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REVIEW ON DEVELOPMENTS IN VARIOUS TECHNIQUES FOR FLATNESS TOLERANCE EVALUATION TO MAXIMIZE THE PERFORMANCE OF AN INSPECTION AND MEASUREMENT SYSTEMS

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ABSTRACT: - *The enhanced development in manufacturing process is due to the use of Computerized Numerical Control (CNC) methods. It results in a high throughput of manufactured products. Inspection and measurement system must be accurate enough to inspect the high-quality products given by manufacturing system. This increases the load on inspection system as they must validate the products. The rate of development in inspection and measurement system is low. Now-a-days measurement and inspection process takes more time for inspection of products. Many researchers devoted themselves to improve the efficiency of measurement and inspection systems. This review comprises the research work done in various techniques for flatness tolerance evaluation. The concept of minimum zone method for flatness evaluation are discussed in the paper. The methods reviewed in this study were mainly applied in 3-axis point to point measurements so far and can be applicable for 5-axis measurements with some modification.*

Keywords: *CMM, Flatness evaluation, Minimum Zone solution, Sampling Method, Sample size.*

1. INTRODUCTION

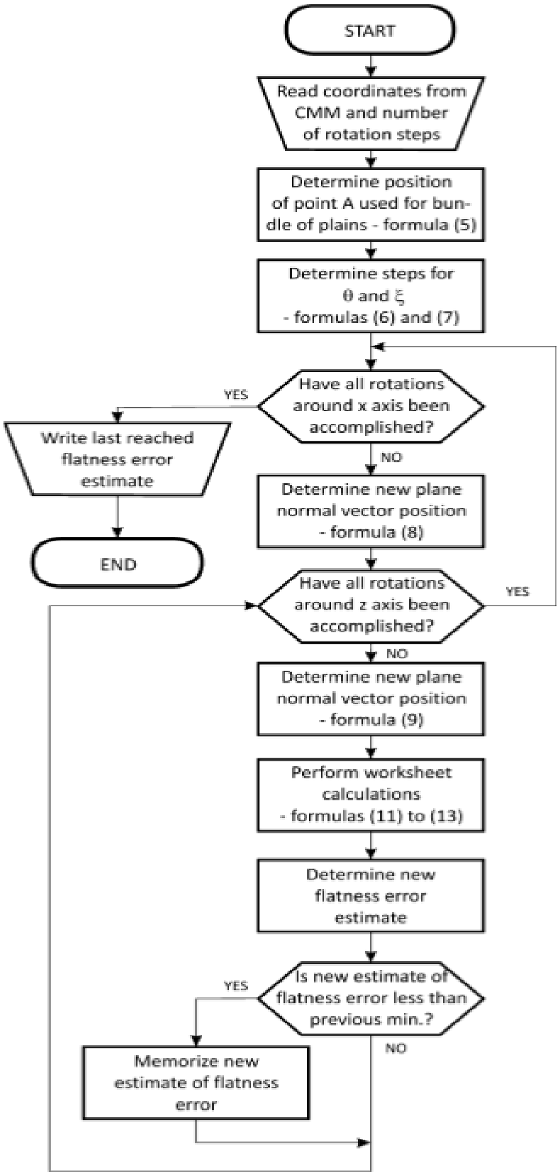
To maximize the product output, inspection and measurement systems were recently combined with CNC methods. These systems are now used to inspect the products for dimensional and geometrical tolerances. Measuring geometrical tolerances is difficult than dimensional tolerances and measured values are always approximate. The variation occurred in two techniques i.e. data acquisition and data fitting of an inspection and measurement system leads to approximate results. In recent years, the focus of researchers is on improving the performance of an inspection and measurement systems. The parameters like sampling distance, inspection plan, dynamics of inspection systems and tolerance evaluating algorithms mainly affects the performance of systems and reduces their efficiency.

In this paper, the focus of review is on developments in various flatness tolerance evaluation techniques. In many applications, flatness tolerances are evaluated to check quality of mating surfaces. The review contains various techniques in brief from the past two decades in inspection strategy and flatness error evaluation. The technologies are examined from the view point of an inspection engineer. The rest of this paper is organized as follows. The developments in various techniques related to flatness tolerance evaluation to improve measurement and inspection process performance are reviewed in Section 2. Section 3 contains conclusions derived from the review conducted in this study about flatness tolerance evaluation techniques. The future research trends were also discussed in this section to further improve the performance of an inspection and measurement system.

2. DEVELOPMENTS IN FLATNESS TOLERANCE EVALUATION TECHNIQUES

Flatness is one of the most important and widely considered geometric tolerance to determine the quality of products. The flatness error is calculated by two general methods i.e. Least Square method and Minimum Zone solution. Flatness tolerance evaluation techniques plays important role in accurate evaluation of flatness tolerance. In recent years, many researchers adapted new techniques to improve the flatness tolerance evaluation. The review of those techniques is as follows:

Figure 2.1: One Point Plane Bundle Method (OPPBM) flowchart [1]



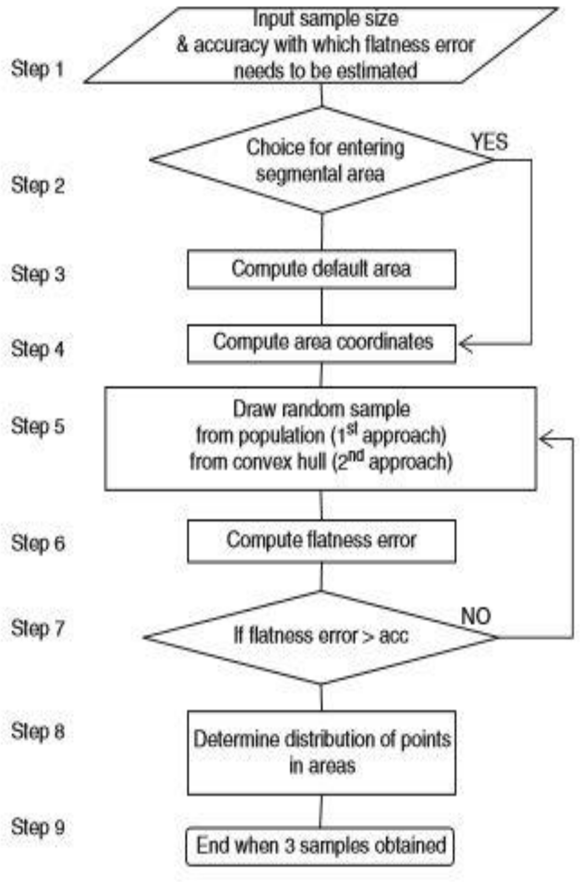
V. Radlovacki et al. [1] designed a new software model for evaluating minimum zone based flatness error. The flatness error was calculated by using reference planes passing through one point in cloud of points gathered by CMM. The method is named as One Point Plane Bundle Method (OPPBM) and the flowchart is shown in Figure 2.1. The method is validated with data from literature and experimental data measured by CMM Carl Zeiss Contura G2 RDS equipped with VAST XXT contact probe. The results show the value of flatness error estimated by OPPBM is close to the Least Square Method (LSM) and Minimum Zone (MZ) with acceptable computational time. The method can also be used to determine other form error like straightness and it can be used as alternative for flatness error evaluation by CMMs software.

X. Wen et al. [2] presented a method for flatness error minimum zone evaluation and uncertainty detection. An improved genetic algorithm (IGA) is used for flatness error minimum zone evaluation. Guide to the Expression of Uncertainty in Measurement (GUM) and Monte Carlo Method (MCM) were used to evaluate flatness error uncertainty. The results of the presented method compared with the conventional methods. The method gives more efficiency and accuracy with presented simple algorithm.

P. V. Rao et. al. [3] proposed a sampling strategy to evaluate flatness error by minimum zone method as well as to prove that the surface roughness has an impact on sampling strategy. The Hammersley sequence is used for sampling strategy and the measuring surface is assumed as unit square; sample points are then calculated by sequence's formula. The experiment consists three different workpieces with different roughness values inspected with the help of CARL ZEISS CMM. The data is then transferred to MATLAB to find minimum zone solution of flatness error. The result shows that the sample size increases with the increase in roughness value of surface.

P. V. Rao et al. [4] proposed an algorithm as shown in Figure 2.2 to find optimal sample size for accurate evaluation of flatness error value. The method used for sampling plan is Hammersley sequence. The experiment consists, measurement on two identical specimens machined at same working conditions by CARL ZEISS CMM. The flatness value is calculated by minimum zone solution which is based on computational geometry QHULL algorithm in MATLAB. The result shows that the flatness value can be estimated at reduced sample size with reasonable accuracy. This study helps to determine process capability of manufacturing systems.

Figure 2.2: Algorithm to find optimal sample size [4]



J. Huang [5] developed an algorithm with the help of three theorems to obtain straightness and flatness error without generation of complete convex hull. The algorithm eliminates redundant data points and generate optimal solution with the help of small number of data points. The algorithm is validated by two examples for each straightness and flatness error. For a problem with large number of data points; the algorithm works efficiently with the help of theorems.

H. Ding et al. [6] proposed an algorithm for flatness error evaluation in which the minimum zone is formulated as linear programming problem. The algorithm calculates the flatness error in O(n) time. The algorithm is compared with existing methods like least squares, convex hull methods from literature. The proposed algorithm is efficient and easy to implement and it produces approximate minimum zone solution with desirable accuracy.

S. Raman et al. [7] conducted an experiment for statistical analysis of sampling strategy to evaluate flatness error. The two factor ANOVA is used as statistical analysis method with two factors, sampling methods and sample sizes. The four sampling methods and five different sample sizes are considered as factors for design of experiment on thirty replicates of plates. The sampling methods are Hammersley Sequence, Halton – Zaremba Sequence, Aligned Systematic sampling and Systematic Random sampling. The accuracy and length of probe path gives priority coefficient to decides the sampling method and sample size. The analysis shows that the Halton – Zaremba Sequence or Systematic Random sampling gives high accuracy of flatness error.

M.S. Shunmugam et al. [8] presented an algorithm for minimum zone and function-oriented evaluation of straightness and flatness. The algorithm is based on computational geometry techniques. The algorithm is validated with the results from literature. The algorithm gives unique solution in short time and less complexity.

J. Mou et al. [9] proposed a method based on feature detection which uses Hammersley sequence and a stratified sampling method to generate sampling plan based on specified data points. Case studies are used to compare results of proposed method. The results show that the reduction in number of sample derived by proposed method which reduces time and cost, while maintaining desired level of accuracy.

Q. Liu et al. [10] studied the CMM measurement error effects on geometric tolerance estimation. The least squares and Min-Max uncertainties algorithms were used to estimate the geometric tolerances. The study states that, the performance of algorithm is based on effect of CMM measurement error on data processing of CMM.

3. Conclusions

The review states that, the focus of researchers was on the techniques regarding sampling strategies and evaluating minimum zone solution. The methods like OPPBM, IGA and QHULL gives minimum zone solution with desired accuracy. These methods take adequate time to give solution and can be applied with less complexity. To determine sampling plan the factors like manufacturing process, cutting tool, material of part, surface roughness need to be consider. The ANOVA was conducted for two factors i.e. Sampling Method and Sample Size. This method shows the effects of these two factors on flatness error. In the results of analysis, two sampling strategies considered as solution which gives accurate flatness error. The number of sample points are directly proportional to surface roughness of measuring surface. The methods given in review were applied for point to point measurement process. The 3-axis measurement systems were used to measure surface and generate point cloud. The accuracy of flatness error is also depending on measurement system. The 5-axis measurement system is new and more accurate than 3-axis measurement system. There was no significant research work found related to flatness tolerance evaluation by 5-axis measurement system. The method given in review can be modified and applied to evaluate flatness tolerance by 5-axis measurement techniques like point-to-point and scanning measurement process.

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