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On Connected Tolerances in Statistical Tolerance-Cost-Optimization of Assemblies with Interrelated Dimension Chains

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Abstract

Identifying a suitable compromise between tight and thus expensive tolerances and wide tolerances that may negatively influence the product quality is a major challenge. This paper focuses on the tolerance-cost-optimization of mechanical assemblies with interrelated dimension chains considering dependencies between the tolerance–cost-relationships. Taking into account interrelated dimension chains the crux is, however, that modifications of a single tolerance can influence several dimension chains as well as the resulting production costs. Based on different existing approaches for the statistical tolerance-cost-optimization, the authors will provide appropriate guidance for the product developer dealing with interrelated dimension chains.

*Keywords:*tolerance allocation; interrelated tolerance-cost-function; connected dimension chains; modification of tolerance-cost-relation

1. Introduction

Today's products are usually designed in a 3D-CAD environment that can only represent the designer's ideal conception of the parts. In practice, however, these ideal conceptions can never be realized. The ideal product characteristics will never be achieved due to variations during manufacture and assembly as well as varying operating conditions (such as a varying temperature during the use) (Figure 1). At this point, tolerances come into play to restrict the acceptable effects of intrinsic variations during production, assembly and operation.

Despite all gained success in research and development of tolerance engineering, the specification of tolerances of products, assemblies, single parts and even individual features is a tightrope walk because each tighter tolerance enhances the production cost while each wider tolerance might endanger significant quality features of a product [1]. Due to the fact that not only the costs, but also the quality of a product is strongly influenced by the tolerance scheme, tolerance design is one of the most important steps in product development.

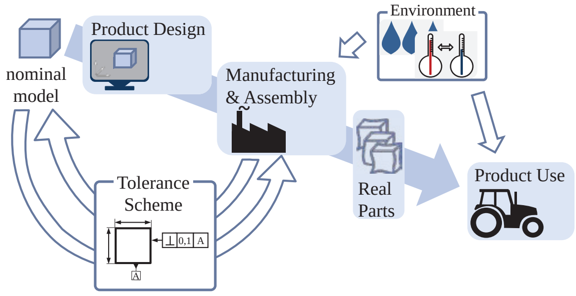

Fig. 1. From the nominal model to the deviation-afflicted real parts

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To ensure quality and flawless functionality of products several methods on tolerance analysis have been established in the last decades. Besides more recent approaches on the representation of tolerances such as Deviation Domains [2], T-Maps® [3] or Skin Models [4], vector-chain-based approaches are widespread in academics and industrial practice [1]. All these approaches have in common that relevant quality features are described by so-called “Functional Key Characteristics” (FKCs) [5] which are influenced by varying factors.

Considering the complexity of products the designer has to cope with several different FKCs that are often interrelated. This means that the modification of a single tolerance value influences more than one FKC. This issue is illustrated in Figure 2, where the interrelation of two dimensional chains, each consisting of five rings, is shown.

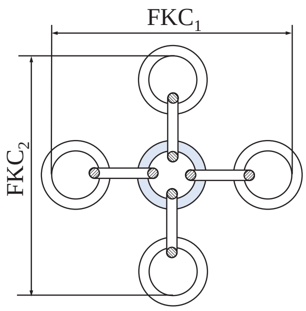

Fig. 2. Interrelated dimension chains

The diameter and roundness of the blue ring influence both FKCs as shown in the drawing

2. Related Work

Specifying a proper tolerance design for each single part of a product effects several departments of a company. Not only production and assembly departments but also the quality management and the rework processes etc. are directly affected by given tolerances. As a consequence, the initial tolerance design of a new product is usually based on previous projects or general tolerances. After the specification of the initial tolerance design a tolerance analysis is usually set up to evaluate the effects of the deviations on certain FKCs. If the functional requirements cannot be fulfilled, the initial tolerance design is changed iteratively until the required scrap rate is under a certain limit. Since tolerances are major cost drivers, finding the “best tolerance design” is essential against the backdrop of technical as well as financial aspects.

Early analytical approaches for tolerance synthesis [6] have been replaced by the first computer-aided approach in 1964 by MOY [7]. The computer-aided approaches were further developed using different algorithms in the 1970s, most famously by SPOTTS and SPECKHART [8], [9]. Even though different tolerance-cost-relations from the 1970s were expanded within the following 20 years by CHASE et al. [10], none of these approaches considers connections of more than one tolerance dimensions.

First, SINGH et al. classifies tolerance chains in [11] and highlights the importance of connections between different dimension chains. According to them, a dimension chain (also called tolerance chain or dimension loop) is an abstract model of an assembly taking geometric relations into account. Thereby, the dimension chain is a sequence of at least two dimensions. The simplest form of a dimension chain is an elementary chain that encounters every end point once. Dimension chains that include a dimension not more than one time are called “simple chains”. Apart from elementary and simple chains, each remaining type of dimension chain is called an “interrelated chain” [11].

SINGH made a first approach defining the optimal tolerance design by means of a Genetic Algorithm (GA) to handle the non-linear dependencies. However, their approach is based on a worst-case tolerance analysis. Consequently, this approach is currently not able to handle different probability distributions of tolerances unlike the state-of-the-art Monte-Carlo-based tolerance analysis.

The above and below mentioned approaches assume that the tolerances for each dimension can be allocated arbitrary within each corresponding tolerance zone. Unlike this assumption LÖÖF points out, that usually tolerances can solely be picked from a limited set of discrete values. Based on this assumption a procedure for tolerance-cost-optimization, coupled with commercial CAT Software, using discrete values is presented. Furthermore the possibility for the consideration of general loss functions is provided within this work [12].

GEETHA also worked in a similar field, focusing on the composition of manufacturing costs. Their enhanced tolerance-cost-model considers several additional significant parameters such as costs arising from machine idle times and machine engaged times. A wheel mounting assembly is used to illustrate the optimization using Genetic Algorithm [13].

In Summary, existing research details on the importance of tolerance-cost-optimization of connected dimension chains. Because manufacturing processes often affect more than one dimension of parts, a dependence of different tolerances is inevitable, however currently not considered satisfyingly.

In this paper the authors provide a methodology for the statistical tolerance-cost-optimization for interrelated dimension chains considering connected tolerances. Therefore, the Particle Swarm Optimization (PSO) is used to identify the optimal tolerance design. The practical use of the proposed methodology is detailed for a driving pulley.

3. Tolerance-Cost-Optimization of interrelated Dimension Chains with connected production costs

Finding the ideal tolerance design for each single part of an assembly is a challenging task since even with known tolerance-cost-models it’s often not obvious which tolerances should be tightened and/or widened. Therefore, a methodology for a systematic statistical tolerance-cost-optimization is presented in this section. Furthermore, existing