Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 56 (2016) 237 – 242

www.elsevier.com/locate/procedia

9th International Conference on Digital Enterprise Technology - DET 2016 – "Intelligent Manufacturing in the Knowledge Economy Era

An Improved Tolerance Analysis Method Based on Skin Model Shapes of Planar Parts

Zuowei Zhu[a], Lihong Qiao[a,] *, Nabil Anwer[b]

[a]*School of Mechanical Engineering and Automation, Beihang University, 37 Xueyuan Road, Haidian District, Beijing,100191, China*
[b]*Automated Production Research Laboratory LURPA, Ecole Normale Superieure de Cachan, 61 Avenue du President Wilson, 94230 Cachan, France*

* Corresponding author. Tel.: +86-10-82317708. *E-mail address:* lhqiao@buaa.edu.cn

Abstract

Geometric deviations have huge influences on the functional behavior of product, which should be analyzed and properly controlled. Tolerance analysis, as a way to evaluate geometric deviations, is an essential part of product development. Current Computer Aided Tolerancing systems provide solutions for tolerance analysis but have limitations in the consideration of form deviations. The Skin Model theory, as a new research topic, represents part with non-ideal model that comprises geometric deviations, thus developing into a new computer aided tolerancing approach. In this paper, the related work with respect to the generation of Skin Model Shapes and its application in assembly simulation and tolerance analysis is briefly introduced. In order to overcome its shortcomings in the tolerance analysis employing SMSs, this paper proposes an improved method by taking advantage of the method adopted in a CAT system. The proposed method supports the analysis of position and orientation tolerances and has been proved to be valid through a case study.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: Skin Model Shapes; tolerance analysis; assembly; GPS.

1. Introduction

Nowadays, along with the rapidly growing requirement for product quality and the enhanced functionalities of CAD, CAM and CAE systems, Computer Aided Tolerancing (CAT) systems are also gaining worldwide application in aerospace and automotive industries and playing an important role in the product development to provide effective solutions for dimension evaluation and control. Mainstream CAT systems provide simulation tools for modelling the effects of tolerances on digital assembly simulation, in which nominal models of the part or product are adopted for simulation and inevitable limitations have been observed, especially when dealing with form deviations resulted from the manufacturing process [1].

In this context, the Skin Model concept is proposed, which stems from the theoretical background of the Geometrical Product Specification (GPS) and is deemed as a physical interface between the workpiece and its environment. Instead of using ideal solid models, the Skin Model represents parts with non-ideal point clouds or surface meshes based on a discrete geometry framework to represent workpieces, including the deviations brought in by manufacturing, measurement and assembly processes in the models [2]. In the further study of Skin Model, Schleich et.al proposed a comprehensive framework for the application of Skin Model in computer aided tolerancing and robust design to make predictions on the later manufacturing process and to derive information about the fitness of the design [3]. In this framework, the concept of Skin Model Shapes (SMSs) is proposed as particular outcomes of the Skin Model and can be understood as virtual workpiece representatives. The skin model shapes can then treated as sample models of workpieces and be used for engineering simulations like assembly simulation and tolerance analysis. According to the available information in different phases of product design,

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production
doi:10.1016/j.procir.2016.10.072

the generation of skin model shapes is divided into two stages, with different approaches adopted in each stage [3]:

(1) The Prediction Stage applies to the early design stages when geometric deviations of the relevant part cannot be observed yet. Assumptions of systematic and random deviations have to be made to predict possible defects of the given specifications. The systematic deviations are modeled by Second Order Shapes according to the characteristics of certain manufacturing process according to previous experience. While the random deviations are modeled using the random fields theory, in which some parameters have to be set to control the shape and resulted deviations, for example, the correlation length to control the impact of one variable on the neighboring variables so as to control the topological coherence of the shape, as well as the mean and standard deviation to control the deviation value. The deviations are then added to each point of the point cloud in its vertex normal to form a Skin model shape .

(2) The Observation Stage applies to the later design stages when manufacturing process simulations and even measurement data of part prototypes may be available. Therefore, a skin model should take the given observations into consideration and simulate possible outcomes of the production process based on few samples. During this process, a training set of the observed samples is established, and then techniques like Statistical Shape Analysis and Kernel Density Estimate are used to estimate the structure of variability of the training set and generate new samples. These samples can also be used to extract information about systematic and random deviations, so as to estimate the parameters in the Prediction Stage [3].

The skin model shapes generated in both Prediction Phase and Observation Phase have to be evaluated to judge whether their deviations conform to the given tolerance specifications of the part, only those that pass the evaluation can be used for the following simulations [4]. This process is called tolerance constraint, in which following the definition of tolerances in GPS, all the points of the toleranced feature of the Skin model shape have to fall within the tolerance zone in order to pass the evaluation. If not, the Skin model shape has to be given up.

The assembly of skin model shapes of planar parts is done by using the relative positioning approach. Since the skin model shapes are based on discrete point clouds with deviations, they cannot be assembled by adding constraints like coincidence or contact [5]. The relative positioning approach is based on the registration of point clouds of the mating parts' skin model shapes. According to the given assembly process, the skin model shape of each target part is rotated and transformed to fit its corresponding reference part, and finally the position of each part is determined to form the resulting assembly [6].

The tolerance analysis based on SMSs can then be conducted based on the generated sample assemblies. However, in existing studies with respect to the tolerance analysis with SMSs, only form tolerances are emphasized, while lacking in a consideration of orientation and position tolerances. In this paper, the tolerance analysis method of a mainstream CAT system is studied and adopted to improve the tolerance analysis based on SMSs to support its consideration of position and orientation tolerances. The paper is structured as follows: In Section 2, the tolerance analysis of a CAT system, 3DCS, is studied. In Section 3, the defects of the existing tolerance analysis based on SMSs are analyzed and the improved method is presented. A case study is given in Section 4 to illustrate the validity of the proposed method. Finally, a conclusion and an outlook are drawn.

2. Tolerance analysis of mainstream CAT systems

In this section, the tolerance analysis techniques of a mainstream CAT system, 3DCS, is studied. 3DCS is seamlessly integrated with CATIA V5 and widely applied in aeronautics, astronautics and automotive industries to provide a mature solution for the dimension analysis and control of parts or assemblies.

3DCS uses a set of 3D points with a statistical distribution associated to each point, to represent the variational class of a tolerance feature. The points are obtained from the surface mesh of the tolerance feature and the statistical distribution gives the likelihood of the position that a point on the feature may occur within the tolerance zone of the specified tolerance[7].

Therefore, 3DCS can generate a number of samples of a part, each described by a point set with different point positions and constrained within the zone described by the assigned tolerances, through a random number generator that maps random numbers to the associated statistical distribution. Apart from normal distribution, other distribution types like Uniform, Triangular, Exponential, Pearson, Gamma, and Weibull distributions are also supported by the system. According to the characteristics of real manufacturing processes, users can specify the best-fit distribution type, so as to make the simulated surface more conform to the actual surface of the manufactured part. The generated part model samples are then assembled according to the specified assembly process. The key characteristics in each sample assembly can then be measured and statistical analysis can be done on the measurement data.

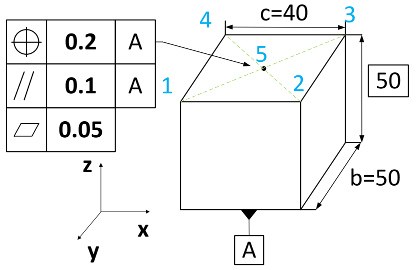

Fig. 1. Specifications on the exemplary part model.

However, how the toleranced features of the non-ideal part model are deviated within the tolerance zone hasn't been well explained to the users. In this paper, a reverse analysis is done to discover the underlying principle of 3DCS in tolerance analysis. As illustrated in Fig.1, an exemplary part with