EVALUATION OF CYLINDRICITY ERROR BASED ON MRS, LSC, MCC, AND MIC

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Abstract

In this paper, we present an efficient methodology for the evaluation of cylindricity error. Based on the proposed methodology, the cylindricity error can be assessed using any of the existing criteria (LSC, MCC, MIC or MRS). The results indicate that the proposed procedure is fast and the results it provides are very accurate.

Key words: cylindricity, straightness, median line, geometric dimensioning and tolerancing

Introduction:

A great majority of mechanical parts comprise of cylindrical features. A basic geometric characteristic that is used to control form and function of cylindrical features is cylindricity. Significant error associated with this characteristic may result in the failure or inadequate functioning of the corresponding part. Accurate measurement of this error is not a trivial task due to the three dimensional nature of the characteristic.

Methods for the assessment of form errors can be generally divided into the intrinsic datum and extrinsic datum methods. In the intrinsic datum method, points on the surface of the part are used as a datum. The most commonly used intrinsic techniques are diametrical measurement, V-block measurement, and bench center measurement. The intrinsic methods are generally inaccurate due to the existence of multiple sources of error with the measurement process.

In the extrinsic method, an external member is used as the datum reference. The most common extrinsic methods for the evaluation of cylindricity error are Minimum Radial Separation cylinders (MRS), Least Square Cylinder (LSC), Maximum Inscribed Cylinder (MIC), and Minimum Circumscribed Cylinder (MCC). All these techniques try to find two coaxial cylinders at minimum separation within which the surface of the measured feature is to fall. The difference is in the method of finding the location and orientation of the common axis. Among these methods, only MRS is based on the ASME Y14.5-1994 standard on Geometric Dimensioning and Tolerancing (GD&T).

Researchers have developed procedures for the evaluation of cylindricity error based on these criteria. Wang [2] proposed a general-purpose algorithm for constrained nonlinear optimization problems for minimum zone evaluation of form tolerances. Shunmugam [3] proposed a method based on the minimum average deviation for evaluating the form error of lines, circles, planes, cylinders and spheres. He used linearizations and the simplex search method to minimize the sum of the absolute deviation values. Karr and Ferreira [4] discussed the nonlinear optimization models for cylindricity and straightness of a median line, developed a verification methodology for computing the minimum zone for the problem, and proposed two linear programs for implementation. Their basic idea is to solve the nonlinear optimization problem using successive linear programs. A strategy proposed by Lai and Chen [4] for minimum zone evaluation of circles and cylinders employs a non-linear transformation to convert a circle into a line and a cylinder into a plane, and then uses straightness or flatness evaluation schema to obtain appropriate control points and minimum zone deviation for the feature concerned. This strategy is an approximation to the minimum zone circles or cylinders. Roy and Xu [6] proposed a computational geometry based technique to generate a pair of concentric cylinders for checking the cylindricity tolerance. In this method, the cylindrical surface is divided into several cross-sections normal to the coordinate measuring machines local Z-axis. Then 2-D convex hulls and voronoi diagrams are used to generate pairs of concentric circles, and these circles are used to find a pair of concentric cylinders to create the minimum zone required for form tolerance analysis. This method requires the axis of the cylindrical feature to be parallel to Z-axis of measurement.

Proposed Approach:

Geometrically speaking, the cylindricity error evaluation problem based on minimum radial separation criteria may be stated as follows: Given a set of three dimensional points collected from the surface of a cylinder, find two concentric cylinders with minimum radial separation within which all the measured points shall fall. The radial distance between these two cylinders defines the cylindricity error.

The proposed methodology for the evaluation of cylindricity error uses the circularity error evaluation problem as a subroutine. The methodology is constructed based on the following fact. If we rotate a cylinder with a perfect form to a position such that its axis parallels the z-axis and then project all points on the cylindrical surface onto the x-y plane, the projection points will form a circle on the x-y plane. It is clear that this circle has a circularity error equal to zero. As the orientation of the axis of the cylinder is changed, the projected points would no longer have a circularity error of zero. Hence, according to this discussion, to find cylindricity error, one can find minimum value of circularity error of the projected points as the cylinder is rotated around x and y axes.

Based on this logic, an efficient algorithm has been developed. The procedure consists of two loops: an inner loop and an outer loop. The outer loop searches for optimal value of rotation angles around x and y axes. The inner loop calculates the value of circularity error for a given set of rotation angles. Given a set of rotation angles, the data points are first rotated around x and y axes. The points are then projected onto the x-y plane. Circularity error of the projected points is calculated and saved in an array. The rotation angles are changed and the steps are repeated until optimal value of circularity error is calculated. The generalized procedure is as follows:

Step 1: Select a set of initial rotation angles and assume a large number as the minimum circularity error value
Step 2: Rotate the collected points around the x and y axes by the rotation angles
Step 3: Project the rotated points onto the x-y plane
Step 4: Calculate the circularity error. Compare this value with the minimum circularity error value. Keep the minimum value.
Step 5. Change the rotation angles and go to step 2.
Step 6: Continue this process until no improvement in the circularity error value can be found.

The inner loop finds the circularity error of the projected points of the surface of the cylinder based on a selected method. As mentioned in the previous section, there are several methods available for the calculation of circularity error, such as minimum circumscribed circle (MCC), maximum inscribed circle (MIC), least-squares circles (LSC) and minimum radial separation circle (MRS). Any of these techniques can be used in the inner loop. In this research, only the

MRS and LSC techniques have been implemented. Many procedures exist for the calculation of the minimum radial separation circles. Wang and Cheraghi [7] proposed an efficient algorithm for calculating minimum zone circles. We used Wang and Cheraghi's algorithm for calculating minimum zone circles in the inner loop. Similarly, there are efficient procedures for the calculation of LSC [8,9], MCC [10] and MIC [11] that can be utilized in the inner loop.

Performance Evaluation:

The proposed procedure for the evaluation of cylindricity error has been implemented into a computer program. To validate the results from the proposed procedure and to study the efficiency of the proposed procedure several example problems were solved. Some of the data sets for these problems were taken from published articles while other others were measured from real parts. The results of these studies are shown in the following sections.

To validate the developed procedure it was applied to a set of data taken from the literature using MRS in the inner loop [4, 13]. The results were then compared with the published results as shown in Table 1. As shown in the table the developed procedure accurately calculates the cylindricity error values.

Table 1. Comparison of the cylindricity error results with the published results

	Cylindricity error - Proposed procedure	**Cylindricity error - Published results**
Data set 1 [4]	0.00100	0.00100
Data set 2 [4]	0.18395	0.18396
Data set 3 [4]	0.00944	0.00941
Data set 4 [13]	0.002788	0.002788

To test the efficiency of the proposed procedure, a program was developed to randomly generate data under different conditions. The developed procedure was tested on data sets containing 25, 50, 75, 100, …, 250 points. The computer program was run on a PC with a 450 MHz Pentium processor. The results are shown in Figure 2. As shown in the figure, the correlation between the number of points and computation time seems to be linear. For a data set containing 250 points it took the procedure only four seconds to arrive at solution.

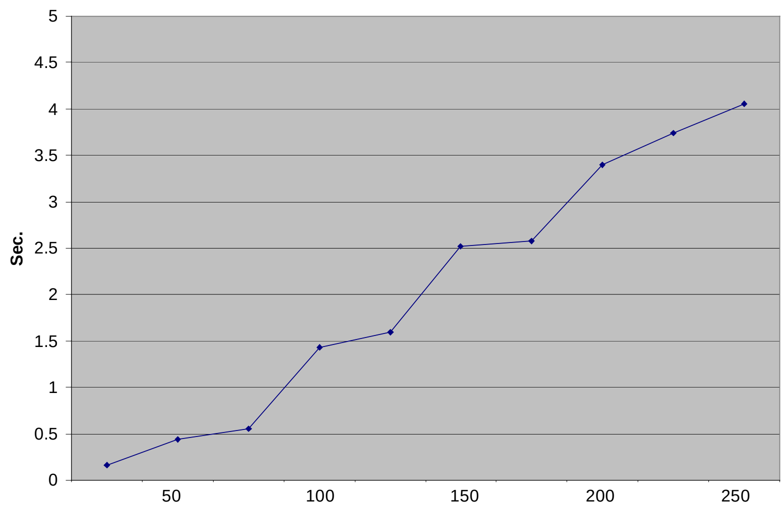

Figure 2. Computational efficiency of the minimum zone method

Conclusions:

This paper presented an efficient procedure for the evaluation of cylindricity error. The procedure uses as a subroutine a circularity error evaluation procedure. The results from the evaluation of the procedure indicate that it is capable of providing accurate results efficiently. An important advantage of the proposed procedure is that it allows different procedures for the evaluation of cylindricity error such as minimum circumscribed cylinder, maximum inscribed cylinder, minimum radial separation or least squares cylinders be used.

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