International Journal of Hybrid Information Technology
Vol.8, No.8 (2015), pp.153-160
http://dx.doi.org/10.14257/ijhit.2015.8.8.14

Different Impact on the Stability Limits Caused by the Selection of Milling Force Coefficient under the State of High-Speed Milling

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Abstract

To analyze the influence caused by different cutting parameters on the cutting force and get the coefficient of milling force obtained under the state of high-speed milling, the high-speed milling test was conducted through carbide cutting tools milling the titanium impeller under the state of high speed. Firstly, the influence on the three target force, caused by every parameter, was analyzed through orthogonal experiment. And then, the milling force coefficient got from two different formula was compared in this article. Calculated and experimental results show that the milling force coefficient got by means of the empirical formula reduced flutter stability limit, however, he milling force coefficient got by means of parsing not. At last, it also provide data to support to avoid the chatter occurred between tool and workpiece and select the processing parameters optimally.

Keywords: *Stability limit, Coefficient of milling force, High-speed cutting, Titanium*

1. Introduction

High speed milling is one of the important basic technology to obtain high-precision machining difficult surfaces，compared with the ordinary milling, in which milling force is relatively low, and by which in ensuring the processing accuracy we can obtain higher material removal rate [1]. Related to product quality and machining efficiency, the optimization of machining parameters is one of the main methods and also the purpose of study on high speed milling technology. Milling force coefficient plays an indispensable role in the process of study on the mechanism of high speed milling stability, and the milling force coefficient is obtained through the test and calculation of milling force needed in all directions. Therefore, the milling force coefficient under the state of high speed cutting could be obtained through cutting experiments based on obtaining the cutting force .In scientific research, to do in-depth research on a certain or some factors, some useful and rigorous data should be obtained by experiment to analysis them. Orthogonal test method is a method that could scientifically arrange and analysis the multi factor test [2]. Orthogonal test method is a engineering design method [3]. Through the statistical analysis on the experimental results of a few experimental scheme of the orthogonal test, we can launch more excellent scheme, but also through the further analysis of the experimental results, obtained more information beyond the experimental results. For example, an important influence degree of each factor on the experimental results and the influence tendency of the experimental results *etc*. [3] The multi factors orthogonal test is the effective tool to explore the influence degree of cutting parameters on cutting force and it also plays an important role on the optimization of the experimental design. By the use of milling force obtained by the cutting parameters, we can infer the milling force coefficient and then find a set of reasonable program. To provide further experimental and data support to avoid Chatter appearing in the System of tool work piece.

ISSN: 1738-9968 IJHIT

2. The Design of the Experimental Scheme

2.1. The Experimental Equipment and Parameters

Experimental machine:Mikron HSM600.Five axis NC high speed machining centers.CNC system:HeidenhoinNC530.The feed speed:40m/min. The maximum spindle speed:42000r/min.Positioning accuracy:0.08mm.Repeat positioning accuracy:0.05mmTest system:KISTLER dynamometer.Model:9257B.multi-channel charge amplifier model:5070A.PC-CARD-DAS16/16 Data display instrument.

2.2. The Experimental Tools and Materials

Experimental material:titanium alloy, the cutter adopts a ball hard alloy 30F milling cutter, The blade is 13mm long, 32mm long blade knife, number 3, radius 5mm, full-length 114.6mm.The selected tool material has a good toughness and thermal shock resistance and can be used for high speed cutting. Machining parts for the impeller blade engine (the shape shown in Figure 2).

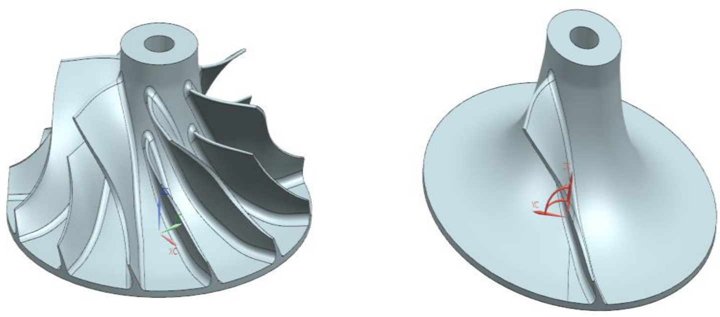

Figure 2. The Impeller and Vane in Three-dimensional State

2.3. The Experimental Scheme

In the process of high speed cutting, the cutting parameters，such as the principal axis speed (V_c/m.min^{-1}), the cutting depth (a_p/mm), feed rate (f_z/mm^{-1}), are the main factors that influence the cutting force and the cutting force coefficient. In this experiment, the existing machining program had been used and in the way of Changing the cutting parameters machine the parts surface. Milling scheme is that: first analyze the milling force coefficient under the state of high speed cutting by using the orthogonal test of three factors and three levels, and then obtain the analyzed optimization of cutting parameters from orthogonal table, the last explore the most significant effect on the cutting parameters of milling force in the high-speed cutting condition. Experiment factors and levels are shown in the Table 1. Experimental data and the numerical of milling force in each direction are recorded in the Table 2.

Table 1. Experimental Factors and Standard

level	a_p/mm	v_c/m.min^{-1}	fz/mm.tooth^{-1}
N1	0.7	700	0.06
N2	1.0	750	0.09
N3	1.3	800	0.12

Table 2. Test Program and Measuring Results of Orthogonal Cutting

Experimental number	(A)a_p mm	(B)Vc $m.min^{-1}$	(C)fz/mm. $tooth^{-1}$	Fx/N	Fy/N	Fz/N
N1	0.7（1)	700（1)	0.06（1)	626.96	514.52	1102.74
N2	0.7（1)	750（2)	0.09（2)	582.11	493.85	1124.33
N3	0.7（1)	800（3)	0.12（3)	909.32	438.47	1154.92
N4	1.0（2)	700（1)	0.09（2)	815.93	562.73	846.79
N5	1.0（2)	750（2)	0.12（3)	851.37	484.99	1065.42
N6	1.0（2)	800（3)	0.06（1)	493.21	520.44	721.38
N7	1.3（3)	700（1)	0.12（3)	630.25	628.79	1179.63
N8	1.3（3)	750（2)	0.06（1)	568.63	562.55	866.03
N9	1.3（3)	800（3)	0.09（2)	400.54	496.28	650.92

3. The Result Analysis

3.1. Analysis of the Process of Obtained Cutting Force Data

For the measured data, because the milling force is reflected by the data analyzer in the form of voltage, and in the same cutting parameters, there are hundreds of group measurement data. Therefore in the process of dealing with the experimental data, we should transform the form of voltage into the the form of milling force. Select 15 the maximum absolute value of peak value in the stable stage of milling process, will the calculation of the the average absolute value as the experimental result. Processing results are showed in Table 3.

Table 3. Results in Every Interval Got from the Certain Milling Force Parameters

Treatment interval	results	Treatment interval	results
1	659.04	9	617.20
2	649.15	10	629.54
3	650.01	11	624.37
4	646.29	12	600.40
5	643.73	13	593.65
6	644.84	14	600.39
7	642.17	15	585.39
8	626.14		

3.2. The Influence on, of Various Factors, on Milling Force and the Optimal Scheme

Judge the results of the analysis by using the comprehensive balance method, analysis of orthogonal test results was shown in the following Table 1.

Table 4. Analysis of Experimental Results

Index		A	B	C
The milling force in direction of X :F_x	K_1	2036.23	2073.14	1688.80
	K_2	2160.51	2002.11	1798.58
	K_3	1599.42	1803.07	2390.94
	k_1	706.13	691.05	562.93
	k_2	720.17	667.37	599.53
	k_3	533.14	601.023	796.98
	Range	561. 09	270. 07	702. 14
	Factors(main→ secondary)	C	A	B
	Optimal solution	C_1	A_3	B_3
The milling force in direction of Y:F_Y	K_1	1446.84	1706.04	1597.51
	K_2	1568.16	1541.39	1552.86
	K_3	1687.62	1455.19	1552.25
	k_1	482.28	568.68	532.50
	k_2	522.72	513.79	517.62
	k_3	562.54	485.06	517.42
	Range	240. 78	250. 85	45. 26
	Factors(main→ secondary)	B	A	C
	Optimal solution	B_3	A_1	C_3
The milling force in direction of Z:F_Z	K_1	3381.99	3129.16	2690.15
	K_2	2633.59	3055.78	4336.65
	K_3	2696. 58	1043. 05	3399. 97
	k_1	1127.33	252.72	896.72
	k_2	877.86	1018.59	1445.55
	k_3	898.86	842.41	1133.32
	Range	748.40	601.94	1646.50
	Factors(main→ secondary)	C	A	B
	Optimal solution	C_1	A_2	B_3

According to the above analysis result, each factor and each index trend graph can be made.shown in Figure 3-Figure 5.

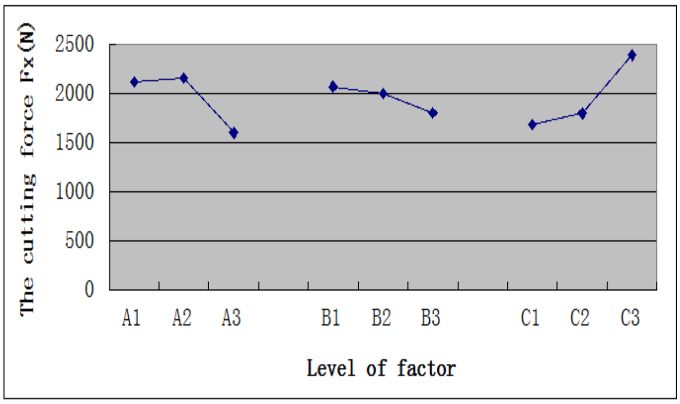

Figure 3. Effect Generated from each Cutting Force on F_x

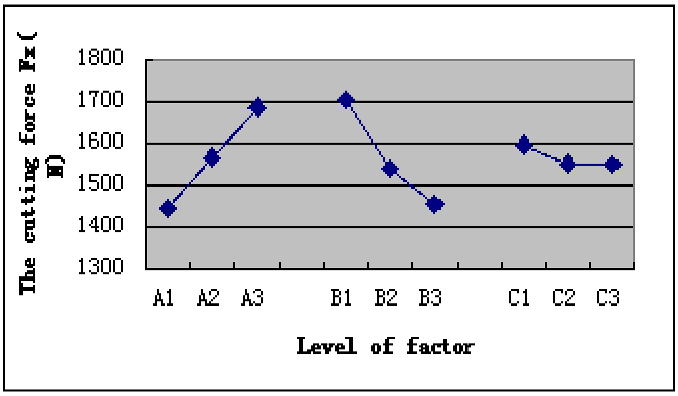

Figure 4. Effect Generated from each Cutting Force on F_y

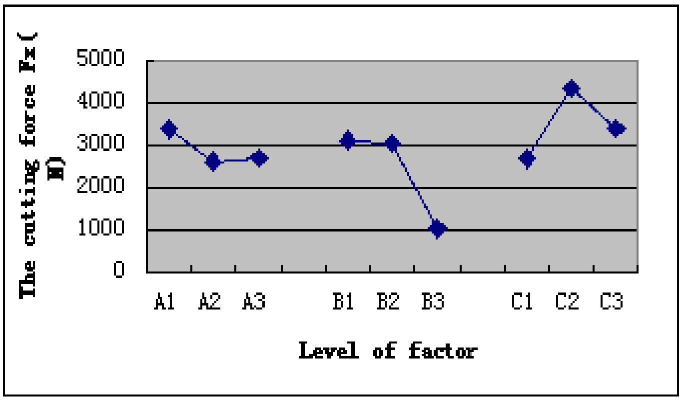

Figure 5. Effect Generated from each Cutting Force on F_z

From Figure 3-Figure 5 can be seen that: for factor A, taking A_3 is better in two index *Fx* and F_z. For F_y, A_2 is better. In the trend Figure 4, as can be seen from the range of A for the secondary factors, influencing factor is smaller, so it is considered from the whole selection A_3.For factor B ,from the three trend figures, we can see that B_3 is the best level for three indexes, so it is the selection. In the same way, C_1 is also the best level for three indexes, so it is the selection. Based on the analysis above, the optimal scheme is $A_2B_3C_1$, however, there is no this combination, so the scheme $A_3B_3C_2$ is selected as the final solution.

3.3. The Acquisition and Optimal Selective Way of Milling Force Coefficient

According to the method in the literature [5], the instantaneous cutting force formula can be obtained as shown in formula1.

$$\begin{cases} Fx = \left\{ \frac{N_{ac}}{8\pi}\left[K_{tc}\cos 2\phi - K_{rc}\left(2\phi - \sin 2\phi\right)\right] + \frac{Na}{2\pi}\left(-K_{te}\sin\phi + K_{re}\cos\phi\right)\right\}_{\phi st}^{\phi ex} \\ Fy = \left\{ \frac{N_{ac}}{8\pi}\left[K_{rc}\cos 2\phi + K_{tc}\left(2\phi - \sin 2\phi\right)\right] - \frac{Na}{2\pi}\left(K_{te}\cos\phi + K_{re}\sin\phi\right)\right\}_{\phi st}^{\phi ex} \\ Fz = \frac{Na}{2\pi}\left[-K_{ac}\cos\phi + K_{ae}\phi\right]_{\phi st}^{\phi ex} \end{cases} \quad (1)$$

N is the number of tool teeth,*N*=3 in this experiment. ϕ_{ex}, ϕ_{st} are the exit cutting angle and entrance cutting angle. a is the cutting depth, c is the amount of feed per tooth. in this experiment $\phi_{st} = 0$ but $\phi_{ex} \neq 0$ .The selection of a is consistent with the data showed in Table 2 and the selection of c and ϕ_{ex} are consistent with the data showed in Table 5.

Table 5. Data Chose in Calculating Coefficient of Milling Force

Number	*C*	Φ_{ex}
N1	0.06	0.72
N2	0.09	0.36
N3	0.12	0.51
N4	0.09	0.51
N5	0.12	0.72
N6	0.06	0.36
N7	0.12	0.72
N8	0.06	0.36
N9	0.09	0.51

According to the formula (1), we can get the result :Ktc=6.0385 × 104, Krc=6.4569×104, Kte=-4.0956×104. In the same empirical data, however, according to the experience model formula of milling force ,we can get the result $K_t = 5.779 \times 10^4$.

3.4. Effects of Different Cutting Force Coefficient on the Stability Limit

Altintas Classical high-speed machining stability limit formula

$$a_{\lim} = -\frac{2\Lambda_R \pi}{Nk_t}(1 + \chi^2) \quad (2)$$

$$\chi = \frac{\lambda_I}{\lambda_R} = \frac{\sin \ w_c t}{1 - \cos \ w_c t} \tag{3}$$

W_c is the chatter frequency, t is the cutting time .According to the formula 2, choosing the milling force coefficient got by using the empirical model formula, in the same milling parameters, would be prone to the phenomenon of flutter, and even seriously affect the quality of the workpiece surface. To prove this conclusion, the experiment were performed in the circumstances that the spindle speed was 2.2×10^4rpm .According to the formula 2, the cutting depth a_{lim}=0.05mm and the quality of workpiece in this condition was shown in the figure 6.However according to the empirical formula, the cutting depth a_{lim}=0.08mm and the quality of workpiece in this condition was shown in the Figure 7.

Figure 9. Quality on the Surface of Workpiece When a_{lim}=0.05mm

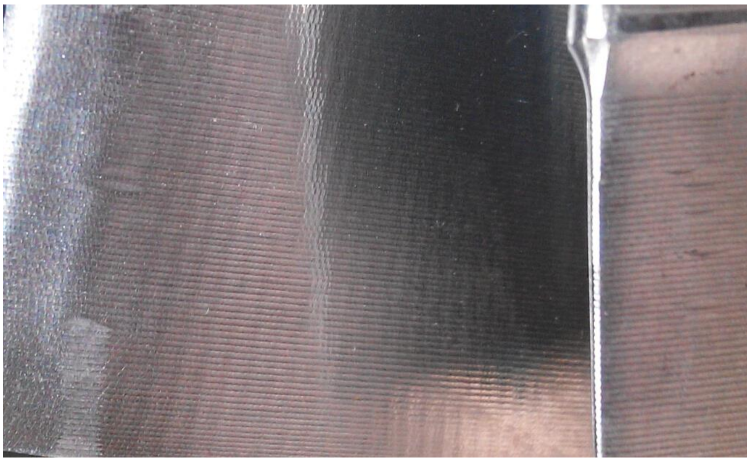

Figure 10. Quality on the Surface of Workpiece When a_{lim}=0.08mm

By comparison, the cutting force coefficients obtained using formula are more accurate relative to the previous empirical formulas to obtain and the way is prone to the optimal selection of the machining parameters in machining process.

4. Conclusion

To research the milling force coefficient in the condition of high speed machining, the experiment was be designed.

(1) By the range analysis of orthogonal test data and the use of integrated balance method, we got the influencing order of each factor to cutting force on each direction. The results of orthogonal test done on machining parameters, such as cutting depth, spindle speed, the amount of feed, show the influencing order of each cutting parameters on cutting force in the station of high speed cutting is that in X and Y two directions, the amount of feed, cutting depth, spindle speed, in the Y direction is cutting depth, spindle speed, amount of feed.

(2) In the orthogonal test, two different cutting force coefficient were obtained by the analysis of orthogonal test data and two different cutting force formula. Because the correction coefficient and intrinsic error exist in the traditional experience formula of milling force. The milling force coefficient obtained by the use of traditional empirical formula would lead to large error when used in the process of selection of machining parameters, however, it would be very accurate when obtained by the use of the analytical method of milling force formula.

(3) The milling force coefficient obtained from the experiment also provide data support and the the optimized scheme selection for the further research on dynamic stability of cutting in the station of high speed machining between the tool and workpiece system and other problem of stability.

Acknowledgements

This work was supported by the national natural Science Found (Project No 51075128 and 51405138) and the national Science Foundation of Heilongjiang Province (Project No QC2012C029).

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