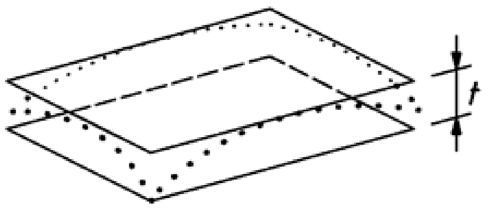
FLATNESS FUNDAMENTALS

WHY MEASURE FLATNESS

The evaluation of flatness deviation is essential to control flat surfaces of workpieces and often to qualify a surface as a primary reference to which the other workpiece elements are referred with orientation and position tolerances.

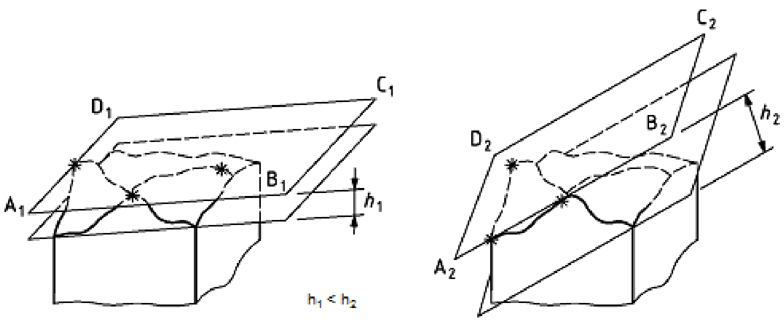
DEFINITIONS (according to ISO 1101) AND GENERALITIES

- Flatness is a property of a plan. It characterizes a surface.
- Flatness tolerance is the linear dimension *t*, which characterizes the tolerance zone where the flat surface location must be considered.
- The tolerance zone is limited by two parallel planes that are distant from each other by a value *t*.



Definition of the flatness tolerance zone of a flat surface

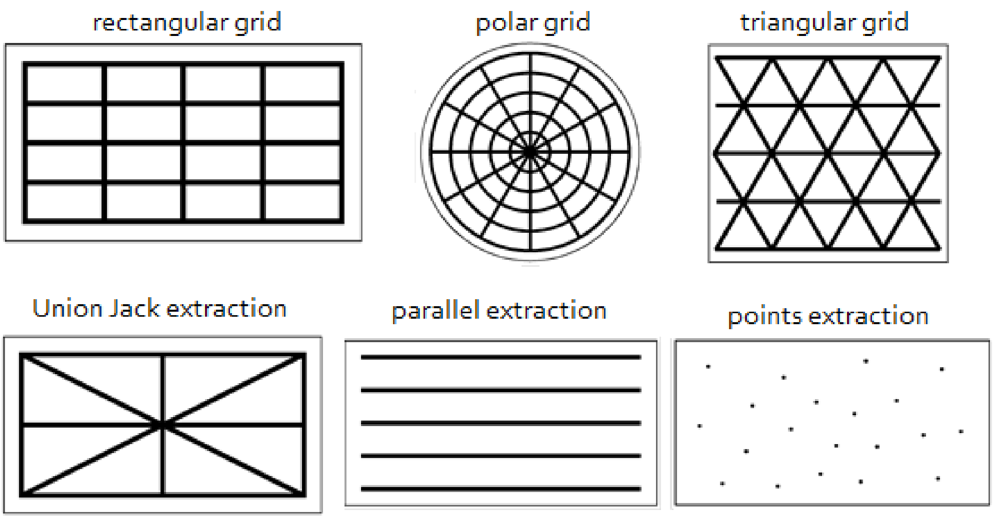
- In the evaluation of flatness deviation of a single element with a given tolerance, the flatness must be in accordance with its specification when the element is contained between two planes, that are distant from each other by a value less than or equal to the specified tolerance value. The orientation of these planes must be chosen so that the greatest distance between them is the minimum possible.



Definition of a flatness tolerance zone

- When determining the orientation of the tolerance zone it is necessary to establish a reference plane – an associated plane adjusted to the flatness surface according to specific conventions, to which the deviations and the flatness parameters are referred. The technical specification ISO 12781-1 considers two procedures for determination of the reference plane:
  - The minimum zone reference plane method (MZPL), that best meets the tolerance zone definition
  - The least squares reference plane method (LSPL), which provides a good approximation for the flatness deviation, although overestimating it, but it is currently the most commonly used in coordinate measuring machines.

- For a reliable evaluation of a flat surface, an appropriate extraction strategy must be adopted, in order to obtain a representative set of points of the workpieces. According to ISO 12781-2, the theoretical minimum density of points necessary to make a flat surface coverage depends on the harmonic representation to be considered. In practice, it is unrealistic to proceed to an exhaustive coverage of the flatness element, defined from this theoretical minimum density of points, in an acceptable time interval and using current technology. In these situations, more limited extraction strategies are used is that providing a more specific information in the flatness evaluation.



Extraction strategies for flatness deviation evaluation

PROCEDURE FOR DETERMINING THE STRAIGHTNESS DEVIATION

The least squares reference plane method (LSPL) is now used to assess the flatness deviation of a given surface of the workpieces. According to ISO/TS 12781-1, the procedure can be described by the following steps:

i) Consider the measuring points extracted from a surface with coordinates (X_i, Y_i, Z_i) at a given measurement reference, in which the z-axis is perpendicular to the plane to be measured.

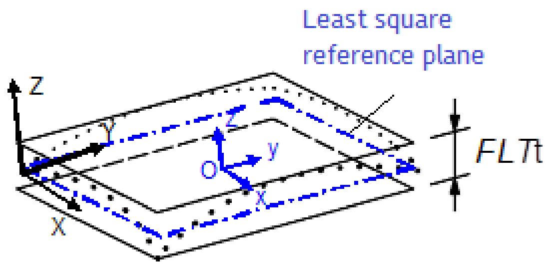
ii) Define the point O with coordinates $(\overline{X}, \overline{Y}, \overline{Z})$, such that:

$$\overline{X} = \frac{\sum X_i}{n}; \; \overline{Y} = \frac{\sum Y_i}{n}; \; \overline{Z} = \frac{\sum Z_i}{n}$$

iii) Consider the point *O* as the origin of coordinates in a new referential. The coordinates of the measuring points in the new referential, can be determined as follows:

$$x_i = X_i - \overline{X}; \; y_i = Y_i - \overline{Y}; \; z_i = Z_i - \overline{Z}$$

iv) Consider the least squares reference plane, LSPL, passing through the point O.



Least squares reference plane (LSPL)

v) Define the equation of the least squares plane as z = ax + by, where *a* and *b* can be estimated from the following expressions (assuming that deviations measurement is performed according to the z direction):

$$\hat{a} = \frac{\Sigma y_i^2 . \Sigma z_i x_i - \Sigma x_i y_i . \Sigma z_i y_i}{\Sigma x_i^2 . \Sigma y_i^2 - (\Sigma x_i y_i)^2}$$

$$\hat{b} = \frac{\Sigma x_i^2 . \Sigma z_i y_i - \Sigma x_i y_i . \Sigma z_i x_i}{\Sigma x_i^2 . \Sigma y_i^2 - (\Sigma x_i y_i)^2}$$

vi) Calculate the deviation between the measured points and the reference least squares plane:

$$e_i = (z_i - \hat{\mathbf{a}}\, x_i - \hat{\mathbf{b}}\, y_i) / (\sqrt{(\hat{\mathbf{a}}^2 + \hat{\mathbf{b}}^2 + 1)})$$

vii) Flatness deviation can be defined by the sum of the value of the maximum positive local flatness deviation, FLT_P, with the absolute value of the maximum negative local flatness deviation, FLTv - peak-to-valley flatness deviation (FLTt).

$$FLT\mathrm{t}\ (\mathrm{LSPL}) = |\, e^{+}_{max}\,| + |\, e^{-}_{max}\,| = FLT\mathrm{p} + FLT\mathrm{v}$$

viii) The FLTt value must be compared with the value of flatness tolerance, to check if the actual surface flatness is in accordance with the corresponding specification.