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Squareness Evaluation using Computational Geometric Approach

N. Venkaiah and N. Srinagalakshmi

Abstract : Manufactured parts generally deviate from their intended shapes due to systematic and/or random errors during manufacturing. These geometric errors can affect the functioning of the parts significantly. In the present work, evaluation of squareness using computational geometric approach is attempted. In order to evaluate the squareness between two edges, coordinate data obtained from a CMM has been used. The present method based on computational geometric principles is found to be yielding better results than that of usually employed least-squares method. Hence the present method can be implemented in CMMs in order to reduce the rejection of good parts during inspection.

Index Terms: CMM, Computational Geometry, Geometric error, Squareness error

I. INTRODUCTION

Engineering components are expected to have some geometric form on them. However, because of certain systematic and/or random errors during manufacturing, the parts produced will deviate from their ideal geometric forms. These geometric errors can affect the functioning of the parts significantly. Hence there is a need to evaluate the form error of engineering parts to know or judge the quality of the parts.

Squareness is important in many occasions. The tool movement should be perpendicular to the workpiece axis while giving depth of cut in the case of a turning operation. Table feed must be perpendicular to the tool movement in the case of a shaper. The slides in a CMM must be mutually perpendicular. Any error in the squareness in these cases can result in errors in the parts being manufactured or measured. Hence squareness evaluation assumes a lot of importance. Squareness is defined as the deviation from a perpendicular relationship of one axis, line, surface, etc., to another. It is a characteristic of having adjacent sides or planes meeting at 90o. Generally, reference gauges such as right-angle gauges and levels are used for the measurement of squareness between two fixed lines. It is obvious that the accuracy of the reference gauge has to be higher enough than the aimed accuracy. However, there exist two problems for the measurement of large ultra-precision components. Firstly, it becomes very difficult and expensive to obtain a squareness reference with a higher accuracy than the ultra-precision component. Secondly, the straightness error of each line of the squareness reference cannot be ignored.

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N. Venkaiah is with Department of Mechanical Engineering, National Institute of Technology, Warangal 506004, India (Corresponding author. Tel.: +91-0870-246-2350; e-mail: n_venkaiah@nitw.ac.in)

N. Srinagalakshmi was pursuing M. Tech in Department of Mechanical Engineering, National Institute of Technology, Warangal 506004, India.

II. LITERATURE REVIEW

The measurement data does not give a direct assessment of form error. Coordinate measuring systems have emerged as the important form verification tools owing to the recent advancements in computerized numerical control and precision machining. However, coordinate measuring systems still encounter difficulties such as correctly and unambiguously interpreting the definition of tolerances given in ANSI Y14.5M [1] standard, formulating the problem of form error evaluation precisely as optimization models (particularly non-linear programs), and developing assessment algorithms which are consistent with ANSI Y14.5M standard, highly efficient, robust, and easy to use. It is necessary to apply a tolerance evaluation algorithm to interpret the continuous part features from the discrete measured coordinates.

In order to estimate the squareness error, first it is required to establish reference lines for the measured data of each of the edges yielding minimum straightness error. To establish the reference lines, the least-squares method (LSM), which minimizes the sum of squared errors, is most widely used in the industry due to its computational simplicity and solution uniqueness. The LSM is only capable of obtaining an approximate solution that does not guarantee the requirements mentioned in the standards. Furthermore, the LSM can result in a possible overestimation of the straightness error and causes the rejection of good products.

To obtain the minimum zone solution, the numerical methods based on Monte Carlo, Simplex and Spiral Search [2] and Simplex linear programming [3], have been adopted. A minimax approximation method was used by Fakuda and Shimakohbe [4]. Shunmugam [5] suggested a new simple approach called the Median technique, which gives minimum value of errors. Using discrete Chebshev approximations, Danish and Shunmugam [6] have arrived at the minimum zone values. Based on the criteria for minimum zone solution and strict rules for data exchange, an algorithm called the Control line rotation scheme was developed for straightness and flatness analysis [7]. The non-linear problem of computing the minimum zone solution was converted into a linear optimization problem by combination of coordinate and scaling transformations [8]. A nonlinear optimization approach itself was used for calculating exact values of straightness and flatness error [9, 10]. The search based numerical methods require a large number of trials to satisfy the convergence criteria and the computational time required is longer.

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Computational geometry based techniques show greater promise for solving the minimum zone problems encountered in the geometrical evaluations. Techniques for dealing with datum related features and definitions based on computational geometry were given to formalize the meaning of geometric imperfections, according to the implications of the standards [11]. Traband et al. [12] carried out the minimum zone evaluation of straightness and flatness based on the concept of convex hull of the data set. Lee [13] proposed a comprehensive search algorithm for minimum zone evaluation of flatness, based on the edges of convex hull. Samuel and Shunmugam [14] proposed algorithms based on computational geometric techniques for minimum zone and function-oriented evaluation of straightness error.

In the present work, evaluation of squareness using computational geometric approach is attempted. In order to evaluate the squareness between two edges, the coordinate data is obtained using a CMM. Then best-fit/reference lines, which result in minimum straightness error, are constructed for the measured data of the edges using computational geometric concepts in this work. Finally, the angle between the reference lines is estimated. Squareness error is found as the difference between the estimated angle and ideal angle (90^o). The results are compared with least-squares results.

III. METHODOLOGY

The methodology of evaluating the squareness error can be given as:

1. Generation of data points of edges for which squareness is to be evaluated.
2. Establishing the reference/best-fit lines for the data points of the edges.
3. Determining the angle between the reference lines.

Table 1 gives the data points of two edges obtained using CMM. The best-fit lines are then constructed based on the minimum zone condition. For establishing the best-fit lines for the data, convex hulls have to be constructed using incremental algorithm as described in section 3.1.

A. Incremental Algorithm

The best-fit line for the data set satisfying the minimum zone condition can be established by constructing a convex hull for the data points. In view of the drawbacks of the earlier algorithms for constructing convex hull, a relatively simple algorithm called incremental algorithm (O'Rourke, 1997) has been adopted in the present work. This algorithm is relatively straightforward in two dimensional cases and can easily be extended to three dimensions also. The basic idea of this algorithm is that any three points, which are not collinear, are taken to form an initial hull (a triangle) and then other points are examined one by one to see if they can form the new hull. If a point under consideration lies outside the hull, it is added to the hull, otherwise it is discarded. In order to know whether a point lies inside or outside the hull, directed edge test is implemented. According to this test, if a point, when traversed in counter clockwise direction, is to the left of every directed edge of the hull, then it lies inside the hull and therefore can be discarded. If the point lies to the right of any directed edge, then it lies outside the hull and therefore, it has to be added to the hull. While updating the hull, the edge for which the point under consideration lies on the right is to be removed and new hull is constructed by adding the point. Similarly, all other points are tested for further updates. Fig. 1 shows the convex hull constructed using the incremental algorithm.

Fig. 1. Convex hull formation using incremental algorithm

B. Antipodal Points

In two-dimensional convex hull, a pair of points that does admit parallel supporting lines is called antipodal. A supporting line for a convex hull is a straight line that passes through a vertex of the hull such that the hull lies entirely on one side of the line. The lines of support can be viewed as the jaws of a clipper, holding the convex hull. After constructing the convex hull for the given data set, the antipodal pairs of points are determined (Samuel and Shunmugam, 1999). The parallel lines resting on convex edges adjacent to one of the antipodal point and passing through the other antipodal point are considered. The pair of lines (Fig. 2.) that gives minimum distance, without intersecting the hull is considered.

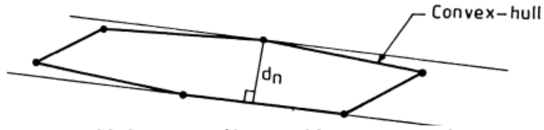

Fig. 2. Establishing pair of lines yielding minimum distance using antipodal pairs

C. Squareness Evaluation

The procedure outlined in the previous sections for constructing the reference lines is followed for both the edges for which the squareness error is to be evaluated. The slope values are then determined for the reference lines of the edges. If m_1 and m_2 are the slopes of the two reference lines, then the angle between the lines (edges) is computed as:

$$\tan\theta = \frac{m_1 - m_2}{1 + m_1 m_2} \tag{1}$$

Squareness error = 90-θ

IV. RESULTS AND DISCUSSION

The data set (Table 1) representing the edges for which squareness is to be evaluated has been created using CMM to test the present algorithm.

The squareness error obtained using the least-squares method is found to be 1.11^o. However, the error value based on the present computational geometric techniques is obtained as 0.9940^o. The present method has also been tested on various sizes of data sets and in all the cases, the error values were found to be lesser than that of least-squares method. Therefore the present method can be employed for better results in the computer aided measuring instruments like CMMs.

Table 1. CMM data of edges

Edge 1		Edge 2	
X (mm)	Y (mm)	X (mm)	Y (mm)
26	111	41	140
35	125	60	110
50	130	75	80
75	145	85	60
63	133	89	47
91	150	97	30
138	178	85	45
110	155	70	70
95	145	50	100
60	120	45	125

V. CONCLUSIONS

Geometric tolerances are essential in today’s mass production scenario because of the ability to assure interchangeable parts. Considering the need for efficient and fast algorithms for processing geometric data in the modern measuring instruments, the algorithms for form evaluation based on computational geometric technique has been developed in the present work for analyzing squareness error. This algorithm is computationally less complex and quite robust in guaranteeing accurate results. Good parts that are rejected because of the less accurate least-squares method can be saved by the present algorithm. This method complies to ANSI/ISO standard. Hence, the present CG based method can be implemented for the evaluation of squareness error in CMMs.

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