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Systematic solving of machining deformation and process optimization for complex thin-walled parts

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Abstract

Complex thin-walled parts are widely used in various fields. But they are prone to deform in machining process because of their unique structures. At present, there is a lack of suitable methods to systematically solve this problem and form a universal and optimized machining process. This paper proposed a systematic method to solve the problem of machining deformation for complex thin-walled parts, and provided an optimized machining process using this method. First of all, this paper found out the machining conflicts through analyzing root causes of deformation, and got the principles of invention which mean the possible directions of problem solving. Then, this paper established the substance-field models based on machining conflicts, and got the corresponding standard solutions which mean the possible way of problem solving. After that, the combination of one standard solution and one principle of invention which are most is selected through computing the semantic similarity between them. This combination of standard solution and principle of invention can be regarded as the conceptual solution which points out the solving direction and solving way. Finally, an optimized and versatile solution of machining process is proposed through using the conceptual solution. The optimized machining process is verified with a machining instance of complex thin-walled part.

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Keywords: Thin-walled part; Machining deformation control; Process optimization; TRIZ; Problem solving

1. Introduction

Thin-walled parts are widely used in aviation aerospace, bridges and other fields because of its light weight, high strength characteristics. In the modern aircraft structures, a large number of integral wall panels, integral bulkhead and wing ribs are used. But the thin-walled structure is complicated. They have low relative stiffness, large machining allowance, and poor manufacturability. They are easy to get shrinkage, warping and other problems. So the machining precision and surface quality of the parts are seriously affected that caused a large number of rework or scrap in production. Thus, the machining efficiency is decreased, and the processing cost is increased.

At present, most of the methods to control the deformation of complex thin-walled parts are to optimize or improve the cutting parameters in machining process. This method is based on personal experience. But the levels of personal experience are uneven. Because of the various types and the complex shapes of thin-walled parts, above methods can only be used for specific kinds of parts, and are hard to form a universal and optimized machining process. For the deformation control of complex thin-walled parts, it is essential to analyze the function of the parts, to find the basic factors that affect the deformation, and to eliminate the conflict between these factors. TRIZ is an important theory for innovation design, and thinks the essence of problem solving is to eliminate technical conflicts, and therefore provides a series of tools and methods, such as the substance-field models, 40 principles of invention and 76 standard solutions. TRIZ has been applied in the process optimization, to help effectively solve many of the technical problems.

In this paper, a systematic solving method to the above problem is carried out by the combination of the standard solution and the principle of the invention in the TRIZ principle, and a universal and optimized machining process is given for the

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deformation control of the complex thin-walled parts.

2. Overview of related work

Due to the wide use of thin-walled parts and the difficulties in its machining process, it has attracted much attention of scholars for a long time. Therefore, the deformation control of thin-walled parts has always been a hot research topic. O Gonzalo used simulated cutting tools to cut aluminium alloy thin-walled structures in order to optimize the cutting conditions [1]. Haruki et al. proposed that the low melting point alloy can be injected into the thin-walled structure cavity. This can greatly improves the rigidity of the workpiece [2]. Kline et al. studied the milling deformation modelling of rectangular thin-walled plates with three edges clamped and fixed, and one side free boundary condition. The model is characterized by considering both the tool and workpiece deformation, and the coupling effect between the tool and the workpiece is ignored because of the large stiffness of the workpiece clamping [3]. Wu Kai, He Ning, et al. used numerical simulation technology to study the deformation law of the web and the side wall of the frame structure parts and the control scheme of the deformation [4]. In order to reduce machining deformation and improve the machining precision, the method of large cut depth and distribution ring cutting was proposed. J.Tlusty, S.Smith, M.D.Tsaild, respectively, proposed the use of the overall rigidity of the parts, the way to optimize the tool path and so on [5-7]. Optimization methods above focus on specific parts, or using a special technique method. Although these methods solved some specific deformation problems of thin-walled parts, they cannot be suitable for more other kinds of parts.

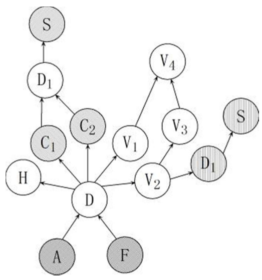
TRIZ theory has long been used to optimize manufacturing process. Joost R. Duflou used TRIZ to optimize the single point incremental forming process, transformed the specific problem into the technical conflict solution, and finally got a corresponding improvement process [8]. M. C. Cakir applied TRIZ principle in DFM, and put forward the effective improvement plan for the chip removal in the process[9]. Andreas Roderburga used TRIZ in the design of manufacturing process, which made the product design take into account the manufacturing process, greatly improved the efficiency of the work [10]. Srinivasan R. and others also used the TRIZ principle to optimize the inherently safer chemical processes problem, and solve its technical difficulties [11]. It is obviously that TRIZ theory can effectively help technicians to solve process optimization problem, but there is no application in the field of machining deformation control process optimization of complex thin-walled parts.

TRIZ theory can be applied to the optimization of machining process of complex thin-walled parts, and the specific problems can be transformed into the process problem to be solved. In the past, most application of TRIZ concerned about the conflict matrix with the principles of invention or the substance-field models with standard solution separately to solve the manufacturing problem. The principles of invention give the directions to solve a problem; the standard solutions give the ways to solve a problem. For the same problem, different methods establish their respective models from different point of views. In fact, the combination of different TRIZ methods can provide more accurate concept solutions [12]. In this paper, we combined the conflict matrix and the substance-field models to analyze the problem of complex thin-walled parts processing deformation control, and combined the standard solution and the principle of invention to solve the problem. This systematic optimization technique is used to optimize the machining process which fits for different kinds of complex thin-walled parts.

3. Systematic problem solving of machining deformation control

3.1. Process conflict discovery based on root cause analysis

The prominent features of complex thin-walled parts in the structure are the complex shapes and thin-walled structure. In the process of machining, due to the low stiffness, large machining allowance and poor machinability, the part is easy to deform and its machining precision is difficult to control. The deformation causes are analyzed using root cause analysis [13] in this paper, as shown in Figure1.



D: Processing deformation	V_1: Tool vibration
A: Machining accuracy	V_2: Workpiece vibration
Q: Surface quality	R: Rigidity
H: Cutting heat	V_3: Fixture vibration
F_1: Cutting force	S: Thin wall structure
F_2: Clamping force	V_4: Vibration of machine tool

Fig. 1. Root cause analysis of deformation.

According to Figure 1, part deformation will reduce the processing precision and surface quality. In order to reduce the deformation, the clamping force and cutting force acting on the workpiece must be reduced. But it will make the parts move in the processing and unfulfillable machining, and then affect the accuracy. So, we think the clamping force/cutting force and machining precision/surface quality as a group of conflict. And they are abstracted to the conflict in the TRIZ conflict parameters which are force and accuracy of manufacturing. This contradiction is shown in Table 1.

Similarly, to improve the accuracy and reduce the deformation, it is necessary to improve the resistance of workpiece to the clamping force and cutting force to make the deformation of the ability. That means, to make its stiffness higher. The direct cause of the low stiffness of the workpiece comes from the thin-walled structure. But if the wall thickness increases, it will affect the performance and structural requirements of its own. Bigger machining allowance brings

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