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Tolerance evaluation of minimum zone straightness using non-linear programming techniques: a spreadsheet approach

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Abstract

In general, non-linear optimization programs are formulated to evaluate the minimum zone straightness. This paper presents a spreadsheet approach that can be applied to determine the straightness errors of discrete data sampled from a continuous shape. The developed approach is easy to implement, and can obtain the minimum zone straightness based on the international standard, ANSI Y14.5M standard on geometric dimensioning and tolerancing. The primary goal of this spreadsheet implementation attempts to help reduce the possibility of making erroneous inspection decision, and then to precisely reflect the effect of inspection as early as possible for the purpose of quality control. An experimental study is conducted on examples taken from the literature and simulation data sets. Comparisons of the proposed approach against the existing methods in the previous studies are reported. Furthermore, the approach is demonstrated to be a viable tool for straightness verification in terms of the simulation data sets in which the theoretical straightness errors are known as a priori.

Keywords: Tolerance evaluation; Minimum zone straightness; Generalized reduced gradient (GRG) methods; Constrained optimization

1. Introduction

Measurement is commonly used to examine the quality of manufactured components against the established standards and specifications. Generally, the features of a manufactured part deviate in size and form. The accuracy of the size and form has a significant effect on the function of the final assembly. The modern manufacturing is characterized by the use of interchangeable parts produced with necessarily slight variation to ensure that they are of functional equivalence. The measurement of straightness

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for manufactured parts is one of the most frequently used procedures in metrology. With the increasing demand of the manufacturing automation, the high-speed measurement instruments such as the coordinate measuring machines (CMMs), machine vision, optical interferometer, etc., have been developed for this purpose.

The computer is generally used for movement control of the instruments and tolerance evaluation of measured data. With the wide acceptance and applications of coordinate measuring instruments in practice, at present manufacturing engineers face a new challenge for the evaluation of geometric tolerances. The reason is that most instruments used in industry depend on discrete points to measure the specified dimensions and tolerances. The measured data do not give a direct assessment of form tolerance. Coordinate measuring systems have emerged to be important straightness verification tools owing to the recent advancements in computerized numerical control and precision machining. However, coordinate measuring systems still encounter difficult problems (Walker, 1988) such as correctly and unambiguously interpreting the definition of tolerances given in ANSI Y14.5M (1982) 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. To evaluate the straightness errors from the measured points of the work piece surface, the ideal lines (substitute features) have to be established from the actual measurement satisfying the requirements defined in the standard, ANSI Y14.5M. The straightness error is then defined as the maximum peak-to-valley distance from the ideal features. The ANSI Y14.5M standard provides requirements for dimensioning and tolerancing. However, it gives little direction concerning the establishment of the ideal features. The least-squares method (LSM), which minimizes the sum of squared errors, is most widely used in the metrology community 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 earlier. Furthermore, the LSM can result in a possible overestimation of the straightness error and the rejection of good products.

During the past decade, some researchers have developed various methods to verify the minimum zone straightness. The issue of minimum zone verification has been discussed comprehensively by Murthy and Abdin (1980). In addition, Murthy and Abdin proposed and compared several methods such as the Monte Carlo method (MCM), simplex method (SPM) and spiral search method (SSM) to evaluate straightness errors. Shunmugan (1986, 1987a,b, 1991) presented various search procedures such as median technique (MDT), minimum deviation (MID), minimum average deviation (MAD), SPM and minimum zone line (MZL) to evaluate the straightness errors. Traband, Joshi, Wysk, and Cavalier (1989) developed a methodology based on the concept of convex hull zone (CHZ) to evaluate straightness errors of measured coordinates from a CMM. Huang, Fan, and Wu (1993) introduced a minimum zone method, namely control line rotation scheme (CLRS) for the straightness analysis. This method is applied to straightness analysis by rotations of the enclosing lines in half-field only. Kanada and Suzuki (1993) discussed the application of five computing techniques for evaluating straightness errors. They compared the solutions obtained by SPM, linear search method with quadratic interposition (QIM), linear search method with golden section (GSM), linearized method (TKM) and mixed method of the above-mentioned TKM and QIM methods. Carr and Ferreira (1995) proposed an algorithm, which solves a sequence of linear programs (SLP) to converge the solution of a non-linear program for the minimum zone straightness. Cheraghi, Lim, and Motavalli (1996) developed an optimization technique