

The FEM Simulation on End Mill of Plastic Doors and Windows Corner Cleaning Based on Deform-3D

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Abstract. In the plastic doors and windows corner cleaning process, the rotating speed, the feed rate and the milling cutter diameter are the main factors that affect the efficiency and quality of the of corner cleaning. In this paper, SolidWorks will be used to establish the 3D model of end mills, and use Deform-3D to research the end mill milling process. And using orthogonal experiment design method to analyze the effect of rotating speed, the feed rate and the milling cutter diameter on the axial force variation, and to get the overall trend of axial force and the selection of various parameters according to the influence of axial force change. Finally, simulate milling experiment used to get the actual axial force data to verify the reliability of the FEM simulation model. And the conclusion obtained in this paper has important theoretical value in improving the plastic doors and windows corner cleaning efficiency and quality.

1. Introduction

Corner cleaning as a main technology in plastic doors and windows production process, the quality of its corner cleaning has a direct impact on the quality and the strength. But in the actual inner countersink slot cleaning, the corner cleaning is incompletely, the cutting edge crack and the serious abrasion in cutter, these problems will affect the quality of the plastic doors and windows. And there are many factors that lead to this phenomenon, such as cutting speed, feed rate, etc[1].

Based on that, the effects of rotating speed, feed rate and milling cutter diameter on milling axial force were analyzed by using orthogonal design method in this paper. First, use SolidWorks to establish the 3D model of end mills, and use Deform-3D to research the end mill milling process. Then, using orthogonal experiment design method to analyze the effect of rotating speed, the feed rate and the milling cutter diameter on the axial force variation, to get the overall trend of axial force and the selection of various parameters according to the influence of axial force change. Finally, use simulate milling experiment to get the actual axial force data to verify the reliability of the FEM simulation model[2].

2. End Mill and Workpiece Model Creatio

2.1. End Mill and Workpiece Model Creation

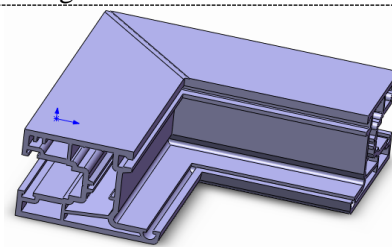
Plastic doors and windows profiles use PVC resin as the main raw material, with a certain percentage of stabilizers, colorants, fillers, UV absorbers and other extrusion molding. Main performance parameters of the plastic doors and windows profile as shown in Table 1.



Table 1. Performance parameters of the profile.

| Project | | Target |
|--|--------|---------|
| Thermal Expansion Coefficient, $10^{-6}/\text{K}$ | \geq | 5 |
| Heat Transfer Coefficient, $\text{W}/\text{m}^2 \text{ K}$ | \geq | 1.91 |
| Elastic Modulus, Mpa | \geq | 3000 |
| Bending Modulus of Elasticity, Mpa | \geq | 100 |
| Melting Point, $^{\circ}\text{C}$ | \geq | 210 |
| Poisson's Ratio | | 0.40 |
| Density, $\rho/(\text{kg}\cdot\text{m}^3)$ | | 1385 |
| Specific Heat Capacity, $\text{c}/(\text{J kg}^{-1} \text{ K}^{-1})$ | | 0.8—1.5 |

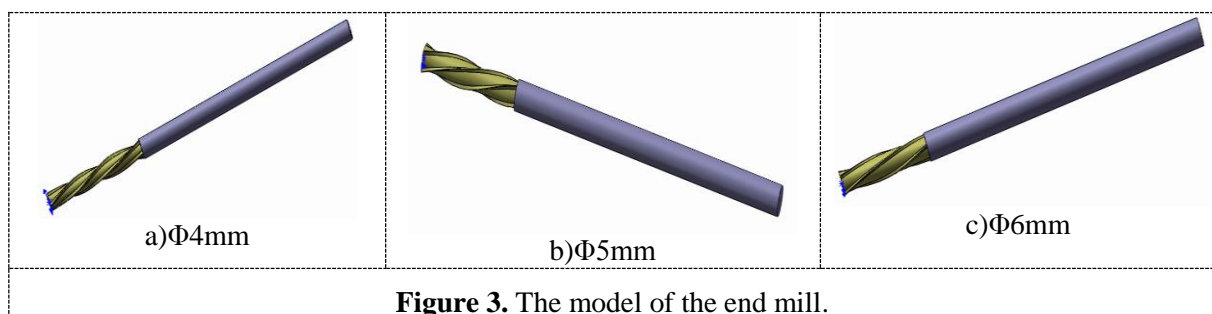
The inner countersink slot cleaning is shown in figure 1. The inner countersink slot cleaning was used to hold the glue strips, and the effect of cleaning will affects the tightness. Use SolidWorks to establish the profile model. And the model of the profile is shown in figure 2.

**Figure 1.** The inner countersink slot cleaning**Figure 2.** Profile model

Use SolidWorks to establish solid model of end mill according to the geometrical parameters of the end mill. The model of the end mill is shown in figure 3.

Table 2. The geometrical parameters of the end mill.

| Diameter | 4 | 5 | 6 |
|-----------------|--------------|--------------|--------------|
| Full Length | 83 | 92 | 101 |
| Blade Length | 24 | 24 | 24 |
| Number of Teeth | 4 | 4 | 4 |
| Rake Angle | 0° | 0° | 0° |
| Clearance Angle | 12° | 12° | 12° |
| Helix Angle | 30° | 30° | 30° |

**Figure 3.** The model of the end mill.

It is necessary to adjust the position relations between the end mill and the workpiece in SolidWorks to reduce the computation time in the process of simulation. Milling simulation model is shown in figure 4.

2.2. Material Selection and Meshing

The end mill material is cemented carbide, and the end mill is set to a rigid type. PVC as the workpiece material was selected, and set the workpiece as a plastic type. Deform-3D uses adaptive meshing method to divide the grid, which can prevent the excessive distortion of the division unit and affect the simulation accuracy. At the same time, in order to reduce the computation time of the simulation, the meshing method of the local mesh should be adopted to make the mesh away from the milling area become thinner gradually when the mesh is divided. End mill relative grid division method, the number of grid 20000[3], but the profile adopt the absolute mesh method, the ratio of the maximum mesh size to the minimum mesh size is set to 2, the minimum cell side length is 0.6 mm[4], the ratio of the maximum mesh size to the minimum mesh size is set to 4, the minimum cell side length is 0.2 mm[5]. The meshed model is shown in figure 5.

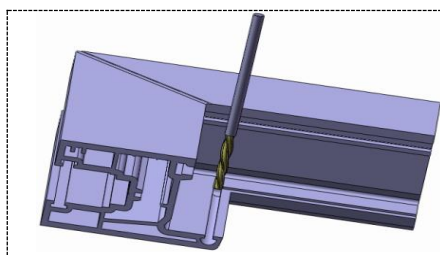


Figure 4. Milling simulation model.

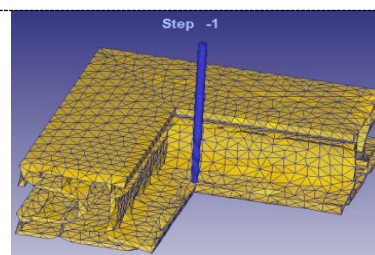


Figure 5. The meshed model.

2.3. Simulation Parameters and Boundary Conditions

Set the milling depth was 3mm, the tool wear parameter a and b are $1e^5$ and 855. In the simulation control window, set the number of steps was 1000, the storage increment is stored once every 25 steps, and the time step is 0.0002s[6].

In the boundary condition setting, set the speed of the workpiece side in the X, Y, Z axis in three directions were 0, to limit the movement of the workpiece. The tool feeds in the -Z direction and rotates around the Z axis. At the same time, set the tool and workpiece surface and all external heat transfer, ambient temperature, the end mill and the workpiece temperature is defined as 20°C, the heat transfer coefficient is 45N/sec/mm/C, the convection coefficient is 0.02N/sec/mm/C. The contact condition of the workpiece is shear friction, and the friction coefficient is 0.6. Its tool wear Usui's model [7]:

$$w = \int a p V e^{-b/T} dt$$

In this formula, w is the wear volume; p is the contact surface pressure; V is the sliding speed; dt is the time increment; a, b are the experimental calibration coefficient, a is $1.0e^5$ and b is 855 according to experience.

3. Simulation Analysis of End Mill

3.1. Simulation Experiment

In this part, the orthogonal experiment design method is used to study the effect of milling parameters on axial force. Then, select milling cutter diameter, feed speed and spindle speed as the three factors, the test factors and level as shown in Table 3.

Table 3. Factor level table.

| Status | Factor | | |
|--------|-------------------------|-------------------|----------------|
| | A:Rotating speed(r/min) | B:Feed Rate(mm/r) | C:Diameter(mm) |
| Level | 1000 | 0.1 | 4 |
| | 2000 | 0.2 | 5 |
| | 3000 | 0.3 | 6 |

3.2. Axial Force Analysis

From the table 3.1, it can be seen that there are three factors (A is rotation speed, B is feed rate and C is diameter) and three levels in the table. The orthogonal table L9 (34) is selected and the plan is discharged according to L9 (34), namely, nine groups of experiments were performed. The axial force variation curve of the end mill in each test condition is shown in figure 6.

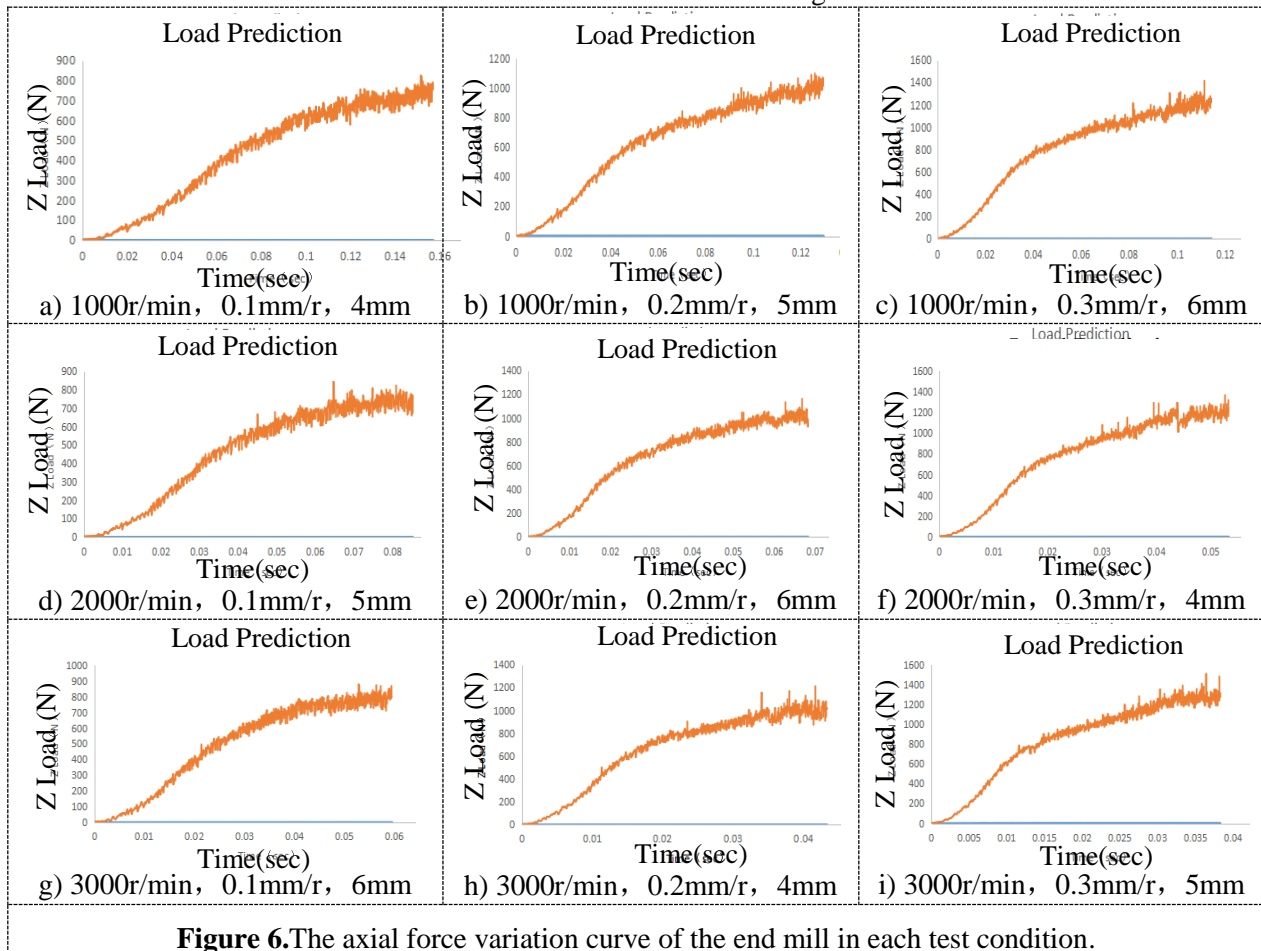


Figure 6. The axial force variation curve of the end mill in each test condition.

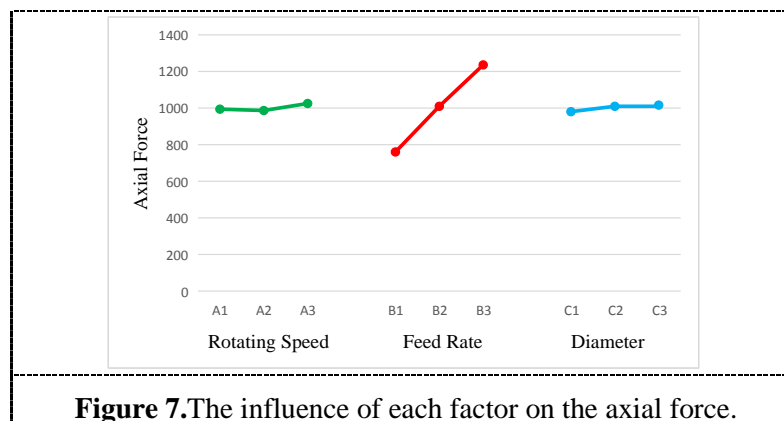
In figure 6, the axial force of the end mill in the test condition is gradually increased as the milling blade and the profile begin to contact with each other in the initial milling force variation curve. The axial force will reach the maximum end mill when the milling cutter edge all involved in the clearance of plastic doors and windows profile milling. Owing to the re-division of the mesh in Deform-3D lead to discontinuities in the simulation process or chip breakage, the curve will fluctuate up and down when the axial force tends to be stable.

According to the simulation results, take the average of the steady-state data to complete Table 4.

In Table 4, the three sets of data in row K1 are the sum of the corresponding axial force of the end mill in the test where the first level of factors A, B and C. the three sets of data in row K2 are the sum of the corresponding axial force of the end mill in the test where the second level of factors A, B and C. And the three sets of data in row K3 are the sum of the corresponding axial force of the end mill in the test where the third level of factors A, B and C. But beyond that, k1, k2 and k3 rows of three sets of data for the K1, K2 and K3 rows corresponding to the three groups of data obtained by dividing 3 respectively. The range is the difference between the maximum value and the minimum value of k1, k2, and k3 in the same column. According to Table 4, the influence of each factor on the axial force is shown in figure 7.

Table 4.Orthogonal test simulation results

| Factor Group | 1 A | 2 B | 3 C | Axial force (N) |
|------------------|---------|---------|---------|-----------------|
| 1 | 1 | 1 | 1 | 747.23 |
| 2 | 1 | 2 | 2 | 1007.57 |
| 3 | 1 | 3 | 3 | 1227.22 |
| 4 | 2 | 1 | 2 | 736.95 |
| 5 | 2 | 2 | 3 | 1025.41 |
| 6 | 2 | 3 | 1 | 1197.37 |
| 7 | 3 | 1 | 3 | 796.19 |
| 8 | 3 | 2 | 1 | 996.05 |
| 9 | 3 | 3 | 2 | 1282.87 |
| K_1 | 2982.02 | 2280.37 | 2940.65 | |
| K_2 | 2959.73 | 3029.03 | 3029.03 | |
| K_3 | 3075.11 | 3707.46 | 3048.82 | |
| k_1 | 994.01 | 760.12 | 980.22 | |
| k_2 | 986.58 | 1009.68 | 1009.68 | |
| k_3 | 1025.04 | 1235.82 | 1016.27 | |
| Range | 38.46 | 475.7 | 36.05 | |
| Optimal Solution | A_1 | B_1 | C_1 | |

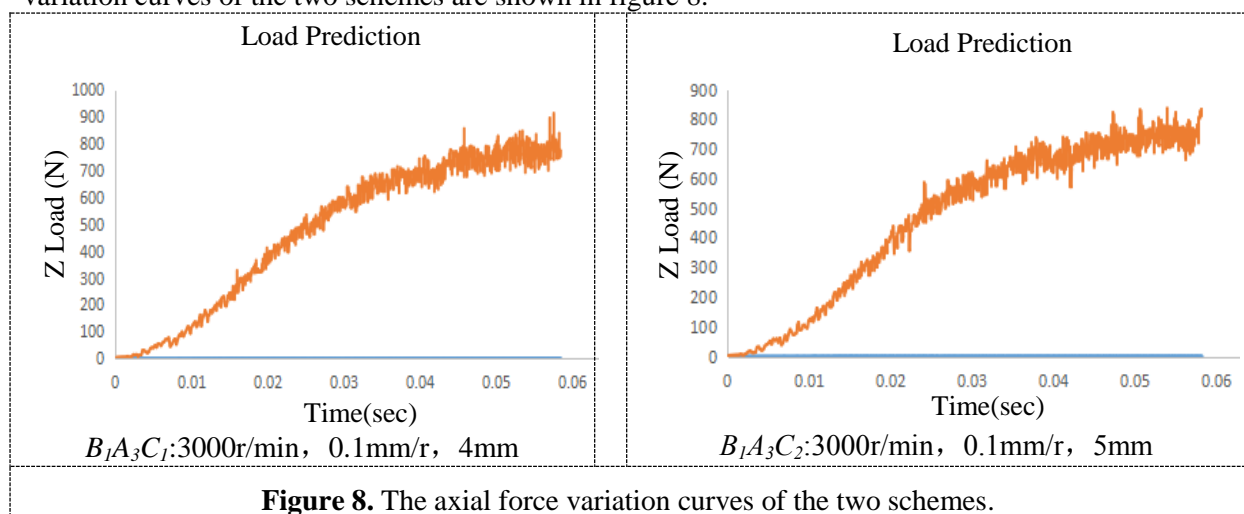
**Figure 7.**The influence of each factor on the axial force.

It can be seen from figure 7 that with the spindle speed increases, making the cutting edge of the blade edge thickness increases, and ultimately the overall increase in the axial force of the trend. But the growth trend is not significant, and it shows that the spindle speed has little effect on the milling force. The axial force increases rapidly when the feed rate increases, which is due to the increase in feed lead to elastic deformation profiles, resistance and friction are also increases. The axial force increases when the diameter of the milling cutter increases, namely, the diameter of the milling edge increases, and the area involved in the milling increases, so that the axial force increases as the deformation and friction increase accordingly. It can be seen that the feed rate of the end mill has the greatest influence on the axial force, and the sort of each influencing factor as follows: Feed Rate>Rotating speed>Diameter.

Generally speaking, the range of the line is different, which shows that the level of the factors change the impact of the test index is different. The larger the range is, the greater the effect of the change of the level of the factor on the test index, and the column of the range of maximum deviation is the main factor to be considered in this article. It can be seen from the table 4 that the three ranges are 38.46, 475.7, 36.05, obviously, the second column (factor B) corresponds to the maximum range, namely, the level of factor B changes in the test index of the most significant factor. So, factor B is an important

factor to be considered in this article. The axial force of the end mill should be reduced in the corner cleaning process to reduce the excessive tool axial force caused by tool wear and chipping phenomenon. The average axial force corresponding to three levels of factor B are 760.12N, 1009.68N and 1235.82N. It can be seen that the axial force corresponding to the first level is the smallest, so, the first level of factor B is the best; Analogously, the value of the first level of factor A and the value of the first level of factor C are the best. Therefore, B1A1C1 is the best scheme.

In order to improve the corner cleaning efficiency, it is important to increase the speed of the end mill for the third factor A, namely, speed is 3000r/min, so, scheme B1A3C1 can be chosen. At the same time, the large diameter of the end mill can be chosen to increase the milling area, namely, scheme B1A3C2 or B1A3C3 also can be chosen. But the scheme B1A3C1 and B1A3C2 did not appear in the nine groups of tests. In order to validate the results of scheme B1A3C3, B1A3C1 and B1A3C2, the milling force simulation tests can be carried out on solutions B1A3C1 and B1A3C2. The axial force variation curves of the two schemes are shown in figure 8.



According to the figure 8, the results of the axial force comparison of the three schemes was completed as shown in Table 5.

Table 5. The results of the axial force comparison of the three schemes.

| Group | Factor | | | Axial Force (N) |
|-------|--------|--------|--------|-----------------|
| | 1 A | 2 B | 3 C | |
| 7 | 3 | 1 | 3 | 796.19 |
| 10 | 3 | 1 | 1 | 779.29 |
| 11 | 3 | 1 | 2 | 762.25 |

It can be seen from the Table 5 that the axial forces of the 10th group and the 11th group are all smaller than those of the 7th group, which shows that the two schemes (B1A3C1 and B1A3C2) are better than B1A3C3, and B1A3C2 is the best. That is to say, feed rate can be selected 0.1mm/r, speed can be selected 3000r/min, and the diameter can be selected 5mm.

4. Simulation Results Verify

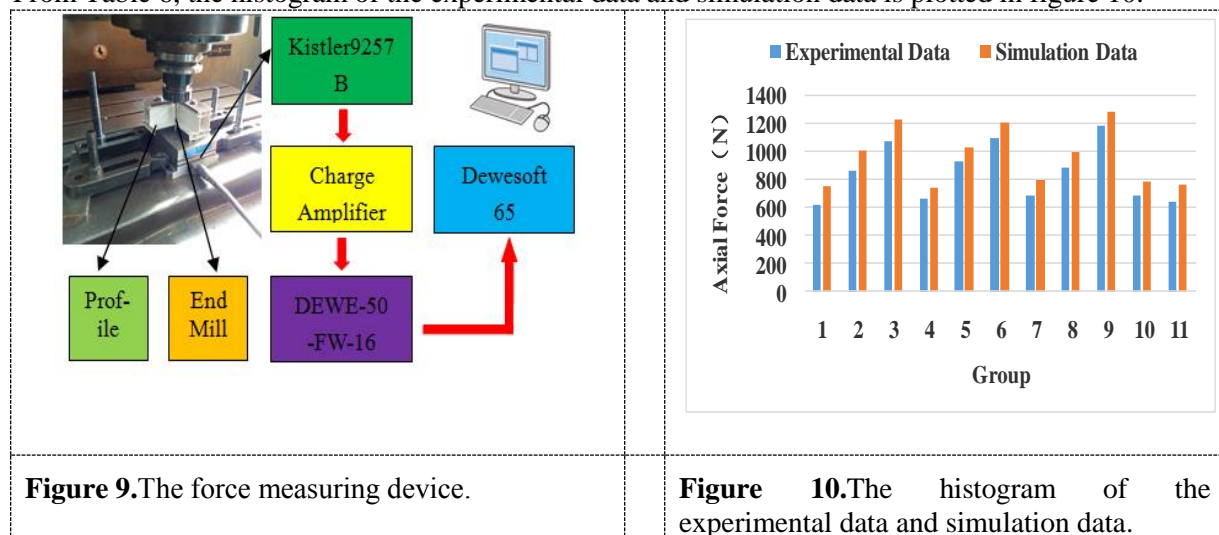
In this article, the axial force test is carried out on 11 experiments in Table 4 and Table 5, to verify the accuracy of the simulation results in section 3.2. The force measuring device included: Kistler9257B three-way dynamic piezoelectric dynamometer, Charge amplifier, DEWE-50-FW-16 cutting force measurement system, Dewesoft65 computer processing system, YCM-V116B CNC, End mill and Profile. The system connection is shown in figure 9.

Milling force tests were carried out on 11 test schemes, and five sets of experimental data were collected for each scheme to reduce the errors caused by the experiment. The mean error of five sets of experimental data for each protocol was compared with the simulation data, and the results in Table 6 were completed.

Table 6. Comparison of experimental data and simulation data.

| Group | Experimental Data (N) | Simulation Data (N) | Relative Error (%) |
|-------|-----------------------|---------------------|--------------------|
| 1 | 614.28 | 747.23 | -17.79 |
| 2 | 862.99 | 1007.57 | -14.35 |
| 3 | 1067.62 | 1227.22 | -13.01 |
| 4 | 660.42 | 736.95 | -10.38 |
| 5 | 922.72 | 1025.41 | -10.01 |
| 6 | 1090.95 | 1197.37 | -8.89 |
| 7 | 681.98 | 796.19 | -14.34 |
| 8 | 885.79 | 996.05 | -11.07 |
| 9 | 1180.07 | 1282.87 | -8.01 |
| 10 | 680.37 | 779.29 | -12.69 |
| 11 | 634.34 | 762.25 | -16.78 |

From Table 6, the histogram of the experimental data and simulation data is plotted in figure 10.



It can be seen from Table 6 that the relative error between the simulation data and the experimental data is within 20%. The effect of data read is the difference between the actual processing environment and simulation processing environment, as well as the installation of the experimental device is difficult to guarantee accuracy. From the figure 10, it shows that the experimental data are in agreement with the simulation data, which indicates that the simulation data of the axial force of the end mill can be referenced by the finite element simulation method.

5. Conclusion

In this article, the SolidWorks were used to establish three-dimensional model of three different diameter end mills, and use Deform-3D to research the end mill milling process. And using orthogonal experiment design method to analyze the milling blade diameter, feed rate and spindle speed on the axial force influence, to get the overall trend of axial force and the selection of various parameters on the influence of axial force change. Finally, simulate milling machining used to get the actual axial force data to verify the reliability of the FEM simulation model.

(1)Through the milling process simulation analysis, the axial force variation curve of end mill is obtained, namely, the axial force will increase gradually when the cutting edge and the profile begin to come into contact in the initial stage. The axial force of the end mill will reach the maximum value when the milling edge is all involved in the corner cleaning of the profile, and then, the axial force of the end mill will tend to be stable with the milling of the milling cutter. And it shows that the feed rate of the end mill has the greatest influence on the axial force, and the sort of each influencing factor as follows: Feed Rate>Rotating speed> Diameter.

(2)Through the analysis and the comparison, it shows that the reasonable value of the parameter in the corner cleaning process of end mill can be selected as feed rate is 0.1mm /r, speed is 3000r/min and diameter is 5mm.

(3)From the conclusions, it can be known that the simulation test data of the axial force of the end mill with the finite element simulation method are relatively reliable, namely, the data can be referenced.

6. References

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