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Tolerance Analysis of rotating Mechanism based on Skin Model Shapes in discrete Geometry

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Abstract

Geometric deviations are inevitably observable on every manufactured workpiece. These deviations affect the function and quality of mechanical products and have therefore to be controlled by geometric tolerances. Computer-aided tolerancing aims at supporting design, manufacturing, and inspection by determining and quantifying these effects of geometric deviations on the product quality and the functional behaviour. However, most established tolerance representation schemes imply abstractions of geometric deviations and are not conform with the standards for geometric dimensioning and tolerancing. These limitations led to the development of a Skin Model inspired framework for the tolerance analysis, which is based on a representation of non-ideal workpieces employing discrete geometry representation schemes, such as point clouds and surface meshes. In this contribution, this Skin Model inspired framework for computer aided tolerancing is extended to systems in motion and applied to the tolerance analysis of rotating mechanism with higher kinematic pairs. For this purpose, the generation of non-ideal part representatives, as well as their processing with algorithms for registration and computational geometry are highlighted. Finally, the results are visualized and interpreted. The procedure as well as the simulation model itself are shown in a case study of a disk cam mechanism.

Nomenclature

CAD	Computer Aided Design
CAT	Computer Aided Tolerancing
(F)KC	(Functional) Key Characteristic
GPS	Geometric Product Specification and Verification
ISO	International Organization for Standardization
ICP	Iterative Closest Point

1. Introduction

Geometric deviations are inevitably observable on every manufactured workpiece. These deviations affect the functional compliance and quality of mechanical products and have therefore to be controlled by geometric tolerances. Thus, tolerancing is a key activity in order to realize high quality mechanism manufactured at moderate costs. It is a responsible task, which requires a high level of expertise. Computer-aided tolerancing (CAT) aims at supporting design, manufacturing, and inspection by determining and quantifying the effects of geometric deviations on the product quality and the functional behaviour.

In the context of CAT, the representation of geometric deviations is still a key issue in tolerance simulation modelling, since most established tolerance representation schemes imply abstractions of geometric deviations. Many models for the representation of geometric *deviations*, which are subsumed as variational geometry approaches and used for the displacement accumulation, and for the representation of geometric *tolerances*, which are referred to as tolerance zone models and used for the tolerance accumulation, have been proposed [1,2]. However, most of these models only consider translational and rotational defects of part features [3,4]. Furthermore, many of the available tolerance simulation tools are not conform with the standards for geometric dimensioning and tolerancing [5].

These limitations led to the development of a Skin Model inspired framework for the tolerance analysis [6,7], which is based on a representation of non-ideal workpieces employing discrete geometry representation schemes, such as point clouds and surface meshes. These workpiece representatives are referred to as Skin Model Shapes, since they can be interpreted as outcomes of the Skin Model as a basic concept in the standards for geometric product specification and verification. In

this regard, Skin Model Shapes are particular finite Skin Model representatives and each single Skin Model Shape is a specific outcome comprising deviations from manufacturing and assembly [6,8].

In this contribution, this Skin Model inspired framework is extended to systems in motion and applied to the tolerance analysis of rotating mechanism with higher kinematic pairs. In the following section, a brief state of the art with regard to tolerance analysis of mechanism is given. Thereafter, the framework for the skin model based tolerance analysis of mechanism is explained and the employed simulation models are highlighted. Finally, a conclusion and an outlook are given.

2. Tolerance Analysis of Mechanism and Systems in Motion

Tolerancing is a basic task in design and comprises the tolerance analysis, i. e. the prediction of the effects of geometric tolerances on the product function and quality [9]. In this regard, tolerance analysis methods can be classified as one-dimensional tolerance stack-up, two-dimensional, and three-dimensional tolerance analysis [10]. All of these tolerance analysis methods require the representation of geometric deviations by mathematical models. Some of these mathematical approaches for the representation of geometric tolerances are Vectorial Tolerancing [11], the model of Technologically and Topologically Related Surfaces [12], the Direct Linearization Method [13], the Deviation Domain [14] based on the Small Displacement Torsor [15], and Tolerance Maps [16].

Based on these tolerance and deviation representation schemes, various approaches for the tolerance analysis of mechanism have been proposed. For example, vectorial tolerancing has been employed for the tolerance analysis of mechanism with lower kinematic pairs considering different kinds of geometric deviations, such as manufacturing-inherent deviations, deviations caused by elastic deformations and thermal expansion, and clearance in linkages [17]. The approach has been extended with regard to the consideration of interactions between these deviations [18] and has also been used for the tolerance-cost optimization of systems in motion [19]. Furthermore, vectorial tolerancing has been employed for the tolerance analysis of mechanism with higher kinematic pairs (bevel gears) utilizing a numerical contact analysis approach [1]. In contrast to that, a parametric tolerance analysis approach for planar mechanism is proposed in [20] and the tolerance zone approach has been used for the computation of the envelope of rotating parts in [21]. The Direct Linearization Method has been employed for the tolerance analysis of mechanism considering position errors in kinematic linkages [22] and taking into account part flexibility in [23]. Apart from this, a rich survey on multi-body systems with imperfect kinematic joints can be found in [24]. Moreover, a discrete geometry approach for the tolerance analysis of gears has been proposed in [25].

However, since these approaches ground on mathematical models for the representation of geometric deviations and tolerances, which imply severe assumptions, most of them only respect translational and rotational defects of part features. Moreover, they involve complex mathematical models for the evaluation of the effects of geometric deviations and their embedding in an integrated CAT process comprising design, manufacturing, inspection, and product testing is difficult.
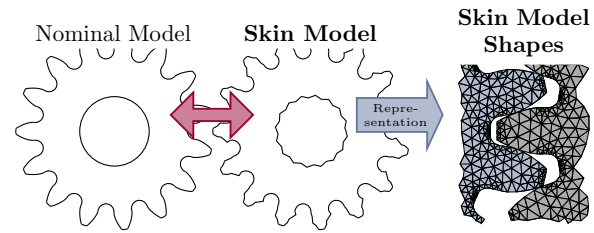

Fig. 1. The Nominal Model, the Skin Model, and the Concept of Skin Model Shapes

3. The Concept of Skin Model Shapes

In order to facilitate and to link the different activities of geometric variations management in design, manufacturing, and inspection, GeoSpelling and the Skin Model concept have been developed and adopted in the standards for GPS (ISO 17450-1) [26], where the Skin Model is a model of the physical interface between a workpiece and its environment. In contrast to the Nominal Model as the designers ideal product geometry proposal, the Skin Model comprises geometric deviations introduced by manufacturing and assembly. Since an infinite description is required to consider all different kinds of geometric deviations from a macro to a micro scale, there exists no possibility for identification and simulation of the Skin Model [27]. Due to this, the concept of Skin Model Shapes has been developed [6], which can be seen as an operationalization of the Skin Model. In this regard, Skin Model Shapes are specific finite outcomes of the Skin Model and serve as virtual part representatives considering geometric deviations. The concept of Skin Model Shapes is not linked to a certain geometry representation scheme, such as discrete (point cloud, surface mesh) or parametric ones (NURBS, Splines). However, a discrete geometry representation is employed for the implementation of Skin Model Shapes, since it is available and processable throughout design, manufacturing, and inspection. For example, a point cloud as well as a surface mesh representation of Skin Model Shapes can be obtained during design by tessellation, whereas part inspection routines by tactile or optical measurement systems lead to such representations during manufacturing and inspection. The difference between the Nominal Model, the Skin Model, and the concept of Skin Model Shapes can be seen from Fig. 1. Since a focus is set on a tolerance analysis approach for rotating mechanism, which requires a contact analysis based on a closed part surface description, a triangle mesh representation of Skin Model Shapes is employed in this contribution.

4. Approach for the Tolerance Analysis of rotating Mechanism based on Skin Model Shapes

In the following, the proposed approach for the tolerance analysis of rotating mechanism with higher kinematic pairs based on Skin Model Shapes is highlighted, where a focus is set on the simulation model for the part assembly and contact evaluation. For the sake of comprehension, it is applied to a study case of a disk cam mechanism as an irregular transmission, which can be seen from Fig. 2. The mechanism is to transmit a circular motion into a longitudinal motion, where the functional key characteristic (FKC) is the altitude of the bolt h_b.