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Simulation of surface morphology and roughness during helical milling

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Abstract

As a new hole-making method, helical milling can improve the surface quality of the machined hole. Some efforts have been directed to simulate the surface morphology and get the surface roughness. In this paper, based on analyzing the helical milling process, a 3D surface morphology simulation model is established to simulate the surface morphology after a helical milling operation, in which the difficulty in surface morphology simulation caused by the axial feed of the tool is overcome. The surface morphology, in which the effect of tool eccentricity is considered, under different cutting parameters is modeled using the established simulation model. The impact of tool eccentricity on the hole surface topography is discussed. In addition, the roughness of the hole surface is obtained from the surface topography result, It is found that this surface roughness calculation method can predict the roughness effectively.

Keywords: Surface morphology, helical milling, secondary cut, speed ratio, surface roughness

1. Introduction

In modern aircraft manufacturing process, thousands of holes need to be made to meet the complex assembly requirements. The performance quality of the machined hole is determined by its surface quality and integrity resulting from the manufacturing process.

Based on the principles of transformation matrix and vector operation, Xu AP et al. [1] derived the trajectory equation of cutting edge relative to workpiece and developed a three-dimensional milled surface topography simulation algorithm. Chen DX et al. [2] presented a digital generation method of surface topography of the grinding wheel using Johnson transformation method and linear filter technique. Based on an improved Z-map model, Li ZQ et al. [3] established a 3D surface topography simulation model to simulate the surface finish profile generated after a helical milling operation using a cylindrical end mill. Shan YC et al. [4] established a theoretical calculation model to get the height remained of the hole after helical milling.

In this paper, a surface topography simulation model is established and the roughness of the machined hole is obtained from the surface topography model. The article content is as follows: part 2 introduces the helical milling method; part 3 introduces the surface topography simulation model; part 4 lists some simulation results.

2. Kinematics of helical milling

Compared with the traditional hole-making method, helical milling is a highly efficient hole-making method. As shown in Figure 1, helical milling is composed of three movements: rotation around the tool axis (spindle rotation), rotation around the axis of the machined hole (revolution) and linear motion along with the axis direction of the machined hole. The circumferential feed and axial feed are provided respectively by revolution and linear motion of the tool. It is convenient to change the machining diameter of hole by varying the eccentricity between the axis of tool and the axis of hole.

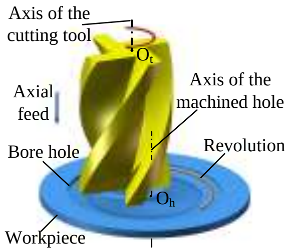

Figure 1. Schematic diagram of helical milling process

3. Modeling of surface topography

3.1. Trajectory of cutting edge considering cutter eccentricity

The machined surface topography is actually the result of the interaction between the tool and the workpiece. The cutting condition of the different edges change when there is eccentricity, thus affecting the surface morphology. The trajectory of cutting edge can be calculated using the follow equation:

$$P_w=\begin{bmatrix}\cos(\varphi+\gamma_t) & -\sin(\varphi+\gamma_t) & 0\\ \sin(\varphi+\gamma_t) & \cos(\varphi+\gamma_t) & 0\\ 0 & 0 & 1\end{bmatrix}\left(\begin{bmatrix}\cos(\mu+\gamma_i) & -\sin(\mu+\gamma_i) & 0\\ \sin(\mu+\gamma_i) & \cos(\mu+\gamma_i) & 0\\ 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix}R_t\cos\alpha\\ R_t\sin\alpha\\ R_t\alpha/\tan\beta_0\end{bmatrix}+\begin{bmatrix}-e\\ 0\\ 0\end{bmatrix}\right)+\begin{bmatrix}(R_h-R_t)\cos\varphi\\ (R_h-R_t)\sin\varphi\\ -a_p\cdot n_g\cdot t\end{bmatrix}$$

where φ is the tool rotation angle around the hole axis, γ_t is the phase angle of cutting point, γ_i is the phase angle of the i_{th} cutting edge, α is the lag angle of the cutting point, β_0 is the tool spiral angle, $e=R_h-R_t$.

3.2. Mesh generation method

The classical Z-map model is used to characterize surface whose projection on the view plane doesn't overlap. The surface of the machined hole is cylindrical and can't use the Z-map model directly. Therefore, the surface of hole was transformed into a plane and then characterized using classical Z-map model. The conversion principle is shown in figure 2.

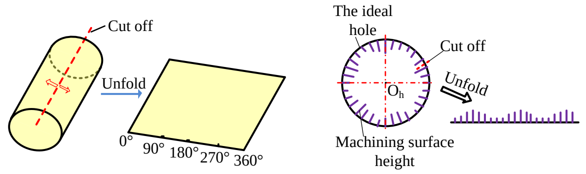

Figure 2. Conversion from hole surface to plane

The surface topography simulation process is as follows:

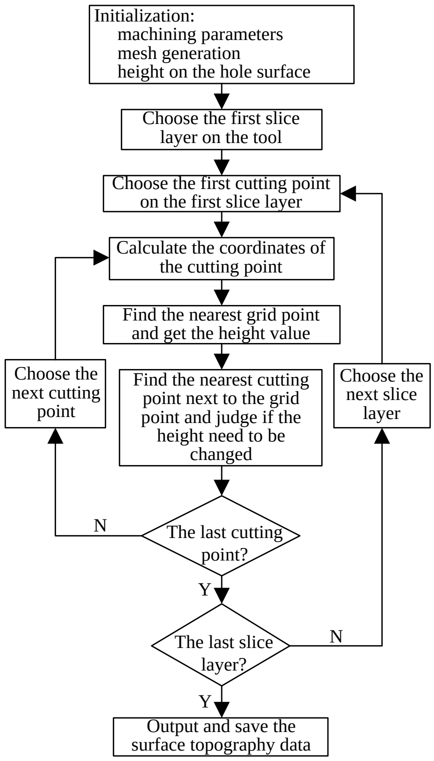

Figure 3. Simulation flow chart of the hole surface topography

3.3. Roughness extraction method

The roughness of the hole can be obtained from the surface topography simulation result and the calculating principle is shown in Figure 4.

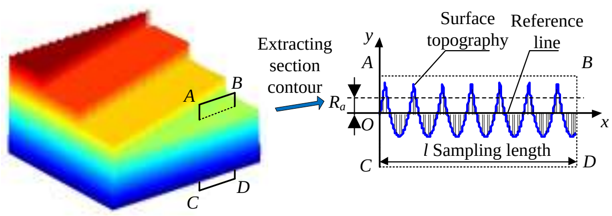

Figure 4. Acquisition method of surface roughness

4. Simulation result

4.1. The impact of cutter eccentricity on surface topography

The value of cutter eccentricity (e_t) will influence the cutting condition of different cutting edges. Figure 5 shows the surface topography under different eccentricity. The tool radius R_t=3mm, the hole radius R_h=5mm, revolution speed n_g=320mm/min, rotation speed n_z=2000r/mim. It can be seen from the overall topography (Figure 5(a)(c)) that the height on the surface after the first cut is small when the e_t takes a small value and the different value between the first cut surface height and the second cut is also small. In addition, it can be seen from the local topography (Figure 5(b)(d)) that the surface topography changes with different value of e_t. One reason is that the value of e_t will influence the number of cutting edges which participate in helical milling process.

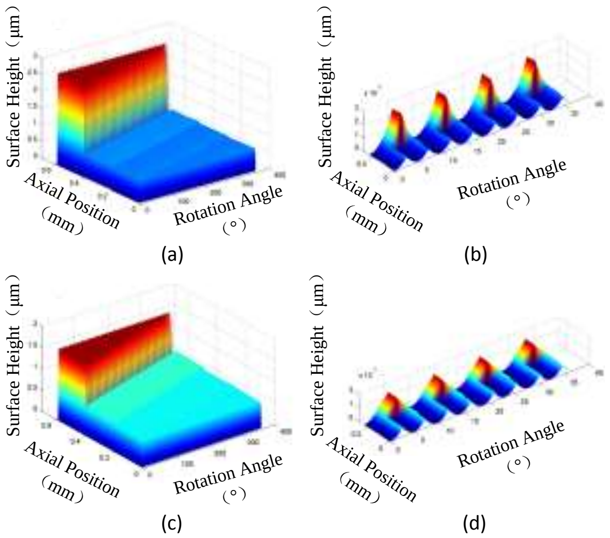

Figure 5. Morphology of the machined surface with different value of tool eccentricity (a)(b) e_t=10μm, (c)(d) e_t=1μm

4.2. The impact of revolution speed on roughness

During the helical milling process, the revolution speed has a significant influence on the surface quality. Fig shows the roughness change rule when the revolution speed changes from 100mm/min to 310mm/min. It is easy to find that the value of roughness gradually increases with the revolution speed increasing. There are two causes of this phenomenon: on the one hand, the increase of revolution speed will lead to the increase of cutting force, which will lead to a poor cutting stability; on the other hand, the increase of revolution speed will lead to the decrease of cutting number of cutting edges on the surface during one revolution. The calculated roughness is in good agreement with that of measured in experiment.

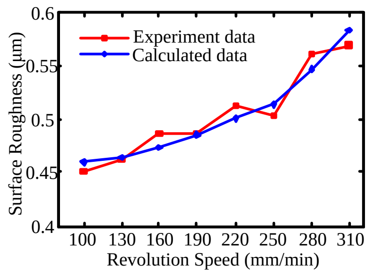

Figure 6. Impact of revolution speed on hole surface roughness

5. Conclusion

The established surface topography model is correct and can be used to investigate the influence of the cutting parameters on the surface topography. The roughness obtained from the surface topography is effective.

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