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Research on Influence of Milling Parameters on Machining Deformation of Rectangular Thin- Walled Parts

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***Abstract*---Aiming at the problem that the machining accuracy of rectangular thin-walled parts are difficult to ensure because of poor rigidity and machining deformation which is easy to produce extremely, it used the three-dimensional finite element method and did analysis and calculation of rectangular thin-walled parts under the action of milling force. It obtained the machining deformation law and the changing trend of the machining deformation of rectangular thin-walled parts with milling parameters in the different milling parameters circumstance by adjusting the milling parameters(milling depth, milling width, feed rate). It provided the theoretical basis for the selection and optimization of thin-walled parts milling parameters in the actual milling process.**

Keywords-milling; parameters; thin-walled parts; milling; deformation; finite element analysis

I. INTRODUCTION

Thin-walled parts are widely used in the stratosphere such as aviation and military. But it is easy to produce “let knife phenomenon” because of milling force during the machining process. It can lead upper thick, lower thin, size difference and poor manufacturability. Seriously the parts will be scrapped[1]. The milling force is mainly connected with milling parameters(milling depth, milling width, feed rate) in the actual milling process. So it is significant to study the influence of milling parameters on the deformation of thin-walled parts.

Many experts and scholars have carried out a lot of research on the prediction of thin-walled parts deformation. Guo Hun, et al. have analysed and calculated on the machining deformation of aviation thin-walled frame parts under the action of milling force and initial stress field. They obtained the law of the machining deformation[2]. Bi Yunbo, Ke Yinglin, Dong Huiyue et al. have carried out the finite element simulation of the machining deformation of aviation aluminum alloy thin-walled parts[2]. Wu Hongbing, Ke Yinglin, et al. have studied the machining deformation of the whole structure parts of the aviation frame[3]. Huang Zhigang et al. have researched on the orthogonal cutting to the prediction of thin-walled parts machining deformation[4]. Qin Guohua et al. have used the neural network method to predict the machining deformation of thin-walled parts[5].

At present the research on the influence trend of the milling parameters on the deformation of thin-walled parts is less. So in order to study the influence of milling parameters on thin-walled parts deformation trend, this paper is established thin-walled rectangular finite element model to study with the help of the software ABAQUS and eventually through experiment verified the correction of deformation trend.

II. KEY TECHNOLOGY OF FINITE ELEMENT ANALYSIS OF MACHINING DEFORMATION OF THIN-WALLED PARTS

A. Geometry Modeling

The part geometric model is shown in Figure I, 100mm long, 30mm high, and the thickness is 5mm. The three-dimensional modeling of rectangular thin-walled parts is simple, so according to the actual milling and the size of the part directly established the 3D model of rectangular thin-walled part at both ends of the unconstrained, at the bottom of the fixed constraint in the finite element analysis software ABAQUS.

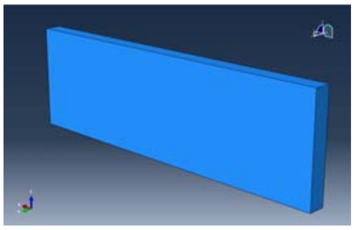

FIGURE I. PART GEOMETRIC MODEL

B. Selection of the Part Material Model

The form of Johnson-Cook constitutive equation is simple. It can solve the problem of high strain rate, high temperature and high temperature deformation in the process of metal material machining. It can truly reflect the flow stress of constitutive behavior of materials under high strain rate, high temperature and large strain. it has been widely used in thermal coupled analysis, especially in the instantaneous dynamic simulation[6]. Therefore Johnson-Cook model is widely used in the process of milling simulation. The expression of the Johnson-Cook constitutive model is:

$$\sigma=\left[A+B\varepsilon^{n}\right]\left[1+CLn\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left[1-\left(\frac{T-T_0}{T_{melt}-T_0}\right)^{m}\right] \quad (1)$$

σ —yield stress value of non zero strain rate, ε —strain,

$\dot{\varepsilon}_0$ —reference strain rate, it is 1s-1, T_0 —reference room temperature, T_{melt} —melting point temperature. A is yield strength of materials (Pa). B is material hardening modulus (Pa). N is strain strength coefficient. C is strain rate strength coefficient. M is thermal softening coefficient.

C. Mesh Division of Part Geometric Model

At present the finite element mesh division has three main methods:

- Lagrange method: In this method, the divided mesh is "pasted" on the material with the material flow.
- Euler method: In this method the mesh is fixed from start to finish, and the flow of the material is in the mesh[7].
- Improved Lagrange method: This method not only avoids the mesh large distortion but also improvs the mesh quality of large deformation problem. And it is significance to shorten the time of simulation and save the computer storage.

In this paper when used ABAQUS software to establish the milling model the improved Lagrange method is used to mesh the part and the cutting tool. As shown in Figure II, during the process of mesh dividing part the mesh that will be milled is refining, and the other is coarsening.

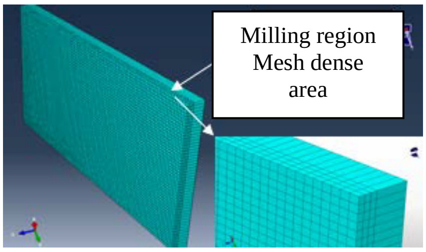

FIGURE II. IMPROVED LAGRANGE MESH DIVISION

D. Boundary Conditions and Load of Milling Force

Aiming at rectangular thin-wall parts, in the actual milling process the fixture of part mostly adopts that the bottom of the part is fixed on the milling machine table, two sides of the part and the upper of the part are in a free state. The milling cutter rotates with the spindle and the part does horizontal feed motion with the table. In order to ensure the validity and accuracy of machining deformation simulation, combined with actual movement of the milling process it adopts that the bottom of the part is added fixed constraints and other end surfaces have no constraints when adding boundary conditions. When the milling cutter is cutting to a part of the workpiece, the milling process is realized by the spiral movement of the cutter teeth. Because of high-speed rotating of the cutter with the spindle in this paper it takes milling force to load the end of the workpiece cutting and moved according to the feed speed until the cutting end of the workpiece. Simulation of milling process is carried out by this process. The size of the load is applied to the milling force data measured in the milling experiments.

III. FINITE ELEMENT SIMULATION DATA ANALYSIS OF THIN-WALLED PARTS MACHINING DEFORMATION

A. Actual Working Condition

According to the above analysis, the finite element analysis of the workpiece is carried out by ABAQUS finite element software. And the simulation parameters are shown in Table I.

TABLE I. SIMULATION PROCESSING PARAMETERS

number	Feeding rate[mm/min]	Milling depth[mm]	Milling width[mm]
1	80	0.05	15
2	120	0.05	15
3	160	0.05	15
4	200	0.05	15
5	120	0.10	15
6	120	0.15	15
7	120	0.2	15
8	120	0.2	20
9	120	0.2	25
10	120	0.2	30

B. Workpiece Coordinate System Setting

In order to facilitate the subsequent calculation and analysis, the direction of the coordinate system is shown in Figure IV X is the direction of the cutter feed. Z is the direction that the cutter is far from the workpiece. Determine the direction of Y axis by X and Z that determined according to the right-hand rule. Refer to the origin rule in figure III (O is the origin of coordinates). AB is denoted as Z=30mm and abbreviated as Z30, so the BC is abbreviated as X100.

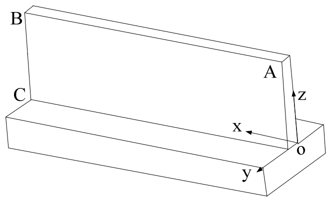

FIGURE III. WORKPIECE MEASUREMENT

C. Simulation Data Acquisition and Analysis

As is shown in figure IV. Milling depth is 0.05mm and milling width is 15mm. At this time it simulated to obtain the XY curve when the feeding rate is 80mm/min, 120mm/min, 160mm/min and 200mm/min.

From Figure IV we can see: When the feed rate increased from 80mm/min to 120mm/min, the workpiece machining deformation increased 22%. When the feed rate increased from 160mm/ to min 120mm/min, the machining deformation of each point increased 26% approximately. And the increasement of each point is very small. When the feed rate increased from 200mm/min to 160mm/min, the deformation of each point increased 34% approximately. When the feed rate increased, the machining deformation of the workpiece becomes larger.

As is shown in figure V. Feeding rate is 120mm/min and milling width is 15mm. At this time it simulated to obtain the

XY curve when the milling depth is 0.05mm, 0.10mm, 0.15mm and 0.20mm.

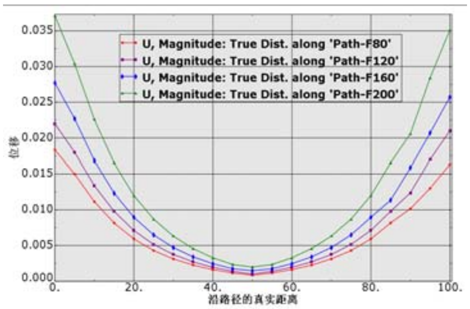

FIGURE IV. INFLUENCE OF FEEDRATE ON THE MACHINING DEFORMATION

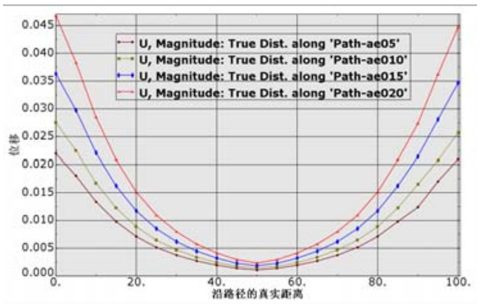

FIGURE V. INFLUENCE OF MILLING DEPTH ON THE MACHINING DEFORMATION

From Figure V we can see: When the milling depth increased from 0.05mm to 0.10mm the workpiece machining deformation increased 26% approximately. And the difference of each point is very small. When the milling depth increased from 0.10mm to 0.15mm the machining deformation of each point increased 31% approximately. When the milling depth increased from 0.15mm to 0.20mm the machining deformation of at each point increased 28% approximately. With the increase of the depth of the milling the machining deformation is gradually increasing, but the trend is slowing down.

As is shown in figure VI Feeding rate is 120mm/min and milling depth is 0.05mm. At this time it simulated to obtain the XY curve when the milling width is 15mm, 20mm, 25mm and 30mm.

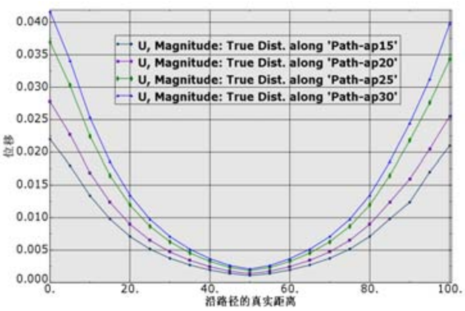

FIGURE VI. INFLUENCE OF MILLING WIDTH ON THE MACHINING DEFORMATION

From Figure VI we can see: When the milling width increased from 15mm to 20mm the direction Y of the workpiece deformation increased 27% approximately. When the milling width increased from 20mm to 25mm the direction Y of the workpiece deformation increased 32% approximately. When the milling width increased from 25mm to 30mm the direction Y of the workpiece deformation increased 25% approximately. With the increase of the depth of the milling the machining deformation is gradually increasing, but the trend is slowing down. when the milling width increases the deformation of the workpiece can be increased obviously. But the deformation of the workpiece is slowing down.

IV. EXPERIMENTAL VERIFICATION

Experiment has been done in XH714 NC machining center by dry milling, reverse milling method. Workpiece material is 45# steel. The size of thin-walled part is the same as the model of finite element simulation, that is, L=100mm, high H=30mm, wall thickness W=5mm. Cutting tool material is hard alloy and the diameter is 16mm. The feed rate, milling depth and width are changed in turn. The specific parameters are shown in Table II:

TABLE II. MAIN CUTTING PARAMETERS IN EACH GROUP

group	Feeding rate[mm/min]	Milling depth[mm]	Milling width[mm]
1	80	0.05	15
2	120	0.10	20
3	160	0.15	25
4	200	0.20	30

The actual process of the workpiece is shown in Figure VII. After the processing the path of the measured deformation value is compared in the simulation. Use the dial gauge to measure the thickness and the measure distance is 5mm. The actual wall thickness value subtracts the theoretical wall thickness to get experiment value of the workpiece deformation.

FIGURE VII. ACTUAL MACHINING PROCESS

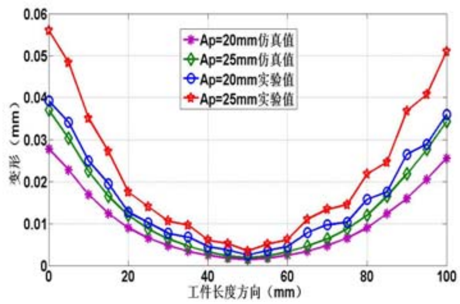

FIGURE VIII. COMPARISON OF MACHINING DEFORMATION OF DIFFERENT MILLING WIDTH

Figure VIII is to obtain the machining deformation contrast of the different milling width when the milling width is 25mm and 20mm respectively.

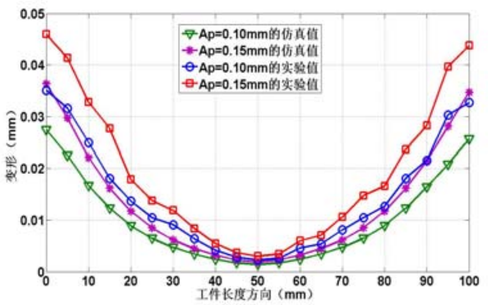

FIGURE IX. COMPARISON OF MACHINING DEFORMATION OF DIFFERENT MILLING DEPTH

Figure IX is to obtain the machining deformation contrast of the different milling depdth when the milling depth is 25mm and 20mm respectively.

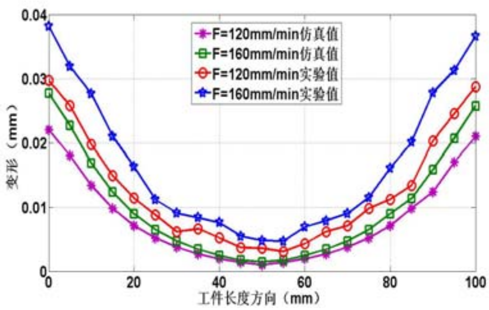

FIGURE X. COMPARISON OF MACHINING DEFORMATION OF DIFFERENT FEEDING RATE

Figure X is to obtain the machining deformation contrast of different feeding rate the when the feeding rate is 120mm/min and 160mm/min respectively.

Through the comparison between the experimental values and the simulation results of different cutting parameters we can see that the change trend of experimental values and simulation values are the same. The simulation results are reliable and can be used as the basis for machining deformation prediction and optimization of milling parameters.

V. CONCLUSION

- Establish the finite element simulation model of machining deformation of rectangular thin-walled parts in the finite element software ABAQUS.
- Through the finite element prediction model the machining deformation is predicted. Obtain the influence law of different milling parameters on the machining deformation of the workpiece by adjusting the parameters.
- Establish the milling experiments that the conditions are the same as finite element simulation. The experimental values of workpiece deformation and the predicted values of finite element simulation are compared and analyzed. The results show that the experimental values and the predicted values have the same trend. This indicates that the established finite element model is reliable. It provides the theoretical basis for the selection and optimization of thin-walled parts milling parameters of actual milling process.

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