

Research on analytical model of the process parameters for the high speed hobbing of ball end milling cutter

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Abstract. The high speed hobbing of ball end mill is affected by equipment and environmental condition, workpiece materials and heat treatment conditions and other factors, led to workpiece parameters analysis calculation error is large of parameters such as feeding speed, spindle speed etc, it is need for modification process parameters, and improve the machining process. A roughness quantitative analytical model is proposed based on joint correlation analysis of dry cutting hob decomposition and cutting speed. The process parameter constraint parameter mathematical model of ball end milling in high speed hobbing is constructed using magneto rheological smooth processing method, high speed hobbing multi-objective variable parameter is optimized by edge estimation of distribution of workpiece the calculation of hobbing process of axial feed velocity and hob beyond stroke feature decomposition to quantify the cutting speed and axial feed, realize the modification of process parameters, the recommended value of smoothness process parameters is obtained. The simulation results show that the new model can reduce the hobbing tooth orientation error and tooth orientation error, workpiece surface roughness measurement values converge to zero, and it has high flatness and good application value.

Introduction

The ball end milling cutter is widely used in the finishing process and the machining process of aviation and aerospace tools because of its good adaptability and high robustness. Ball end milling roll through the high-speed machining takes complex surface machining of the workpiece, the complex surface vibration cutting workpiece by rolling from strong local geometric micro amplitude changes, cutting feed direction, and the influence of cutter axes vector dynamic characteristic changes and other factors, which leads to the problem of surface roughness and machining quality decline prone process the ball head milling cutter, and the spindle amplitude error exceeds the allowable range of precision gear will accelerate tool wear and reduce the service life of high speed ball end milling hobbing machine by the status of the equipment and environmental conditions, the work piece materials and heat treatment conditions and other factors, the stability of machine tool precision and machining quality and the system is difficult to control^[1]. Therefore, the high speed hobbing of ball end mill flatness analytical model of process parameters optimization is studied, the process parameters are modified to improve the processing technology and related model research in improving the machining accuracy and improve the quality of the workpiece is important.

High speed ball end milling hobbing is a dynamic process of instability, strong self-excited vibration cutter and the workpiece, the workpiece surface quality is decreased^[2], in the traditional method, the smoothness of the process parameter optimization method of ball milling in high speed hobbing is mainly used in finite element method, modal theory and vibration dynamic monitoring method^[3], the boundary cutter contact region of ball end milling cutter curve is segmented, finite element inertia and shear deformation analysis is taken, the tool contact zone model is established accurately, and the process optimization is realized, obtained certain research results, among them, a curved surface of ball end milling cutter contact zone is proposed based on semi analytical modeling of multi axis machining optimization model in references [5], the semi analytical tool to

establish the contact zone of complex surface of ball end milling multi axis machining, and applied in the plane milling and side wall milling, improving processing technology, but the method in the tool feed direction uncertain difference and local geometric features of large workpiece, the processing precision is not good. References [6] proposed a hobbing parameters optimization model of high-speed dry fuzzy TOPSIS method based on edge distribution estimation method and the number of turning enumeration method combining algorithm, with introducing the theory of cost cutting high-speed dry cutting the hobbing process parameter calculation, achieve the target of milling ball cutter variable parameter optimization, and the reliability of the method is verified by an example, but this method has The problem is that the thermal error interference is not strong, and the correction accuracy of the cutting parameters such as cutting speed and groove number is not high^[7].

Aiming at the above problems, this paper proposes a decomposition of dry cutting hob cutting speed and axial feed combined correlation roughness parameters based on the analytical model, constraint parameter mathematical model parameters firstly using magneto rheological formation processing method of construction of ball end milling in high speed hobbing, parameter optimization of multi targets through the workpiece edge distribution estimation high speed hobbing machining, and then calculate the hobbing process of axial feed velocity and hob beyond stroke feature decomposition to quantify the cutting speed and axial feed, realize the modification process parameters, process parameters are the smoothness of the recommended value. Finally, the performance test is carried out by the simulation experiment, and the conclusion is drawn, which shows the superiority of this method in improving the flatness and precision of the ball end milling cutter.

Process parameters and mathematical modeling of ball end milling cutter

Constraint parameter model for high speed hobbing of ball end milling cutter.

In order to realize the high speed hobbing ball mill flatness optimization, it needs to build the ball end milling surface milling process parameters of three axis model firstly, process flow diagram of ball end milling in high speed hobbing is shown in Figure 1.

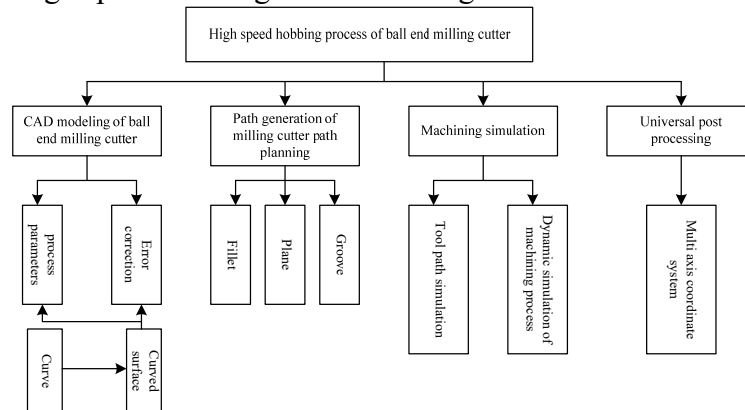


Figure. 1 Process flow diagram of ball end milling in high speed hobbing

According to the ball mill high speed hobbing process shown in Figure 1, it knows that the main process parameters analysis contain feed trajectory CAD design, processing production, processing simulation and post-processing module, using OXYZ as the ball end milling cutter coordinates to describe the rotation space complex surface ball head milling multi axis machining through mathematical analysis, rotational inertia of milling cutter is:

$$K = \frac{1}{2} \sum_{i=0}^6 [I_i \dot{q}_i^2 + m_i (\dot{x}_i^2 + \dot{z}_i^2)] \quad (1)$$

At the same time, I_i is the local geometric parameters of the ball end milling cutter, the potential energy of the contact between the tool geometry and the workpiece geometry in the contact area of the cutter is:

$$P = \sum_{i=0}^6 m_i g z_i \quad (2)$$

Wherein:

m_i —Geometric characteristic parameters of tool contact area, $i=0,1,2,\dots,6$ are six degrees of freedom motion space; l_i —Tool track spacing; a_i —Axial position angle; q_i —Cutting edge of micro axial position angle; θ_i —Cutter radius.

Based on the above analysis, the problem of constrained parameter model analysis of the ball end milling cutter in high speed cutting is converted into a complex surface intersection problem for solving boundary curve analysis:

$$\begin{aligned} \min \quad & F(x) = (f_1(x), f_2(x), \dots, f_m(x))^T \\ \text{s.t.} \quad & g_i \leq 0, \quad i = 1, 2, \dots, q \\ & h_j = 0, \quad j = 1, 2, \dots, p \end{aligned} \quad (3)$$

Under the constraint of geometric parameters of high speed dry cutting hob, the geometric relationship between adjacent lines for processing is obtained as:

$$\begin{pmatrix} X \\ P(X) \end{pmatrix} = \begin{Bmatrix} a_1, a_2, \dots, a_m \\ p(a_1), p(a_2), \dots, p(a_m) \end{Bmatrix} \quad (4)$$

Wherein, $0 \leq p(a_i) \leq 1 (i=0,1,2,\dots,m)$ shows the total number of degrees of freedom of hob rotation. Based on the above analysis, the constraint parameter model of the ball end milling cutter in high speed hobbing is constructed, which provides the input parameters and the calculation basis for the development of the process parameter optimization system and the improvement of the machining process.

Calculation of the process parameters of hobbing process.

The parameter constraint parameter mathematical model of ball end milling in high speed hobbing is constructed based on magneto rheological smooth machining method, parameter optimization of multi targets by the edge of the workpiece of high speed hobbing for estimation of distribution, in the magnetic field change effect for roughness is optimized using magnetorheological fluid, in order to improve the machined surface flatness, high speed hobbing of ball end milling of permanent magnet yoke and the magnetic field distribution model, according to the magnetic field distribution of the permanent magnetic yoke, the width of the workpiece of the ball end milling cutter is 52 mm, the height is 55 mm and the air gap is wide is 2 mm, polishing groove along Ox and Oy axis respectively at a rate of VX and VY translational reciprocation, for hobbing continuous trajectory control points, in the workpiece coordinate system, $\sin \theta_p = \theta_p$, $\cos \theta_p = 1$, the relative trajectory equation in the tool coordinate system is set up:

$$\begin{cases} \dot{x}_1 = x_3 \\ \dot{x}_3 = f_\theta(X, t) + g_\theta(X, t)u(t) + d_\theta(t) \\ \dot{x}_2 = x_4 \\ \dot{x}_4 = f_x(X, t) + g_x(X, t)u(t) + d_x(t) \end{cases} \quad (5)$$

Wherein, $X = [\theta, x, \dot{\theta}, \dot{x}]^T$, $f_x(X, t)$, $f_\theta(X, t)$, $g_x(X, t)$, $g_\theta(X, t)$ denote the workpiece around the origin of the workpiece coordinate system O hob teeth and grooves and rotating axial feed, the axial feed speed balance control is taken based on the damping weighting method, feed rate cutting time = Axial travel / Axial feed rate. Based on the estimation of the edge distribution of workpiece, the multi parameter optimization of high speed hobbing process is obtained:

$$u_{eqx} = X_m U_m \lambda (-\hat{f}_x - \lambda_x \dot{e}_x - \alpha e_x + \ddot{x}) / (A_m \lambda g_x + B_m g_\theta) \quad (6)$$

Wherein, $X_m \in R^n$, $U_m \in R^m$ indicates the approaching stroke in the axial method, A_m and B_m is the ball milling cutter's rolling cut over travel and moment of inertia. Thus, the correlation calculation of the process parameters of the hobbing cutter is realized, which provides an accurate data base for the optimization of the process parameters.

Optimization of process parameter analytical model

In the above of ball end milling in high speed hobbing process parameter analysis and mathematical modeling on the basis of hobbing flatness parameter optimization parameters, an analytical model for decomposition of dry cutting hob cutting velocity and axial feed rate is proposed based on the smoothness of the combined correlation process, calculation of axial feed hobbing process hob speed and beyond stroke is taken, in determining the cutting edge of micro axial position angle, the axial position of micro cutting edge angle K as a variable to get the cutter contact area of cutting edge element combination of nonlinear equations:

$$\begin{cases} m\dot{V} = -mg \sin \theta - c_x q S_M + P \\ mV\dot{\theta} = -mg \cos \theta + c_y^\alpha q S_M \alpha + P(\alpha + \delta_\varphi) + m_R l_R \ddot{\delta}_\varphi \\ J_{z1} \ddot{\phi} = -c_{y1}^\alpha q S_M (x_g - x_T) \alpha - q S_M m_{dz} l_k^2 \dot{\phi} / V \\ -P(x_R - x_T) \delta_\varphi - m_R \dot{W}_{z1} l_R \delta_\varphi - m_R l_R \ddot{\delta}_\varphi (x_R - x_T) - J_R \ddot{\delta}_\varphi \end{cases} \quad (7)$$

The formula describes the longitudinal feed ball end milling surface smoothness constraint variables as φ 、 $\dot{\varphi}$ 、 α 、 θ 、 δ_φ . Based on the estimation of the edge distribution of workpiece, the multi parameter optimization of the high speed hobbing process is optimized as:

$$\begin{cases} \Delta \dot{\theta} = c_1 \Delta \alpha + c_2 \Delta \theta + c_3 \Delta \delta_\varphi + c_3'' \Delta \ddot{\delta}_\varphi + \bar{F}_{gr} \\ \Delta \ddot{\phi} + b_1 \Delta \dot{\phi} + b_2 \Delta \alpha + b_3 \Delta \delta_\varphi + b_3'' \Delta \ddot{\delta}_\varphi = \bar{M}_{gr} \\ \Delta \varphi = \Delta \theta + \Delta \alpha \end{cases} \quad (8)$$

Wherein, $c_1 = \frac{1}{mV} (57.3 c_y^\alpha q S_M + P)$, $c_2 = \frac{1}{V} g \sin \theta$, $c_3 = \frac{P}{mV}$, $b_1 = \frac{57.3}{J_{z1} V} m_{dz} q S_M l_k^2$, $b_2 = \frac{57.3}{J_{z1}} c_{y1}^\alpha q S_M (x_g - x_T)$, it is the skew angle of oblique plane, the approach stroke of vertical

direction, the cutting time and cutting parameters. While $d = 4, s_c = \frac{3}{2}$, with the multi step dynamic prediction of radial cutting depth, the smoothness constraint matrix $J(x)$ is obtained:

$$J(x) = \begin{pmatrix} \frac{\partial v_1(x)}{\partial x_1} & \frac{\partial v_1(x)}{\partial x_2} & \dots & \frac{\partial v_1(x)}{\partial x_n} \\ \frac{\partial v_2(x)}{\partial x_1} & \frac{\partial v_2(x)}{\partial x_2} & \dots & \frac{\partial v_2(x)}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial v_N(x)}{\partial x_1} & \frac{\partial v_N(x)}{\partial x_2} & \dots & \frac{\partial v_N(x)}{\partial x_n} \end{pmatrix} \quad (9)$$

Critical exponent is defined as $s_c = \frac{d-1}{2}$, the decomposition equilibrium solution is obtained (u_0, u_1) , the objective function of the combined quantitative decomposition of the cutting speed and the axial feed of the dry cutting hob is given:

$$F(x) = \sum_{q=1}^Q e_q^T e_q = \sum_{q=1}^Q \sum_{k=1}^m e_{kq}^2 = \sum_{i=1}^N v_i^2 \quad (10)$$

Under the maximum chip thickness, the key parameters affecting tool life is $u_n - \Delta u + |u|^p u = 0, (p > 4)$, Removal depth is measured at four adjacent points, material removal rate of workpiece surface is:

$$J(x) = \begin{pmatrix} \frac{\partial e_{11}}{\partial w_{11}} & \frac{\partial e_{11}}{\partial w_{12}} & \dots & \frac{\partial e_{11}}{\partial z_{mt}} \\ \frac{\partial e_{21}}{\partial w_{11}} & \frac{\partial e_{21}}{\partial w_{12}} & \dots & \frac{\partial e_{21}}{\partial z_{mt}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial e_{mQ}}{\partial w_{11}} & \frac{\partial e_{mQ}}{\partial w_{12}} & \dots & \frac{\partial e_{mQ}}{\partial z_{mt}} \end{pmatrix} \quad (11)$$

Because of the smoothness of the surface of the workpiece and the material removal rate of each point on the workpiece, the solution of the optimal value of the process parameters of the hobbing cutter is obtained:

$$R_\beta X = U \{E \in U / R | c(E, X) \leq 1 - \beta\} \quad (12)$$

The calculation of the axial feed rate and the cutting stroke of hobbing cutter are:

$$\begin{cases} a(H_{ac}) = 1 - \frac{H_{ac}}{\max(H_{ac}) + l} \\ \max(H_{ac}) = \log_2 k \end{cases} \quad (13)$$

In the strong magnetic induction gap position and magnetic yoke on both sides by three curves enclosed, a semi analytical model for the contact area of the machining of sculptured surfaces is established, the objective function of the process parameters is obtained by the decomposition of the cutting speed and the feed quantity:

$$x_{k+1} = x_k - [J^T(x_k)J(x_k) + \mu_k I]^{-1} J^T(x_k)v(x_k) \quad (14)$$

Wherein, the Y axis and the other axis into a right-handed, when μ_k is maximum, intersection tool sphere and the workpiece surface of the circular arc curve, finally get the flatness parameters recommended value calculation formula is described:

$$\min(f) = \sum_{i=1}^m \sum_{j=1}^n C_{ij} X_{ij} \quad (15)$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^n X_{ij} = a_i, i = 1, 2 \dots m \\ \sum_{i=1}^m X_{ij} = b_j, j = 1, 2 \dots n \\ X_{ij} \geq 0, i = 1, 2 \dots m, j = 1, 2 \dots n \end{cases} \quad (16)$$

In summary, the quantitative characteristics of cutting speed and axial feed decomposition process parameters is taken, parameter optimization is obtained, multi parameter optimization of high speed hobbing process is realized, the flatness of the high speed hobbing machining of ball milling cutter is improved.

Simulation analysis

In order to test the performance of this method in the optimization of the high speed hobbing of ball end milling cutter, the simulation experiment is carried out based on the model of CAD/CAM mechanical simulation software system, the experiment is taken based on the CAD/CAM mechanical simulation software system model, the experimental computer processor is Pentium (R) Dual-Core 3 GHz, memory of 2 GB, workpiece surface takes Z-map model, Ball end milling cutter radius is 6mm, normal cutting depth is 0.9mm, hob mounting angle is $180 / \pi$, the spindle speed is 1000rad/s, the axial feed rate is 10m/s, the installation interval of high-speed dry cutting gear is 0.25 mm, according to the above simulation environment and parameter setting, the simulation experiment of ball end milling cutter with high speed hobbing is given. The workpiece model is shown in Figure 2.

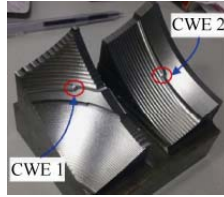


Figure 2 Test workpiece

Figure 2 gives the test pieces for the test object, process simulation is carried out, Powermill@ software is taken for process parameters acquisition and real-time analysis. Using the method of this paper to analyze and optimize the process parameters of ball end milling cutter with high speed hobbing, combined with the traditional method of performance analysis, get the hobbing tooth orientation error and tooth profile error results are shown in Figure 3.

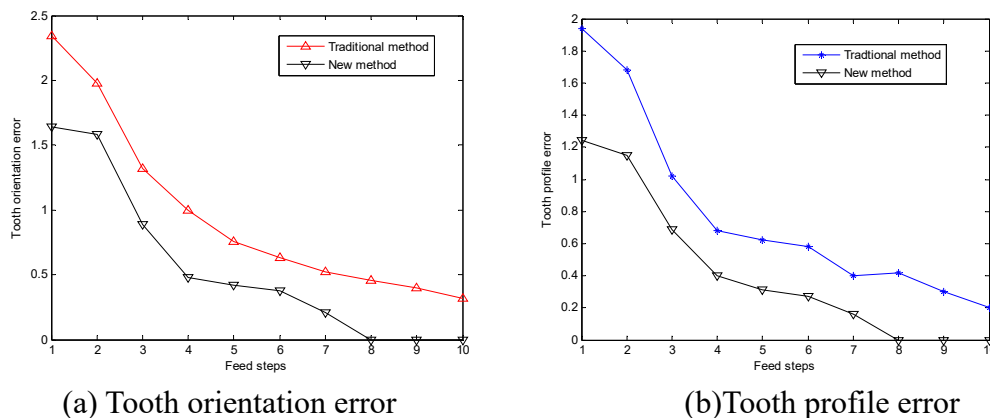


Figure 3 Performance comparison

According to the above results, it is concluded that the method of this paper can reduce the error of the high speed hobbing of the ball end milling cutter, and the surface roughness of the workpiece can quickly converge to zero, the flatness of workpiece is improved.

Conclusions

In this paper, roughness parameters analytical model is proposed based on quantitative analysis of the correlation between cutting speed and axial feed of dry cutting hob, the mathematical model of process parameter constraint parameters for high speed hobbing of ball end milling cutter is established by using the method of magnetorheological finishing, the quantitative characteristics of cutting speed and axial feed are decomposed, and the process parameters are modified, the process parameters are modified to get the recommended values of the process parameters. Simulation results show that the new model can reduce tooth profile error and tooth orientation error, and the surface roughness of the workpiece is measured to zero, it has high application value.

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