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An Extracting Points Strategy for Flatness Measurement on Components by means of CMM

Raffaele Rosa [(a)], *Sergio Rizzuti* [(a)]

Dept. of Mechanical Engineering, University of Calabria Rende (CS) Italy, 87036

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Corresponding author:
Raffaele Rosa
Tel.:+390984494601
e-mail: r.rosa@unical.it
Address:Cubo 45 C, via Pietro Bucci,
Arcavacata di Rende (CS) Italy

Abstract

The paper presents a semiautomatic procedure able to evaluate flatness error on real components by means of Coordinate Measuring Machine. The main problem in digital metrology is related to the dimension of the sample point size to be used in order to measure form errors with sufficient accuracy. The recent GPS rules establish a set of steps in which the measurement must be made. extraction is the step in which metrologists are urged to trade-off between small sample sizes (related to reduced costs and time) and accuracy (which should require a higher number of points).

The best choice is to use the smallest sample size able to limit the uncertainty in measurements. These points should be extracted in the zones of maximum heights and valley.

The paper discusses a procedure that has been tested introducing in the pre-analysis the qualitative methodology generally used for flatness evaluation by means of Prussian blue. This treatment shows the zones with peaks and valleys in a quick and easy way and the Metrologist is therefore able to extract points from these selected areas.

The paper presents the results obtained about the flatness measurement on a matrix for injection moulding.

1 Introduction

The need to develop industrial products with better geometric quality has led, in the recent past, towards a new way of viewing a part, suggesting a unified approach that starts in the design phase, in which functional requirements or specifications are defined, till arriving at the control phase, where measurements must verify what has been specified.

Nowadays Coordinate Measuring Machines (CMMs) are generally employed in the industrial process, in order to check geometric tolerancing on the parts produced or during the production process [1] and so to verify whether specifications, defined in the design phase, have been satisfied. At the same time it is necessary to underline that CMMs have some drawbacks.

First of all, the data to be processed are in discrete format and special care must be addressed to the sampling strategy to avoid aliasing distortion. Furthermore, it must be taken into account that the analysis may be carried out by means of several algorithms whose results can depend on several factors, among which: the robustness of the algorithm, the systematic and non-systematic errors present in the machine, the type of geometric error to be analyzed, the general state of the surface, the sampling method and the sampling point sizes [2].

The measurement reliability is strictly connected to the number of points to be acquired and, at the same time, costs also grow rapidly with this. So it is important to trade off these two aspects. In order to limit uncertainty it is important that designers, manufacturers and metrologists subscribe to a protocol to check the geometric characteristics, avoiding economic considerations (related to time and verification costs) being able to lead to the use of incorrect sample point sizes, stopping the correct evaluation of the real geometric error of the part.

In the geometrical product specification and verification (GPS) system there are included metrological aspects covering dimensional and geometrical tolerancing, surface properties and the related verification principles, measuring equipment and calibration requirements including the uncertainty of dimensional and geometrical measurements [3].

The ISO/TS 12781, general GPS document, gives the complete specification operator for flatness.

Quoting what was reported in ISO/TS 12781-2: “In order to obtain a reliable assessment of flatness form, an appropriate extraction strategy for obtaining a representative set of points is required. Of prime importance in determining an appropriate strategy is the harmonic content of the workpiece to determine the theoretical minimum density of points”. Since it is difficult to achieve a complete covering of the feature flatness by minimum density of points, more limited extraction strategies are suggested in ISO/TS 12781-2 annex B.

In this paper the authors compare two strategies suggest in ISO/TS 12781-2 annex B: the rectangular grid extraction strategy and the points extraction strategy, introducing in the pre-analysis for the points extraction strategy the qualitative methodology generally used for flatness evaluation by means of Prussian blue.

This treatment shows the zones with peaks and valleys in a quick and easy way and the metrologist is so addressed to extract points from these selected areas by coordinate measurement machines (CMMs).

2 State of art

In this section the emphasis will be placed on the major problem related to form tolerance evaluation by a CMM.

The problem is related to sampling strategy. This moves from the lower bound for Discrepancy demonstrated by Roth [4] when a characteristic is sampled by a finite set of sampling points. A set of sampling strategies have been applied till now for flatness error evaluation: the Hammersley sequence was compared by Woo and Liang [5] with respect to uniform sampling demonstrating that the former reaches a quadratic reduction in the number of samples. Also the use of Halton-Zaremba sequence has confirmed this results [6].

The Hamersley sequence has been generalized on various geometric features in [7] and compared with a uniform and random sequence, confirming that the former is the sequence that leads to the limited number of points while maintaining the same level of accuracy.

Following a statistical analysis, Menq et al. [8] developed a method based on the given design tolerance and machining accuracy to determine the optimum number of measuring points.

Statistical problems involved in the inspection process are discussed in Dowling et al. [9] including issues relevant to model fitting and evaluation, sampling design and sources of measurement error, confirming that the estimation of form tolerance is seriously biased when the sample size is small. The influence of sample point size on flatness error was also verified by the authors in a previous paper [10].

Kim and Raman [11] studied the accuracy of flatness for four types of sequences: Hammersley, Halton-Zaremba, aligned systematic and systematic random for really reduced sample point sizes: 4,8,16,32,64. Introducing the concept of CMM probe path, strictly connected to the time for point extraction, they verified a tradeoff between accuracy of flatness and shortest CMM probe path.

Badar et al. [12] presented an adaptive sampling procedure which exploits the knowledge of manufacturing surface pattern and uses heuristic searches, presented by the same authors in [13], obtaining flatness of relevant accuracy (92% and 91%) with a reduced sample point size (13 and 9 points respectively). Experimental analysis by means of this approach has been presented in [14] and alternate methods for sampling are suggested and verified in [15].

Raghunandan and Rao [16] reached high accuracy level (90% and 95%) by reduced sample size of 20 and 25 points employing an iterative procedure and [17] established that roughness does play an important role in determining the sample size for accurate inspection of flatness error.

Pedone and Romano [18], employing the kriging method, developed an adaptive procedure able to determine form errors (straightness and flatness) with a very small sample point size and with highest accuracy.

Many of these latter methodologies try to extract some hints from the manufacturing process from which the search for to most suitable extraction point can be guided.

3 Methodology

The present methodology instead does not take in consideration machining parameters or manufacturing process. It is based on the duality principle (see Srnivasan [19]) between specification and verification. Therefore in the verification phase it is not necessary to know how the surface has been obtained, instead it can give data on which the manufacturer can reason *a posteriori* about the quality of the process and flatness error.

Therefore , in a sort of “blind” process, the best and few points, able to measure flatness error with sufficient accuracy, can be extracted over the surface.

The methodology is based on a prior qualitative morphological study of the surface to be measured. Morphological analysis is performed with the Prussian blue technique introduced by Joseph Whitworth in 1830.

Joseph Whitworth popularized the first practical method of making accurate flat surfaces by using engineer's blue and scraping techniques on three trial surfaces. Prior to his scraping technique, the same three plates method was employed using polishing techniques, giving less accurate results. This improvement led to an explosion in the development of precision instruments using these flat surface generation techniques as a basis for further construction of precise shapes.

Like two century ago, morphological analysis allows us to detect higher sub-areas, intermediate sub-areas and lower sub-areas on the surface.

Therefore the metrologist is able to extract points from these selected areas by coordinate measurement machines (CMMs).

4 Case of study

The experiment involved the measurement of flatness error on a matrix for injection moulding fig. 1.

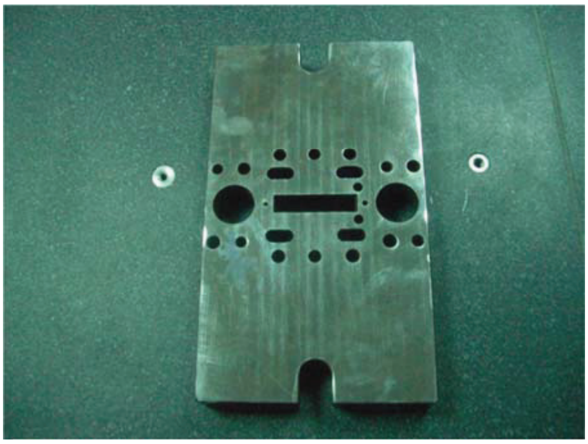

Fig. 1 Matrix for injection moulding.

The only manufacturing element that could be hypothesized consisted in a highly finished surface that can be specified to this kind of component.

All measurements were made on the CMM ARES 10.7.5 by Coord3™ at the Dept. of Mechanical Engineering, having an accuracy MPEE of (3.0 + 3.5 L/1000) µm (where L is expressed in [mm]), and the data have been processed by ARCO CAD 2.6 software.

As reference measurement a set of 715 points have been extracted along a rectangular grid.

The pattern labelled as “reference pattern” was organized on a rectangular grid of 234X126 mm where the distance between the points, in horizontal and vertical directions, was maintained at 6 mm. From this pattern regularly spaced points were removed from those points in correspondence with the holes.

The points extracted were associated to a flat surface

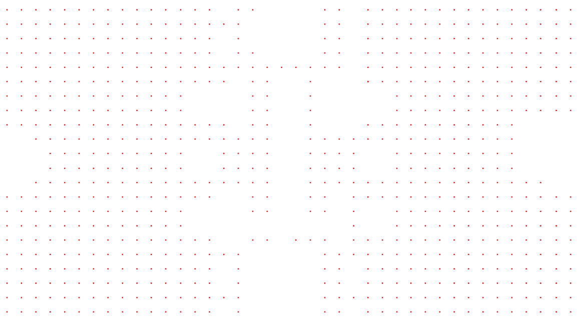

Fig. 2 Rectangular grids.

In order to carry out the morphological analysis of the surface it was subjected to "blue painting".

Engineer's blue was prepared by mixing Prussian blue with a non-drying oily material (in this case, ***linseed oil***). The coloured mixture was rubbed onto a reference surface and the workpiece was laid on it; then the workpiece was softly moved on the surface, being separated from it by means of the thin oily film. After having turned over the workpiece, it appeared partly coloured (see fig. 4).

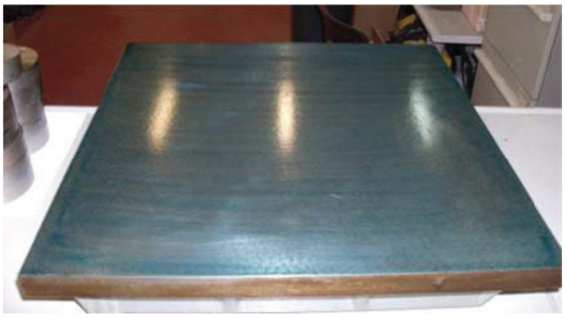

Fig. 3 Reference surface.

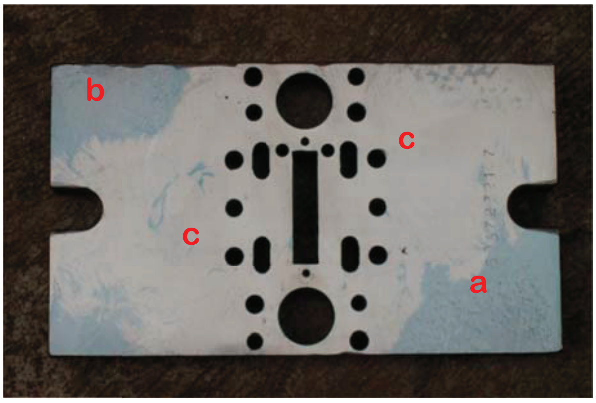

Fig. 4 Coloured surface on workpiece.

The coloured zones **a** and **b**, with some blue dark dots are those where the transfer (by contact) of the pigment occurred between reference surface and workpiece and indicate the position of high points (peaks).

The zones not coloured indicate where can be located the lower points (valleys) and those only coloured without dots are in a middle position (e.g. that near the lower left corner).

A realistic flatness measurement requires that peaks and valleys be extracted as sample points, therefore the search for these can be addressed to the coloured and non-coloured zones.

Three sub-zones were recognized: zones **a** and **b** are those coloured with blue dots and are associated with "potential" peaks; zone **c** is not coloured and is associated with "potential" valleys (see fig. 4).

With these hints, 7 flatness measurements were planned employing growing sample point sizes of 10; 12; 14; 16; 18; 20; 25 points.

In the first column of Tab. 1 there are the number of sample points extracted and, between brackets () there are the number of sample points extracted respectively in the sub-areas **□-b-c**. are subdivided into the three zones a, b and c. In every sample the points were subdivided between the peaks sub-area and valley sub-area. The peaks sub-area were further subdivided into zone **a** and **b**, with at least three points per each sub-area. For higher sample dimension more points were extracted from sub-area **a** because of its wider surface, with respect to sub-area **b**.

In each area point extraction was done randomly.

In the second column of Tab.1 there are the measured flatness errors for every sample point.

In the third column of Tab. 1 there are the ratio between measured flatness error for every sample point and measured reference flatness error.

Number of extracted points sample (a-b-c)	Flatness error (µm)	Flatness/ Reference Flatness
10 (3-3-4)	25	0.81
12 (3-3-6)	25	0.81
14 (4-3-7)	29	0.94
16 (5-3-8)	25	0.81
18 (6-3-9)	28	0.90
20 (7-3-10)	30	0.97
25 (8-4-13)	29	0.94

Tab. 2. Flatness error evaluation in each of 7 reduced sample point size

All measurements ranged from 25 to 30 µm with a flatness not lower than 81% than flatness reference 31 µm, and in the best case equal to 97% of the flatness reference.

A further investigation could allow us to estimate an assessment for the uncertainty related to the extraction phase. Even the theme of uncertainty can hide some traps if the global context is not clearly defined, the authors believe its evaluation for the extraction phase can be associated with the relative standard deviation of the flatness, measured with different sample sizes.

After the evaluation of the mean flatness error, equal to 27.29 µm, the standard deviation is 2.21 µm. This latter, related to the reference flatness, gives 0.07.

5 Conclusion

A methodology for flatness measurement has been presented, in conjunction to a strategy for the selection of peaks and valleys. The Prussian blue technique was used in an easy and quick way to enhance these zones, on which metrologist can extract points on a plate surface.

A really reduced number of points was sufficient to reach a high accuracy in the measurement of flatness, without previous knowledge of the manufacturing process employed to produce the workpiece.

The results obtained are promising and a lot of measurements should be planned on several kinds of component, with different levels of accuracy, in order to generalize the usage of the technique.

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