Computer-Aided Design 45 (2013) 1604–1616

Contents lists available at ScienceDirect

Computer-Aided Design

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

A method for computer-aided specification of geometric tolerances

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HIGHLIGHTS

- Automated generation of GD&T specifications for mechanical assemblies.
- Data-driven identification of most precision requirements from assembly process data.
- Rule-based selection of datum reference frames and tolerance types on parts.
- Text-based input and output, discussion of CAD implementation issues.

ARTICLE INFO

Article history:
Received 28 September 2012
Accepted 15 August 2013

Keywords:
Tolerancing
Tolerance specification
Geometric tolerances
Assembly requirements
Datum selection

ABSTRACT

The paper describes a method for the generation of tolerance specifications from product data. The problem is nontrivial due to the increasing adoption of geometric dimensioning criteria, which call for the use of many types of geometric tolerances to completely and unambiguously represent the design intent and the many constraints deriving from manufacturing, assembly and inspection processes. All these issues have to be modeled and explicitly provided to a generative specification procedure, which may thus need a large amount of input data. The proposed approach tries to avoid this difficulty by considering that most precision requirements to be defined relate to the assembly process, and can be automatically derived by analyzing the contact relations between parts and the assembly operations planned for the product. Along with possible user-defined additional requirements relating to function, assembly requirements are used in a rule-based geometric reasoning procedure to select datum reference frames for each part and to assign tolerance types to part features. A demonstrative software tool based on the developed procedure has allowed to verify its correctness and application scope on some product examples.

1. Introduction

The way of specifying tolerances on manufactured products has progressively changed during the last two decades. In traditional practice, allowable variation limits were simply assigned to dimensions regarded as critical for fit and function (linear tolerancing). This is no longer sufficient, since the advent of Geometric Dimensioning and Tolerancing (GD&T) has put forward the idea that part features need to be controlled in many different geometric characteristics (size, form, orientation, location, profile, runout). While overcoming the ambiguity, incompleteness and inefficiency issues involved by linear tolerances, this approach forces the designer to become familiar with complex tolerance standards [1,2] and able to apply them to a diversity of design cases. The difficulty of doing that has encouraged the development of computer-aided tools for the design of geometric tolerances [3]. They pursue different levels of support (guidelines, interactive procedures, data-driven software) to three main tasks, which are illustrated in Fig. 1 on a conceptual example:

- tolerance specification: the types of tolerances on functional features and the datum reference frame are chosen for each part;
- tolerance allocation: the values of all specified tolerances are determined by either refining empirical tentative values or optimizing them according to cost–tolerance functions;
- tolerance analysis: the stackup of errors allowed by selected tolerance values is evaluated and compared to design requirements (possibly more than once during the allocation procedure).

To date, little support exists for tolerance specification and allocation, while software tools for tolerance analysis are available on a growing number of CAD platforms.

This paper presents a method for the solution of tolerance specification problems, which was previously reported at an early development stage [4] and has been extended and implemented into a demonstrative software tool. Specification is less studied than allocation and analysis, because it was not an issue with linear tolerancing and is actually inherent to the geometric approach. It can be viewed as a missing link in the tolerancing chain, which provides the two downstream tasks with a correct and complete geometric description of design requirements in the GD&T language.

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http://dx.doi.org/10.1016/j.cad.2013.08.007

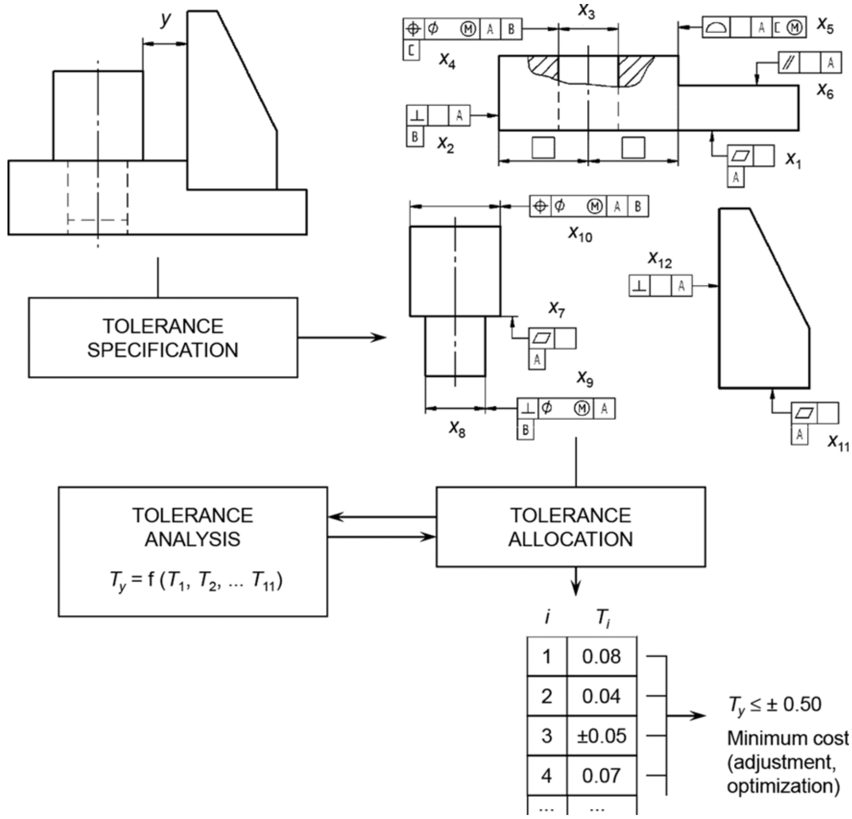

Fig. 1. Tasks involved in geometric tolerancing.

Compared to available approaches to tolerance specification, the proposed method attempts to streamline the flow of input information, which can be difficult to manage for a designer. This is done by putting most design requirements in relationship with product data, thus avoiding the need to provide them in input to the specification procedure. The method aims also at ensuring that specified tolerances are presented to the designer with a clear representation of the reasoning steps behind them. Both motivations can help to effectively treat complex products and to improve the acceptance of a computer-aided tool in the design environment.

2. Background and approach

As noted in a recent survey [5], tolerance specification has often been referred to by different names to emphasize its distinction from allocation (qualitative tolerancing) or the need for a modeling of design requirements (tolerancing for function, tolerancing for assembly). Its role within the tolerancing process and its relationships to downstream tasks have been clarified in some early papers [6,7]. Although it involves detailed part design, it should be anticipated to the earlier stage of assembly design as suggested in [8,9]. Acceptance conditions on the tolerances generated by a specification procedure include the unambiguous positioning of part features [10,11] and the compliance to syntax rules stated by technical standards [12]. Tolerance values are not specified as they will be optimized in the allocation task along with possible alternative choices for tolerance types and datum reference frames [13].

The basic input for tolerance specification is the nominal product geometry as it could be extracted from a geometric modeler, although only a few studies report a true CAD integration. The processing of geometric data involves a preliminary selection of the features to be toleranced. In most cases, these are classified according to the types of assembly relations with features of mating parts. The classification adopted here has some resemblance to the one proposed in [14], based on the number of actual contact points and on the degrees of freedom subtracted to the relative motion of parts. Additional product data considered in the proposed method include the assembly sequence, whose influence has been pointed out and discussed in [15].

Input data can be completed with additional precision requirements set by the designer. In linear tolerancing, requirements are mainly related to tolerance chains as widely discussed in [16]. In the context of GD&T this concept is better specialized with the definition of key characteristics, delivered by chains of geometric relations identified by means of flowdown procedures [15]. Alternative ways proposed to represent design requirements include assembly geometric tolerances [17], pseudo-TTRS [18], virtual boundary requirements [19], functional–structural models [20] and hierarchies of hypergraphs [21]. The chance to generate some of the requirements from product data, which was explored in this work, has its roots in previous research on the identification of ending gaps of tolerance chains through search in graph-based models of assembly relations [22–24].

Available knowledge for the solution of the specification problem comes from tolerance standards and technical handbooks in the form of rules and application examples. Most of them are concerned with the selection of datum reference frames on parts, a subproblem which is usually regarded as the core of a specification procedure. It involves geometric reasoning on many properties of part features including shape, size, types of assembly relations, relevance for product function, ease of access during the manufacturing process. Datum selection is usually restricted within typical configurations classified in [25] and connected to designs of machining and inspection fixtures.

In an attempt to formalize such knowledge, a major question is how a feature with given geometric properties can be toleranced with respect to one or more datums. It has been pointed out that finite sets of tolerancing cases can be classified. A set of 44 cases is