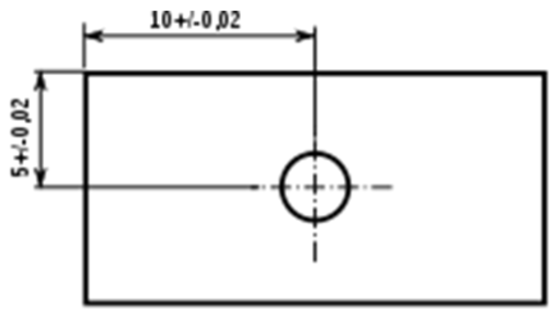
GEOMETRIC TOLERANCING

Geometric dimensioning and tolerancing (GD&T) is a symbolic language used on engineering drawings and computer generated three-dimensional solid models for explicitly describing nominal geometry and its allowable variation.

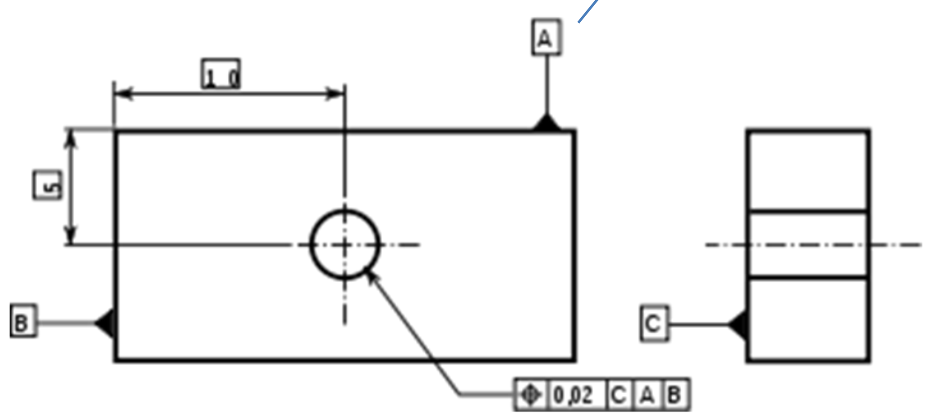
TYPES OF CONTROL NEEDED FOR PARTS

POSITION OF FEATURES WITHIN PARTS
(linear dimensions and diameters)
Such as holes



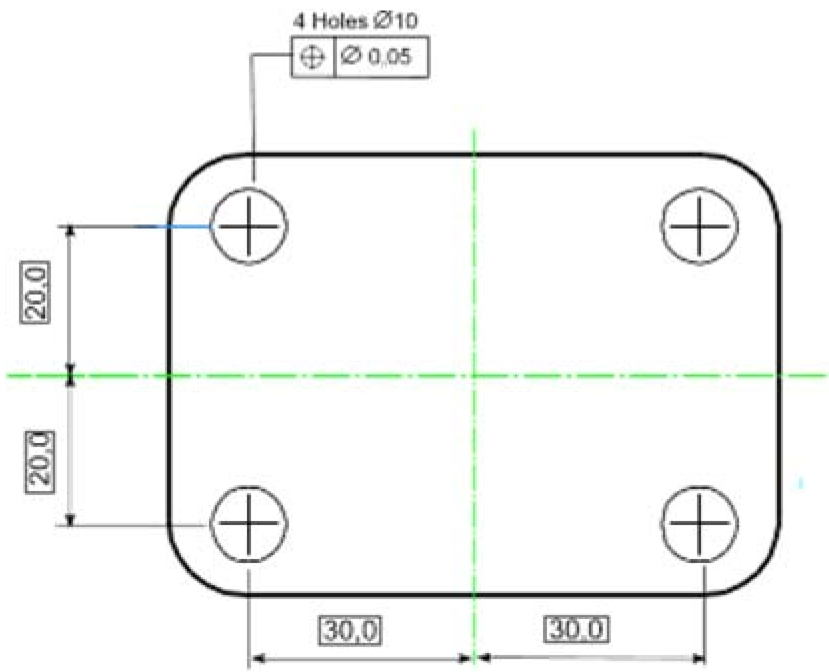
FORM or SHAPE of FEATURES
Such as straightness, angularity or parallelism of spesific portions of the part

A datum is a feature of a part that acts as a master reference used to locate other features of the part. A datum can be a point, a line, or a plane

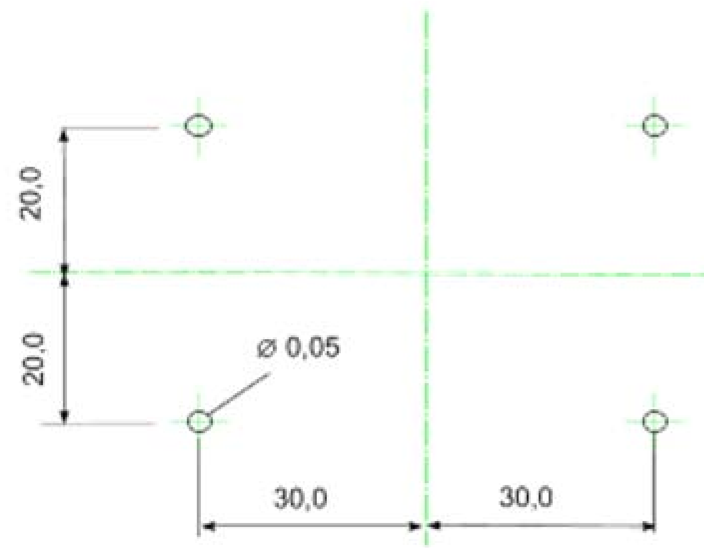


Theoretically exact dimensions

The dimension determining the theoretically exact form, orientation or position respectively must not be toleranced. The corresponding actual dimensions may only vary by the tolerances of form, orientation or position specified within the tolerance frame. This is illustrated in the figure below



Dimension



Requirement - The axes of the four holes to be contained within the cylinderical tolerance zones each 0,05mm dia.

Type of tolerance	Geometric characteristics	Symbol
Form	Straightness	⏤
Form	Flatness	⏥
Form	Circularity	○
Form	Cylindricity	⌭
Profile	Profile of a line	⌒
Profile	Profile of a surface	⌓
Orientation	Perpendicularity	⊥
Orientation	Angularity	∠
Orientation	Parallelism	∥
Location	Symmetry	⌯
Location	Positional tolerance	⌖
Location	Concentricity	◎
Runout	Circular runout	↗
Runout	Total runout	⌰

Tolerances are given along with modifiers

Symbol	Modifier
F	Free state
L	Least material condition (LMC)
M	Maximum material condition (MMC)
P	Projected tolerance zone

LMC: Least material condition of a component at that limit of size where the material of the feature is at its minimum everywhere, e.g. maximum hole diameter and minimum shaft diameter.

LMS: The dimension defining the least material condition of a feature.

LMVS :The size generated by the collective effect of the least material size, LMS of a feature and the geometrical tolerance (form, orientation or location).

LMVC: Least material virtual condition. The condition of a component of least material virtual size.

LMR: Least material requirement, defining a geometrical feature of the same type and of perfect form, with a given dimension equal to LMVS, which limits a feature on the inside of the material e.g wall thickness.

MMS :Maximum material size; The size of the maximum material condition.

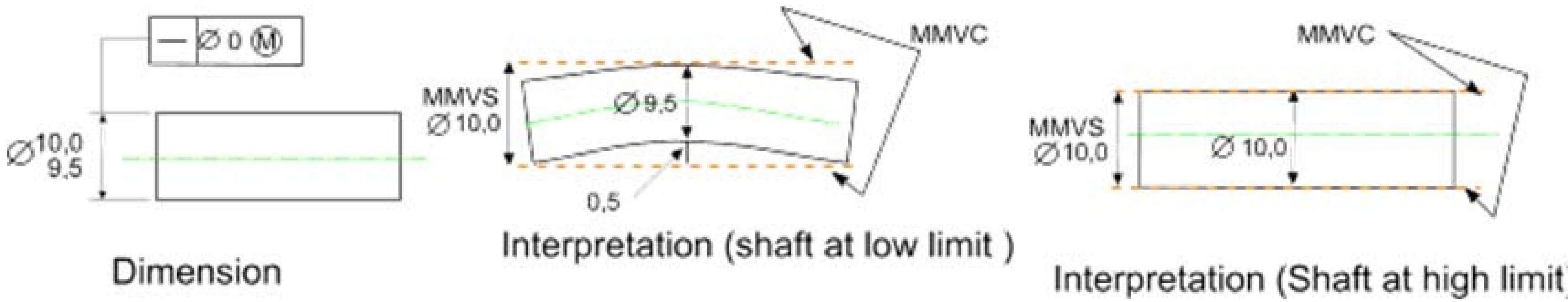
MMVC: Maximum material virtual condition, is a perfect form condition of the feature.

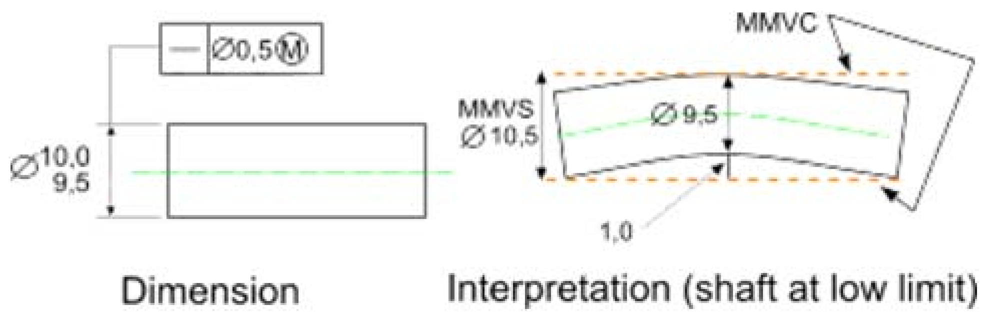
MMVS: Maximum material virtual size, is the size generated by the collective effect of the maximum material size, MMS, of a feature of size and the geometrical tolerance (form, orientation or location) given for the derived feature of the same feature of size. Maximum material virtual size, MMVS, is a parameter for size used as a numerical value connected to MMVC.

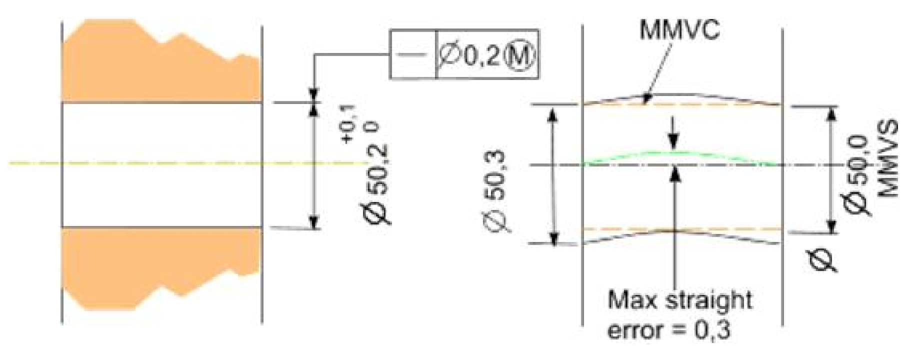
PJ: Projected tolerance zone. A geometric tolerance zone which projects from an actual design features such as a hole

Maximum Material Requirement Ⓜ

The minimum assembly clearance occurs when each of the mating components is at its maximum material size (e.g. the largest pin size and the smallest hole size) it additionally occurs when the geometrical deviations e.g. the form, orientation and location deviations of the components size and their derived features centre line surface form are also at their maximum.

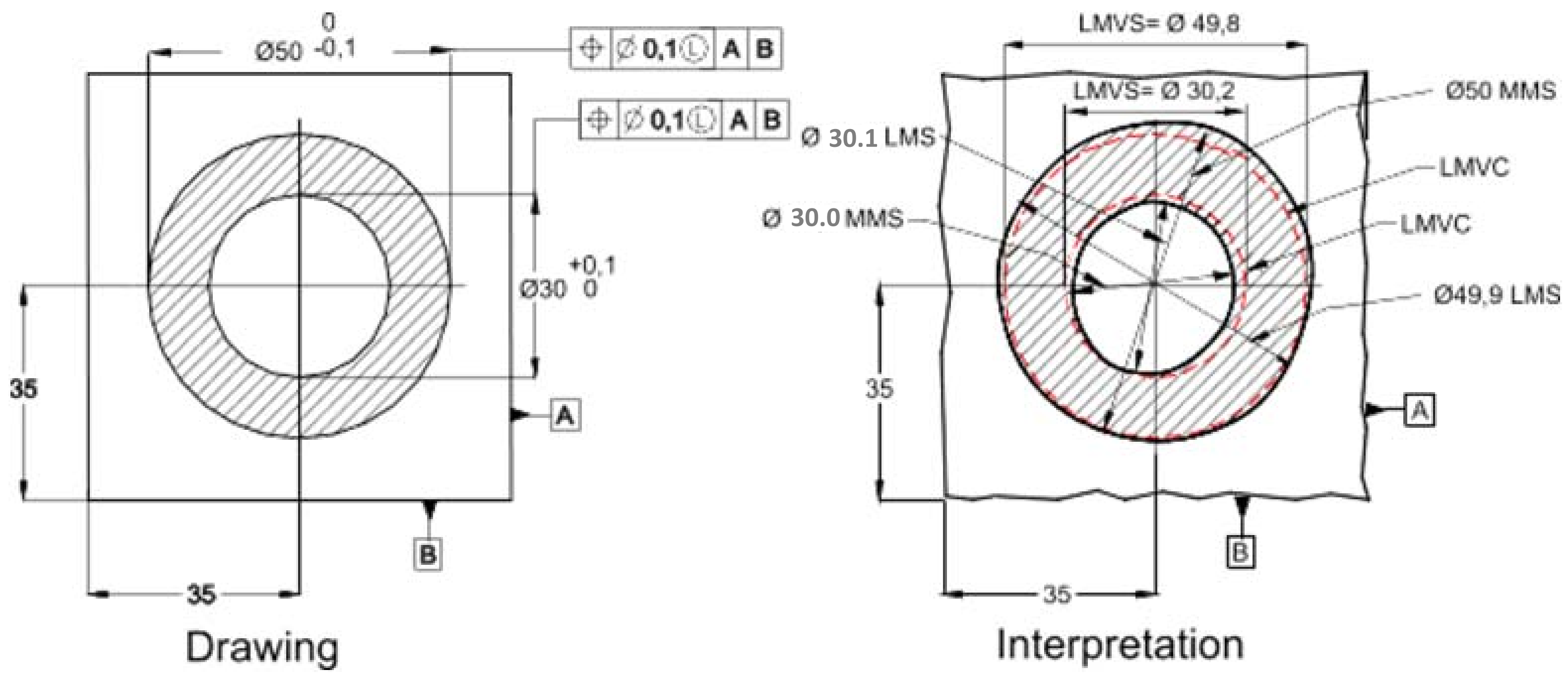






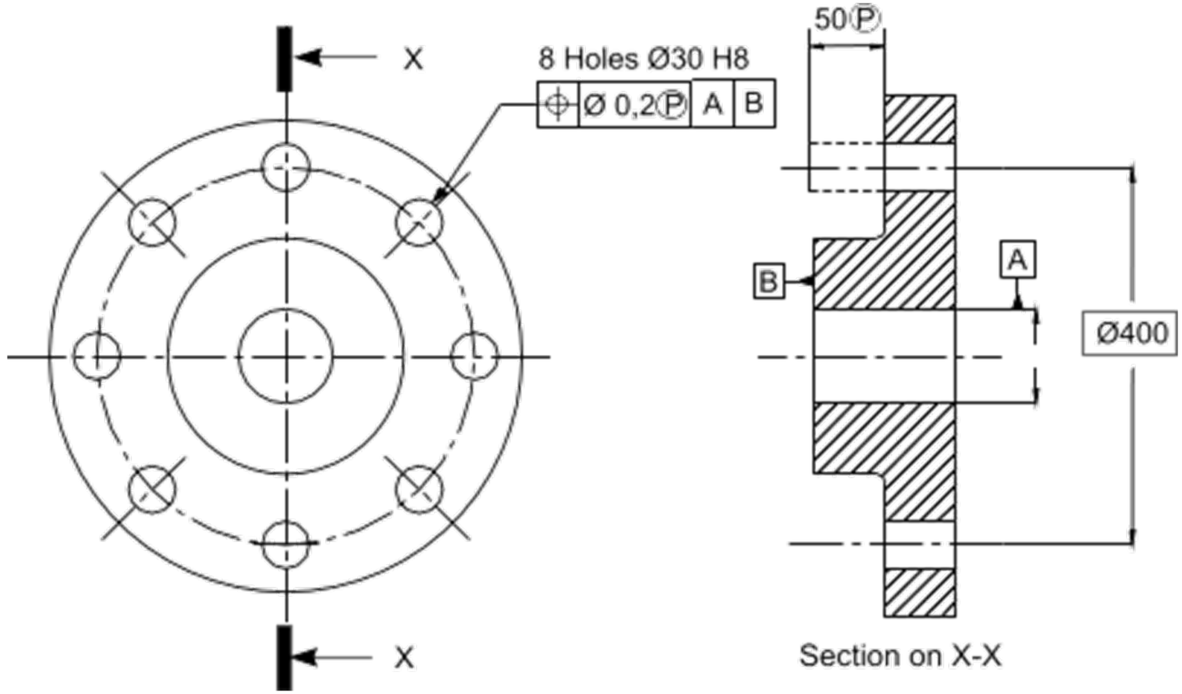
Least Material Requirement Ⓛ

Assembly clearance are maximized when the sizes of the assembled features of size are at least material size e.g. the smallest shaft size together with the largest hole size and when the geometrical variations e.g. the form, orientation and location deviation and their derived features are at zero.



Projected tolerance zones Ⓟ

In some cases, the tolerance of orientation and position shall apply not to the feature itself but to the external projection of it. Such projected tolerance zones shall be indicated by the symbol P (in circle)



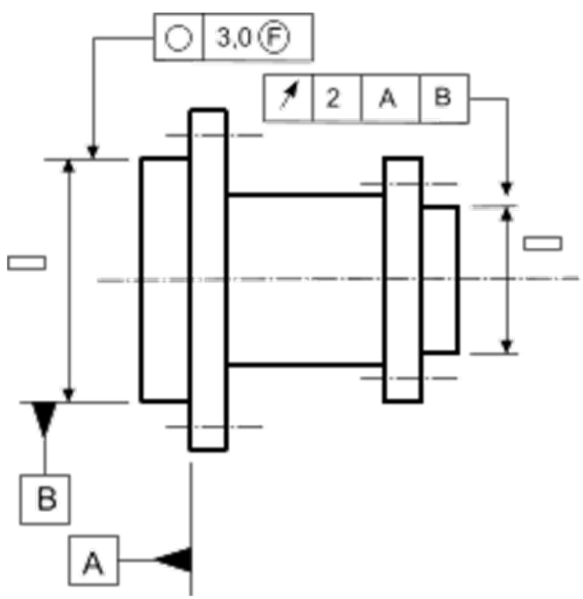
Free State Ⓕ

This condition applies to parts made of elastic or plastic materials or of thin flexible materials.

The free state condition of a part: it is not restrained and subjected only to the force of gravity.

The distortion of such a part should be such that it will be brought within the specified tolerances for verification at assembly or by assembly using forces expected under the normal assembly conditions.

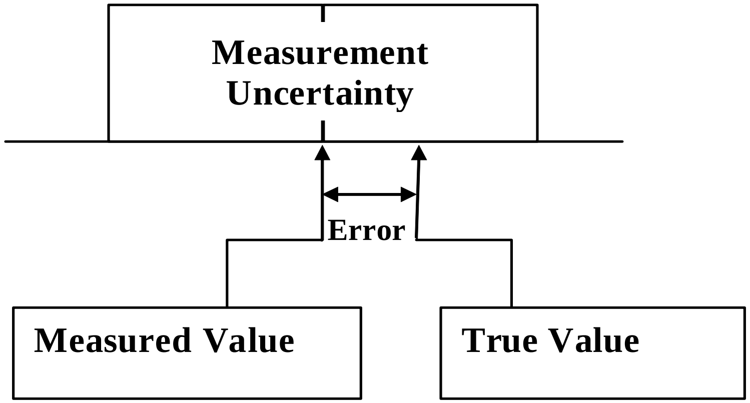
An example of how a free state geometrical tolerance is applied is provided in the figure below. The interpretation of this figure is that the tolerances followed by shall apply in the free state. The other tolerances apply in the assembled condition



BS ISO 10579 -NR

Restrained condition: The surface identified as datum A is mounted (with 24 bolts M6 tightened to a torque of 9N.m to 15 N.m and the feature identified a datum B is restrained at the corresponding maximum material limit.

Measurement Error and Uncertainty



The difference between *measurement error* and *measurement uncertainty* should be explained clearly to evaluate the measurement results correctly. The term **measurement error** means the difference between the "true value" and the value found by a measurement.

According to the Guidance to Expression of Uncertainty in Measurement (GUM), measurement errors are distinguished as random and systematic errors.

Random Error

Random error in measurement *typically arises from unpredictable variations* of influence quantities. These random effects under apparently equal condition at a given position give rise to variations in repeated observations of the measurand. *Although it is not possible to compensate for the random error of a measurement result, it can usually be reduced by increasing the number of observations and only be expressed statistically*. Random errors include: positioning and allignment errors, non-determinable fluctiations in ambient conditions, transient fluctiations in the friction in the instrument and operator errors such as reading errors.

Systematic Error

Systematic error, like random error, can not be eliminated but it can be reduced. If a systematic error arises from *a recognized effect of an influence quantity on a measurement result, hereafter termed a systematic effect*, the effect can be quantified and *a correction* or *correction factor* can be applied to compensate for the effect. Recognized systematic errors can generally be correlated with position along an axis and can be corrected for if the relative accompanying random error is small enough. *Systematic errors can often be compensated to a certain degree using calibration techniques.* Systematic errors include calibration errors and changes in ambient conditions.

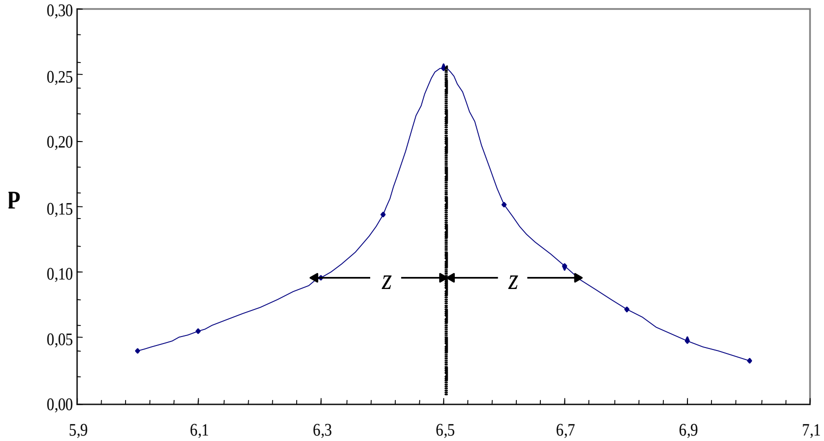
Random errors cannot be compensated for without real time measurement and feedback into correction servo loop. Thus when evaluating the error budget for a machine two distinct sub-budget based on systematic and random errors should be kept.

See ME410 lecture notes for more information about random and systematic errors:
http://www.me.metu.edu.tr/courses/me410/notes/Week3/Week3.PPT

Measurement Uncertainty

The lack of exact knowledge of the value of the measurand explains the uncertainty of the result of a measurement. The result of a measurement after correction for recognized systematic effects is still only an estimate of the measurand's value due to the uncertainty arising from random effects and from imperfect correction of the result for systematic effects.

It is used to describe an interval in which the true value can be expected to lie with a specified level of confidence (p). For example, if u_c is assumed to represent a normal (Gaussian) uncertainty distribution, then a 99.7% confidence interval corresponds to using an expanded uncertainty obtained with k_p = 3



Type A Uncertainty

$$U_p = k_p \times u_c$$

$$y - U_p \le Y \le y + U_p \qquad (8)$$

$u_c \rightarrow$ Combined Standart Uncertainty

$U_{95\%} \rightarrow$ Expanded Uncertainty ($k_{95\%} = 2$)

$U_{99\%} \rightarrow$ Expanded Uncertainty ($k_{99\%} = 3$)

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-z^2/2}, \quad z = \frac{x-\mu}{\sigma}$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu)} = \text{Standart Deviation}$$

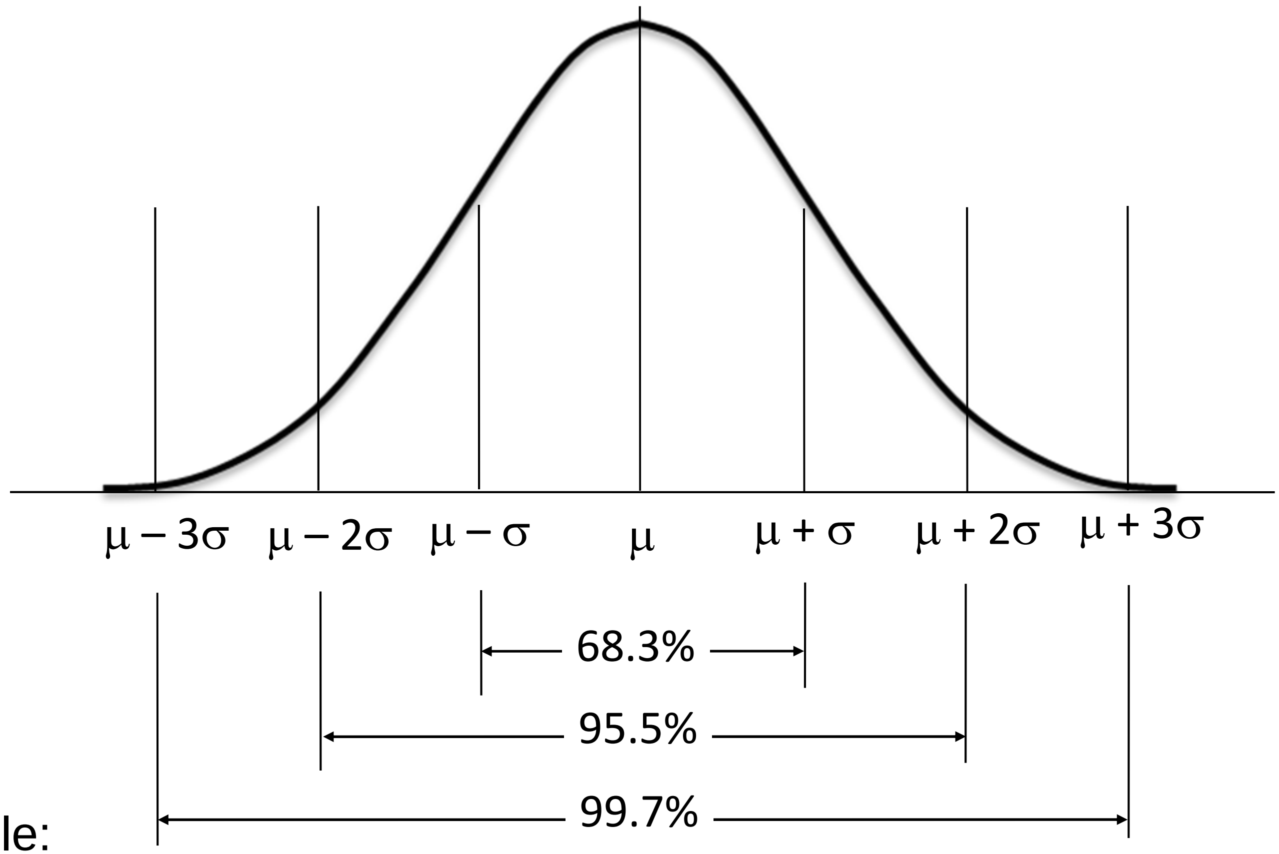
$$\text{Uncertainty} = u(x) = \frac{\sigma}{\sqrt{n}}$$

$$\mu = \frac{\sum x_i}{n} = \text{Arithmetic Mean of Repeated Measurements}$$

$n =$ Number of Repeated Measurements

$\sigma =$ Standart Deviation

Measurement Uncertainty (Continued)



A generally accepted rule:

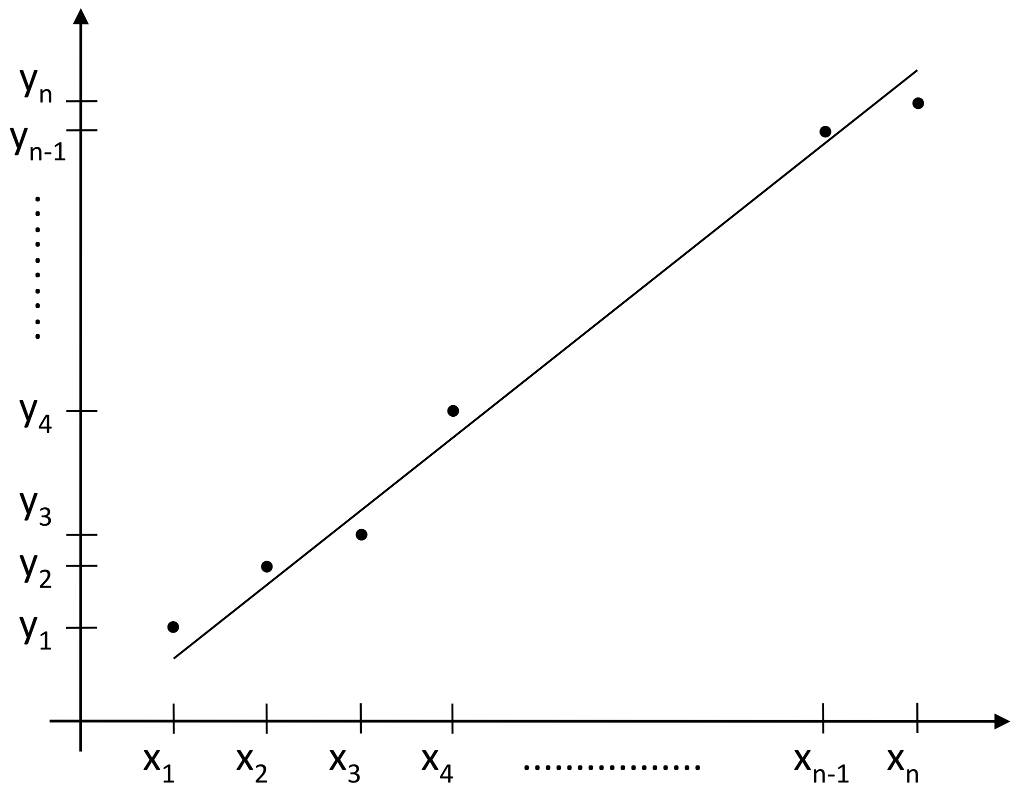
Measuring accuracy should be within the 10% of the workpiece tolerance. Suppose that standart deviation in the dimensions of products is σ_p due to random causes only. Then in order to have at least 99.7% of the products acceptable, the manufacturing tolerance should be $T \geq 6\sigma_p$.

Least Square Principle

Most probable value of the observed quantities is the one which renders sum of the squares of residual errors a minimum.

- Single variable $\Rightarrow$ arithmetic mean: $X = \Sigma x_i/n$

- Two dependent variables $\Rightarrow$ ex: straight line Y = aX + b



$$\bar{x} = \frac{\sum x_i}{n}, \ \bar{y} = \frac{\sum y_i}{n}$$

$$a = \frac{\sum \left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sum \left(x_i - \bar{x}\right)^2}, \ b = \bar{y} - a\bar{x}$$

Uncertainty Source Chart