Robotics and Computer–Integrated Manufacturing 46 (2017) 15–24

Contents lists available at ScienceDirect

Robotics and Computer–Integrated Manufacturing

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

Manufacturing signature in jacobian and torsor models for tolerance analysis of rigid parts

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A R T I C L E I N F O

Keywords:
Tolerance analysis
Manufacturing signature
Jacobian model
Torsor model

A B S T R A C T

Geometric deviations characterize manufactured workpieces and have great influences on the quality and function of mechanical products. Therefore, geometric variations management has to be performed to ensure the product function despite the presence of these deviations. Dimensional and Geometric Product Specification and Verification (GPS) are standards for the description of the workpiece. The Skin Model is an abstract concept of the physical interface between a workpiece and its environment. In contrast to this understanding, established models for computer-aided modelling and engineering simulations make severe assumptions about the workpiece surface. Therefore, this paper deals with operationalizing the Skin Model concept in discrete geometry for the use in geometric variations management. The Skin Model Shape has been connected with manufacturing processes, in order to bring closer the Computer Aided Tolerancing (CAT) simulation tools to reality. The pattern left by a turning process has been considered the discrete geometry framework of the skin model shape of the assembly components in a tolerance analysis approach. The obtained results are significantly different from those due to the traditional approaches.

1. Introduction

The geometric variation management is a need in design, manufacturing, and all other phases of the product life cycle [1]. It is due to the fact that, even though modern manufacturing processes achieve an increasingly high accuracy, geometric deviations are observable on every manufactured part. Geometric deviations have huge influences on both the function behaviour and on the customers' quality perception of the product. To control and to manage these geometric deviations along the product life-cycle, the first step is to consider during the design stage the tolerance specification, the tolerance allocation and the tolerance analysis [2].

In the context of Computer-Aided Tolerancing (CAT), various models for the representation of dimensions and geometric tolerances and for the solution of the tolerance chains have been developed, such as vector loop [3], variational [4], matrix [5], Jacobian [6], torsor [7], unified Jacobian-torsor [8] and the T-Map®[9]. Many commercial CAT software packages support the product development in these activities for geometric product specification and tolerancing, such as 3-DCS of Dimensional Control Systems®, VisVSA of Siemens®, CETOL®, and so on [10]. However, there is a growing interest in considering working conditions and operating windows in CAT [11,12]. These computer models for tolerance simulation and analysis make severe simplifications about observable geometric deviations, since they are reduced to rotational and translational feature defects [13,14]. This leads to results with large ranges of uncertainty and a discrepancy between the virtual models and the observed reality [15]. Furthermore, the tolerancing tasks in design as well as all other activities of geometric variations management, should be incorporated in a complete and coherent tolerancing process [16,17]. As a response to these needs, Skin Model Shape concept was proposed [1]. It is a model of the physical workpiece surface in contrast to the nominal model, which is a "simple" model of the intended workpiece not taking into account inevitable geometric deviations [1].

The aim of this paper is to connect the Skin Model Shape to the manufacturing processes, in order to bring closer the CAT simulation tools to reality. The discrete geometry framework of the Skin Model Shape has been represented by the pattern left on a surface by a turning process that is a widely used manufacturing process. The turning process involves a correlation among the points on the manufactured surface that is called signature; it has been inserted in the framework of the Skin Model Shape.

In the present work, the manufacturing signature has been integrated into two models of the literature for tolerance analysis: the jacobian and the torsor ones by using an approach based on a Skin Model Shape framework in agreement with what has been done in [18].

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http://dx.doi.org/10.1016/j.rcim.2016.11.004
Received 29 March 2016; Received in revised form 21 October 2016; Accepted 16 November 2016
0736-5845/

Three methods to integrate the form deviations due to the manufacturing signature have been developed. To demonstrate the effectiveness of considering manufacturing signature the modified approaches have been applied to a case study made up of three parts: a rigid box and two profiles that fit within it. The case study has been chosen simple to be solved manually, but representative since it allows to consider both dimensional and geometrical tolerances applied to the same profile. The obtained results have been compared with those due to the use of the two models of the literature. Matlab® and Minitab® software packages have been used to carry out the tolerance analysis and the statistical analysis of the obtained results respectively.

The paper is organized as follows: In Section 2, the case study and the manufacturing signature of the circular profiles are presented. In Section 3, the jacobian model with and without manufacturing signature is solved. In Section 4, the torsor model with and without manufacturing signature is described in detail and solved. In Section 5, the obtained results are compared and discussed.

2. Case study

The case study is composed by three parts: a hollow box and two circular profiles that fit within it, as shown in Fig. 1. The aim of this 2-D tolerance analysis is the measurement of the variation of the gap g between the second profile and the top side of the box (Δg) as a function of the dimensions and tolerances applied to the components. In particular, r is the value due to the dimensional tolerance (equal to ± 0,0145 mm) and d is the value due to the form tolerance (equal to 0,0145 mm). The tolerance analysis has been carried out by considering the rectangular box fixed and the geometrical tolerances applied to the two circular profiles variable while remaining within the applied tolerance ranges (dimension and form). A circular profile is simulated as shown in Fig. 2a for the jacobian and torsor model of the literature, since the form deviations are not taken into account. However, a circular profile typically ranges as shown in Fig. 2b due to the deviations of the manufacturing process. Each manufacturing process leaves on the surface a systematic pattern that characterizes all the surfaces machined by that process, i.e. a signature. In this work, the signature of the turning process has been considered to represent the form deviation of a circular profile. In particular, the signature has been represented by means of the autoregressive-moving average (ARMAX) model proposed in [19]. It combines a harmonic model with a second-order autoregressive model of the noise in the following parametric model:

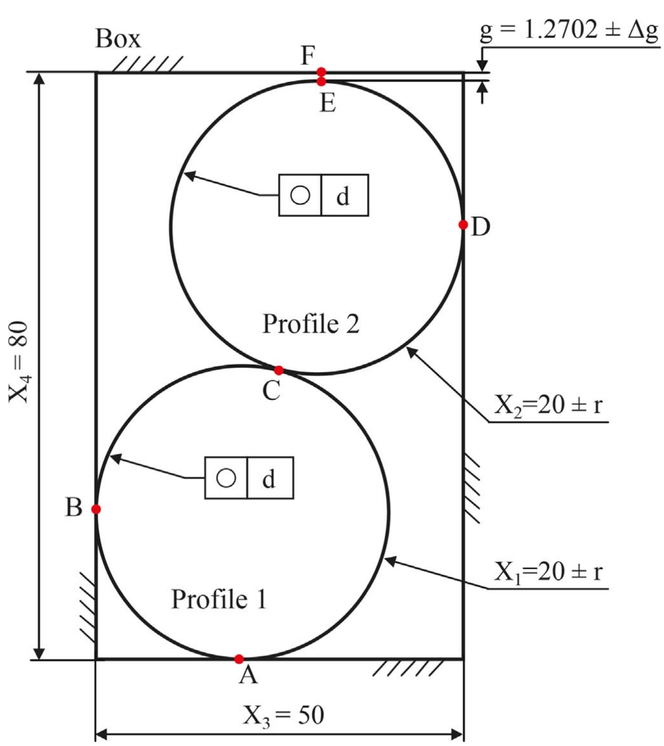

Fig. 1. Case study.

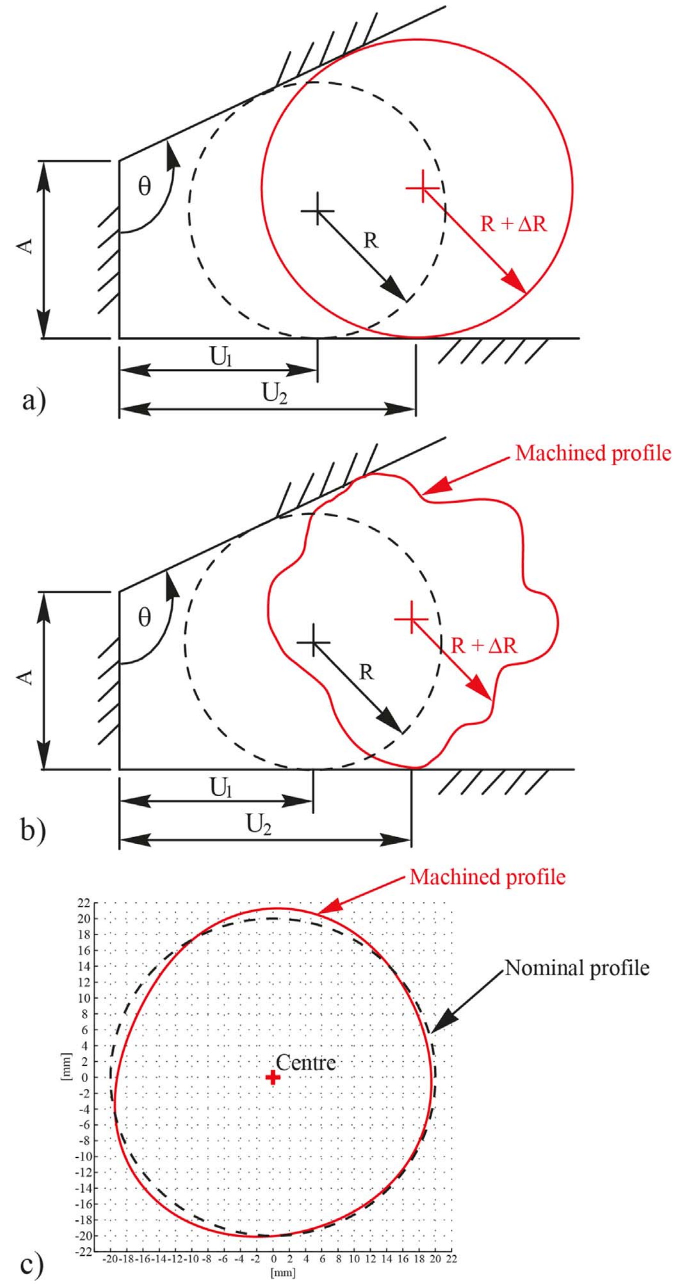

Fig. 2. How simulate the radial variation of a circular profile: a) literature models, b) general profile and c) profile due to ARMAX model.

$$Y_t = \sqrt{\frac{2}{N}} \sum_{i=2}^{3} \left[b_{2i-1} \cdot \cos\left(\frac{i \cdot t \cdot 2 \cdot \pi}{N}\right) + b_{2i} \cdot \sin\left(\frac{i \cdot t \cdot 2 \cdot \pi}{N}\right) \right] + \frac{1}{1 - a_1 B - a_2 B^2} \cdot \varepsilon_t \tag{1}$$

where $t=1,2, ...,N$ is the index of data points in the sampled profile, B is the backshift operator, N is the number of equally spaced points measured on that profile. For each index t, Y_t represents the radial distance between the actual point and the least square substitute circle, measured at angular position $\theta_t=2\pi t/N$. Thus, the signature model in Eq. (1) is a linear combination of two harmonic terms plus a second-