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Wavelets-based method for variation analysis of non-rigid assemblies

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Abstract

This paper proposes a new method based on wavelets analysis and finite element method (FEM) for the variation analysis of non-rigid assemblies. It is well known that the part fabrication variation, coupled with the part's deformation during the assembly process, is one of the main factors affecting the assembly quality. But little investigation has been done on how component variations with different scales contribute to the final dimensional variation of non-rigid assemblies. The proposed approach takes the part variation as a signal and applies wavelets transform to decompose it into different scale components. The deformation of non-rigid assemblies that corresponds to these different scale components is calculated by using FEM. Since the part variation is resulted from manufacturing, manufacturing engineers can apply this method to get valuable information to avoid major variation causes in manufacturing process and make a better process plan. The proposed method is illustrated through a case study on an assembly of two flat sheet metal parts.

Keywords: Variation analysis; Non-rigid assembly; Finite element method; Wavelet transform

1. Introduction

Product quality is one of the most concerned issues in product design and manufacturing. Reducing and controlling the assembly dimensional variation plays an important role in product quality improvement in today's competitive market [1,2]. According to the material flexibility/stiffness, mechanical components can be roughly classified into two categories: rigid parts and no-rigid parts. Non-rigid parts, like sheet metal parts, are widely applied in many industries such as aerospace, automobile and electronic industries. Since sheet metal parts tend to deform during the assembly process, the manufacturing variation of parts will be coupled with other factors, such as the tool variation, fixture layout, and assembly sequence, to impact the assembly dimension variation [3,4]. Methods for rigid assemblies are not directly applicable to non-rigid assemblies [5]. The dimensional analysis and control for non-rigid assemblies are apparently more difficult than that of rigid assemblies [2].

For variation analysis of non-rigid assemblies, the component variation is generally recognized as a major problem in elastic assembly processes [5,6]. The uncertainties in a manufacturing environment would result in different scale structures of the part variation. Even if two parts reach the same dimensional tolerance, they may have quite different scale components in the tolerance zone [7]. In order to reduce and control the final assembly variation, it is very important to analyze the variation structure of the parts and its influence on the final assembly quality.

There are in the literature a number of modeling and analysis approaches for non-rigid assemblies to simulate the assembly processes and to analyze the assembly variation in the past a few years [5,6,8,9]. However, no method addresses components with different scales in the part manufacturing variation, and no one can be used to analyze the contribution of component variations with different scales in the tolerance zone to the final dimensional variation of non-rigid assemblies. In this paper, a new method based on wavelet analysis and finite element method (FEM) to analyze the non-rigid assembly variation is developed and investigated. The part variation will be considered as a signal and decomposed into different scale components by wavelet transform. The deformation of non-rigid assemblies with respect to these different scale components is calculated by using FEM. Manufacturing

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engineers can apply this method to get valuable information on major variation causes in the manufacturing process. A case study on an assembly of two flat sheet metal parts is presented to illustrate the proposed method.

2. Literature review

The variation analysis for non-rigid assemblies is an emerging research area [3–6,8,9]. Liu and Hu [5] considered the compliant nature of sheet metal parts and proposed an influence coefficients method to analyze the effect of component variation and assembly spring-back on the assembly variation by applying linear mechanics and statistics. The influence coefficients method was a key technique to get the component stiffness matrix. Camelio et al. [10] successfully extended this approach to model the product variation in multi-station assembly systems. Hu [3] set up the 'stream of variation' theory for the automotive body assembly variation analysis. Ceglarek et al. [4] made a detailed review on the stream of variation theory in terms of the state space model characterizing variation propagation in the multistage assembly. Ceglarek and Shi [8] proposed a new variation analysis methodology for the sheet metal assembly based on physical/functional modeling of the fabricated error using a beam-based model. Hu et al. [9] developed a numerical simulation method for the assembly process incorporating compliant non-ideal components. The effects of various variation sources were analyzed. In addition, Heieh and Oh [6] represented a procedure for simulating the combined effects of deformation and dimensional variation in the elastic assembly. Cai et al. [11] discussed the fixture schemes and demonstrated that the N-2-1 fixture scheme was better than the 3-2-1 scheme for non-rigid assemblies. Recently, Liao and Wang [7] applied the fractal geometry to include variations of surface micro-geometry of components into the modeling of variation analysis of non-rigid assemblies. A fractal function, named Weierstrass–Mandelbrot (W–M) function, is used to extract and represent the characteristics of the component variation microstructure. The reconstructed variation profile by the W–M function is taken as an input of the finite element analysis to calculate the deformation of the final assembly. This method is efficient for variation analysis of the non-rigid assembly, when the part variation is fractal.

In this paper, a general method based on the wavelet analysis is proposed to predict the contribution of different scale components in the part tolerance zone to the final assembly variation. In the next section, the non-rigid assembly process modeling is introduced. The wavelet transform and its application to the decomposition of part variation will be presented in Section 4. The flowchart of variation analysis for non-rigid assemblies based on wavelet transform and finite element method (FEM) is discussed in Section 5, and a case study in Section 6 is provided to illustrate the proposed method.

3. Non-rigid assembly process modeling

The 'real' complex non-rigid assembly process in a typical assembly station can be modeled as a four- step procedure (see Fig. 1) through the mechanistic simulation methodology developed by Liu and Hu [5]. This methodology assumes: all process operations occur simultaneously; the component deformation is linear and elastic; material is isotropic; fixtures and tools are rigid; no thermal deformation occurs during the assembly process; and the stiffness matrix remains constant for deformed component shapes.

(i) Placing components (Fig. 1(a)). Components are loaded and placed on work-holding fixtures using a locating scheme (Fig. 1(a)). Since the fabrication error of components is a natural phenomenon in component manufacturing, the component variation $\{\delta_u\}$ offset from the design nominal will inevitably cause the initial matching gap. Here, the index u refers to un-joined

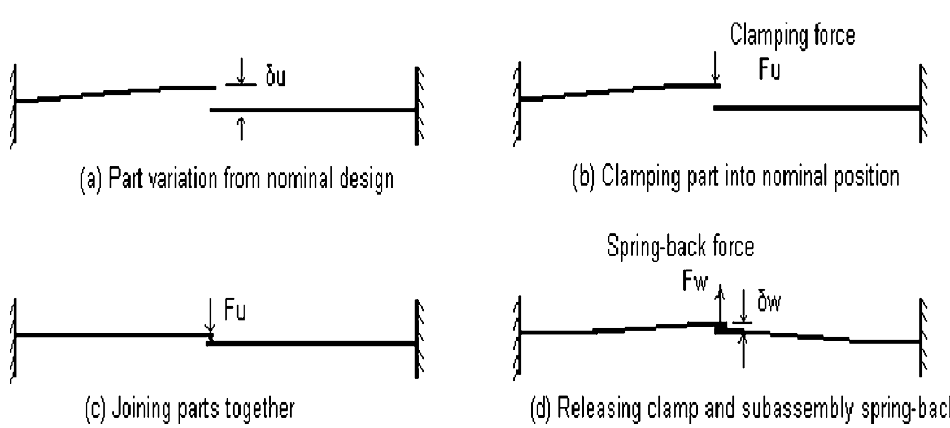

Fig. 1. The non-rigid assembly process [5].