FLATNESS MEASUREMENT BY MULTI-POINT METHODS AND BY SCANNING METHODS

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Abstract: Paper deals with some of the flatness extraction strategies on measurement by means of coordinate measuring machine. There are the choice flatness measurement by multi-point and scanning methods compared. There is the difference in a number of points and on their arrangement and there is also the difference at measurement by multi-point and scanning methods application. There are a single methods considered following a measured flatness values in practice comparison. At the conclusion there are the references in practice pronounced.

Keywords: flatness, measurement, extraction strategy, coordinate measuring machine

Introduction

Machine production`s result are machine parts designed and produced in order to their express function specifications achievement. However, it is impossible to produce ideal products. Therefore, the deviations that are to result on parts surfaces and elements are natural production result [1]. There is a flatness measurement usually applied for example on the tables working surfaces of a planers, milling machines and on the chuck plates of a vertical turning lathes, too. Accordingly, there is a flatness measurement applied on the bed plates of a swing drilling machines and so on. There are a surface plates, straight edges and a levels usually applied for the flatness measurement whereby these equipments are setting on an each other orthogonal directions or on a diagonal directions. For more exacting flatness measurement there are a measuring accuracy bridges and a plates with sensitive dial gauges or a heliotropes applied [2]. It is need to determine by means of measurement these deviations. However, even thought standard STN EN ISO 1101: 2006 [3] does not define the term deviation absolutely. It introduces the term "tolerance zone" that is defined as a circumscribed area by one or more geometrical exact lines or surfaces. This tolerance zone is characterized by linear dimension that is called "tolerance" [1].

1 Flatness

The standard STN EN ISO 1101: 2006 [3] defines the term "flatness tolerance" as a zone that is delimited by two parallel planes with their radial distance equal to value "t".

It appears from this that flatness tolerance determines a limit values of surfaces and of planes and lines symmetries straightness deviations on a flat surface. That means the all points of surface (real point of surface or symmetrical planes) must be found between two parallel planes with their radial distance that is specified by tolerance on mechanical drawing. The distance between two planes must be minimal [1].

There is an urgent request of general need for obtain a measured plane surface that is replaced by profiles or points arrangement and then this surface can be faced with plane (perfect surface) whose position compared with a surface under consideration it is necessary to specify correctly at which a normal size of both surfaces difference is presented as the flatness deviation.

Plane that is faced with measured surface we called that "reference plane". This is defined as associated plane fitting the flatness surface in accordance with specified conventions, to which the deviations from flatness and the flatness parameters are referred. Reference plane can be:

1. *Minimum zone reference planes MZPL:* two parallel planes enclosing the flatness surface and having the least separation (see Fig. 1):
   - *outer minimum zone reference plane:* minimum zone reference plane outside the material;
   - *inner minimum zone reference plane:* minimum zone reference plane inside the material;
   - *mean minimum zone reference plane:* arithmetic mean plane of the minimum zone reference planes.
2. *Least squares reference plane LSPL:* plane such the sum of the squares of the local flatness deviations is a minimum (see Fig. 2) [4].

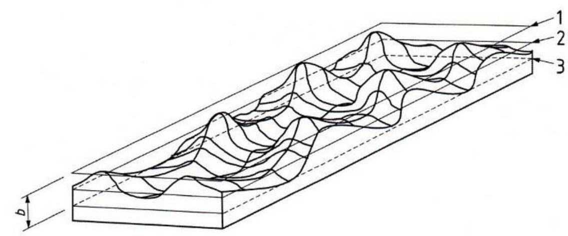

Fig. 1 Minimum zone reference planes (STN P CEN ISO/TS 12781-1: 2008)
b – least separation, 1 – outer minimum zone reference plane, 2 – mean minimum zone reference plane, 3 – inner minimum zone reference plane

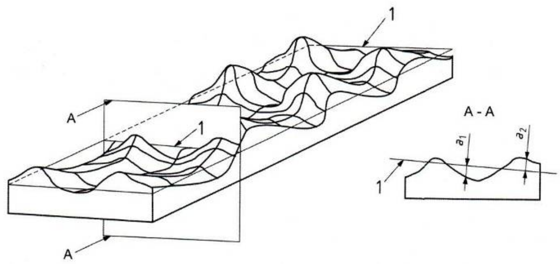

Fig. 2 Least squares reference plane (STN P CEN ISO/TS 12781-1: 2008)
a_1 – negative local flatness deviation, a_2 – positive local flatness deviation, 1 – least squares reference planes

In respect to 3D properties of machine parts (i.e. flatness, cylindricity) it is very difficult to comply with a geometrical accuracy definitions in the course of measurement. The development of machine-industries measuring accuracy technique with its electronic equipment and the growth of software possibilities make them possible more and more to approximate to a geometrical properties definitions in the course of an accuracy to form inspection [5].

2 Flatness measurement

The surface of a plane is an area. An area can be thought of as the combination of two profiles where the directions of the two profiles can be used to establish a coordinate system for the area.

In the case of a plane the two profiles are orthogonal to each other within the plane, with any position on the plane being located by giving its coordinates with respect to its distance in the direction of one profile and distance in other profile`s direction from an origin.

The surface of a plane is an area and so the sampling intervals along the two defined orthogonal directions need to be specified [6].

2.1 Extraction strategies

In order to obtain a reliable assessment of flatness form, an appropriate extraction strategy for obtaining a representative set of points on the workpiece is required. These extraction strategies requests are specified by the standard STN P CEN ISO/TS 12781-2: 2008 [6].

In practice, it is often difficult to achieve a complete covering of the feature of flatness given by the theoretical minimum density of points. In these situations more limited extraction strategies are employed that give specific rather than general information concerning the assessment of flatness form. These include the

- rectangular grid extraction strategy,
- polar grid extraction strategy,
- specified grid, e.g. “Union Jack” and triangular extraction strategies,
- parallel extraction strategy,
- points extraction strategy [7].

An indication of the ability of each of the extraction strategies to assess harmonics is as follows [6]:

a) Rectangular grid extraction strategy

The main characteristic of the rectangular grid extraction strategy is a high density of points along both the orthogonal profiles. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in both directions relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness.

The extraction strategy consists of equally spaced straightness profiles in two orthogonal directions to form a rectangular grid (see Fig. 3).

b) Polar grid extraction strategy

The main characteristic of the polar grid extraction is a high density of points along both the radial and roundness profiles. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in both the radial and circumferential directions relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness that is nominally a disk.

The extraction strategy consits of equally spaced concentric circular profiles about a defined centre together with equally angled radial straightness profiles through the defined centre to form a polar grid (see Fig. 4).

c) Specified grid extraction strategy “triangular grid extraction strategy”

The main characteristic of the triangular grid extraction strategy is a high density of points along the profiles which define the “triangular grid”. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in the directions defining the triangular grid relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness as an alternative to the rectangular grid and polar grid extraction strategies.

The extraction strategy consists of equally spaced straightness profiles in three directions 60° apart form each other to form a triangular grid (see Fig. 5).

d) Specified grid extraction strategy “Union Jack extraction strategy”

Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy a limited ability to assess the harmonic content in the directions defined by the “Union Jack” relative to the form content. This extraction strategy is limited by the small number of profiles used and the large areas not sampled. Hence, this extraction strategy ahould be used only if the longer wavelength content of the feature of flatness is negligible, where it is a quick extraction strategy. The rectangular, polar and triangular extraction strategies are recommended, before the Union Jack extraction strategy, as the sampling strategy for the assessment of the total flatness if the wavelength content of the surface is not known a *priori*.

The extraction strategy consists of a series of a grid with three profiles in each direction together with two straightness profiles across the main diagonals of the grid to form a “Union Jack” (see Fig. 6).

e) Parallel extraction strategy

The main characteristic of the parallel extraction strategy is a higher density of points in the direction of the profile relative to the density of points orthogonal to the profile. This gives the extraction strategy the ability to assess very much higher harmonic information in the direction of the profile in comparison to harmonic information orthogonal to the profile. Hence, this extraction strategy is recommended only if high harmonic information is of interest in one direction compared to the direction orthogonal to it.

The extraction strategy consists of equally spaced straightness profiles in one specified direction to form a series of parallel profiles (see Fig. 7).

f) Points extraction strategy

The density of points is typically lower than with the other extraction strategies listed in above. This restricts the ability to assess the harmonic content of a feature of flatness. The lower number of points also presents problems when filtering. It is for this reason that the points extraction strategy is not recommended unless only approximate estimates of the flatness parameters are required.

The extraction strategy consists of points taken at random or patterned on the flatness surface (see Fig. 8).

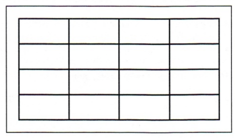

Fig. 3 Rectangular grid extraction strategy (STN P CEN ISO/TS 12781-2: 2008)

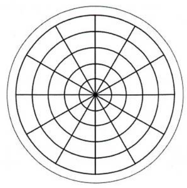

Fig. 4 Polar grid extraction strategy (STN P CEN ISO/TS 12781-2: 2008)

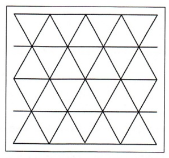

Fig. 5 Specified grid extraction strategy “triangular grid extraction strategy” (STN P CEN ISO/TS 12781-2: 2008)

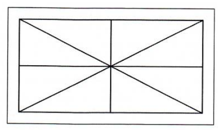

Fig. 6 Specified grid extraction strategy “Union Jack extraction strategy” (STN P CEN ISO/TS 12781-2: 2008)

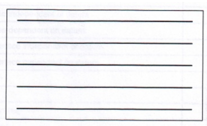

Fig. 7 Parallel extraction strategy (STN P CEN ISO/TS 12781-2: 2008)

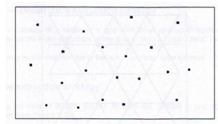

Fig. 8 Points extraction strategy (STN P CEN ISO/TS 12781-2: 2008)

3 Experimental work

For variously flatness measurement by multi-point methods and by scanning methods of outer plane surface experimental work there was a component part with its 300 x 250 mm dimensions. A flatness measurement on this component part was realized by means of coordinate measuring machine ZEISS PRISMO NAVIGATOR 5 that was controlled by means of operating software ZEISS CALYPSO 4.4.04.01, too. A component part`s plane surface was measured by several *multi-point methods* and by several *single points instantaneous positions continuous scanning methods*:

1. Measurement by multi-point methods – there were applied: coordinate measuring machine ZEISS PRISMO NAVIGATOR 5, operating software ZEISS CALYPSO 4.4.04.01

- *rectangular distribution of 50 points in 10x5 arrangement* – there was a sensor with radius of 1 mm applied;
- *rectangular distribution of 72 points in 9x8 arrangement* – there was a sensor with radius of 1 mm applied;
- *rectangular distribution of 100 points in 10x10 arrangement* – there was a sensor with radius of 2,5 mm applied.

2. Measurement by single points instantaneous positions continuous scanning methods – there were applied: coordinate measuring machine ZEISS PRISMO NAVIGATOR 5, operating software ZEISS CALYPSO 4.4.04.01
   - *parallel profile extraction strategy in number of 2000 points* – there was a sensor with radius of 1 mm applied;
   - *parallel profile extraction strategy in number of 7500 points (it was realized in a direction of X-axis)* – there was a sensor with radius of 2,5 mm applied;
   - *parallel profile extraction strategy in number of 7500 points (it was realized in a direction of Y-axis)* – there was a sensor with radius of 2,5 mm applied;
   - *triangular grid extraction strategy in number of 2000 points* – there was a sensor with radius of 1 mm applied.

There is a single flatness deviations measurement by multi-point methods and by single points instantaneous positions continuous scanning methods summary of results listed in Tab. 1.

Tab. 1 Flatness results and flatness measurement results comparison

Flatness measuremnt by multi-point methods and by scanning methods	*Δ [μm]*	*Δ* [%]*
Rectangular distribution of 50 points in 10x5 arrangement	2	*28,6*
Rectangular distribution of 72 points in 9x8 arrangement	2	*28,6*
Rectangular distribution of 100 points in 10x10 arrangement	3	*42,9*
Parallel profile extraction strategy in number of 2000 points	27	*385,7*
Parallel profile extraction strategy in number of 7500 points in a direction of X-axis	9	*128,6*
Parallel profile extraction strategy in number of 7500 points in a direction of Y-axis	6	*85,7*
Triangular grid extraction strategy in number of 2000 points	7	*100*

Nommenclature:
Δ – measurement by multi-point methods and by scanning methods results
Δ^* - measurement by multi-point methods and by scanning methods results comparison in percentage statement $[(\Delta / \Delta_{\text{triangular grid extraction strategy}}) \cdot 100\%]$

An above-mentioned flatness measurement by multi-point methods and by scanning methods were on each other compared whereby measurement by means of triangular grid extraction strategy was considered to be the reference measurement forasmuch as it was consisted of equally spaced straightness profiles in three directions 60° apart from each other to form a triangular grid that is considered to be the sampling strategy for the assessment of the total feature of flatness as an alternative to the rectangular grid extraction strategy in this case. Tab. 1 also presents an above-mentioned measurement by multi-point methods and by scanning methods results comparison with reference measurement in a percentage statement.

There are the above-mentioned different applied flatness measurement methods graphical outputs listed in the following undermentioned figures.

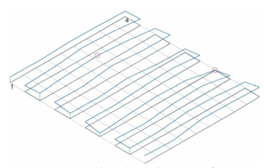

Fig. 9 Rectangular distribution of 50 points in 10x5 arrangement

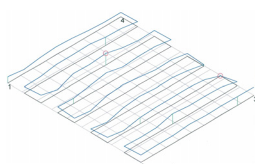

Fig. 10 Rectangular distribution of 72 points in 9x8 arrangement

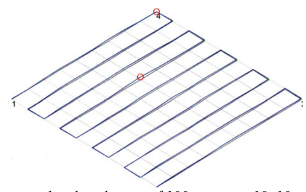

Fig. 11 Rectangular distribution of 100 points in 10x10 arrangement

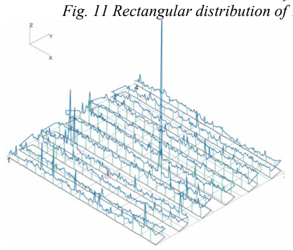

Fig. 12 Parallel profile extraction strategy in number of 2000 points

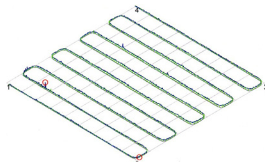

Fig. 13 Parallel profile extraction strategy in number of 7500 points in a direction of X-axis

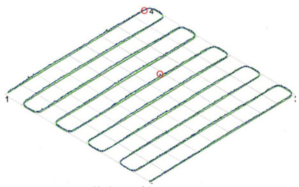

Fig. 14 Parallel profile extraction strategy in number of 7500 points in a direction of Y-axis

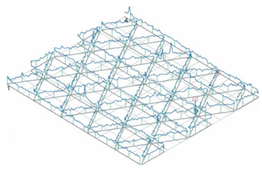

Fig. 15 Triangular grid extraction strategy in number of 2000 points

Conclusions

Measured flatness results that were obtained by the above-mentioned different applied flatness measurement methods we can summarize as follows:

- There were the least flatness values by means of measurement by multi-point methods (i.e. by rectangular distribution of 50 points in 10x5 arrangement and rectangular distribution of 72 points in 9x8 arrangement and by rectangular distribution of 100 points in 10x10 arrangement, too) and they were equalled less than in compare with reference measurement (i.e. by triangular grid extraction strategy in number of 2000 points). These values were in the concrete equalled 28,6 till 42,9 percentage of measurement by means of triangular grid extraction strategy value. These percentual results are consequent on a low number of measured points.
- In the case of measurement by means of parallel profile extraction strategy in number of 2000 points there is an expressive failure that it can be seen in Fig. 12. There was a flatness value in the concrete equalled 3,86 times more than in compare with measurement by means of triangular grid extraction strategy what is as mucha s 385,7 percentage of this reference measurement. Therefore, there is an urgent request of general need for remove this result from additional obtained values processing.
- In the case of measurement by means of parallel profile extraction strategies in number of 7500 points that were realized in a direction of X-axis and in a direction of Y-axis there were a flatness surfaces results approximated to the triangular grid extraction strategy result. These flatness values were in the concrete equalled 85,7 till 128,6 percentage of measurement by means of triangular grid extraction strategy value.
- In the case of measurement by means of triangular grid extraction strategy in number of 2000 points there is a sufficient in numbers of points and an appropriate of points arrangement, too. There is not a flatness measurement density by an expressive failure. Hence, this flatness measurement by means of triangular grid extraction strategy is possible to

consider it as a convenient and an accurate flatness measurement. From the above-mentioned this extraction strategy gives its the ability to assess the harmonic content in the directions defining the triangular grid relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness as an alternative to the rectangular grid extraction strategy in this case.

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