The Design of Cutting Force Calculation System for Orthogonal Experiment

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Abstract. Based on the design of orthogonal cutting tests, study the processing and the analysis method of orthogonal test data, program the module for solving regression equation, research on the calculation of cutting force curve, drawing and display issues based on the cutting test data which is stored cutting database. The software, developed by using the development plat of Visual C + +, can easily deal with orthogonal experiment data , draw and display the fitting equation of the test curve after user enters the relevant parameters according to needs intuitively, has laid the foundation for the draw curve , such as tool wear, tool life, the chip breaking test. Thus it is enriched the cutting data storage capabilities of the database, and data processing capabilities and test curve processing capabilities.

Introduction

At present, many countries have started to create cutting database which famously is the CUTDATA developed by the United States and the INFOS developed in Germany. Establishment of cutting database can bring considerable economic benefits for the users, cutting database allows processing costs decreased by 10% or more according to the CIRP survey of the economic benefits of cutting database. Usually the amount of cutting data in cutting database obtained by two ways: cutting testing and cutting manual. Proceed from the design of orthogonal cutting tests, study the calculation of the cutting force curve, drawing and display issues based on the cutting test data stored in the cutting database. Rao[1] research the influence of speed, feed, depth of cut on cutting force and surface roughness by Taguchi method. Patel [2]research the optimization of machining parameters, such as speed, feed, depth of cut, tool geometry, cutting environment, tool material, work material, etc. using the technique of Taguchi and ANOVA. Durai[3] uses the matlab genetic algorithm solver to do the optimization of cutting parameters by experimental design which use the Taguchi method. Badadhe[4] uses the Taguchi orthogonal array method to deal with the response from multi-variables in order to select the combination of optimum cutting parameters which will result in better surface finish. Kilickap[5] select glass fibre reinforced plastic composite as experimental material for investigation of cutting parameters (cutting speed, feed rate and tool geometry) affecting delamination in drilling operation by Taguchi method. Yang[6] uses the Taguchi method, which is a powerful tool to design optimization for quality, to find the optimal cutting parameters for turning operations, employs an orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to investigate the cutting characteristics of S45C steel bars using tungsten carbide cutting tools. Cicek[7] researches the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills by Taguchi method. Nalbant[8] uses the Taguchi method to find the optimal cutting parameters for surface roughness in turning, employs The orthogonal array, the signal-to-noise ratio, and analysis of variance to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. As a powerful tool to design optimization, orthogonal

experiment or Taguchi method usually is used to research the cutting parameters, a common tool as part of the cutting database is developed to compute the orthogonal experiment data automatically in this paper. This tool contains various utility functions such as fitting the data of experiment, displaying the fitting curve, saving the fitting formula in the database.

Orthogonal Regression Experimental Design

Cutting force F_f usually is affected by three factors(the depth of cut a_p , feed rate f and cutting speeds v_c) in the process of metal cutting. Based on the experimental results, can be calculated in terms of the depth of cut a_p , feed rate f and cutting speeds v_c . The empirical formula is as follows [9,10]:

$$F_{f} = C_{F_{f}} a_{p}^{x_{F_{f}}} f^{y_{F_{f}}} v_{c}^{z_{F_{f}}} .$$
(1)

Where F_f is cutting force, a_p is the depth of cut, f is feed rate, v_c is cutting speeds, the coefficients, x_{F_f} , y_{F_f} , z_{F_f} , C_{F_f} are constants obtained from curve fitting.

Logarithmic Eq.(1), then

$$\ln F_{f} = \ln C_{F_{f}} + x_{F_{f}} \ln a_{p} + y_{F_{f}} \ln f + z_{F_{f}} \ln v_{c}.$$
(2)
Let $y = \ln F_{f}, b_{0} = \ln C_{F_{f}}, b_{1} = x_{F_{f}}, b_{2} = y_{F_{f}}, b_{3} = z_{F_{f}},$ then

$$y = b_0 + b_1 \ln a_p + b_2 \ln f + b_3 \ln v_c.$$
(3)

The Coding of Levels of Factors. In order to scientifically design orthogonal regression test, process the test data using regression analysis, reduce the number of test, solve the regression equation, it is necessary to code the level of factors, establish the correspondence relationship between the level of factors and "coding" by the appropriate conversion to the value of factors, achieve the purpose of simplifying the calculation of the regression equation. Here, given the change interval of the depth of cut a_p is $[a_{p1}, a_{p2}]$, the change interval of feed rate f is $[f_1, f_2]$, the change interval of cutting speeds v_c is $[v_{c1}, v_{c2}]$, the equation is as follows:

$$x_{1} = \frac{2(\ln a_{p} - \ln a_{p2})}{\ln a_{p2} - \ln a_{p1}} + 1.$$
(4)

$$x_2 = \frac{2(\ln f - \ln f_2)}{\ln f_2 - \ln f_1} + 1.$$
(5)

$$x_{3} = \frac{2(\ln v_{c} - \ln v_{c2})}{\ln v_{c2} - \ln v_{c1}} + 1.$$
(6)

Thus after coding, the regression problem is transformed into the following:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3.$$
⁽⁷⁾

Determining the Experimental Plan. This experiment has three factors and two levels, using the tables of single(linear) orthogonal regression design, $L_8(2^7)$, table1 shows the experimental plan.

Table1. experimental plan							
factors Number	<i>x</i> ₁	<i>x</i> ₂	<i>x</i> ₃	<i>x</i> ₁ <i>x</i> ₂	<i>x</i> ₁ <i>x</i> ₃	<i>x</i> ₂ <i>x</i> ₃	$x_1 x_2 x_3$
1	1	1	1	1	1	1	1
2	1	1	-1	1	-1	-1	-1
3	1	-1	1	-1	1	-1	-1
4	1	-1	-1	-1	-1	1	1
5	-1	1	1	-1	-1	1	-1
6	-1	1	-1	-1	1	-1	1
7	-1	-1	1	1	-1	-1	1
8	-1	-1	-1	1	1	1	-1

Calculate Regression Coefficient. According to the experimental design eight tests will be need, if the test results are y_i ($i = 1, 2, L_{2}, 8$), then a regression mathematical model is as follows:

$$y_{i} = \beta_{0} + \beta_{1}x_{i1} + \beta_{2}x_{i2} + \beta_{3}x_{i3} + \varepsilon_{i} \quad (i = 1, 2, L, 8).$$
(8)
The structure matrix is

The structure matrix is

	1	x_{11}	<i>x</i> ₁₂	<i>x</i> ₁₃
X –	1	x_{21}	<i>x</i> ₂₂	<i>x</i> ₂₃
Λ -	Μ	Μ	Μ	Μ
	1	<i>x</i> ₈₁	<i>x</i> ₈₂	<i>x</i> ₈₃ _

Obtain the least squares estimation of the parameters β

$$b_j = \frac{1}{8} \sum_{i=1}^{8} x_{ij} y_i \ (j = 0, 1, 2, 3) .$$
⁽¹⁰⁾

Thus

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3.$$
⁽¹¹⁾

Significance Test. After otained regression equation, it is necessary to conduct the statistical tests, which can test the significant of the regression equation and coefficients.

Significance test of regression equations usually use F-Test, given the significance level, statistics can be calculated by the following equation.

$$F = \frac{\frac{4}{3} \times 8\sum_{j=1}^{3} b_{j}^{2}}{\sum_{i=1}^{8} y_{i}^{2} - \frac{1}{8} (\sum_{i=1}^{8} y_{i})^{2} - 8\sum_{j=1}^{3} b_{j}^{2}} > F_{\alpha}(3,4).$$
(12)

So, regression equation significant in the significant level α .

While significance test of regression coefficient use F-Test too, given the significance level α , statistics can be calculated by the following equation.

$$F_{j} = \frac{4 \times 8b_{j}^{2}}{\sum_{i=1}^{8} y_{i}^{2} - \frac{1}{8} (\sum_{i=1}^{8} y_{i})^{2} - 8 \sum_{j=1}^{3} b_{j}^{2}} > F_{\alpha}(1,4) \quad (j = 0,1,2,3).$$
(13)

So, regression coefficient significant in the significant level α .

Solve the Regression Equation. After substitution variable by Eq.(4)-Eq.(6), the regression equation is gain.

$$y = b_{0} + b_{1}x_{1} + b_{2}x_{2} + b_{3}x_{3}$$

$$= b_{0} + b_{1}\left(\frac{2(\ln a_{p} - \ln a_{p2})}{\ln a_{p2} - \ln a_{p1}} + 1\right)$$

$$+ b_{2}\left(\frac{2(\ln f - \ln f_{2})}{\ln f_{2} - \ln f_{1}} + 1\right) + b_{3}\left(\frac{2(\ln v_{c} - \ln v_{c2})}{\ln v_{c2} - \ln v_{c1}} + 1\right)$$
(14)

Software System Design

Using access database to store test data, VC6.0 as a development tool, the software system is developed on the development platform VC6.0, mainly to calculate the coefficient of the regression equation and draw fitting curve, based on the algorithm of drawing curve[11,12]. System diagram shown in Fig.1.



Fig.1 The system structure

The run result of the software shown in Fig.2-Fig.5.



Fig.2 The interface of the software

TestFile - DrawTest		
D 📽 🖬 X 🖻 🖻 🎒 😵		
	Pitting Test Data number Force Parameters 1 291.000000 0.500000 2 303.000000 3.500000 3 153.000000 0.200000 4 177.000000 0.500000 5 45.00000 70.000000 6 40.00000 110.000000 7 21.000000 0.000000 8 30.000000 0.000000	
	OK CANCEL	
Please Enter F1 Key to Help		

Fig.3 The experimental Data

🛃 TestFile - DrawTest			
File Edit View Operation Melp			
	Draw Setting	×	
	Y[kN] X(mm)	CuttingForce -	
	Parameter(mm/r)	FeedRate 💌	
	CuttingSpeed(m/min)	85	
	<u> </u>		
Please Enter F1 Key to Help			

Fig4 Setting parameter



Fig.5 Draw curve

Conclusions

With the program designed and developed in this paper, regression orthogonal experimental data can be easily calculated and can carry out the drawing and display of the fitted curve, making the results more intuitive, lay the foundation for drawing tool wear curve, tool life curve, chip breaking test curve. Thus it is enriched the cutting data storage capabilities of the database, and data processing capabilities and test curve processing capabilities.

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