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Assembly Error Calculation with Consideration of Part Deformation

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Abstract

Traditional assembly do not consider mechanical deformation based on the rigid body hypothesis, while assembly precision has close relationship with part' deformation in practice. In this paper, temperature, gravity and working load are taken into account to calculate the deflection occurred in assemblies. Both manufacturing error and deformation error are taken into consideration to establish deviation calculation model based on Jacobian-torsor model. A tailstock is taken as an example to verify the feasibility of the proposed method.

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1. Introduction

A mechanical assembly consists of two or more components or subassemblies. Owing to variation in manufacturing, it is impossible to completely avoid variations in component dimensional and geometrical characteristics. Also mechanical products are easily affected by the working environment in the assembly process. Load, temperature and gravity will bring about part' deformation, increasing the product assembly errors and affecting the assembly quality. An effective and rapid assembly error calculation method taking both part machining errors and deformation errors into consideration will provide a significant guide for reasonable and economical accuracy in design.

Many different approaches for calculating assembly errors have been developed over the years. Bensheng Xu et al. [1] choose to use the relationship between mechanical finger's differential motion and joint's small displacements to establish the model of tolerance accumulation; Tang and Davies [2] present a complete matrix tree chain method for determining the accumulated tolerances and the working dimensions. Paul et al. [3] estimate the tolerance by the calculation of the tolerance sensitivity of critical assembly features with respect to each source of dimensional variation in the assembly. C. LU et al. [4] propose a concept called sensitive tolerance to evaluate the assemblability according to its assembly sequence. Besides, the Jacobian [5], the T-Map model and the deviation domain model [6-7], the direct linearization method (DLM) [8], the torsor model [9], the matrix model [10], the vector loop model [11] and the unified Jacobian-torsor model [12] have been presented successively. These mentioned tolerance calculation processes assume that the manufacture parts are rigid without consideration of deformation in assembly.

In actual working condition, temperature, load and part gravity may result in changes in dimension, angle and shape, then influencing the matched space position and final system reliability. So there is a great need to consider the deformation in design stage.

So far, several researchers have discussed the tolerance analysis integrated the part elastic deformation and displacement. S. Samper et al. [13] present four models in that allow elastic deformations of mechanisms in tolerancing. Pierre et al. [14] have integrated thermos-mechanical strains into tolerance analysis, where they have used finite element method to determine the strains. G. Jayaprakash [15] proposes an optimal tolerance design method for mechanical assembly considering thermal impact, and further takes both thermal and inertia impact into account. NSGA II and finite element are used to obtain proper component tolerance values [16]. Benichou et al consider thermal expansion of parts integrated within functional tolerancing [17]. As demonstrated in [18-19] a wider set of operating factors can

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be included in computer-aided tolerance analysis such as thermal, wear and pressure. Rotating machinery in boring processing, the static deformation of the spindle shaft is calculated by finite element method [20]. Tolerance allocation in assembly with time-variant deviation induced by mobility and wear is performed to optimize the tolerance specification [21]. FE simulation as a virtual tool is used to calculate actual deformations in a designed mechanical part due to all of its service loads [22]. Weiming Zhang et al extends and modifies the Jacobian-torsor tolerance model in actual working condition, quantitatively expresses the impact of actual working condition on working performance and tolerance design [23]. The methods proposed above either only suitable for deformation in special conditions without commonality or concerns no relation to accumulated assembly error, Jianyong Liu [24] puts forward a computational method for assembly error with consideration of parts deformation. Nevertheless, analysing dimensional accuracy in deformation situation only, invalid for the relevant location and form error.

This paper presents a new method to establish deviation propagation and calculation model considering manufacturing error and deformation error simultaneously. Deformation error results from the effects of temperature, gravity and working load on assembly part. Jacobian–torsor model is adopted to obtain comprehensive error.

The organization of the article is as follows. The factors that have an impact on part deformation are discussed in Section 2. Section 3 proposes the theory and procedures for assembly error calculation in Jacobian–torsor model. A three-part assembly is taken as an example to illustrate the calculative process.

2. Influence factors of part deformation

2.1. Temperature

Most materials change length as temperature is changed. As a result of this change, the dimensions and tolerances of a product become at variance with the design values. Therefore, thermal impact must be taken into effect during the design process, particularly when a complicated product with multiple components and various materials operates under a wide range of temperature. As shown in Fig.1, a hollow cylinder in working condition produces deformation because of the induced heat.

2.2. Gravity

The gravity leads to the deformation of the component, as shown in Fig.2. In an ideal 3-dimension model, part locates in desired position, the centre of the shaft is generally coincide with hole centre in a hole shaft assembly. However, in actual situation, part will shift from its axis under the influence of gravity, offset distance is associated with the diameter of the hole and shaft, and their geometric tolerance.

The amount of deformation is proportional to the mass of parts, and can be calculated using finite element analysis. Then it is incorporated in the tolerance stack up progress, improving the precision of the error estimation.

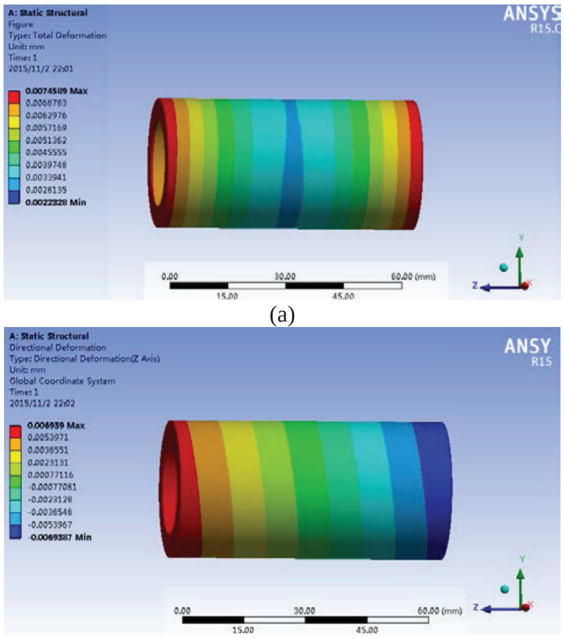


Fig.1 Heat deformation nephogram. (a) Overall deformation; (b) Axial deformation.

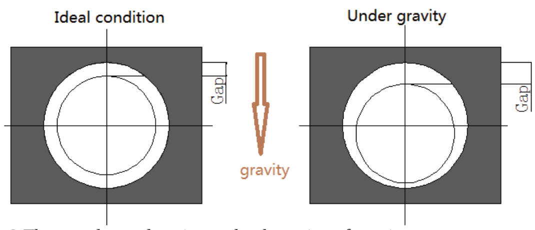
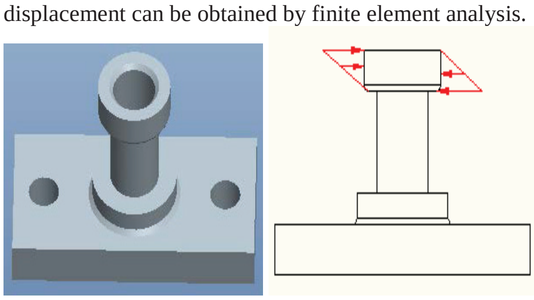


Fig.2 The actual parts location under the action of gravity

2.3. Load

During a practical working situation, the force field applied to single parts or assembly results in geometric errors and dimensional changes in size, direction and magnitude in spatial six degrees of freedom. Taking a bourdon tube as example, it bears bending load when it works, and the whole bourdon tube tilts to the side of the load. The larger the bending load, the bigger the bending deflection. Concrete displacement can be obtained by finite element analysis.



(a) (b)