Mechanism and Machine Theory 77 (2014) 148–163

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

A discrete geometry approach for tolerance analysis of mechanism

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ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form 19 February 2014
Accepted 21 February 2014
Available online 15 March 2014

Keywords:
Tolerance analysis
Tooth Contact Analysis
Discrete geometry

ABSTRACT

Tolerance analysis aims at predicting the effects of inevitable geometric deviations on the quality and function of mechanical products and is therefore an import tool in the design and dimensioning of mechanism. Since geometric deviations have various sources, different simulation tools and computer-aided engineering applications must be applied to determine them. Most of these tools are based on a surface or volume discretization, which leads to a workpiece representation in discrete geometry. In this contribution, an approach for the tolerance analysis of mechanism employing these discrete geometry representations is proposed. It is based on the processing of non-ideal workpiece representatives and helps to incorporate results from different validation applications. The approach is applied to the tolerance analysis of spur gears by employing a Tooth Contact Analysis algorithm.

1. Introduction

Manufacturing imprecisions and measurement uncertainties lead to observable geometric deviations, which decrease the function and quality of mechanical products and have thus to be limited by geometric tolerances. In particular, the design and manufacturing of high performance mechanism to moderate costs leads to an inevitable need for geometric variations management and computer-aided tolerancing [7]. In order to specify relevant tolerances, various tolerancing tasks have to be performed during design, such as the tolerance specification, where relevant features and datums are identified, the tolerance allocation, where values for the chosen tolerances are set, and the tolerance analysis [4]. In this regard, tolerance simulations are important tools, which aim at predicting the effects of geometric deviations on the product's functional behavior. In the past, various mathematical approaches for the representation of geometric tolerances in tolerance simulation models have been proposed, such as Vectorial Tolerancing [62], the model of Technologically and Topologically Related Surfaces [15], the Direct Linearization Method [20], the Deviation Domain [21] based on the Small Displacement Torsor [6], and Tolerance Maps [14]. Up to now, these models have mainly been used for assembly-oriented tolerance analysis, i. e. analyzing the effects of geometric tolerances on the assemblability, as this has been the main concern in tolerancing for many years [58]. However, due to steadily increasing requirements on the quality of technical products, there exists a growing interest in considering the functional behavior and operating conditions in computer-aided tolerancing for ensuring the product function during use, which is commonly known as functional tolerancing. In this context, e.g. [5] determine critical operating conditions, such as temperature and pressure, for assemblies with parameter-depended dimensions and evaluate admissible operating windows based on a tolerance stack-up.

In the context of functional tolerance analysis of mechanism, Joskowicz et al. [30] present a general method for kinematic tolerance analysis, whereas Sacks and Joskowicz [41] introduce an algorithm for worst-case kinematic tolerance analysis of

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http://dx.doi.org/10.1016/j.mechmachtheory.2014.02.013
0094-114X/

general planar mechanical systems in generalized configuration space, which can be used to study kinematic variation. Muvengei [38] reviews the evolution in considering imperfect kinematic joints in the dynamic analysis of multi-body systems. Most highlighted approaches take into account operating-dependent deviations due to joint clearances, but do not consider deviations as a consequence to elastic deformations and only respect parametric tolerances. In contrast to that, e.g. Dupac and Beale [18] and Stuppy and Meerkamm [50] also account for elastic deformation due to motion-induced forces. Furthermore, Walter et al. [59] illustrates an approach for the tolerance analysis of mechanism respecting different kinds of geometric deviations as well as their interactions. The obtained results can then be used for the tolerance optimization (see e.g. [32,37,60]). However, these approaches focus on general mechanical and multi-body systems with a kinematic aspect, which do not require the determination of contact positions between parts. Therefore, they cannot simply be applied to gears and similar mechanism, which make a contact analysis necessary [7]. To overcome this challenge, for example Bruyère et al. develop an approach for the statistical tolerance analysis of bevel gear [7,8]. Their vectorial tolerancing approach is based on a geometrical specification model for gear [11] and Tooth Contact Analysis (TCA) as illustrated in [33,35]. In Dantan et al. [12] they use this approach for the tolerance allocation based on discrete optimization. Beside this, finite-element analysis is employed to determine the elastic clearance domain of cylindrical gears in [43]. However, no tolerance analysis is performed based thereon. In Watrin et al. [61], a methodology for the tolerance specification of bevel gear is developed, which aims at supporting product development. Unfortunately, no details about the employed simulation models for TCA and tolerance analysis are given.

Though, when dealing with various sources of geometric deviations, which are to be considered in tolerance analysis, a drawback of most of the established models for geometric tolerance representation employed in the highlighted approaches for tolerance analysis of mechanism becomes obvious. These models tend to make severe assumptions about the geometric deviations since only rotational and translational defects of surface features are considered [3,28] or the geometric deviations are somehow parametrized, which hinders the identification e.g. based on measurements. As a consequence, it is difficult to consider results obtained from manufacturing process simulations (see e.g. [54]) and measurements [22] in these models. Therefore, in this paper, an approach for the tolerance analysis of mechanism based on a discrete geometry representation of non-ideal parts is proposed, which is based on a triangle surface mesh representation of workpieces. Since many computer-aided engineering tools employ a discretization of workpieces, results obtained from such tools, such as manufacturing process simulations or structural simulations based on the finite element method, can be considered in the highlighted approach. Thus, functional kinematic tolerance analysis of mechanism respecting various sources of geometric deviations can be performed.

In the following section, the tolerance analysis of mechanism employing a discrete geometry workpiece representation is highlighted. For this purpose, firstly the general approach is explained, whereupon the steps of this procedure, namely the generation of non-ideal part representatives, the model for the system behavior, and the result interpretation, are highlighted. Finally, a conclusion and an outlook are given.

2. Tolerance analysis of mechanism employing a discrete geometry representation

Following Dantan et al., three main issues have to be regarded in tolerance analysis, namely finding models for the representation of geometric deviations, developing models for calculating the effects of these deviations on the system behavior, and applying solution techniques or analysis methods, such as worst-case or statistical [13]. In the following, a general approach for the tolerance analysis of mechanism based on a discrete geometry representation is proposed. This approach is then applied to perform a tolerance analysis for spur gears. For this purpose, approaches for each of these three aspects are highlighted, namely a random field method for the generation of non-ideal part representatives, a discrete geometry approach for the Tooth Contact Analysis, and finally a statistical result interpretation.

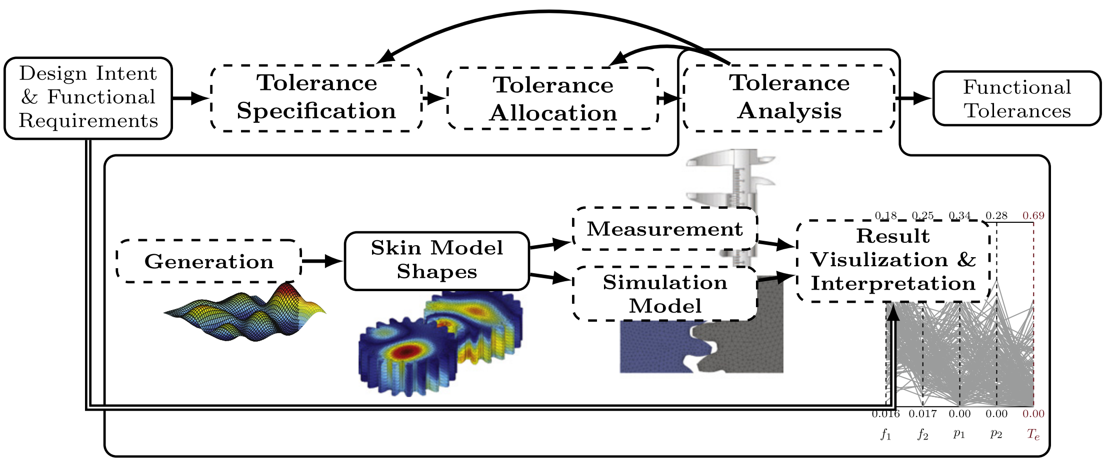

Fig. 1. The tolerance analysis approach of mechanism in discrete geometry.