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From Functions to Tolerance Analysis Models by Using Energy Flow Model in Characteristics-Properties Modelling

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Abstract

In the product design process, the designer needs to figure out how to integrate tolerancing process to ensure the transition from function to tolerances. Our proposition is to use energy flow modeling in Characteristics-Properties Modeling (CPM). CPM creates a framework containing function and structure of the product. Energy flow creates the link between function and structure in CPM using energy-based behavior modeling. Considering both qualitative and quantitative aspects, the result is an approach to create a quantitative function-behavior-structure relationship to ensure the transition from function to geometrical specifications. This systematic approach can be used to evaluate the tolerance impact on system's function.

Keywords: Product development; product modeling; Characteristics-Properties Modeling; CPM; functional analysis; tolerancing; energy flow

1. Introduction

In designing products, the main objective is designing products with high quality. The quality of a product can be defined by its efficiency. Efficiency is related to the losses in the system. So, if different losses are reduced, the efficiency can be increased. In many cases, the losses are related to the gaps between moving parts, assembled parts or any other gaps that are necessary and unavoidable or avoidable in functioning of the product. Any gap is related to the dimensions of two or more parts. This gap can be modified by changing the tolerances of related dimensions. Therefore, taking into account the liaison between efficiency and tolerances, one of the approaches to improve product quality is tightening tolerances. In this approach, the key point is to find the related tolerances to the performance of the product.

Commonly, there are four aspects of tolerancing: Tolerance representation, tolerance specification, tolerance analysis, and tolerance synthesis [1,2].

The aspect of tolerance specification is to identify the related tolerances to the performance and function of the system. Several approaches are presented in literature for this aspect [3]–[6]. The determined relations in these approaches are qualitative. So, two aspects of tolerance analysis and synthesis are used to have a quantitative model of system based on the identified qualitative links. Moreover, Dantan *et al.* [7] proposed a multi-level approach, which includes parallel processes of conceptual design and tolerancing process as shown in Fig. 1.

In these approaches, the designer studies the functional performance of a product and then looking for geometrical requirement that might effect on the performance. Then, based on the geometrical requirements, the related tolerances are identified. So, in tolerance analysis, the designer needs to model the functional characteristics, component deviations, and environmental impacts. So, both qualitative and quantitative relations should be in the system's model.

Thus, the designer first needs to find the link between system's function and its specifications. Second, the impact of related tolerances to each specification is analyzed on the performance of the system. The difficulty is to link the qualitative functional requirements to the quantitative

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functional tolerances. So, a multi-physical approach is needed to assure the transition from function to tolerances taking into account both qualitative and quantitative aspects.

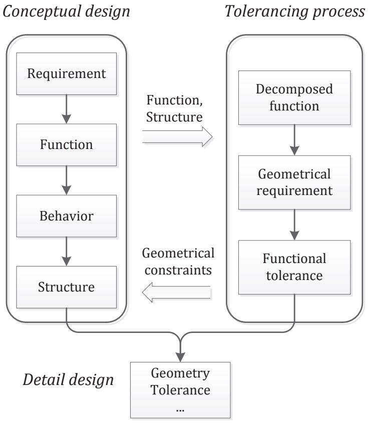

Fig. 1. Common approach for function-tolerance analysis [7]

This paper proposes a systematic approach to create a quantitative link between functional performance and functional tolerances. In this approach, which includes two phases, the qualitative functional and tolerance requirements are combined with quantitative relations. The first phase is to create a quantitative model of the product based on the functional performance, behavior and structure of the product. The model establishes a link between functional performance and geometrical dimensions. In the second phase, the model is used to analyze the impact of tolerances on functional performance.

In the first phase, to create the model, Characteristics-Properties Modeling (CPM) [8,9] is used as a framework of the approach. Basically, this framework is used to demonstrate a quantitative link between function and structure of a product. However, establishing this link, bearing in mind the coupling of design elements, is not straightforward.

In order to identify such relationship, a complementary model which is based on physical links in the product is required. Among the possibilities, there are three types of flows that can create such link: material flow, information flow and energy flow. Material flow is the best means in designing manufacturing processes. Information flow is mostly used in system engineering or processes. For modeling mechanical products, energy flow is one of the best means to find the physical links between the elements [10].

Thus, energy flow is used in this paper to determine the relationships in CPM and therefore find the passage from functional performance to functional tolerances.

Using this energy approach, the model in CPM is built step by step, based on the functional, behavioral and structural descriptions. This approach creates a passage from function to structure of a system. Structure of a system mostly includes geometrical dimensions. Each dimension has its tolerances which are related to the precision of manufacturing process. So, by using the proposed approach the designer can have a passage from function to tolerances.

After creation of the model, in analysis phase, the model is used to analyze the modifications' impact of product structure, including tolerances, on product performance.

In the second section, after a brief introduction of energy flow modelling and CPM, the approach is presented (phase 1). In section 3, it is shown how this approach can be used to analyze the impact of tolerance modifications on the performance of the product (phase 2).

2. Phase 1: Creation of the quantitative model

2.1. Energy flow modeling

The proposed energy flow modeling begins with required function of the system. Based on the required function, system's function is defined in the first level (Fig. 2). As Fig. 2 illustrates, the input and output of the system are types of energy.

Fig. 2. First level of energy approach

In second level, the system's function is decomposed. The decomposition is based on the energy point of view in subsystems. For this level, energy model proposed by Pailhès [11] is used. This model studies the behavior of the system based on the energy flow. The model, which is also called CTOC, studies the system in both functional and structural point of view. According to [11], functioning of the system components is defined by transmission or transformation of energy.

In this model, a system can consist of four elements: Converter (to convert one type of energy to another), Transmitter (to transmit the received energy), Operator (to fulfill the required action of the system), and Control (to insure the functioning of other elements). Fig. 3 illustrates a general representation of this model.

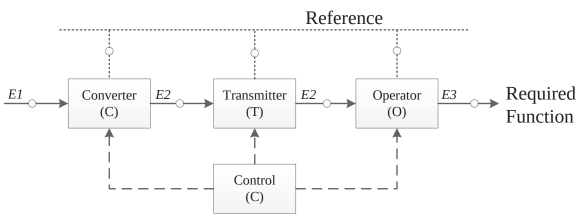

Fig. 3. Second level of approach (extracted from [11])

In Fig. 3, the element of "Reference" is the physical contact of the system with external environment. Reference can be, for instance, the handle of a device or ground. Different subsystems (elements) could be connected by interaction elements such as wires, tubes or casings. These elements are shown as small circle on the arrow between two elements. These elements are important in structural view.