Journal of Manufacturing Systems 32 (2013) 348–356

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Systems

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

Technical paper

Dimensional variation propagation analysis in straight-build mechanical assemblies using a probabilistic approach

Z. Yang[a,b,*], S. McWilliam[b], A.A. Popov[a], T. Hussain[a,b], H. Yang[c]

[a] Manufacturing Research Division, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[b] Materials, Mechanics and Structures Research Division, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[c] School of Mechanical and Electric Engineering, Soochow University, Suzhou 215006, PR China

ARTICLE INFO

Article history:
Received 16 May 2012
Received in revised form 5 October 2012
Accepted 26 November 2012
Available online 30 January 2013

Keywords:
Straight-build assembly
Tolerance analysis
Monte Carlo simulation
Variation propagation control
Probabilistic approach

ABSTRACT

Product quality in mechanical assemblies is determined by controlling the propagation of manufacturing variations as the structure is built. This paper focuses on straight-build assembly and uses a probabilistic approach to analyse the influence of component variation on the eccentricity of the build. Connective models are used to predict assembly variations arising from individual component variations, and a probabilistic approach is used to calculate the probability density function (pdf) for the eccentricity of the build. The probabilistic approach considers three different straight-build scenarios: (i) direct build; (ii) best build; and (iii) worst build, for two-dimensional "axi-symmetric" assemblies. The probabilistic approach is much more efficient than Monte Carlo simulation. The paper also uses numerical examples to investigate the accuracy of the probabilistic approach in comparison to Monte Carlo simulation.

© 2012 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Dimensional variations always exist in mechanical components due to imperfections in the manufacturing process. These variations are observed as small deviations in the dimensions of individual components from their nominal design, and propagate and accumulate as components are assembled together. The accumulated variations can quickly drive assembly dimensions out of specification [1–4], and for this reason tolerance assignment in mechanical engineering, product design and manufacture is critical both for product quality and performance, as well as manufacturing cost [5].

Improving quality and reducing cycle time and cost are the main objectives for competitive manufacturing today. These objectives can be achieved at least partially by effectively controlling the propagation of variations in mechanical assembly [6,7]. The traditional methods for studying assembly tolerance stack-up are usually based on engineering experience, worst-on-worst (WOW) tolerance analysis method [8,9], or root-sum-square (RSS) tolerance analysis method [5,10,11]. These methods are used frequently in the analysis of single- and multi-dimensional chains, and treat the tolerances as limits on the parameters of a parametric model. Typically, the parameters are derived from the drawing dimensions. However, the ANSI standard defines tolerances geometrically as zones within which the part features or their resolved geometries (centreplane, centreline, centrepoint) are constrained to lie. Therefore they are not well suited to the analysis of geometric tolerances [12]. In particular, the WOW method gives results that can be overly pessimistic, while the RSS method only gives results for the mean-square variation which are too optimistic. Furthermore, these methods do not take into account the practical assembly procedures, and are generally difficult to use in practice. There is a clear need to take account of random component features to determine the probability that the mechanical assembly cannot be satisfactorily assembled.

The most popular method for statistical tolerance analysis is the Monte Carlo simulation method. Random dimensions for each component are generated according to known or assumed statistical distributions, and the relevant key characteristic (e.g. eccentricity) is computed for each set of component values. In this way a sample of response function values is generated, and the probability calculated that the key characteristic is satisfied or not. The main drawback of Monte Carlo simulation is that to obtain accurate estimates of potentially small probabilities of failure, it is necessary to generate a large number of samples, and this can be computationally intensive. This issue is particularly apparent if a tolerance analysis is carried out within an iterative loop of the more complex tolerance synthesis problem. In this situation, the solution can

---

[*] Corresponding author at: Materials, Mechanics and Structures Research Division, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK. Tel.: +44 115 8467683; fax: +44 115 9513800.
E-mail address: zhufang.yang@googl.com (Z. Yang).

0278-6125/$ – see front matter © 2012 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jmsy.2012.11.008

become extremely time consuming and computationally expensive. Of course, if the Monte Carlo simulation is performed with an inadequate number of samples, the results will be inaccurate. Also, if the distributions of the independent variables change, the whole analysis must be redone, as there is no way of adjusting the existing results. Authors who have discussed the Monte Carlo simulation approach include: Wu et al. [12], DeDoncker and Spencer [13], Nadler [14], ElMaraghy [15], Pandit and Starkey [16], Turner [17], and Turner et al. [18]. An alternative approach to using Monte Carlo simulation to predict the probability of failure is the first order reliability method (FORM) [19]. This method approximates the probability of failure by linearising the limit state function at the most likely failure point, where the limit state is a condition of a structure beyond which it no longer fulfils the relevant design criteria. It has received much attention in the research literature (see, for example [20–22]). This method is not well suited to analysing the problem considered in this paper, because the limit state function is likely to have multiple failure points.

This paper uses a probabilistic approach to analyse variation propagation in straight-build assemblies composed of nominally axi-symmetric rigid components. A key characteristic here is to give a 'straight line' within specified tolerances between the centres of the parts in the assembly process. An assembly process targeted at satisfying this key characteristic is named as a 'straight-build assembly'. Connective assembly models [23] are used in conjunction with the (practical) assumption that the dimensional variations of each component are small compared to its nominal. This, together with the axi-symmetric character of the assembly, allows the connective assembly model to be linearised. The linearised models are used to analyse three different straight-build scenarios: (i) direct build; (ii) best build; and (iii) worst build. Best build assembly (BBA) takes advantage of the axi-symmetric property of the components and minimises the eccentricity of the build. This is achieved by rotating each of the components about its nominal axis of symmetry, and selecting the combination of component orientations that minimises the eccentricity. The eccentricity is a measure of the deviation of the component centre from the assembly axis. Worst build assembly (WBA) is the antithesis of BBA and rotates each of the components about its central axis so as to maximise the eccentricity. By contrast, direct build assembly (DBA) corresponds to the standard straight-build process in which the axi-symmetric components are assembled without considering different orientations to control the eccentricity of the build. WBA has been used previously by Lin and Zhang [24] to analyse tolerance stack up. As BBA and WBA are able to provide the best and worst possible outcomes, these indicate that the methods are useful to obtain the boundary for the tolerance synthesis. To understand the benefits of controlling the eccentricity, the component variations are assumed to be random and the statistical variations in the eccentricity predicted. Yang et al. [25] used fully non-linear connective models in conjunction with the Monte Carlo simulation method to investigate different optimisation strategies for straight-build. In this paper, the linearised connective assembly models are use as a basis for applying a probabilistic approach to determine the probability density function (pdf) for the eccentricity, using DBA, BBA and WBA. The pdf is then used to calculate the probability that the eccentricity does not exceed a particular threshold value.

Throughout this paper, the components are considered to be nominally two-dimensional axi-symmetric structures. This assumption is made to aid visualisation of the problem and simply the presentation. Section 2 presents an overview of the connectivity models used in straight build assembly, whilst Section 3 applies a probabilistic approach to Direct Build, Best Build and Worst Build Assembly. In Section 4, the proposed probabilistic approach is compared with Monte Carlo simulation, and Section 5 summarises the conclusions from the study.

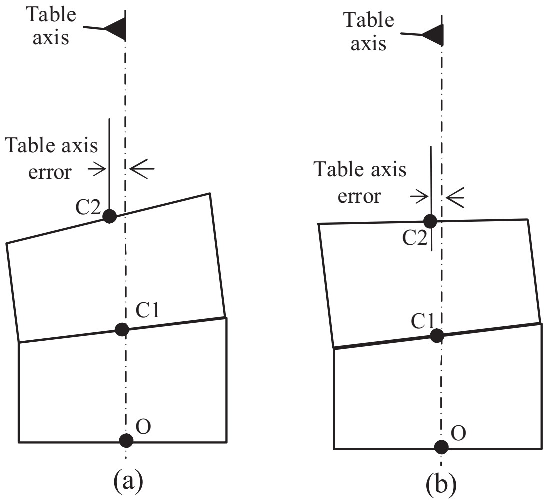

Fig. 1. Straight-build assembly: (a) without orientation and (b) with orientation.

2. Modelling for straight-build assembly

Straight-build assembly is the process of assembling axi-symmetric rigid components so as to achieve an axi-symmetric build. Due to the presence of manufacturing variations, neither the components nor the assembly are perfectly axi-symmetric, and it is often necessary to monitor and control the build-up of assembly errors. In this work, the eccentricity (or table-axis error) of the complete assembly is used as a measure of the quality of the build.

Fig. 1 shows a two-component assembly with the upper component shown in two different orientations. Fig. 1a shows the upper component in its original orientation, whilst Fig. 1b shows the upper component rotated by 180° (or flipped) about its axis of symmetry. The eccentricity of each build is defined by the so-called "table-axis error", which is the perpendicular distance of the centre of the upper-most component (C2) from the so-called table axis, which is defined by a line that passes through the centre of the base of the first component and is perpendicular to it. For the case shown, it is clear that the configuration shown in Fig. 1b has a smaller table axis error than that shown in Fig. 1a. By selecting the orientation of the upper component that minimises the table-axis error, the quality of the build can be improved and the "best build" achieved. In later sections, all components in the assembly are rotated to achieve minimal eccentricity. This approach is simplified in what follows by considering the analysis for two-dimensional component only. As a result of this simplification, only two possible orientations of each component need to be considered.

Mathematical models are used to predict the location and orientation of components in the assembly, and these methods are presented next. A connective model is presented and applied to nominally axi-symmetric components and assemblies. It is shown that the connectivity model can be linearised for the case when the components are axi-symmetric and the dimensional variations are very small, compared to the dimensions of the components. This allows analytical expressions to be obtained for the eccentricity, which are used as the starting point for a probabilistic analysis of the eccentricity as considered in Section 3.

Connective assembly models [23] are used to quantify the propagation of component variations through the assembly. The components are assembled by joining mating features to each other [23] and transformation matrices are used to relate the location and orientation of different features on one component to another component. Fig. 2 shows an example for a two-component axi-symmetric assembly. In this assembly the mating features are defined by coordinate reference frames: $O_0X_0Y_0$, $O_1X_1Y_1$ and

Download English Version:

https://daneshyari.com/en/article/1697591

Download Persian Version:

https://daneshyari.com/article/1697591

Daneshyari.com