International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 7 ǁ July 2015 ǁ PP.26-32

The optimization and active compensation on the deformation error of the large thin-walled parts

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Abstract:*This paper mainly studies the springback error control of large thin-wall parts in the machining process which proposed the subregions optimization compensation method based on the tolerance. And considering the coupling effect of the compensation value and workpiece deformation, which used the finite element simulation and actual machining experience to establish the different deformation region and the coupling coefficient of the workpiece.. In the experiment, it comprised the results of two methods which based on the machining of large thin wall aerial parts. The results show that the optimization compensation of the sub region can better reduce the machining errors and provide a reference for the deformation control of the large thin wall parts.*
Key words*:springback error, local optimization compensation, coupling coefficient*

I. Introduction

Due to the poor rigidity, the thin-walled parts will occur large deformation in the machining process due to the effect of cutting force. And the cutter contact points of the actual cutting depth are less than the cutting depth of the theory, which produces a knife phenomenon and resulting in the residual of cutting material. After the machining elastic deformation is recovered and produce the let knife error of the parts. In the condition of certain machining parameters, the thickness of the workpiece is thinner. The let knife phenomenon more serious which caused by the cutting force, and the error is higher. The error caused by the elastic deformation is inevitable, and it needs to be solved by the method of multiple repeat finishing processing or active deformation compensation. Due to the low efficiency of multiple repeat finishing processing. Therefore, active compensation of the deformation for the part to offset the springback machining error caused by the deformation is the main research direction of the deformation control of the thin wall parts. At present, there are a lot of researches on the error compensation technology at home and abroad, and there are some shortcomings.The multi cycle style is iterative computations between the correct cutter point and the cutting force model,until the processing error surface meets the accuracy requirements of the accuracy [3].The literature [7]is analyzed the single cycle and multi cycle level error compensation scheme, and only considering a single part.Hu Weihua put forward the use of deformation contour offset milling path to compensate for the processing deformation of the thin wall web processing.Lou Wen ming correct the milling parameters based on the different deformation contour line and the deformation degree to realize the compensation of the machining deformation.ChenWeifang[6] proposed two kinds of path compensation method for the layering full compensation and optimization compensation which based on the complete compensation.A local error compensation method based on tolerance is proposed, and by correction of the NC program to compensate the processing error[1].

From the existing literature, the research mainly focuses on the prediction and compensation of the processing error and the prediction of the deformation for the side wall parts and the off-line active error compensation. Often the compensation amount of each point on the tool path is generally equal to the predict deformation value or multiplied by the coefficient of resilience deformation, that is single layer fully compensated.Some scholars have studied the layered total compensation and the compensation of the optimization. But it is suitable for the research on the active compensation method for the large thin wall parts of aviation is lesser.On the basis of the existing literature, this paper makes a deep analysis on the on-line detection of large thin wall parts deformation and the optimization of the partition regionAnd using the milling processing of the large Aerospace Thin-walled Parts as an example, and analysis and comparison the result about local optimization compensation and complete compensation method for processing by using a combination of finite element simulation analysis and test method .From it, we can obtain the conclusion that the local optimization compensation can better reduce the deformation error. It is provides a better active compensation method to control the deformation of the large thin-wall part which caused by the milling force.

II. The active optimization compensation of feed

For the poor rigidity of the large thin-walled parts, the deformation of the workpiece is large under the function of milling force in the machining, which caused the seriously springback phenomenon and large machining error.The mechanical deformation model of the thin wall parts can be simplified to a simply supported beam, and its principle is shown in Figure 1.In the machining process of thin-walled parts, the deformation is large and the rebound phenomenon of deformation is serious, which resulting in the actual machining surface deviates from the machining surface and produce “let knife phenomenon”.And after the machining, the elastic deformation is recovery caused the actual machining surface deviates from the theoretical surface of the workpiece and produce a processing "springback error".

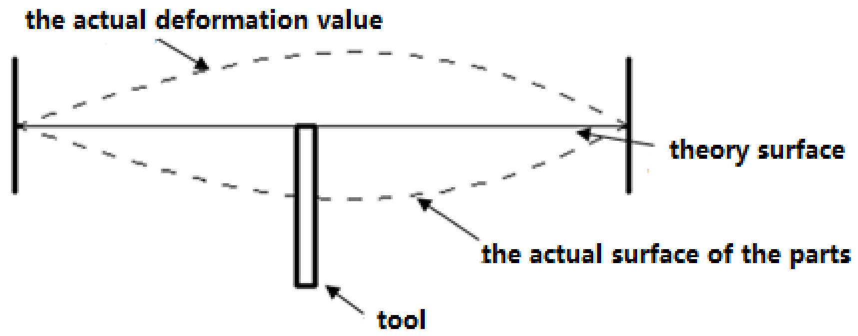

Fig.1 the springbackphenomenon in processing

In order to reduce the springback machining error, it put forward an active compensation method which is change the feed to correct the tool path. Namely,in the machining processing by using the online detection device to obtain the real-time deformation of the machining area on the parts,and then optimization the compensation feed according to the real-time deformation value to reduce or eliminate the machining error caused by deformation. At present, the research of the active compensation method is mainly concentrated in the following two aspects, one is the single time to go with the knife, another is the multiple knife compensation.Those two methods have their own advantages and disadvantages.Firstly, for the single tool compensation it use one accuracy machining process to complete all the compensation caused by deformation error ,Although, the efficiency is high in the process of single walk compensation but it will cause a large secondly deformation in some deeply compensate region and resulting a low accuracy compensation.ForMultipass compensation tool it need repeatedly finish machining compensation to complete the error compensation, compared with the single tool compensation it has a relatively high compensation accuracy, because each finish compensation is smaller so the secondary deformation is smaller.But the efficiency will be greatly reduced due to the multiple knives. In order to improve the production efficiency, in the actual production process we will tend to choose the former. There are mainly two ways to compensate for the deformation in the single finish machining, which is the exact mirror compensation and the local optimization compensation.

1.1 Complete mirror compensation

Complete mirror compensation is the compensation method that the cutter compensation value at each station on the path is equal to the deformation of the point.Suppose deformation size at Q on the workpiece is Z, the distance between the real processing surface and the theory is Z.In order to eliminate the error at this point,we take the compensation value of the feed is Z, make the feed compensation curve is symmetry with the actual processing surface along the theoretical tool path. Therefore it is called the complete mirror compensation for feeding.It is clearly that the feed compensation value equal to the deformation value of the complete mirror compensation,so we can obtain the compensation feed path by the continuous in the different position of the deformation value.As show in the figure, if the theory position on the tool path isxd , the distance between the actual processing surface and theory surface at this position is xa.According to the principle of the completely mirror compensation, we only need to accurate reading each real-time deformation,and correct the NC code at each site and adjust it to the position xc in the processing. Then you can effectively reduce or eliminate the machining error caused by the workpiece deformation.

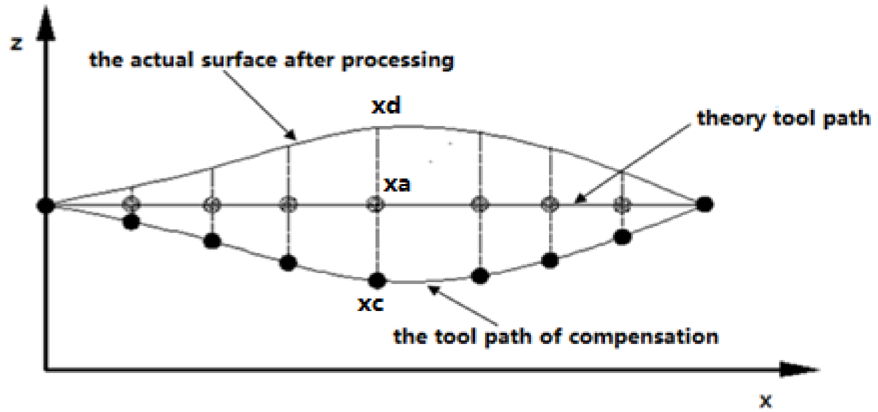

Fig.2 the complete mirror compensation principle picture

This method is simple in calculation, but it did not consider the coupling relationship between the feed compensation value and the deformation of the parts, that is the amount of feed increase ,the cutting force becomes larger which leads to the deformation increases and the deformation after compensation is greater than the location deformation. So it cannot completely eliminate the machining error caused by the phenomenon of the cutter. To research the question about the deformation compensation coupling, Zheng Lianyu presented with the deformation volume multiplied by a coefficient of restitution as the amount of compensation, but it not gives a specific analysis of the problem of ensuring the restitution coefficient.Wei Fang Chen put forward the optimization compensation method of the processing deformation and the coupling relationship which based on the deformation prediction. That is according to a set of optimal compensation values to fitting and interpolation a most optimal compensation path.But compensation on above is optimization by the theoretical prediction value, while there is a certain error between the predicted value and the actual measurement value in the actual application process. And the efficiency is relatively low when it needs to have an offline optimization compensation on each position of the tool path.In view of this situation, this paper proposes a local optimization compensation method based on online deformation measurement, in order to solve the coupling relationship between feeding the compensation amount and the distortion of parts and reduce the processing error meets to the accuracy requirements scope.

1.2 The local error compensation based on tolerance

In the actual machining process, if we compensation all the position on the processing path,it will reduce the processing efficiency.In fact, the actual processing surface often becomes a curved surface due to the deformation of the parts.Such as show in the fig3 there are only in the presence of part distortion region Q0~Q1. Other areas are all in the required error range, so we only need to compensate for the large deformation areas, and make machining error fall into the requirements range of the tolerance. Then we treat is meeting the requirement.So this paper put forward a local optimize compensation method which based on the machining accuracy.In the process of machining, the surface contour deformation is gradually changing, and we only need to optimization compensation the feed in the large deformation of Q0~Q1 to meet the requirements of the machining precision and deformation region which meet the requirements will processing according to the original amount of feed.

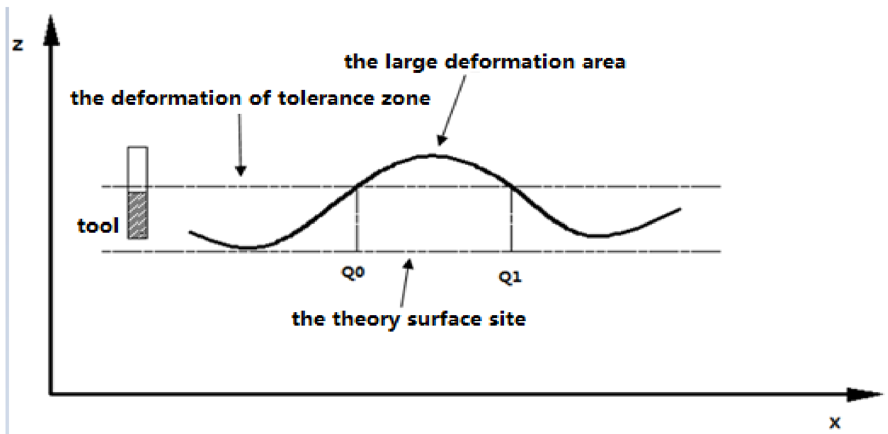

Fig.3 the deformation error in the processing

The definite principle algorithmof local optimal compensation is as follows

(1) Determining the key region of the deformation. We suppose the processing precision of the parts is ±T. According to the laser displacement sensor actual measurement we can obtain the deformation distribution about the each cutter point of the parts in the processing. If the deformation value u is exceeding the cutter point of the precision processing, then we can see it as the key point for deformation. Those series of deformation key points consist of the areas of the deformation error which key regional Q0~Q1 area is as show in the fig 3. The original processing area which the deformation amount does not exceed the poor part, the compensation feed will keep the original.

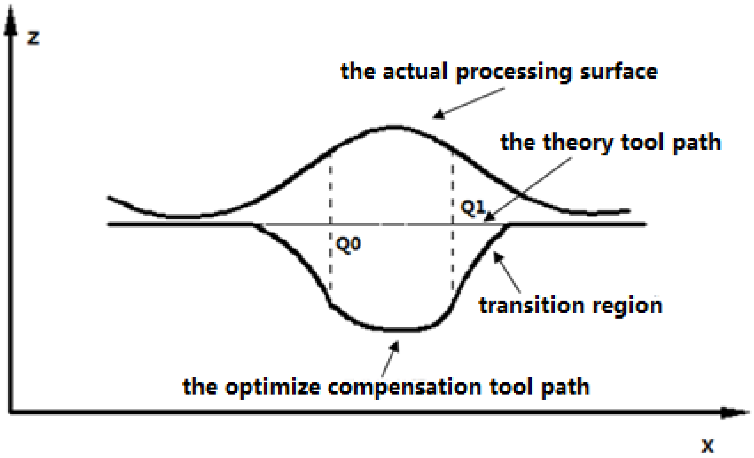

Fig.4 the compensation of the feed based on the tolerance

(2) the optimization compensation of the feed in the key deformation optimization. Suppose the deformation value of the key station Q in the deformation regional δ, and it is exceeding the scope of machining accuracy. According to the deformation at this point to determine the feed compensation amount z_i, usually the values are determined in two ways:①Using the fully mirrored compensation principle, the deformation measurement value is directly used as the amount of the compensation feed of the fully mirrored compensation.②Using the local optimization patch compensation model to obtain the actual optimization and compensation value z_i'.

$$z_i' = \lambda \cdot k \cdot \delta \qquad (1)$$

In the formula, δis deformation value which is the real measured at this position, λ is the springback value of deformation, K is the coupling coefficient of deformation at this position.As to the question of how to determine the coefficient, because of the large thin-walled cylinder parts which are in the specific loading conditions(the two ends of the cylinder) in the different cutting position have a different cutting force.In this paper, the 3D model of the large thin wall cylinder parts is built by the finite element software for the large thin wall cylinder parts to element the different deformation in the different cutting force and the different machining state. And combined with the actual deformation of parts in the actual milling process.We can obtain the whole deformation of the part is shown in figure.

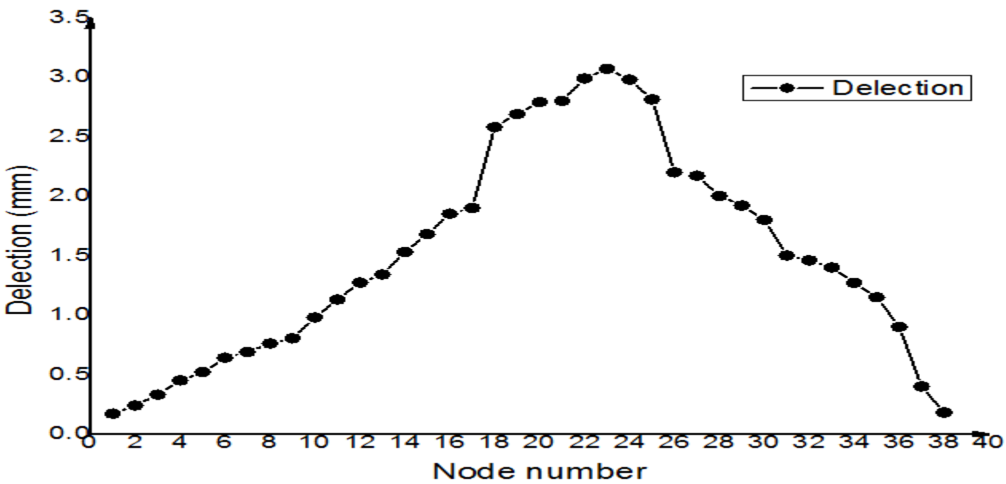

Fig.5 the deformation law of the whole parts

The deformation law can be found in the picture in the same condition. At the ends of the two ends of the tube, the rigidity of the part is good and the deformation is small. In the middle part of the tube section, because of the poor rigidity, the deformation amount is large.In order to eliminate the influence of the cutter relieving error which produced in the processing of the parts. We need to have a real-time compensation on the feed to reduce or eliminate the influence of the cutter relieving error on the machining accuracy.And because the poor rigid of the thin-walled parts, the compensation feed amount will make a secondary deformation when have a compensation on it.That is the coupling phenomena of the compensation amount of feed and the secondary deformation of the parts.In order to eliminate the effect of this kind of coupling phenomenon to the compensation accuracy, this paper puts forward a coupling coefficient of compensation in the compensation process, which reduces the influence of the coupling phenomenon. From the deformation law on above we can find the parts in a different position have a different deformation which the compensation amount of the feed is same.In order to have a more precise compensation, the regional division is carried out according to the whole deformation law of the parts which obtain from the simulation and the actual processing. Near the two ends the clip region is a low deformation region, the middle region is high deformation region. Different regions were determined for different coupling coefficients. According to the simulation results and practical experience, the coupling coefficients of different parts of the parts are as follows: the low deformation area is K1, and the high deformation area is K2. (0<K2<K1<1). The optimized compensation model of the whole workpiece is

$$Z_i{}' = \begin{cases} k_1 \cdot \lambda \cdot \delta \\ k_2 \cdot \lambda \cdot \delta \end{cases} \quad (2)$$

When the machining position in the region I we choose the coupling coefficient K1, when the processing area in the second we choose the coupling coefficient K2.According to the calculation and optimization of the Q which based on the equation (2),we obtained the compensated feed position Q

$$Q' = Q + Z_i{}' \quad (3)$$

The optimized tool path is optimized by optimizing the points of all the key regions of the deformation.
(3) The determined of the compensation feed in other region. As for the small amount of the machining deformation in the original processing area,we used the original amount of feed in processing. The adjacent region between the original machining area and the deformed region is using the smooth circle to transitional and connection. By the method which mentions on the above to optimize and compensation the different deformation and form the optimized tool path to control the deformation of thin-walled parts in the processing.

III. Experiment

In the picture,the local schematic diagram of the thin wall parts of the aerospace, the material is aluminum alloy 2219, the shape of the part is highly 2000mm, the outer circle diameter is 3350mm, the wall thickness is 15mm. Is a typical large thin-walled deformation parts. Due to its poor reality and its easy deformation which influenced by processing parameters and many other factors in the machining process, it is not easy to guarantee the machining quality and the cost only by the technique method. This paper is mainly testing deformation compensation of the thin-walled parts to verify the local compensation of the feed which the above mentioned is effective and feasible. Here we only by a single local grid (as show in the picture and other processing is similar) processing as the example to illustrate this problem.

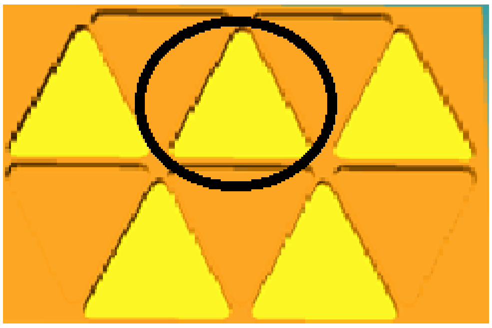

Fig.6the diagram of single grid processing

4.1 experimental conditions

In this paper, the large thin-walled parts are processing by the special vertical numerical control machine and the clamping scheme is arranged on the two ends of the cylinder, and the local support is used to reduce the deformation of the workpiece in the processing.The cutting way is spiral milling ,the too is useφ20mm PCD milling cutter ,the milling parameters is the speed n=6000rad/min, cutting depth ap=4mm. The cutting width ratio is 65%, the feed rate is F=4000mm/min. In the process of testing, it is using the laser displacement sensor to measure the real-time deformation of the parts and transmitted to the numerical control machine.The CNC system by judging the parts deformation to determine the optimal compensation value, then compensate it into the feed. To realize the control of the deformation error which caused by processing. In order to determine the deformation coupling coefficient,we selected the local single grid of the parts for milling and confirm the site of this gird on the overall area parts.Under the same experimental conditions, we separately conduct the optimum compensation test and complete mirror compensation experiment of the parts. The real-time deformation of the single grid which is measuring in a fixed test condition in the processing is as show in the diagram. While the requirement machining accuracy of the optimizing compensation test parts is -0.1mm~+0.2mm. Therefore according to the local optimization compensation principle for the measured data more than 0.3mm are needed to optimize compensation in the amount of feed.

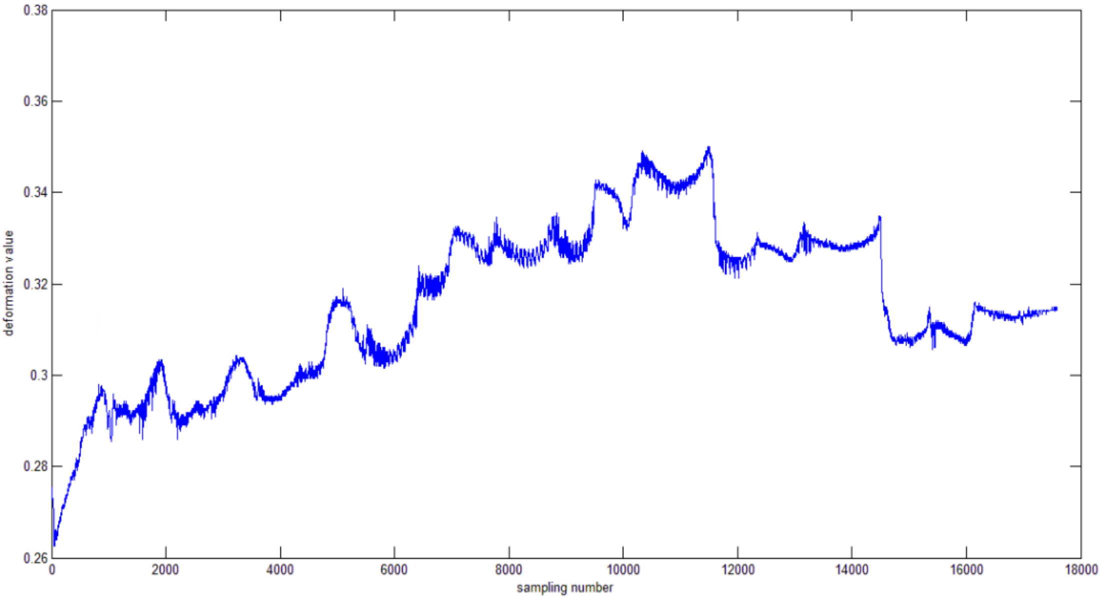

Fig.7 the real-time deformation data of processing parts

Fig the horizontal axis is represented by the real-time sampling point number of the deformation in the process and the vertical axis represents the real time deformation size in the machining process.For the large deformation section, we optimization compensation the feed according to local optimization compensation method in Section 2 above. And use the OLYMPUS ultrasonic thickness gauge to measure the thickness of the processing result to contrast the two test results. And the results obtained
from the processing department, as showed in fig8..

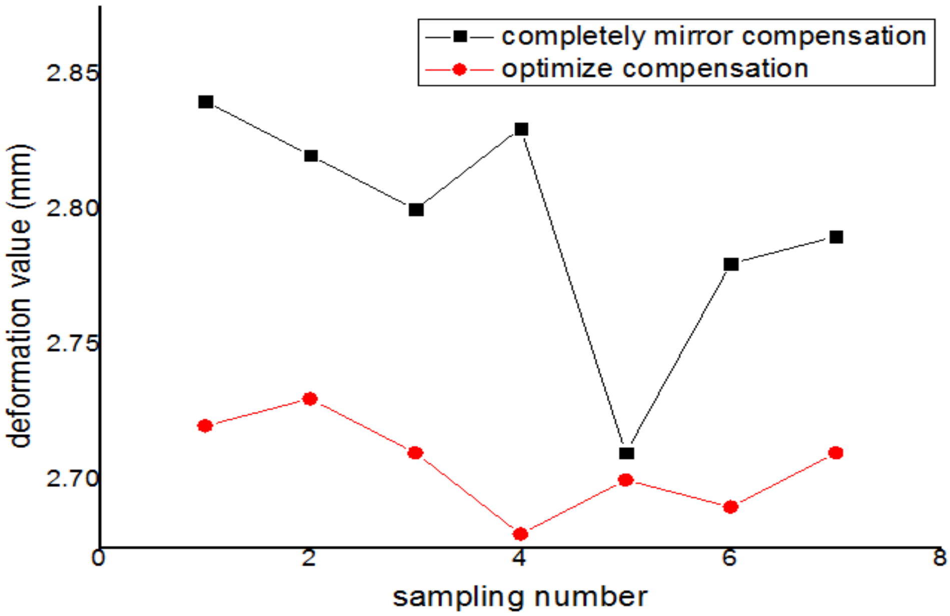

Fig.8 the compare of those compensation method

Form the graph.We can see that the thickness of the optimization compensation of the feed is all in the required precision and the thickness distribution is better than the processing area which using a fully mirrored compensation.

IV. conclusions

(1)The key problem of the thin-walled parts of machining to ensure the machining assurance and quality is the control of machining deformation. At presently,the method to control the deformation of this kind of large thin-walled parts. And in this paper proposed sub regional optimization method aimed at compensate this kind of part, and puts forward using the different coupling coefficient to optimization the compensation value of the feed in different areas, which greatly improved the accuracy of the compensation.

(2)Compared with the traditional off-line fully mirrored compensation method, this method is online optimization compensation which considering the coupling relationship between the compensation value of feed and parts deformation.And it greatly improves the machining efficiency and precision.

(3) This paper mainly studies the result of different compensation method using the machining processing for the aerospace thin-walled parts. Through analysis and comparison of the test results, shows that the two compensation method was all able to achieve the control deformation error,but the local optimization compensation results are significantly better than the former.And it provides a reference basis for the Machining deformation control of this kind of large thin wall parts.

References

[1] Zhou Jing, Chen Wei-fang, Qu Shao peng, Active error compensation methods for numberical control machining[J]. Computer Integrated Manufacturing Systems,2010,16(9):1902-1906.

[2] Zheng Lian-yu, Wang Shu-chun, Approaches to improve the process quality of thin-walled walled workpiece in NC machining[J]. ActaAeronautica et Astronautica Sinica,2001,22(5):424-428.

[3] Ratchev S, Liu S, Huang W, et al. An advanced FEA based force induced error compensation strategy in milling [J].International Journal of Machine Tools and Manufacture,2006,46(5):542-551.

[4] Ratchev S, LiuS,BeckerAA.Error compensation strategy in milling flexible thin-wall parts[J].Journal of materials processing Technology,2005,162-163:673-681.

[5] Wan Min, Zhang Weihong, Overviews of technique research progress of form error prediction and error compensation in milling process[J]. ActaAeronautica et AstronauticaSinica, 2008,29(5):1340-1349.

[6] Chen Weifang, Lou Peihuang, Chen Hua, Active compensation methods of machining deformation of the thin-walled parts[J]. ActaAeronautica et AstronauticaSinica, 2009（30）:570-576.

[7] DenpinceP,Hascoet J Y.Active integration of tool deflection effects in end milling. Part2. Compensation of tool deflection[J]. International Journal of Machine Tools & Manufacture,2006,46(9):945-956.