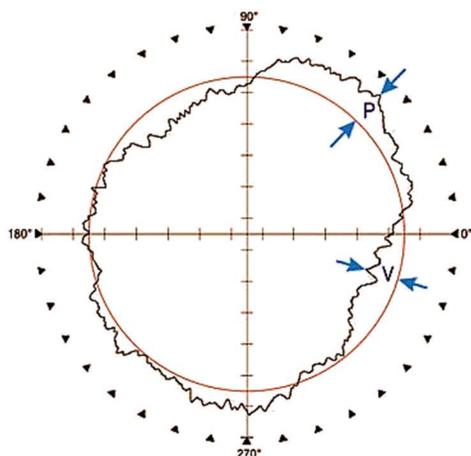


Instrument with rotating spindle:  
workpiece remains stationary



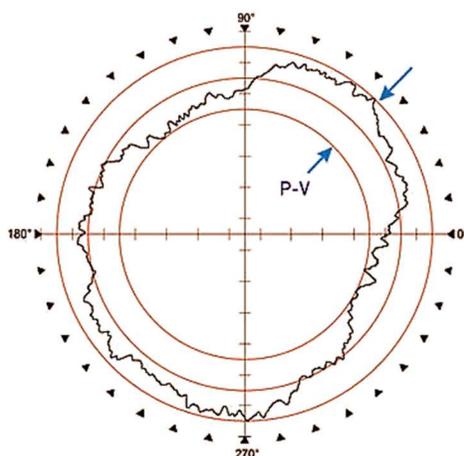
## Analysis of Roundness using Reference Circles

- Four ways of using Reference Circles for analysis of **Peak-to-Valley Out-of-Roundness (RON)**:
  - **Least Squares Circle (LSC)**: The circle fitted such that the sum of squares of the deviations is minimum. RON is *the distance from the highest peak (P) to the lowest valley (V), knowing that V is always negative*.
  - **Minimum Zone Circles (MZC)**: Two concentric circles positioned to enclose the profile so that radial deviation is minimum. RON is *the radial separation of the two circles*.
  - **Minimum Circumscribed Circle (MCC)**: The circle of minimum radius enclosing the profile (**Ring Gauge Reference Circle**). RON is *the maximum deviation of the profile from this circle*.
  - **Maximum Inscribed Circle (MIC)**: The circle of maximum radius enclosed by the profile (**Plug Gauge Reference Circle**). RON is *the maximum deviation of the profile from this circle*.



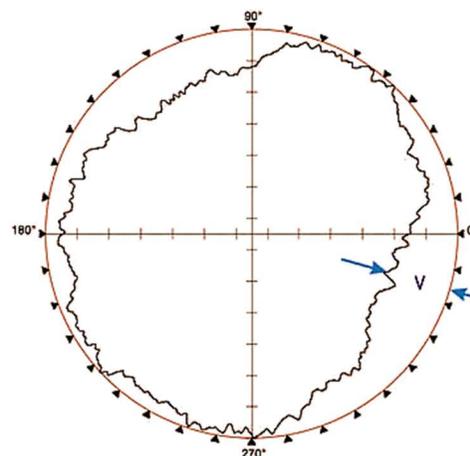
Least Squares Circle

$$RON = P + V$$



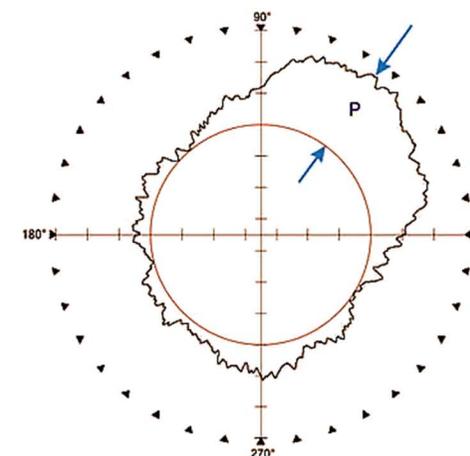
Minimum Zone Circles

$$RON = P - V$$



Minimum Circumscribed Circle

$$RON = V$$



Maximum Inscribed Circle

$$RON = P$$



## Defining Least Squares Circle (LSC)

a) The roundness profile is given.

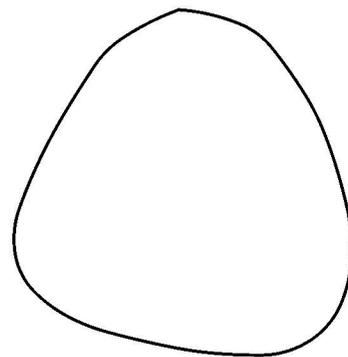
b) It is divided by equispaced lines wrt random center. Points intersecting the profile refer to radial ordinates *More points gives better results.*

c) The coordinates (**X & Y**) are found wrt a selected datum (**0**). For easier calculations, it is better to choose such datum that gives only positive values of **X & Y**.

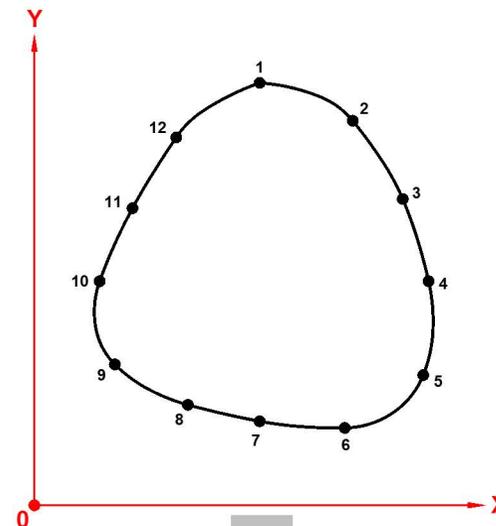
d) Datum is shifted (by **a & b**) so that the center of LSC (**0'**) is defined. New coordinates (**X' & Y'**) are found based on the updated datum (**0'**).

e) Radial distances (**r**) are obtained wrt the center of LSC (**0'**).

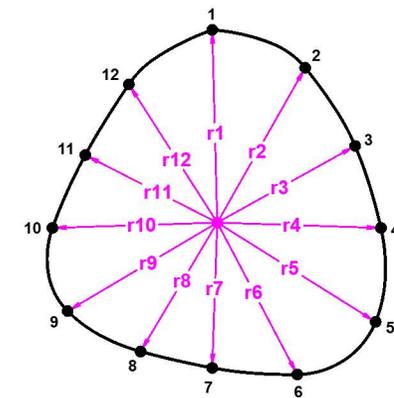
f) Radius of LSC (**R**) is determined.



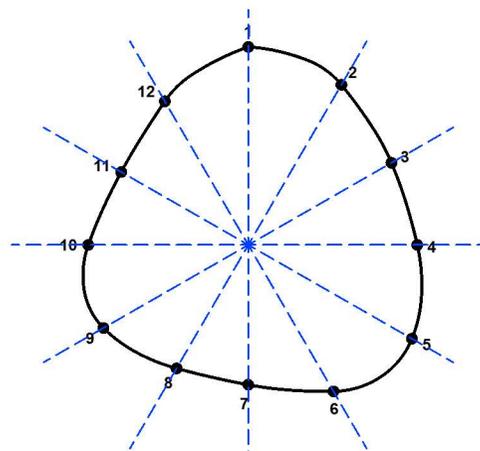
(a)



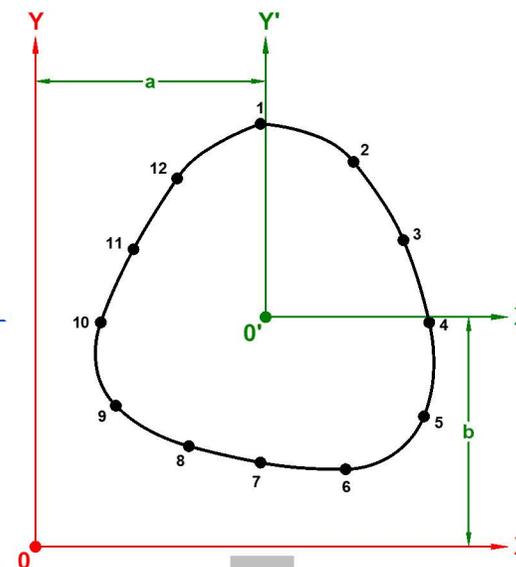
(c)



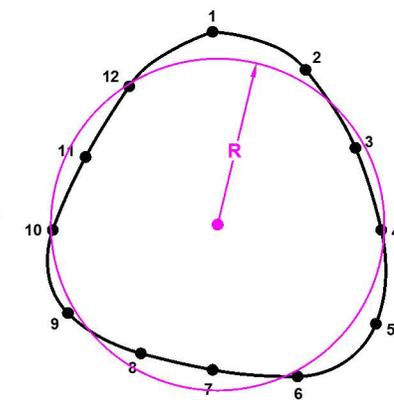
(e)



(b)



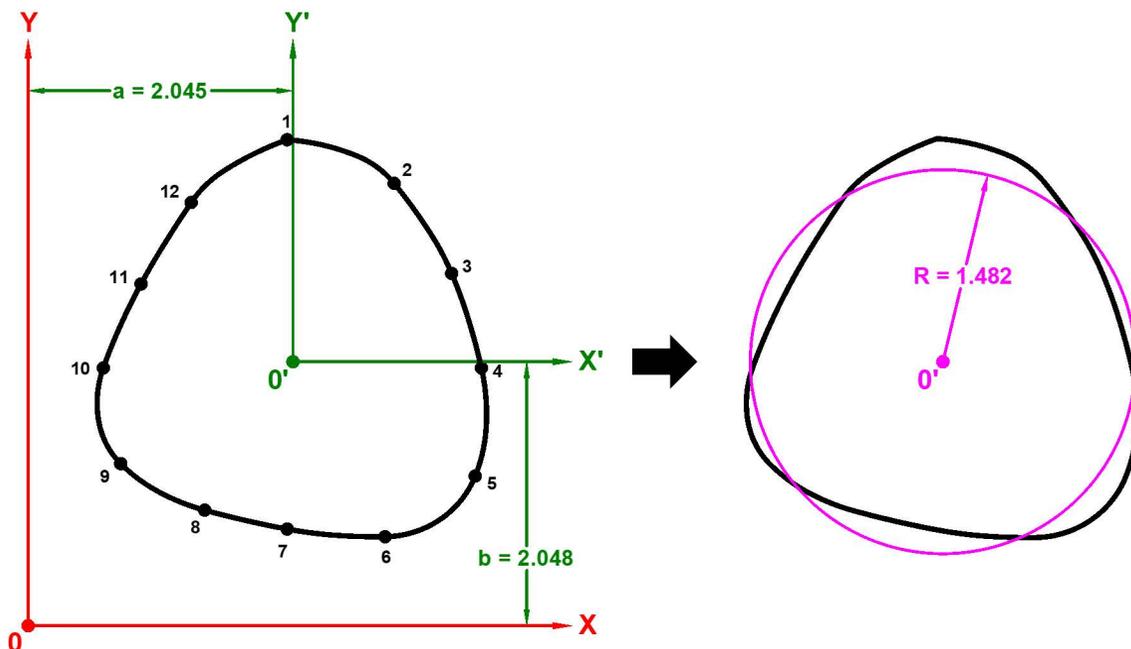
(d)



(f)

### Example: Obtaining LSC

- The profile is divided into 12 equispaced points, so:  $n = 12$
- Based on initial datum (0), initial coordinates (X & Y) are found.
- Datum shifting (a & b) is done based on arithmetic mean of X & Y.
- New coordinates (X' & Y') are found based on shifted datum (0').
- Radial distances (r) are found based on X' & Y'.
- Radius of LSC (R) is found based on arithmetic mean of r values.



n	X	Y	X'	Y'	r
1	2.00	3.77	-0.045	1.722	1.723
2	2.83	3.43	0.785	1.382	1.589
3	3.28	2.71	1.235	0.662	1.401
4	3.50	2.00	1.455	-0.048	1.456
5	3.45	1.16	1.405	-0.888	1.662
6	2.73	0.69	0.685	-1.358	1.521
7	2.00	0.75	-0.045	-1.298	1.299
8	1.35	0.90	-0.695	-1.148	1.342
9	0.71	1.26	-1.335	-0.788	1.550
10	0.58	2.00	-1.465	-0.048	1.466
11	0.86	2.63	-1.185	0.582	1.320
12	1.25	3.27	-0.795	1.222	1.458

$$a = \frac{\sum X}{n} = 2.045 \quad r = \sqrt{(X')^2 + (Y')^2}$$

$$b = \frac{\sum Y}{n} = 2.048 \quad R = \frac{\sum r}{n} = 1.482$$

### Example: Calculating RON

- Reference Circles are found wrt the closest & the farthest points:

**Minimum Circumscribed Circle (MCC) =  $r1 = 1.723$**

**Maximum Inscribed Circle (MIC) =  $r7 = 1.299$**

- Then, the highest peak (P) and the lowest valley (V) are:

**$P = MCC - LSC = 1.723 - 1.482 = 0.241$**

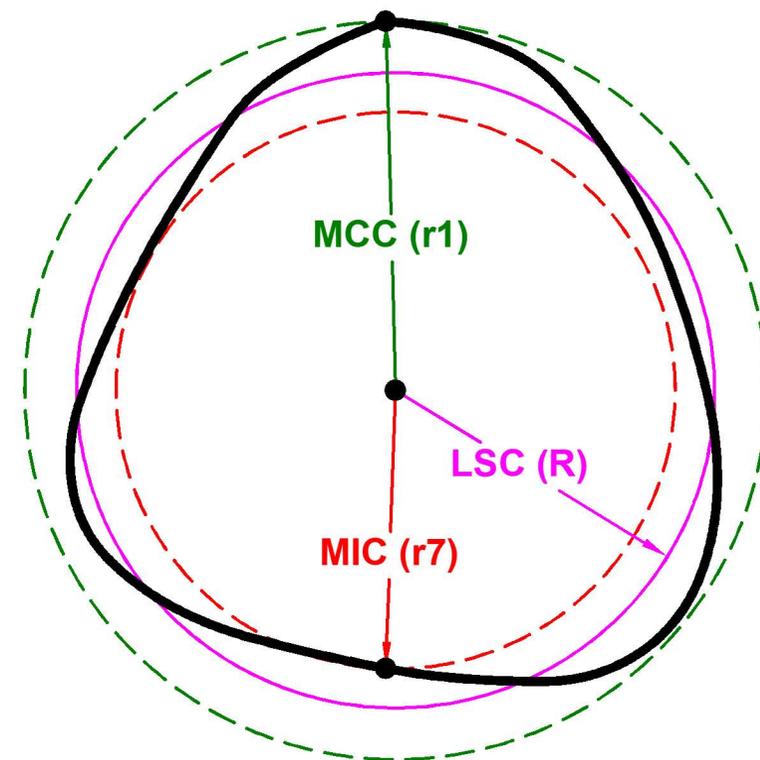
**$V = MIC - LSC = 1.299 - 1.482 = -0.183$**

- Therefore, RON based on Least Squares Circle (LSC) is:

**$RON (LSC) = P + V = 0.241 + (-0.183) = 0.058$**

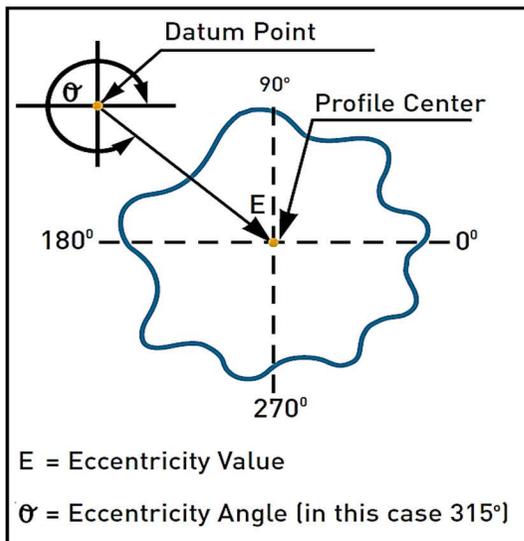
- However, RON based on Minimum Zone Circles (MZC) is:

**$RON (MZC) = P - V = 0.241 - (-0.183) = 0.424$**



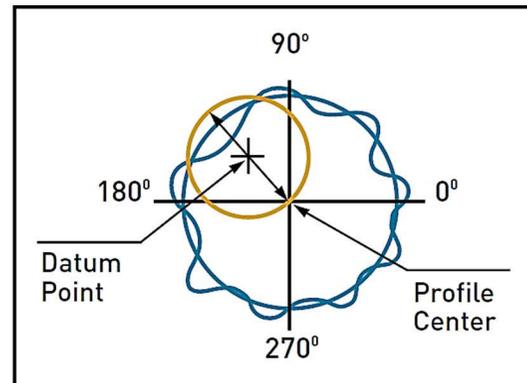
### Eccentricity

- The position of center of profile relative to a datum point.
- Vector quantity with **magnitude and direction**.
- Magnitude is the distance from profile center (i.e. center of fitted reference circle) to datum point.
- Direction is an angle from datum.



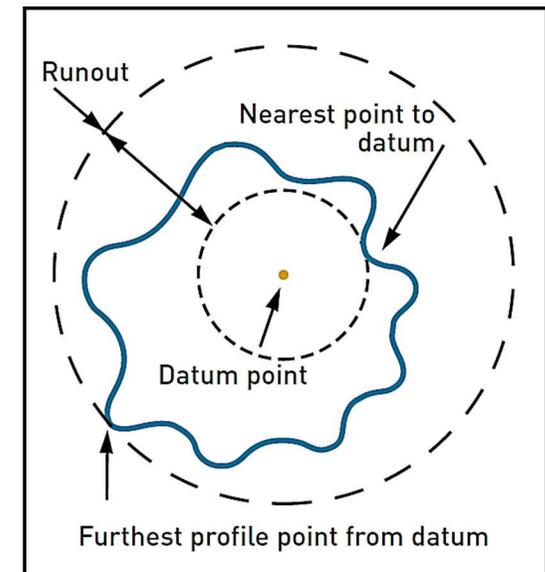
### Concentricity

- The diameter of circle described by profile center when rotated about the datum point.
- **Only magnitude (no direction)**.



### Runout

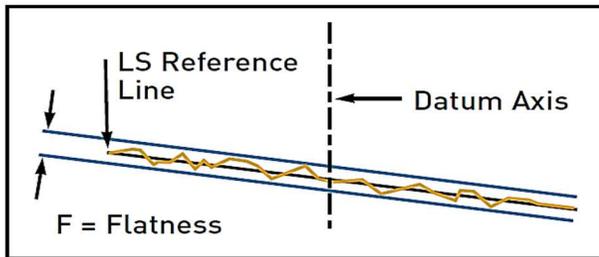
- The radial difference between two concentric circles centered on the datum point that are drawn such that one coincides with the nearest and the other coincides with the farthest point on the profile.
- Combine effect of **form error & concentricity** to give a predicted performance when rotated about a datum.





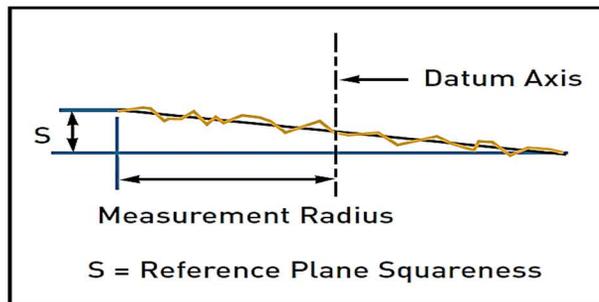
## Flatness

- The peak-to-valley departure from a reference plane.
- Planes of **Least Square** or **Minimum Zone** are used.



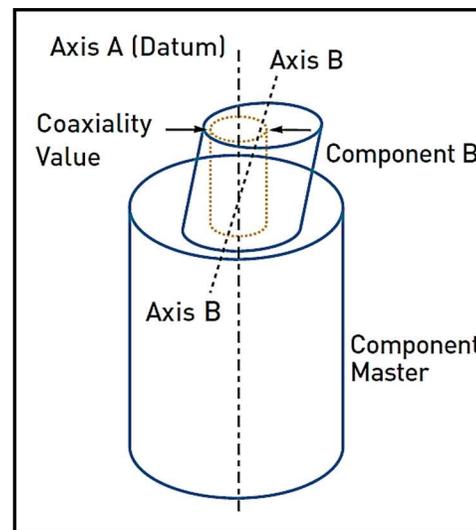
## Squareness (Perpendicularity)

- The minimum axial separation of two parallel planes normal to the reference axis, which totally encloses the reference plane.
- Planes of **Least Square** or **Minimum Zone** are used.



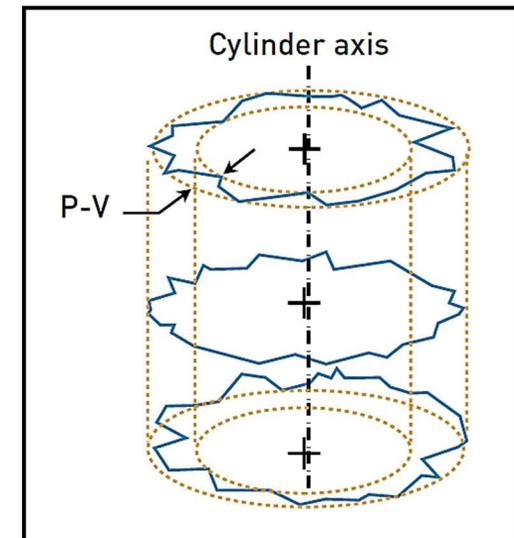
## Coaxiality

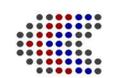
- The diameter of a cylinder that is coaxial with the datum axis, and just encloses the axis of cylinder referred for coaxiality evaluation.



## Cylindricity

- The minimum radial separation of two cylinders that are coaxial with the datum axis.
- Cylinders of **Least Square**, **Min. Zone**, **Max. Inscribed** or **Min. Circumscribed** are used.





		Laser Interferometry	Autocollimator	Laser Alignment	Electronic Level & Clinometer	Dial Indicator (Circular Tracing)	TalyMaster *
Flatness		✓			✓		✓
Straightness			✓	✓			✓
Parallelism			✓	✓			✓
Squareness			✓	✓	✓		✓
Roundness						✓	✓
Concentricity							✓
Cylindricity							✓
Coaxiality							✓
Eccentricity							✓
Runout							✓

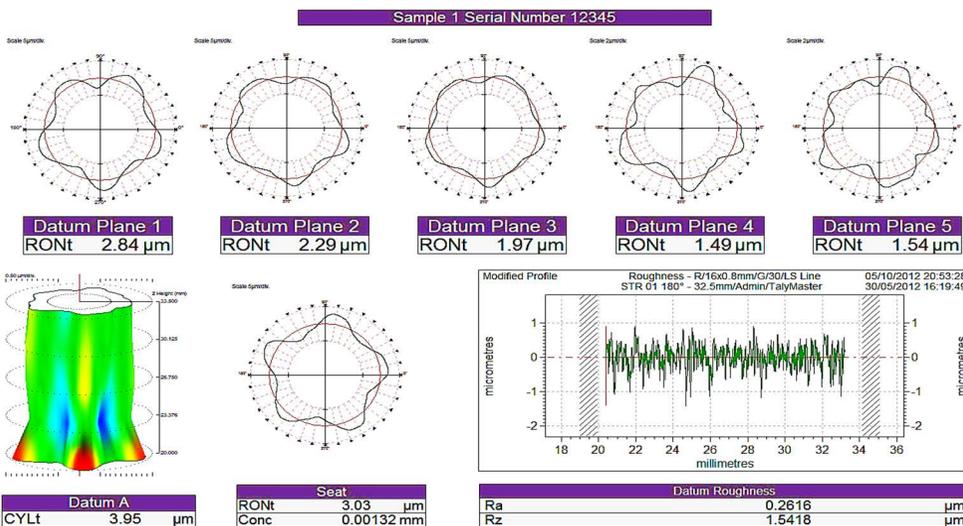
\* Multi-featured & multi-part inspection/measurement of contours, form tolerances, surface texture ([www.taylor-hobson.com](http://www.taylor-hobson.com))

## TalyMaster: All-in-One Measurement

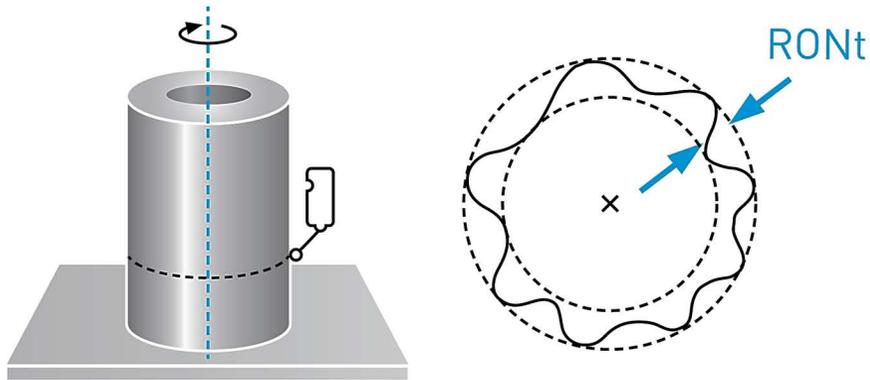
- Multi-featured & multi-part measurement system.
- Can be used for rotational & rectilinear measurements.
- Integrated software for rapid & precise analysis of results.
- Fully automated & high-precision measurement/inspection of:
  - Contours (length, diameter, angle, etc.)
  - Form Errors (roundness, flatness, runout, etc.)
  - Surface Texture (primary, waviness, roughness)



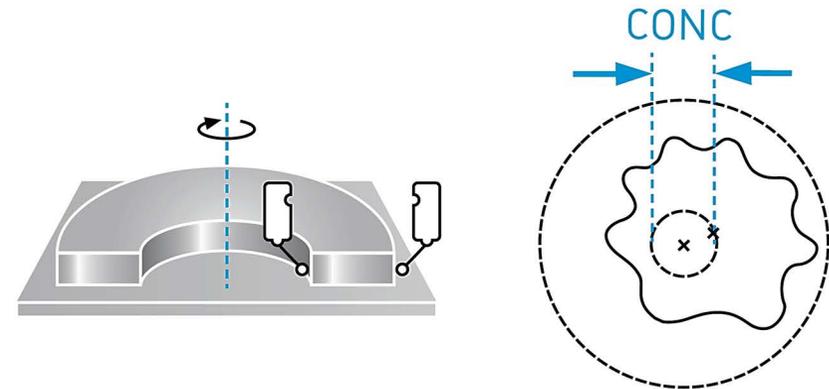
Courtesy of Photos & Info: [taylor-hobson.com](http://taylor-hobson.com)



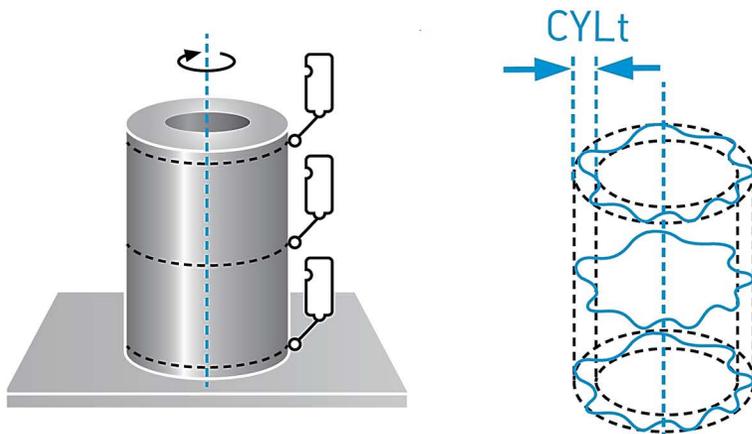
**Roundness (Rotational)**



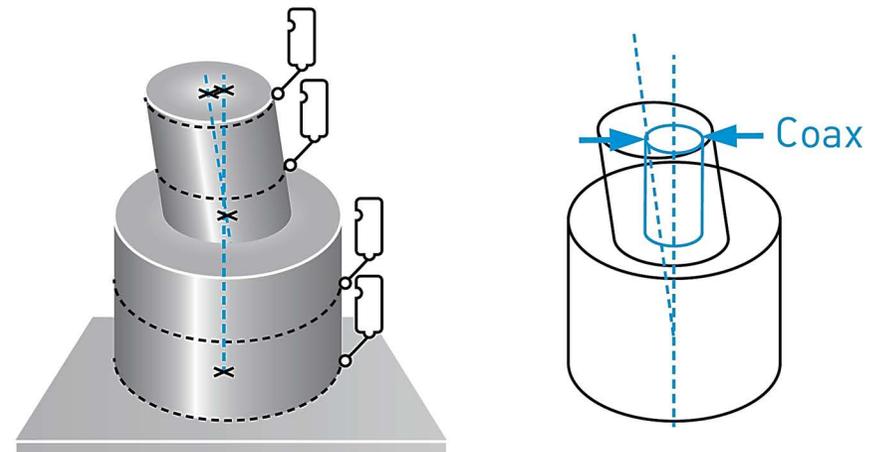
**Concentricity (Rotational)**



**Cylindricity (Rotational)**

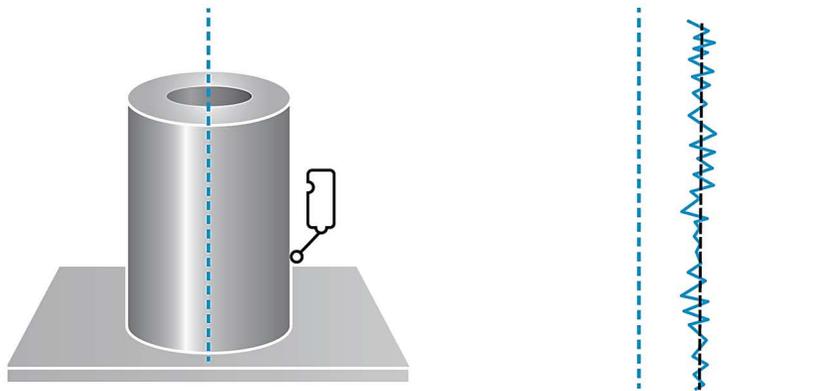


**Coaxiality (Rectilinear)**

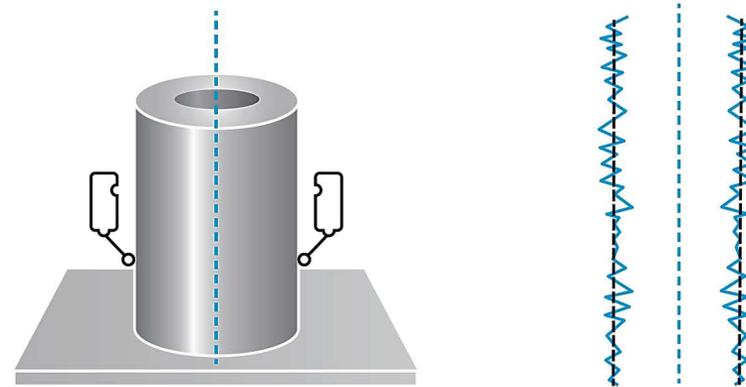




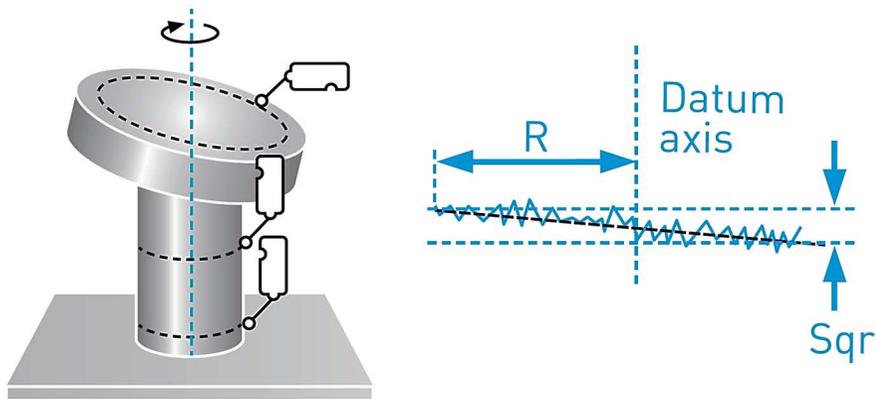
**Straightness (Rectilinear)**



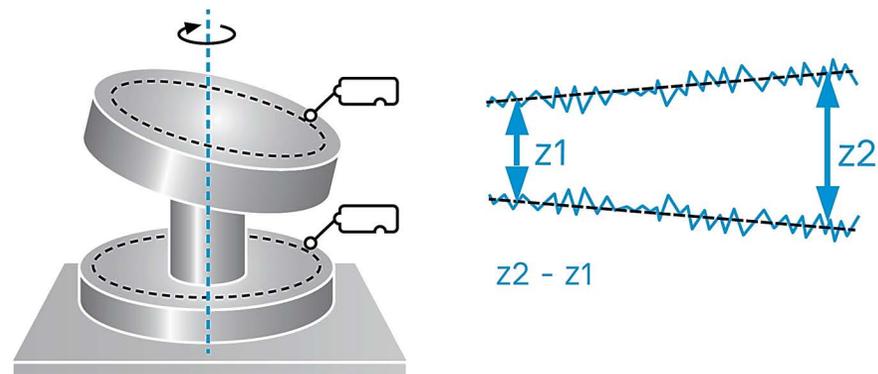
**Parallelism (Rectilinear)**

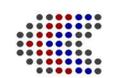


**Squareness (Rotational)**

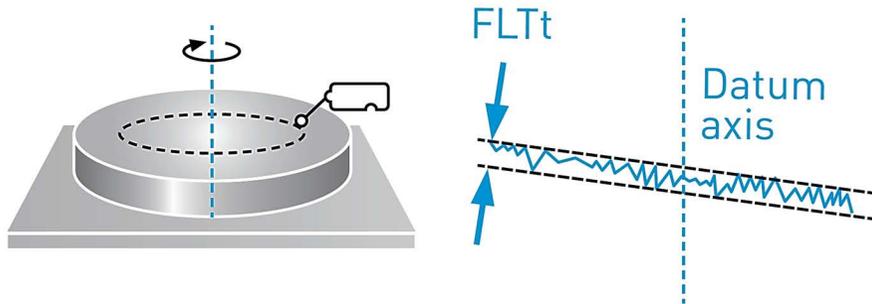


**Parallelism (Rotational)**

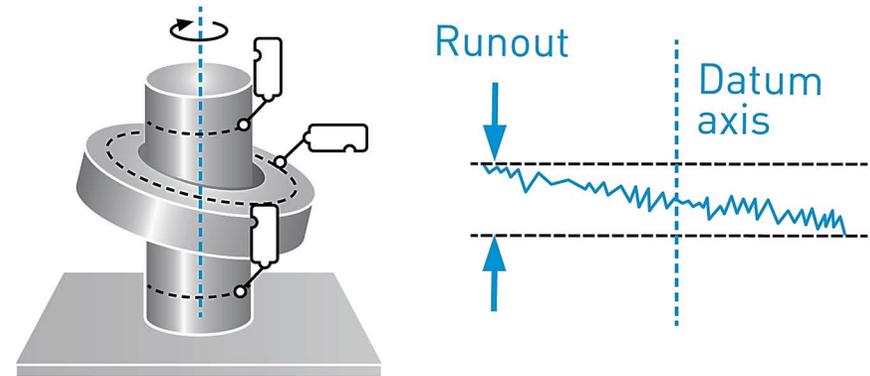




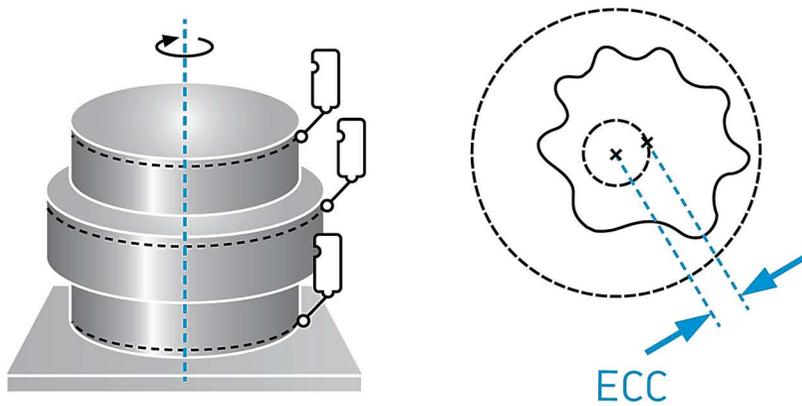
**Flatness (Rotational)**



**Axial Runout (Rotational)**



**Eccentricity (Rotational)**



**Radial Runout (Rotational)**

