

A Novel Approach to Create Dimensional Tolerance Requirements from Expert Knowledge

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ABSTRACT

Geometric Dimensioning and Tolerancing is used to describe the allowed feature variations regarding the product design. Tolerance specification is important in many stages of all phases on product development. The product development engineering need to define the symbols to use on the Feature Control Frame of every component. Since the component function has an increment on its complexity year over year, it is not trivial to define those symbols anymore. The determination of dimensional tolerance shall be preceded by careful specification of the types of tolerance and symbols that will be applied in controlled features. Poor tolerance specifications can increase the production cost, require late product changes or lead to legal issues. In this scenario, this paper presents a method to evaluate this engineering information for a few number of GD&T technical experts in a specific system, like chassis or powertrain, and translate it into dimensional tolerance requirements to support the tolerance specification process using fuzzy logic. Also, the method suggests the best set of symbols based on the feature geometry, assembly and function analysis and classify these features to generate significant information on the automotive industry.

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INTRODUCTION

Product definition must be based on functional requirements. There is an really important thing to be considered in tolerancing a component: function [1]. The determination of dimensional tolerance shall be preceded by careful specification of the types of tolerance and symbols that will be applied in controlled features. Since the selection of basic positioning features, known as datums system, to the choice of a modifier material or the diameter symbol usage modify the tolerance zone designed and impact on the measurement of the part [2].

A lot of research has been done regarding the assignment of geometric tolerances on manufactured parts [3]. The methods developed can be classified in three categories: tolerance specification, tolerance allocation and tolerance analysis. Designers are responsible for set numerical values on tolerance allocation phase and engineering verifies design requirements, as gaps and angles, on tolerance analysis.

On tolerance specification, the designer shall select datums, important features and all symbols to be used inside the Feature Control Frame (FCF). The selection of each symbol depends on the designer's experience that determines the best sequence to create the FCF. Some industries developed internal design rules to support tolerance

specifications for common cases, but it is not enough to avoid poor tolerance specifications. Designer's experience on tolerancing is a tacit knowledge, defined as skills or experiences they know and are not easily codified or even expressed [4]. Regarding GD&T, it is hard to codify this tacit knowledge and transform it in explicit knowledge.

GD&T aligned with international standard, right people trained, key characteristic identification based on functional requirements and identify customer's product requirements are important and applied factors on dimensional management system process [5].

According to [2], improvements on tolerance specification are expected in three areas: the treatment of product data, the general strategy for problem solution, and the compatibility with downstream tolerancing tasks. Some improvements need to be made to the treatment of design requirements, as the automated identification of assembly requirements. Functional requirements need to be better modeled and classified.

Regarding tolerance and requirements classification, software permit tolerances for a feature to be associated with an entity in a CAD file since 1999. But the way this tolerance requirement is stored and

associated with the entity is not yet standardized, and the information is not as readable as a 2D drawing by the engineering team [6]. It creates a barrier in establishing a GD&T database possible to be read and analyzed by computer methods.

This paper presents a method to evaluate this engineering information for a few number of GD&T technical experts in a specific system, like chassis or powertrain, and translate it into dimensional tolerance requirements to support the tolerance specification process. In addition, the method proposes a way to classify these features and generate important data on the automotive industry.

CURRENT APPROACHES ON TOLERANCE SPECIFICATION

Experts and researchers have tried to systematize tolerancing knowledge in the form of concepts and rules, including empirical rules for the selection of datums and geometric symbols and classifications of tolerancing cases to define a limited sets of solutions [2].

Datum selection is evaluated in tolerancing handbooks grounded on ASME standards [7] and case studies of tolerance specification [8]. A basic rule suggests selecting the features that establish the most important assembly relations for product function as Datums. Rotation axis or mating surfaces can be selected as datums. Once a Datum Reference Frame (DRF) has been selected, tolerances shall be selected on all target features of the part.

To specify a geometric tolerance, every target feature is toleranced with respect to a DRF including previous tolerance features. Most classifications are based on the concept of invariance. All features possible deviations from nominal geometry must be restricted within tolerance zones to be controlled. Invariance is based on degrees of freedom concept. The model classifies part surfaces in seven classes according to their invariance according to translations and rotations, defined as spherical, planar, cylindrical, helical, rotational, prismatic, and generic [9].

Associations between two surfaces belonging to the same part are Technologically and Topologically Related Surfaces (TTRSs) [9]. With the TTRS is possible to define the geometric characteristic symbol to be used. Consider a cylinder (target) with a plane (datum). If the cylinder is perpendicular to the plane, the resulting TTRS belongs to the invariance class of rotational surfaces and corresponds to a perpendicularity tolerance. If it is parallel to the plane, the TTRS corresponds to a position tolerance. The result of the TTRS concept is a limited set of tolerancing cases and can be explored in a generative specification procedure. The classification according to TTRS model is not the only one, as it assumes a definition of invariance classes, which may not cover the diversity of features, designed on manufactured parts. [2].

Many methods were proposed for the selection of DRFs and tolerance types on part features. The primary and most frequently cited method was developed from the TTRS model. The method

approach define each surface by an invariance class and a set of Minimum Geometric Datum Element (MGDE). When two surfaces are related with each other, these data allow one to determine the tolerances needed to control their relative position. It is associated to an invariance class and a MGDE. This concept builds a hierarchy of TTRSs on the functional features of each part [2].

Some other methods were developed to support the geometric tolerance specification. The analysis of the degrees of freedom of part features [10,11]. The propagation of datums and geometric controls from special features, also called mirrors methods [8]. Function decomposition of requirements at the feature level by simplification of the assembly relation graph [12]. Amillotta defined a method with possible user-defined additional requirements related to function, assembly requirements to select DRF for each part and to assign tolerance types to part features [13]. Geometrical position tolerance assignment in reverse engineering to suggest position tolerances sets [14], positioning table method, based on the propagation of requirements on individual parts from relational information [15] and variational loop circuit [16] are other methods available too.

All presented approaches focus on the choice of geometric characteristic symbol. FCF is the representation of geometric control characteristic, modifiers and datums. Different sets of modifying symbols can drastically affect the tolerance zone and shall be select based on the fit and function. According to the Appendix E at ASME Y14.5 2009, designers must consider both the stabilization of the part and the functional requirements of the features when documenting design intent [17]. The lack of experience can be a barrier to use those modifying symbols for each required function and it can lead to a poor specification.

KNOWLEDGE MANAGEMENT ON PRODUCT DEVELOPMENT

Knowledge definitions are influenced by people specific challenges or their predispositions about a particular topic. There is a difference between data, information and knowledge, as well as a level of hierarchy between these terms. Data consist of sequences of symbols or characters, such as letters or digits, which combination has a meaning and conforms to certain rules. However, raw data are not interpreted, and can not be completed on a specific subject only with these data [18].

Information, on the other hand, is created when the data is evaluated in context. By adding one perspective or economic interpretation, raw data are converted into meaningful information that can be used to guide operations and decisions. Knowledge is developed when the information is connected to a goal and classified within a context of experience. Dependence on context creates the issue in which the same information can generate different forms of knowledge about the same conditions, when used in different contexts based on experience. Create and manage knowledge about a particular product is crucial to the development and automotive product and should be treated as a high-priority process [19].

The product knowledge emerges in multiple sources. As the basic human knowledge is learned through education that we received during our childhood, in many different ways, the acquired knowledge about the product is naturally developed in every human being who has interest in the specific product. For the organization, this means that the management of information and knowledge of the product should be used to build a collective knowledge base in order to establish and preserve this knowledge. In this context, knowledge of the product is the entire body of existing information on it [19].

According to [20], knowledge is defined as a set of experiences and skills that individuals use to solve problems. This ability also known as competence is well defined at the time that the knowledge is applied. Core competencies, considered extremely important for organizations, are a collection of specific knowledge skills and technologies that can not be easily copied by competitors. These skills enable organizations to meet the needs of customers and it can be transferred to new products and areas [21].

Knowledge can also be defined as their psychology, expression and carrier [22]. About the skill of expression, knowledge may be tacit, classified as a skill that can not be explained by spoken or written words and can only be demonstrated, or explicit, which is the codified knowledge through manuals and papers [23].

The tolerance specification is important in many stages of all phases on product development. Therefore, the management of this specific knowledge is required to ensure competitive and economic advantages of the organizations during the development of new vehicles. Also, according to [24] there is no question that GD&T is a complex issue that can only be learned through excessive practice. Once GD&T is not a constant task through product development process, it is difficult to the designer to learn how to choose the right symbols on tolerance specification phase.

METHOD

The aim of this method is to organize the process to develop dimensional tolerance requirements and ensure that organizations can transform tacit knowledge related to tolerances specification into explicit knowledge.

1. Choose the default geometric feature, defined as a geometric feature whose function is repeated in different sets. For example, a threaded hole for fixing a locating pin or a rotating axis.
2. Classify this feature, in order to be able to reuse the results achieved from a structured database.
3. Set the hypothesis or question to be answered. This question is fundamental to determine the inputs and rules as well as understand the output of fuzzy model.
4. Design the model inputs, the linguistic variables.

5. Select the experts according to the application being evaluated. The number of experts shall be sufficient to ensure that the result is valid.
6. Develop and apply the survey questionnaire to the experts.
7. Apply the results in a fuzzy expert system.
8. Analyze the outputs.
9. Document the outcome, converting it into a dimensional engineering requirement.

The specification tolerances has as its starting point the analysis of geometric feature and its connection with other features, in other parts, and its function in the assembly [7]. The development of dimensional tolerance requirements need a structured classification system. This classification structure is important to organize the data in the process of tolerance specification and it is accord with the classification of geometric features at ASME Y14.5 2009 and the basic functions of a mechanical system, such as rotation and translation movements. Moreover, it evaluates the component and features connected with the main geometric feature (Figure 1).

The Fixed Fastener System Case Study

Fixed fastener system is a condition where two or more parts are joined together. One part locates a fastener in a fixed manner utilizing threaded holes or undersized hole for stud or pins and other parts have clearance holes. The threaded hole FCF of a fixed fastener system will be analyzed in this paper. This application is widely used in the automotive industry (Figure 2).

The threaded hole on the first analyzed component can be classified as a cylindrical surface, part of the regular feature of size cluster. It is a static powertrain assembly and the design intent is to have the mating surfaces in touch condition. Its function is to attach the mating part to the component with a fastener. Also, the analyzed mating parts have different thickness. According to the final assembly team, thick parts present more issues to be assembled. This feature were classified according the geometry and assembly analysis.

The position tolerance is frequently applied to a threaded hole, to assure the correct assembly of the parts in this system. Three different sets of modifying symbols were found in this automotive industry database to the fixed fastener application. In the first analyzed case, designers used only the position tolerance control without any modifying symbol on the FCF. In this condition, the position tolerance is the same independent of the feature produced diameter, also called Regardless of Feature Size (RFS). Designers have used the Maximum Material Condition (MMC) symbol in some other drawings. In the third scenario, designers applied the MMC and Projected Tolerance (PT) zone Symbol together on the FCF. All evaluated FCF have their DRF filled according the assembly needs. The FCF information were get from 2D drawings available on database (Figure 3).