Precision Engineering xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Study on the evaluation of cylinder's global sizes

Zexiang Zhao*, Bin Li, Guoqing Zhang, Hechun Yu, Wenbo Wang, Xin He, Xiaoshuai Hou, Xupeng Cheng, Bo Yao

School of Mechatronics Engineering, Zhongyuan University of Technology, Zhengzhou 450007, China

ARTICLE INFO

Article history:
Received 29 August 2016
Received in revised form 9 February 2017
Accepted 10 February 2017
Available online xxx

Keywords:
Global sizes
Optimization algorithm
Genetic algorithm
Steepest descent algorithm
Maximum inscribed diameter
Minimum circumscribed diameter
Least-squares diameter

ABSTRACT

In ISO 14405-1, the global sizes, such as least-squares diameter, minimum circumscribed diameter and maximum inscribed diameter are defined. The diameters above can be measured by using cylindrical coordinate measuring method like the circular section measuring method of cylindricity error. The determination method of the least-squares diameter was firstly given based on the cylindrical measuring system, and the optimization models of the minimum circumscribed diameter and the maximum inscribed diameter were built, respectively. The corresponding objective functions were unified as "minimax" expressions. For the four axis parameters of the cylinder with the minimum circumscribed diameter or the maximum inscribed diameter, the searching ranges of cylinder's axis parameters for their optimal solutions were defined numerically. Thereafter, the genetic, steepest decent and BFGS-0.618 algorithms were introduced, and the optimization evaluation algorithms of two kinds of diameters mentioned above were given. Based on many cylinders' profiles obtained by the circular section measuring method on a measuring instrument of cylinder's global sizes which was developed by Zhongyuan University of Technology, Zhengzhou, China. The accuracy, efficiency and suitability of three optimization algorithms were investigated through the evaluation of a lot of the minimum circumscribed diameters and the maximum inscribed diameters. The measurement uncertainty of the global sizes for the cylindrical specimen was analyzed, and the measurement uncertainties of the sizes in the radial and z directions are $\pm0.95\,\mu$m and $\pm0.5\,\mu$m, respectively. The total measurement uncertainties of the global sizes of the cylindrical specimens with the specifications of $\phi10\times120$ mm and $\phi100\times300$ mm are $\pm3.8\,\mu$m and $\pm5.7\,\mu$m, respectively. The investigation results showed that for the evaluation of the globe sizes, any one of three algorithms above is not absolutely prior to the other two algorithms while considering both evaluation accuracy and efficiency, and the difference of their evaluation results do not exceed $0.5\,\mu$m. On the other hand, many points between the maximum value and the least value do not affect the evaluation results in optimization process. For improving the evaluation efficiency, by de-selecting those points while considering the characteristic parameter was also studied based on the statistic method and experiment. Coefficient t should be less than 0.3 to ensure the evaluation accuracy. This research may be useful for developing the next generation measurement instrument for the global sizes and the way forward for the digital manufacturing.

1. Introduction

To ensure the function of the specimen, its dimension and form accuracies are usually controlled according to the tolerances specified in ISO 286 and ISO 1101 respectively. Many cylindrical elements are characterized by both dimension and form accuracies to achieve higher assembly efficiency and reliability [1,2]. In fact, the integrated effect of the actual size, form and position errors should be considered for a fit of hole and shaft, and its actual clearance or interference of fit is determined not only by the actual sizes of hole and shaft, but also by their form errors, such as cylindricity error, roundness error and straightness error. In ISO 14405-1, some new sizes of a cylindrical specimen, such as the global sizes and the calculated sizes, are defined. The global sizes of a cylindrical specimen include the least-squares diameter, the minimum circumscribed diameter and the maximum inscribed diameter, which are the comprehensive dimension of actual size and form errors of a cylindrical specimen. The calculated sizes consist of the circumference diameter, the area diameter and the volume diameter [3,4,5]. The definitions of the three kinds of the global diameters are based

* Corresponding author.
E-mail address: zexiang_zhao@126.com (Z. Zhao).

http://dx.doi.org/10.1016/j.precisioneng.2017.02.007

on three kinds of evaluation methods of the cylindricity errors, and these methods are least-squares, minimum circumscribed and maximum inscribed methods. The least-squares diameter is two times of the mathematic expectation of all the distances between the sampling points and the axis of the rotary table, which is a mean value of the measured feature. The minimum circumscribed and maximum inscribed diameters may satisfy the requirement of the relative principle in the tolerance principle, which includes envelope requirement, maximum material requirement and least material requirement. Besides, the global sizes of a cylindrical specimen may be measured by using one measuring instrument, which may make dimensioning and tolerancing in drawing more concise and measurement more convenient in the future, and may conform to the development direction of the digital manufacturing. According to the definitions of these sizes of a cylindrical specimen, except for 3D coordinate measuring machine, the currently used measuring instruments of cylindrical specimens don't have the capability of measuring these sizes. There are some disadvantages, e.g. low efficiency and low accuracy in measurement, by using this kind of machine. The cylindrical coordinate measurement for cylindrical specimens should be considered. For the measurement of cylindrical form & position errors [6], some measuring instruments, such as the cylindricity measuring instrument and the roundness tester [7], adopt the cylindrical coordinate measuring method, whether it is a turntable-based measuring instrument or it is a turn-axis-based measuring instrument, the polar values in the radial direction are the related measuring values. Therefore, the measuring instruments are not really a cylindrical coordinate measuring machines(C^2M^2 [8]). Although the development of the cylindrical coordinate measuring machine is pressing, this kind of measuring instrument has not been coming into the market due to the fact that the problem of calibration of the absolute polar sizes is not really resolved. Besides that the development of new measuring instrument for the global and calculated sizes is needed, more focus should also be on the issues of the optimization algorithms in their evaluation. Although the absolute measurement technique of the global sizes is quite different, the evaluation method is interchangeable between the evaluation of cylindricity error and the evaluation of the global sizes for the same type of the extracted profiles. The evaluation of cylindricity error has been defined by ISO standard, however, its evaluation method is still updated continuously by new developments of mathematic algorithms to achieve higher evaluation accuracy and efficiency [9]. Mathematic optimization methods with different accuracy and efficiency, such as steepest decent, BFGS-0.618, genetic, computational geometry and neutral network, were designed and applied to the evaluation of cylindricity error by different researchers [10–15]. All the algorithms mentioned are based on the iterative searching strategy with the initial values obtained through the linear least-squares algorithm. In the evaluation algorisms for form errors, the computational geometry algorithm has advantage in the evaluation accuracies of the straightness, flatness and roundness errors [16,17]. In this paper, the genetic, steepest descent and BFGS-0.618 algorithms were used, and their evaluation efficiencies and accuracies were compared. For improving their evaluation efficiencies, the selection rule of the characteristic points in the optimization process was also studied based on a lot of experiments and statistic analyses.

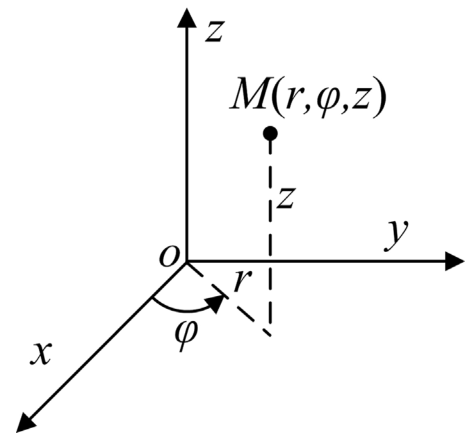

Fig. 1. Cylindrical coordinate system and rectangular coordinate system.

2. The evaluation models of cylinder's global sizes

2.1. Cylindrical coordinate measurement of a cylindrical specimen

The evaluation of a cylindrical specimen's global sizes is based on its profile extraction, which is usually conducted on the cylindrical coordinate measuring machine. In the cylindrical coordinate system, as shown in Fig. 1, *r*, *φ* and *z* are three variables of the system, and in the rectangular coordinate system shown in Fig. 1, *x*, *y* and *z* are three variables of the system. In the evaluation of cylinder's global sizes, the *r*, *φ* and *z* in the cylindrical coordinate system

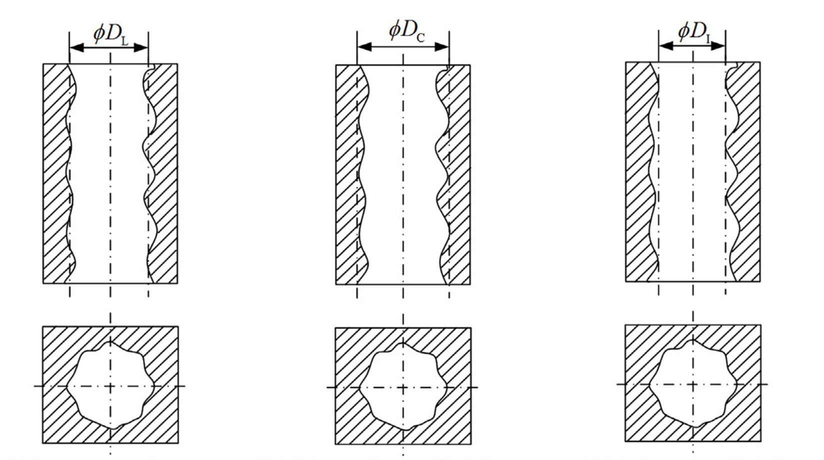

Fig. 2. Schematic of the internal feature's global sizes.