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Determination of tolerances
Position and shape tolerances
Tolerance analysis

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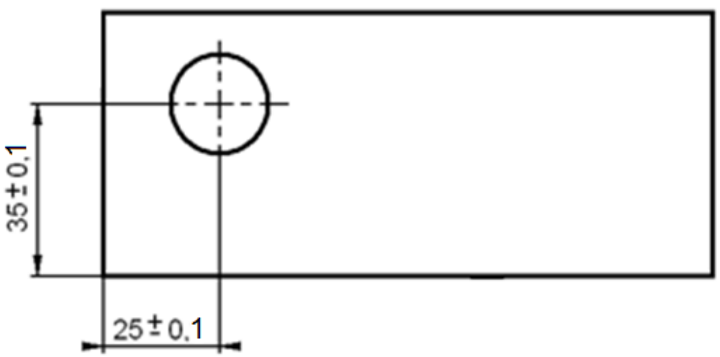
Geometrical and positional lolerances in drawing

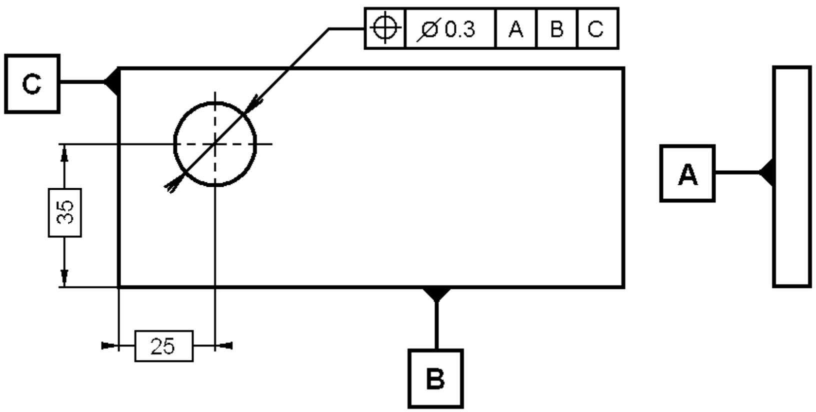
Provideing of shape and position tolerances are determine by the standard **EN ISO 1101**.

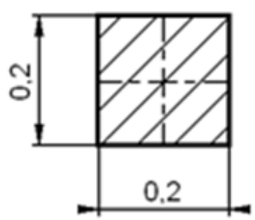
General tolerances are determine by the standard **ISO 2768**

Datum reference frame

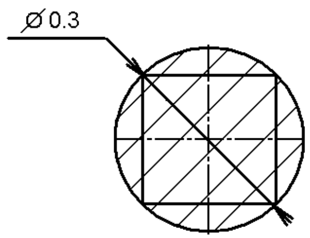
Conversion of Position (Cylindrical) Tolerance Zones to/from Coordinate Tolerance Zones







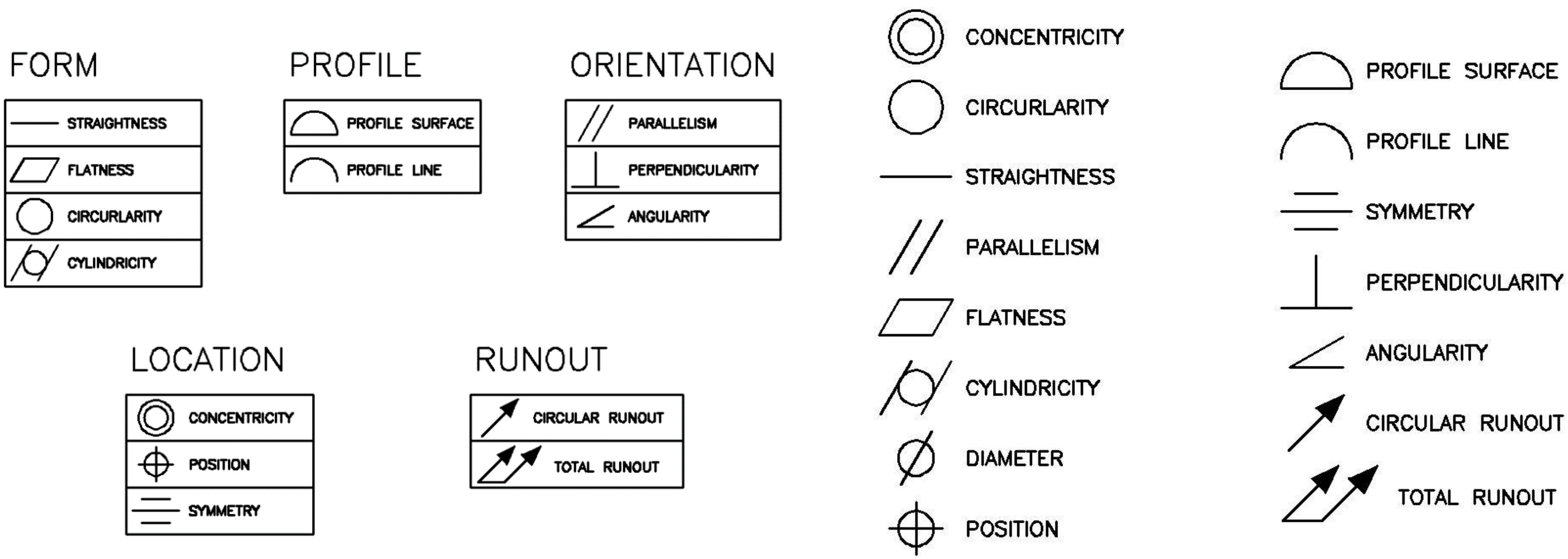
tolerance zone



tolerance zone

http://www.gdandtbasics.com/gdt-training/

Position and shape tolerances



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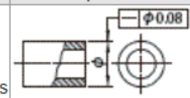
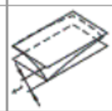
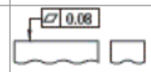
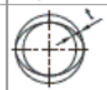
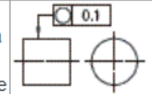
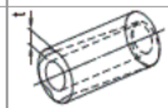
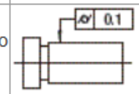
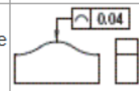
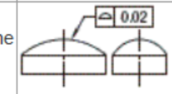
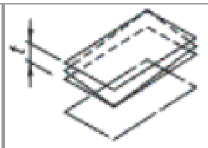
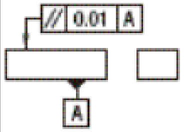
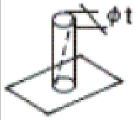
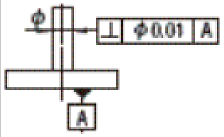
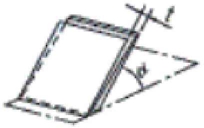
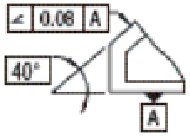
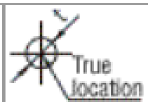
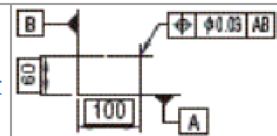
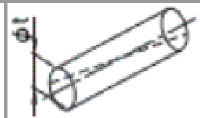
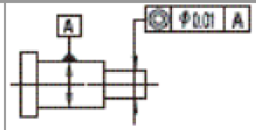
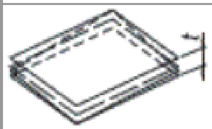
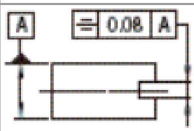
Position and shape tolerance

Type of tolerance		Symbol	Definition of tolerance range		Examples of drawings and their interpretations	
Shape tolerances	Straightness tolerance	—		If the symbol φ is attached before the numerical value that indicates the tolerance range, this tolerance range is the range within a cylinder of diameter t.		If a tolerance frame is connected to a dimension that indicates the diameter of a cylinder, the axis line of the cylinder shall be contained within a cylinder of 0.08mm diameter.
	Flatness tolerance	▱		The tolerance range is the area between two parallel planes separated by distance t.		This surface shall be contained within two parallel planes separated by 0.08mm.
	Circularity tolerance	○		The tolerance range in the considered plane is the area between two concentric circles separated by distance t.		The circumference in any section normal to the axis shall be contained between two concentric circles separated by 0.1mm on the same plane.
	Cylindricity tolerance	⌭		The tolerance range is the range contained between two coaxial cylinder surfaces separated by distance t.		The considered surface shall be contained between two coaxial cylinder surfaces separated by 0.1mm.
	Profile tolerance of line	⌒		The tolerance range is the range contained between the two envelope curves formed by a circle with diameter t, the centre of which is situated on the theoretically correct profile curve.		In any cross-section parallel to the projection plane, the considered profile shall be contained between the two envelope curves formed by a 0.04mm diameter circle, the centre of which is situated on the theoretically correct profile curve.
	Profile tolerance of surface	⌓		The tolerance range is the range contained between the two enveloping surfaces formed by a sphere with diameter t, the centre of which is situated on the theoretically correct profile surface.		The considered surface shall be contained between the two enveloping surfaces formed by a 0.02mm diameter sphere, the centre of which is situated on the surface containing the theoretically correct profile.

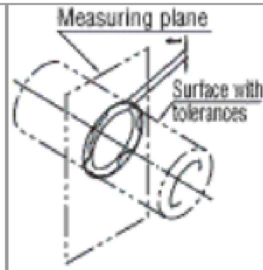
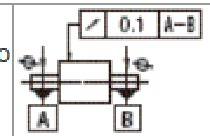
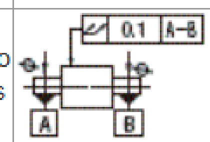
Position and shape tolerance

Orientation tolerances	Parallelism tolerance	//		The tolerance range is the range contained between two planes parallel to the datum plane and separated by distance t.		The surface shown by the arrow of the indicator line shall be contained between two planes parallel to the datum plane A and separated by 0.01mm in the direction of the arrow of the indicator line.
	Perpendicularity tolerance	⊥		If symbol φ is attached before the numerical value indicating the tolerance range, this tolerance range is the range contained within a cylinder of diameter t that is perpendicular to the datum plane.		The axis of the cylinder shown by the arrow of the indicator line shall be contained within a cylinder of diameter 0.01mm that is perpendicular to the datum plane A.
	Angularity tolerance	∠		The tolerance range is the range contained between two parallel planes inclined at a specified angle to the datum plane and separated from each other by distance t.		The surface shown by the arrow of the indicator line shall be contained between two parallel planes which are inclined with theoretical exactness by 40 degrees to the datum plane A, and which are separated by 0.08mm in the direction of the arrow of the leader line.

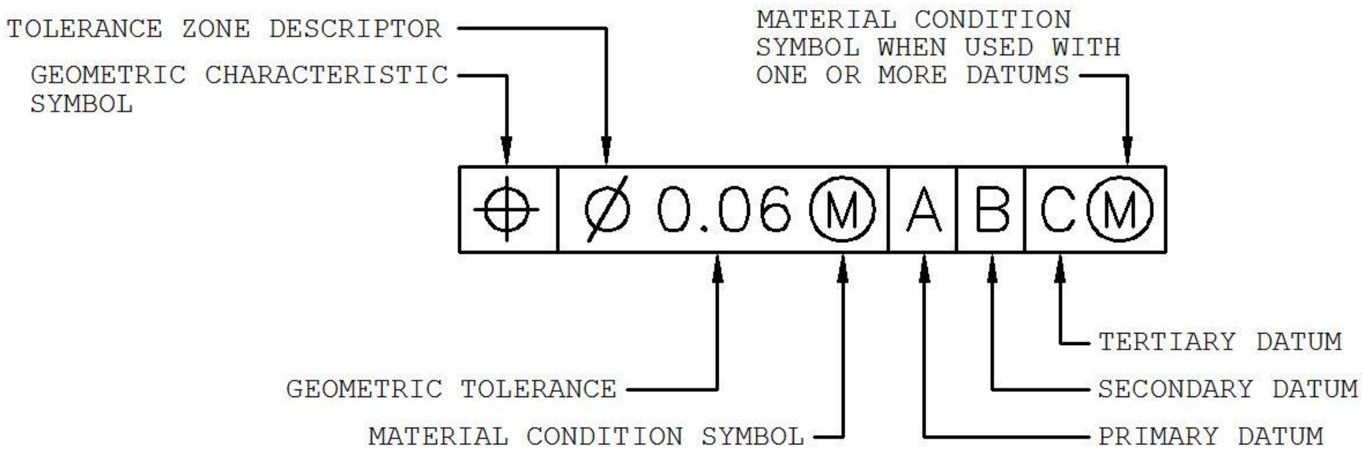
Position and shape tolerance

Positional tolerances	Positional tolerance	⌖		The tolerance range is the range contained within a circle or sphere of diameter t with its centre situated at the theoretically exact location of the considered point (hereafter referred to as the "true location").		The point shown by the indicator line shall be contained within a 0.03mm diameter circle with its centre situated at the true location 60mm from datum line A and 100mm from datum line B.
	Coaxiality tolerance or concentricity tolerance	◎		If symbol φ is attached before the numerical value that indicates the tolerance, the tolerance range is the range within a cylinder of diameter t whose axis matches the datum axis line.		The axis of the cylinder shown by the arrow of the indicator line shall be contained within a cylinder of diameter 0.01mm whose axis matches datum axis line A.
	Symmetry	⌯		The tolerance range is the range contained between two parallel planes separated by distance t and arranged symmetrically with respect to the datum centre plane.		The centre plane shown by the arrow of the indicator line shall be contained between two parallel planes separated by 0.08mm and arranged symmetrically with respect to the datum centre plane A.

Position and shape tolerance

Run-out tolerances	Circular run-out tolerance	↗		The tolerance range is the range contained between two concentric circles separated in the axial direction by distance t and the centres of which are situated on the datum axis line on any measuring plane normal to the datum axis line.		The radial run-out of the cylinder surface shown by the arrow of the indicator line shall not exceed 0.1mm on any measuring plane normal to the datum axis line when the cylinder is rotated by one rotation about the datum axis line A-B.
	Total run-out tolerance	⌰		The tolerance range is the range contained between two coaxial cylinders having axes agreeing with the datum axis line and separated from each other by distance t in the radial direction.		The total radial run-out of the cylinder surface shown by the arrow of the indicator line shall not exceed 0.1mm at any point on the cylinder surface when the cylindrical part is rotated about the datum axis line A-B.

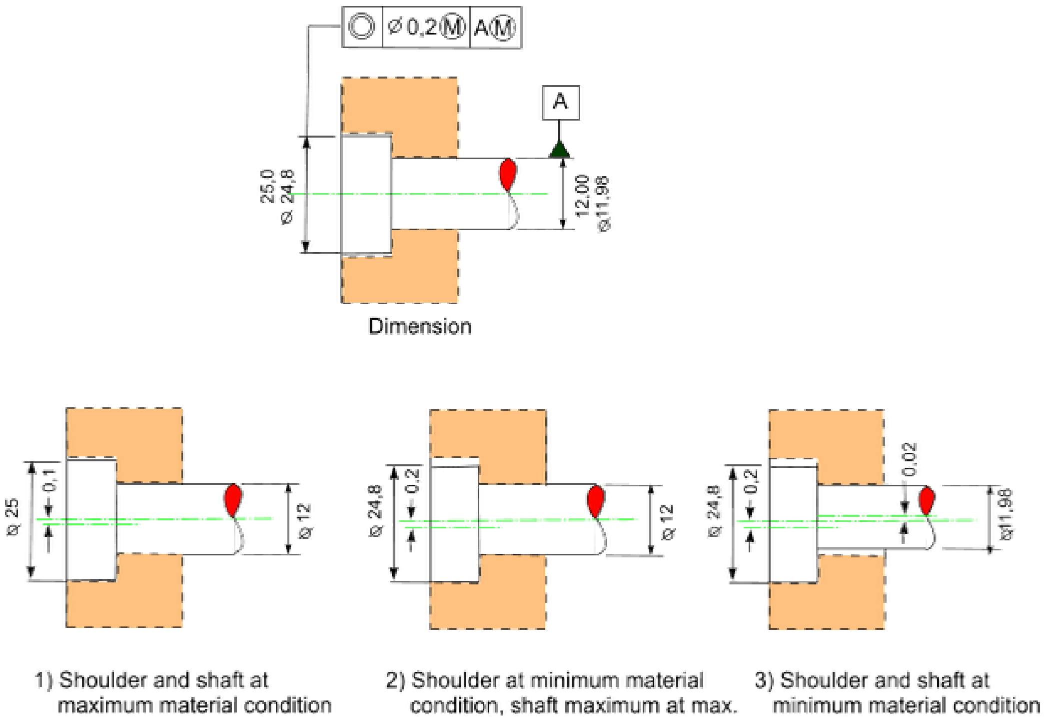
Position and shape tolerance



Geometric Characteristic Symbols

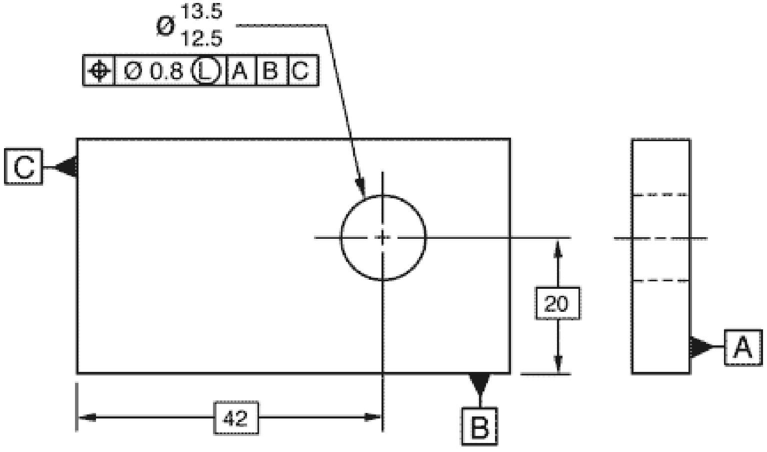
TERM	ABBREVIATION	SYMBOL
MAXIMUM MATERIAL CONDITION	MMC	Ⓜ
LEAST MATERIAL CONDITION	LMC	Ⓛ
PROJECTED TOLERANCE ZONE	—	Ⓟ
TANGENT PLANE	—	Ⓣ
DIAMETER	DIA	⌀
RADIUS	—	R
CONTROLLED RADIUS	—	CR
REFERENCE	—	( )

An example of the application of maximum material requirement to coaxiality is illustrated in the figure below



An example of the application of minimum material requirement

The feature control frame indicates that the 0.8 tolerance applies when the hole is at its least material condition, or at size 13.5. At size 12.5, the available geometric tolerance would be 0.8 “stated tolerance” + (13.5-12.5 or 1.0 “bonus” tolerance) = 1.8 mm.



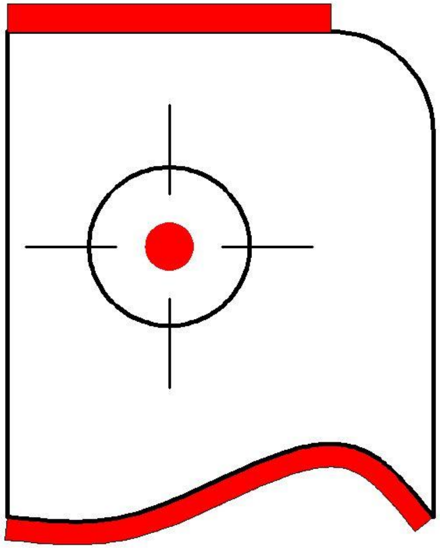
Geometric Characteristic Symbols

Tolerance Type	Geometric Charac-teristics	Symbol	Applied To		Datum Reference Required	Use L or M Material Condition	Gages Used
			Feature Surface	Feature of Size Dim.			
Form	Straightness	—	YES	YES	NO	YES	YES***
	Flatness	⏥		NO		NO	NO
	Circularity	○					
	Cylindricity	⌭					
Location	Positional Tolerance	⌖	NO	YES	YES	YES	YES***
	Concentricity	◎				NO	NO
	Symmetry	⌯					
Orientation	Perpendicularity	⊥	YES	YES	YES	YES	YES***
	Parallelism	//					
	Angularity	∠					
Profile	Profile of a Surface	⌓	YES	NO	YES*	YES**	NO
	Profile of a Line	⌒					
Runout	Circular Runout	↗	YES	YES	YES	NO	NO
	Total Runout	⌰					

Tolerance Zone

If the zone is identified as a diameter, the zone is a cylinder.

If there is no zone description, it is parallel to the surface or a uniform boundary in the shape of the desired form.



Tolerance analysis

Is the general term for activities **related to the study of accumulated variation in mechanical parts and assemblies**. Its methods may be used on other types of systems subject to accumulated variation, such as mechanical and electrical systems. **Engineers analyze tolerances for the purpose of evaluating geometric dimensioning and tolerancing.**

The choice of method of calculation of tolerances and limit deviations of dimensional chain components affects **manufacturing accuracy** and **assembly interchangeability of components.** Therefore, **economy of production and operation depends on it**. To solve tolerance relations in dimensional chains, engineering practice uses **three basic methods**:

- arithmetic method of calculation ***WC***
- statistical method of calculation ***RSS***
- method of group interchangeability

Other tolerance analysis are

- Analysis of a dimensional chain deformed as a result of temperature change.
- Extended statistic analysis of dimensional chain using the "6 Sigma„ method.
- Tolerance analysis of a dimensional chain during selective assembly including optimization of the number of assembled products.

All solved tasks enable work with standardized tolerance values, both in designing and in optimization of the dimensional chain.

Theory

A linear dimensional chain is a set of independent parallel dimensions which continue each other to create a geometrically closed circuit. They can be dimensions specifying **the mutual position of components on one part** (*Fig. 1*) or **dimensions of several parts in an assembly unit** (*Fig. 2*).

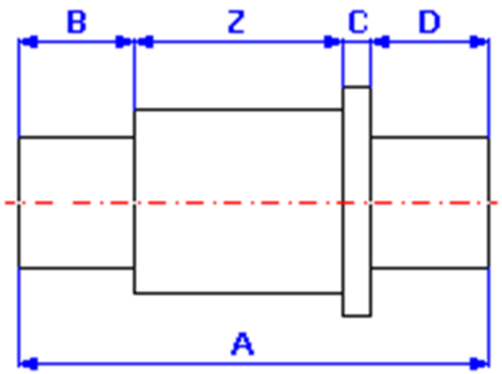


fig. 1

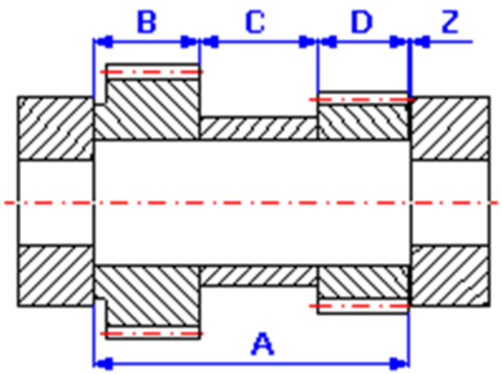


fig. 2

Theory

A dimensional chain consists of **separate partial components** (input dimensions) and ends with a **closed component** (resulting dimension). Partial components (A, B, C,…) are dimensions either directly dimensioned in the drawing or following from previous manufacturing, possibly assembly operations. The closed component (Z) in the given chain represents the resulting manufacturing or assembly dimension, which is the result of combining partial dimensions as a scaled manufacturing dimension, possibly assembly clearance or interference of a component. The size, tolerance and limit deviations of the resulting dimension depend directly on the size and tolerance of partial dimensions. Depending on how the change of partial component affects the change of the closed component, two types of components are distinguished in **dimensional chains**:

- **increasing components** - partial components, the increase of which results in an increase of the closed component
- **decreasing components** - partial components, the increase of which results in a decrease of the closed component

Theory

When solving tolerance relations in dimensional chains, two types of problems occur:

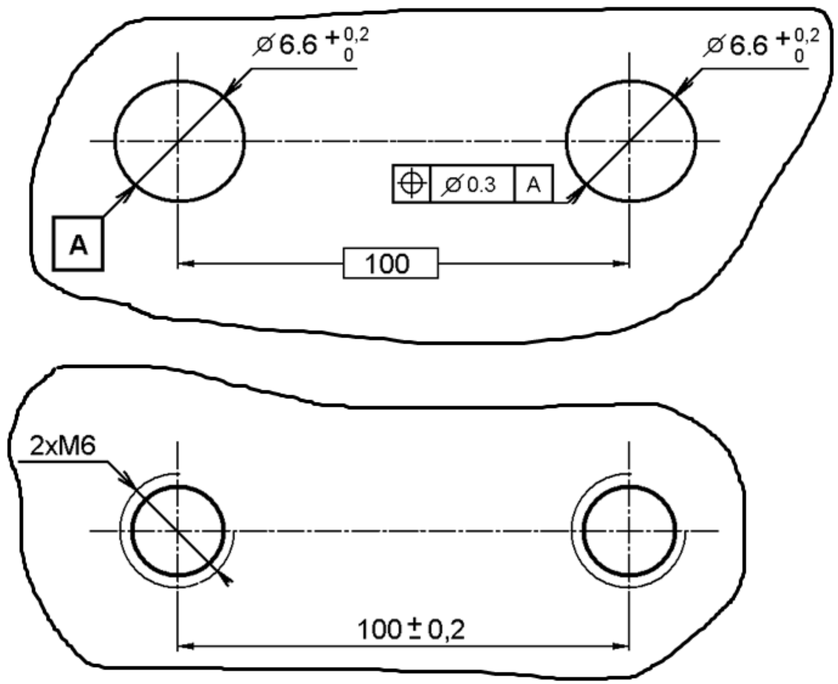
• **Tolerance analysis** - direct tasks, control. Using known limit deviations of all partial components, the limit deviation of the closed component is set. Direct tasks are nambiguous in calculation and are usually used for checking components and assembly units manufactured according to the specific drawing.
• **Tolerance synthesis** - indirect tasks, designing. Using known limit deviations of a closed component given by the functional demands, limit deviations of partial components are designed. Indirect tasks are solved when designing functional groups and assemblies.

Tolerance analysis

Worst-case

Worst-case tolerance analysis is the traditional type of tolerance calculation. The individual variables are placed at their tolerance limits in order to make the measurement as large or as small as possible. This model predicts the maximum expected variation of the measurement. Designing to worst-case tolerance requirements guarantees **100 % of the parts will assemble and function properly**, regardless of the actual component variation. The major drawback is that the worst-case model often requires **very tight individual component tolerances**. The obvious result is expensive manufacturing and inspection processes and/or high scrap rates. Worst-case tolerancing is often required by the customer for critical mechanical interfaces and spare part **replacement interfaces**.

Worst-case – base example



Tolerance analysis

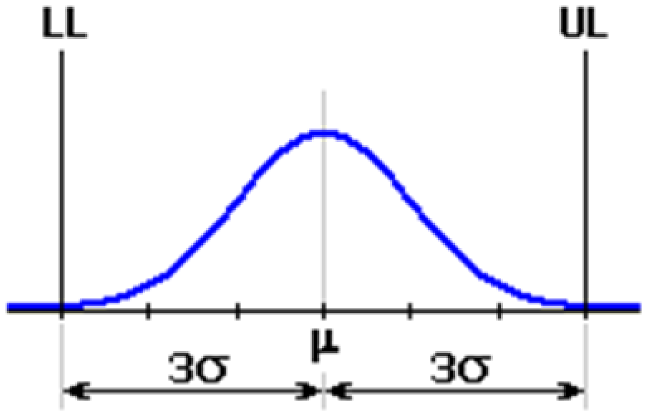
Statistical variation RSS (Root Sum Squares)

The statistical variation analysis model takes advantage of the principles of statistics to relax the component tolerances without sacrificing quality. Each component's variation is modeled as a statistical distribution and these distributions are summed to predict the distribution of the assembly measurement. Thus, statistical variation analysis predicts a distribution that describes the assembly variation, not the extreme values of that variation. This analysis model provides increased design flexibility by allowing the designer to design to any quality level, **not just 100 percent.**

Tolerance analysis

RSS (Root Sum Squares) method

This method of calculation is a traditional as well as the most widespread method of statistical calculation of dimensional chains. The RSS method is based on the assumption that individual partial components are manufactured with the level of process capability (quality) 3σ.



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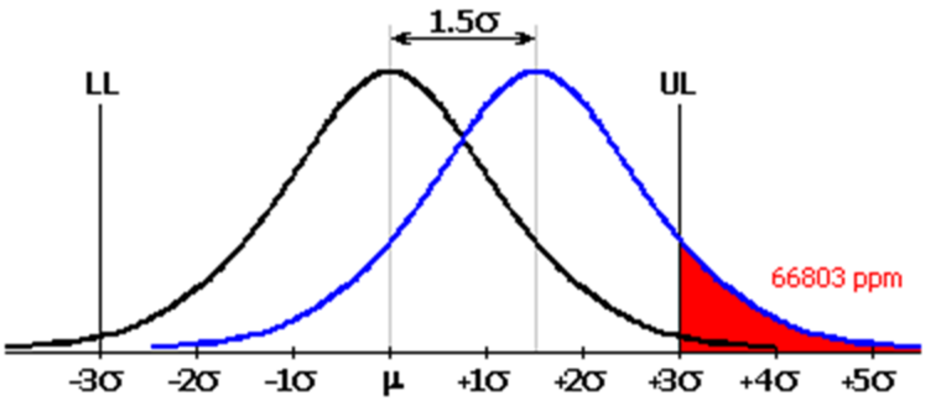
6 Sigma method
(selective assembly)

In general engineering, the manufacturing process was traditionally considered satisfactorily efficient on level 3σ. That means an estimated **2700 rejected products per one million produced**. Although such portion of off-size products seems very good at first sight, it is considered ever more and more insufficient in some spheres of production. Besides, it is almost impossible to keep the mean value of the process characteristic curve exactly in the middle of the tolerance field in the long term.

In case of large production volumes, the mean value of the process characteristic shifts in the course of time due to the influence of various factors (erroneous set-up, wear of tools and jigs, temperature changes, etc.). A shift of 1.5σ from the ideal value is typical. In case of traditionally approached processes with 3σ level of capability, that represents an increase of the off-size product ratio to approx. **67000 per one million produced.**



Group interchangeability method

(selective assembly)

The selective assembly method is used in mass and large-lot production of precise products which do not require working interchangeability of components inside the product. The assembly of the product is preceded by **sorting of individual components into tolerance subsets.** Manufacturing dimensions of components may be prescribed with a larger tolerance. The narrowed resulting dimensional tolerance is achieved by the functional matching (combination) of sorted subsets.

Group interchangeability method

(selective assembly)

The selective assembly method is a very effective method of solving dimensional chains, enabling a substantial increase in manufacturing tolerances of partial components and thus a significant reduction in manufacturing costs. On the other hand, application of this method places **increased demands on product assembly. Operating costs will also increase, as it is usually necessary to replace the whole assembled component in case of wear or damage of a partial component.**

http://nvlpubs.nist.gov/nistpubs/jres/104/4/html/j44mac.htm#c1

http://www.mitcalc.com/doc/tolanalysis1d/help/cz/tolanalysis1dtxt.htm

http://www.tcdcinc.com/media/NADCA%20GD&T.pdf

https://books.google.cz/books?id=tesKAAAAQBAJ&pg=PA502&lpg=PA502&dq=datum+reference+symbol&source=bl&ots=MP-wuCczrI&sig=AkmBHRXbA7wGsbNKDkBIwl3K_Sc&hl=cs&sa=X&ei=0HsJVd_tGInAPIj8gbgM&ved=0CD0Q6AEwAw#v=onepage&q=datum%20reference%20symbol&f=false

http://www.tec-ease.com/gdt-terms.php

http://www.qualitydigest.com/inside/metrology-column/establishing-datum-reference-frames.html

http://www.meadinfo.org/2009/05/gd-datum-better-insight-asme-y145.html

http://nvlpubs.nist.gov/nistpubs/jres/104/4/html/j44mac.htm#c1

http://www.roymech.co.uk/Useful_Tables/Drawing/draw_geom_notes.html

https://in.misumi-ec.com/contents/tech/press/23.html