Prediction Model of Milling Surface Roughness Based on Regression Analysis

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Keywords: Surface roughness; High speed milling; Multiple regression analysis; Prediction model

Abstract. Based on the orthogonal test results, a prediction model for surface roughness of high-speed milling work-piece with ring cutter is established by regression analysis method, the regression equation and coefficient of the model are tested for significance. The model is highly significant for the prediction of surface roughness. The effect of milling amount on the surface roughness is studied through the analysis of the orthogonal test intuitionistic diagram. It provides a reliable basis for the rational selection of milling parameters.

Introduction

In NC machining, surface roughness is one of the important indexes for parts design and measurement of surface quality. Roughness affects the wear resistance, corrosion resistance and fatigue resistance of parts directly, and also affects the accuracy and quality of assembly. Because of the high speed cutting mechanism of surface roughness formation is not mature, there are many factors influencing the high-speed cutting surface roughness, the coupling between each other. Therefore, the influence of machining parameters on surface quality should be analyzed through cutting experiments, and the surface roughness model is established, which provides a reliable basis for reasonable selection of milling parameters.

Test Conditions for Cutting

On the DMU125P five axis milling machine, P1.2738 plastic die steel was cut by ring milling cutter with a diameter of 25mm, and oil mist cooling was applied. The surface roughness was measured by the surface roughness tester. The test results of each group were measured for 10 times, and the mean value was taken as the measurement result.

The orthogonal test method to test the number of main contradiction may be less exhausted by the orthogonal table to find the influencing factors of the comprehensive comparison and statistical analysis, this test mainly aims at cutting parameters : cutting speed(spindle speed), feed rate and milling depth, the radial feed, tool diameter and other conditions in the premise as the known conditions of the surface roughness, using four factors and four levels orthogonal table (second column empty column) based tab. Table 1 shows the level of each factor, and the result of the test is listed in table 2.

The Establishment of the Prediction Model of Surface Roughness.

In high speed end milling, cutting parameters mainly include cutting speed (or spindle speed), feed speed, axial cutting depth and radial cutting depth. On the premise of determining the characteristics of the machine tool and the geometric parameters of the tool, the exponential relation between the surface roughness and the cutting amount is established by the orthogonal regression test.

$$Ra = Ka_p^{b_1} n^{b_3} f_z^{b_3} a_e^{b_4} \tag{1}$$

Here, K —Correction factor determined by the processing material

b_1, b_2, b_3, b_4 — The index of each cutting amount

Table 1   Level of four factor and four level test factor

| level | test factor | | | |
	Milling depth $a_p[mm]$	Spindle speed n [r/min]	Feed per tooth f_z [mm/r]	Milling spacing $a_e[mm]$
1	0.05	6000	0.05	2
2	0.10	6500	0.10	4
3	0.15	7000	0.15	6
4	0.20	7500	0.20	8

Table 2 Orthogonal experimental design $L_{16}(4^5)$

No.	Milling depth $a_p[mm]$	Spindle speed n [r/min]	Feed per tooth f_z [mm/r]	Milling spacing $a_e[mm]$	surface roughness Ra（um）
1	0.05	6000	0.05	2	0.434
2	0.05	6500	0.10	4	0.536
3	0.05	7000	0.15	6	0.599
4	0.05	7500	0.20	8	0.682
5	0.10	6500	0.15	8	0.664
6	0.10	6000	0.20	6	0.743
7	0.10	7500	0.05	4	0.389
8	0.10	7000	0.10	2	0.378
9	0.15	7000	0.20	4	0.654
10	0.15	7500	0.15	2	0.610
11	0.15	6000	0.10	8	0.631
12	0.15	6500	0.05	6	0.434
13	0.20	7500	0.10	6	0.723
14	0.20	7000	0.05	8	0.535
15	0.20	6500	0.20	2	0.555
16	0.20	6000	0.15	4	0.667

Since the upper form is a nonlinear function, the logarithms of the upper two sides are taken at the same time so that they can be converted into linear functions. The simplification is as follows

$$\lg Ra = \lg K + b_1 \lg a_p + b_2 \lg n + b_3 \lg f_z + b_4 \lg a_e \tag{2}$$

Let $y = \lg Ra$, $x_1 = \lg a_p$, $x_2 = \lg n$, $x_3 = \lg f_z$, $x_4 = \lg a_e$, $b_0 = \lg K$,The Eq.2 is simplified as

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \tag{3}$$

The linear equation consists of four independent variables x_1, x_2, x_3, x_4, and the results of the test is y. In order to determine the specific value coefficient of b_0, b_1, b_2, b_3, b_4, 16 sets of experiments are contained using four factors and four levels of income, the corresponding variables of the i-st group test recorded as x_{i1}, x_{i2}, x_{i3}, x_{i4}, , the test results recorded as y_i, from 16 sets of test data with random variable error ε in the test can establish multiple linear regression equation:

$$\begin{cases} y_1 = \beta_0 + \beta_1 x_{11} + \beta_2 x_{12} + \beta_3 x_{13} + \beta_4 x_{14} + \varepsilon_1 \\ y_2 = \beta_0 + \beta_1 x_{21} + \beta_2 x_{22} + \beta_3 x_{13} + \beta_4 x_{14} + \varepsilon_2 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \\ y_{16} = \beta_0 + \beta_1 x_{161} + \beta_2 x_{162} + \beta_3 x_{163} + \beta_4 x_{164} + \varepsilon_{16} \end{cases} \tag{4}$$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{16} \end{bmatrix} \quad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_4 \end{bmatrix} \quad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_{16} \end{bmatrix} \quad X = \begin{bmatrix} 1 & x_{11} & x_{12} & x_{13} & x_{14} \\ 1 & x_{21} & x_{22} & x_{23} & x_{24} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{161} & x_{162} & x_{163} & x_{164} \end{bmatrix}$$

Let
Finishing type of Eq.4 :

$$Y = X\beta + \varepsilon \tag{5}$$

The least square estimation b_0, b_1, b_2, b_3, b_4, of the parameters $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ is set, respectively. The regression equation to determine the parameters is as follows:

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \tag{6}$$

In Eq.6, $\hat{y}$ is the statistical variable and b_0, b_1, b_2, b_3, b_4 is the regression coefficient, it can be calculated by calculation.

$$b = (X'X)^{-1} X'Y \tag{7}$$

The Establishment of Empirical Formula

In order to transform the model into a linear model, it is easy to establish prediction models for mathematical regression analysis. The natural logarithms of the test data tables can be obtained according to Eq.4 ~ Eq.7.

$$b = [0.7279 \ 0.0720 \ \text{-} \ 0.1967 \ 0.2903 \ 0.1912]' \tag{8}$$

The predictive regression equation based on the experimental data can be obtained by Eq.8.

$$\hat{y} = 0.7279 + 0.0720 x_1 - 0.1967 x_2 + 0.2903 x_3 + 0.1912 x_4$$

As a result, the calculation formula of the surface roughness value of the plastic die steel P1.2738 work-piece by using the milling cutter is as follows:

$$Ra = 10^{0.7279} a_p^{0.0720} n^{-0.2449} f_z^{0.2903} a_e^{0.1912} = 7.9524 a_p^{0.0720} n^{-0.1967} f_z^{0.2903} a^{0.1912}$$

The Significance Test of the Surface Roughness Model

The Saliency Test of the Regression Equation. In order to evaluate the fitting degree of the surface roughness prediction model, we need to make a significant test on this assumption. We usually decompose the sum of the total S_T deviations squared into the two parts : the sum of squares S_A and the sum of squares S_E. It is assumed $b_i=0 (i=1,2,3,4)$ that the statistics of the F test method are as follows:

$$F = \frac{S_A/p}{S_E/(n-p-1)} \sim F(p, n-p-1) \tag{9}$$

The number of the test groups is n, $n=16$; the number of variables is p, $p=4$. The calculation results are listed in table 3 .

Table 3 Regression analysis of variance

Source of variance	Sum of squares	Freedom	mean square	Ratio of F
regression S_A	0.2107	4	0.0527	
Surplus S_E	0.0444	11	0.0040	13.175>3.36
Total S_T	0.2552	15		

When the test level is α=0.05, $F(4,11)$=3.36 , because 13.175>3.36, the prediction model of the surface roughness value when the milling cutter is milling the surface is highly significant.

The Significance Test of Regression Coefficient. Regression test can verify the significance of regression equation. In order to investigate the influence of every independent variable on dependent variable, we need to test the significance of regression coefficient.

The application of the F test method, assuming b_i=0(i=1,2,3,4) that the statistics can be calculated in a pressing way:

$$F = \frac{b_i^2 \big/ c_{ii}}{S_E \big/ (n - p - 1)} \sim F(1, n - p - 1)$$

(10)

The number of the experimental groups is n; the number of the independent variables is p; c_{ii} is the element on the diagonal in the correlation matrix $c = (X'X)^{-1}$.

According to Eq.10, we know that: F_1=1.0504(a_p)；F_2=0.2001(n)；F_3=17.0801(f_z)；F_4=7.4098(a_e)

When the test level is α=0.05, $F(1,11)$=4.84 , because 17.0801 and 7.4098 are more than 3.23, the effect of the milling cutter on the surface roughness F_3, F_4 is highly significant. Through the above analysis, the plastic mold steel P1.2738, which was ranked as: feed speed f_z > spaced axial a_e > cutting depth a_p >cutting spindle speed n, spindle speed and cutting line spacing influence is consistent with the results obtained in the range of the law, the order of the other two factors influence is relatively small and slightly different in this method, it is also affected by other factors.

Conclusion

The prediction model of surface roughness is get through analyzing of the orthogonal test results. The regression equation and the coefficients were significant test . The results showed that the regression equation of surface roughness formula is significant; the surface roughness empirical formula can be achieved on the prediction of surface roughness, and provide the basis for the optimization of cutting parameters.

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