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Hybrid Tolerance Representation of Systems in Motion

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Abstract

Dimensional management deals with the fact that the real geometry of every manufactured part deviates from its ideal shape. To evaluate the effects of these deviations tolerance analysis, which are often based on vectorial models, are carried out. Nevertheless the use of vectorial models has one major disadvantage – they cannot adequately represent form deviations. As a consequence new concepts of representations based on the GPS' Skin Model have been established. Since the use of Skin Model Shapes (SMS) is time-consuming and does not always offer advantages over vectorial models, the Hybrid Tolerance Representation (HTR) which combines the advantages of vectorial and discretely represented tolerances is introduced in this paper. The HTR is based on a classification of the contact situation of the cinematic chain into lower and higher kinematic pairs. Based in this classification all higher kinematic pairs are going to be represented by SMS whereas lower pairs, are represented by vectors. Besides the simulation of the contact situation of all higher kinematic pairs the coupling of vectorial and discrete geometry representations is a challenge. The practical implementation of the presented method is shown on an X-ray shutter.

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1. Introduction

Every technical system is designed to fulfill certain tasks under certain circumstances. Although all parts of a technical system are designed using ideal shapes, deviations from these ideal will occur. These deviations can be caused by manufacturing processes, assembly operations or operating conditions which will always lead to a deviation from the ideal situation.

One of the main tasks of dimensional management is to adequately consider these deviations from the ideal status. During tolerance analysis the effects of geometric deviations on Functional Key Characteristics (FKCs) [1] of a system are calculated and assessed. After the assessment, the product designer can decide whether a tolerance schema is suitable for a system and its individual parts or not.

For the calculation as well as for the assessment different tools and methods can be used. These tools and methods differ at the underlying mathematical assumptions as well as at the presentation form of the deviations. Selecting the best form of representation can be a tight-rope walk since a major simplification might lead to inaccurate results while a very accurate form of representation goes along with higher computational effort. Furthermore, it is necessary to have detailed information about part deviations which allow a detailed modelling of these deviations.

In the following, a brief overview of different forms of representations will be given whereas the focus is on vectorial and discrete geometry representations. Additionally, some basic terms regarding mechanism design will be outlined. Based on this theoretical background the methodology for HTR is introduced. This novel approach combines the advantages of vectorial and discrete tolerance representations for systems in motion. To illustrate the application, the methodology is applied on an X-ray shutter which is used as a case study.

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2. State of the Art

Tolerance Analysis focusses on the effects of non-ideal parts and processes on FKCs. Such an analysis, which is based on a defined tolerance schema, can be done using a worst-case scenario where every dimension is considered as an extreme value. Consequently, the limits of every FKC can be calculated by an addition of all minimum or maximum values of the tolerance chain. Since this worst-case method is not capable to handle different kinds of distributions which occur during production processes, statistical methods like the Monte Carlo method are frequently used to calculate the effects of geometric deviations. Worst-case as well as statistical methods can be combined with different forms of geometry representations to calculate the effects on a certain FKC.

Besides vectorial descriptions which are detailed below, many different mathematical models have been developed in the last decades. T-Maps [2], Deviation Domains [3], Polytops [4] and the Small Displacement Torsor (SDT) [5] are the most prominent representatives. Although every single concept has its specific pros and cons they have one shortcoming in common. All the mentioned approaches are partly suitable when form-deviations play a major role. To handle these form-deviations discrete tolerance representations have been established in the recent years (see 2.2) [6]. Since the HTR is based on the coupling of two methods, the following sections describe in detail the vectorial and discrete tolerance representations.

2.1. Vectorial tolerance representation

For vectorial tolerance analysis a FKC has to be described with a vector chain, whereby features of every part can be described by vectors. Based on the permissible deviations from the ideal the orientations and lengths of the vectors a varied to represent deviation afflicted features.

WALTER deals with tolerance analysis of systems in motion whereas he focusses on the consideration of interactions between occurring deviations and their effects. In his works he extends the vectorial tolerance-model by integrating meta-models to represent the interactions between deviations. [7]

GEIS also worked in a similar field focusing on the integration of vectorial tolerances in a CAD-system. Motivated by the B-Rep description which is used in CAD-systems, the integration yields at a more user-friendly tolerance-analysis. [8]

Vectorial tolerance representations are also widespread in the field of Tolerance-Optimization [9,10]. The focus of this research field lies on the improvement of tolerance schemes while other aspects like tolerance-cost-relations or scrap rates are considered.

2.2. Discrete tolerance representations

Representing geometry with point-clouds or grids is the main idea of discrete tolerance representations. This strategy enables engineers to consider form-deviations more precisely.

STOLL developed a concept for the representation of non-ideal geometries based on point-clouds. In [11] he focused on the optimization-based approach for the 3-dimensional positioning.

POLINI and MORONI also worked in this field and focused in [12] on the integration of manufacturing signatures. The 2 -dimensional case study is extended to another dimension in [13] whereas operating conditions like gravity and friction are additionally considered.

Besides these approaches, the concept of SMS has been developed in the last few years. The basic idea can be dated back to 1993 where BALLU and MATHIEU introduced the idea of Skin Models in [14].

In contrast to the infinite Skin Model, a SMS is one discrete realization. The handling of these SMS can be divided into three major steps. In the pre-processing individual SMS are generated based on the Skin Model. Thereafter, the assembly and positioning of parts can be simulated while the effects on certain key characteristics are assessed during the final step, the post-processing. Besides this assessment, the results can also be visualized and should be interpreted during the post-processing. [6]

2.3. Mechanism Terminology

A mechanism is the part of a machine which transfers and modifies motion and forces from a power source to an output. Such a mechanism consists of links which are connected via joints. Although small deformations are possible, joints are considered as ideally rigid bodies – as a consequence all elastic parts, such as dampers or springs, are no links. The rigid links are connected with movable joints which enable relative movements between the rigid bodies. These joints can be categorized into two groups, namely full or half joints. For full joints, also called lower pairs, the contact between the links is surface. [15]

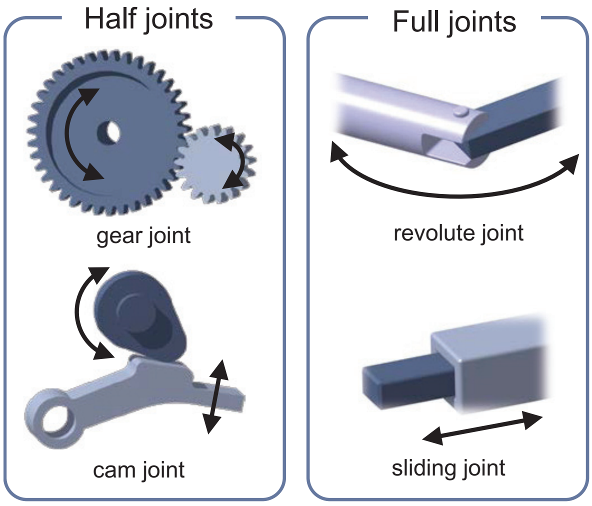

Figure 1 Full and half joints

As shown in Figure 1, revolute pairs or prismatic joints are typical examples for such a full joint. Other joints such as

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