The Optimization of Machining Process Parameters for Factors Influencing KDP Crystal Surface Quality

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Abstract. In order to improve the surface quality of KDP crystals, the factors of process parameters on surface quality of KDP crystal was researched，the KDP crystal was machined by quadratic regression rotation optimization method and single point diamond turning technology.On-line monitoring the surface roughness and waviness of KDP crystal,using multi-factor interaction to get analysis rules.Finally, partial least squares method and lingo software were used to obtain optimal processing program,the tool radius of 9mm,speed of 800 r / min,feed rate of 9.184μm / r,turning back of 21μm.With these process parameters to machine KDP crystal ,surface waviness can be achieved0.020μm, and surface roughnesscan be achieved 0.017μm, has important guiding significancefor machining large-size and high quality KDP crystals.

1 Introduction

Large diameter KDP crystal is the only optical crystal materials [1]can be used for inertial confinement fusion system of high power laser drive Pockels box. In high power laser system, the technical requirements of KDP crystal is low surface roughness and surface waviness and high precision surface shape quality [2, 3].At present ,only a very few countriessuch as the USA and Japan can process the high requirements of products, KDP crystals industrialization of our country has a great gap with developed countries. Using orthogonal experimental method and extreme difference analysis for KDP crystal machining process parameters optimization research, got the KDP crystal surface roughness value of 0.028 um,and the surface waviness a value of 0.033um [3], in the end,the experiment was optimized by using quadratic general rotary combination method and multi-factor analysis the main factors influencing the surface quality of KDP crystal. Carried out in the process of KDP crystal SPDT cutting surface roughness and waviness of the optimization and control technology research, to raise the level of our country to satisfy the requirements of large diameter KDP crystaland has practical implications for breakingthrough the foreign technology blockade.

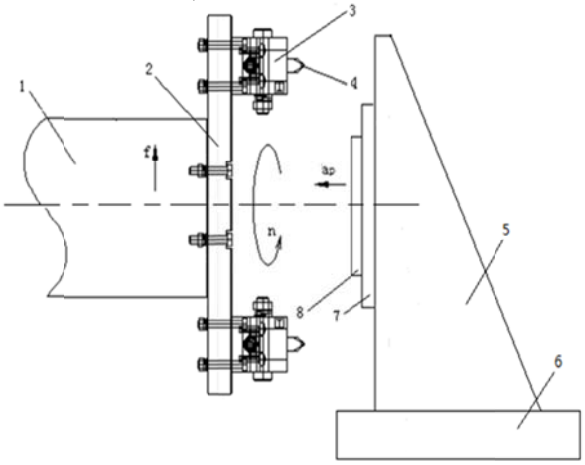
2 Organization of the Text

2.1. The SPDT principle method and the experimental results

KDP crystal is a good kind of the nonlinear optical crystal. SPDT is an ideal method [4]for KDP crystal machining, through fly knife to remove parts surface thin layer materials,access to nanoscale surface quality and shape accuracy, no need to polishing, can effectively improve the laser damage threshold of crystal components [5, 6].

The experiment used ultra-precision horizontal machine tool as the platform, the SPDT technology of KDP crystals for machined part cutting experiment, specimen is 180 mm * 180 mm * 12 mm, experimental tool for diamond circular arc, the arc radius of 5 mm,6 mm,7 mm,8 mm and 9 mm, cutting tool rake Angle are all 0 °, after cutting tool Angle are all 7 °, with no chip breaker groove, processing principle is shown in figure 1.

The design of Quadratic general rotary combination, test of N is distributed in three radius of the sphere of unequal [7].As the independent experimentvariable m is the cutting tool radius of circular arc, spindle speed, feed, turning back for four factors, respectively signified Z_1, Z_2, Z_3, Z_4. Based on the quadratic general rotary combination design parameter table, take N = 31 [8]. When carried on the quadratic general rotary combination design, first ensure the upper and lower levels of each factor Z_{2j} and Z_{1j}, and then calculate the zero Z_{0j} and change spacing Δ_j, j = 1, 2,... , m. Hand down the factors in the actual experiment Z_m through coding formula into coding factors X_m (m = 1, 2, 3, 4), there will be units of natural variables Z_j had became no unit specification X_j, draw up the factor levels coding value table, do the experiments of each set of data and test them, gathered 18 group of measurement results, is shown in table 1.



1. Spindle 2.Cutter3.Cutting Angle Adjustment Device
4. Radius Forming Tool 5.Holder 6.Stage
7. Vacuum Sucker 8.KDPCrystal

Fig. 1 The Single Point Diamond Horizontal Fly Cutting Schematic of KDP Crystal

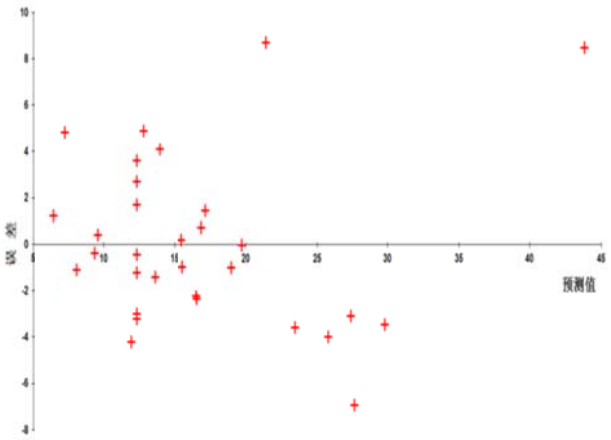


Fig.2 The Residual Scatter Plot of Waviness

Tab. 1 Quadratic Regression Rotation Experimental Design and Test Result Data

Serial number	X_1	X_2	X_3	X_4	Z_1 mm	Z_2 r/min	Z_3 μm /r	Z_4 μm	Roughness nm	Waviness nm
1	1	1	1	1	8	625	13	16	33	7.7
2	1	1	1	-1	8	625	13	6	28	17.7
3	1	1	-1	1	8	625	5	16	19	14.3
4	1	1	-1	-1	8	625	5	6	21	19.7
5	1	-1	1	1	8	275	13	16	30	7
6	1	-1	1	-1	8	275	13	6	32	12.2
7	1	-1	-1	1	8	275	5	16	22	24.3
8	1	-1	-1	-1	8	275	5	6	20	26.3
9	-1	1	1	1	6	625	13	16	62	18.6
10	-1	1	1	-1	6	625	13	6	59	17.6
11	-1	1	-1	1	6	625	5	16	18	18
12	-1	1	-1	-1	6	625	5	6	19	14.6
13	-1	-1	1	1	6	275	13	16	55	14.2
14	-1	-1	1	-1	6	275	13	6	53	15.7
15	-1	-1	-1	1	6	275	5	16	21	20.7
16	-1	-1	-1	-1	6	275	5	6	20	19.8
17	2	0	0	0	9	450	9	11	19	10
18	-2	0	0	0	5	450	9	11	37	18
19	0	2	0	0	7	800	9	11	34	7.7
20	0	-2	0	0	7	100	9	11	39	30.1
21	0	0	2	0	7	450	17	11	104	21.8
22	0	0	-2	0	7	450	1	11	17	52.3
23	0	0	0	2	7	450	9	21	35	12.1
24	0	0	0	-2	7	450	9	1	35	9

25	0	0	0	0	7	450	9	11	38	9.1
26	0	0	0	0	7	450	9	11	38	9.3
27	0	0	0	0	7	450	9	11	44	15
28	0	0	0	0	7	450	9	11	45	11.1
29	0	0	0	0	7	450	9	11	46	14
30	0	0	0	0	7	450	9	11	36	15.9
31	0	0	0	0	7	450	9	11	48	11.9

2.2.TheAnalysis of the influential factors of KDP crystal surface waviness

The establishment and analysis of quadratic regression mathematical model for surface waviness. Based on regression model, regression coefficients and the striation values in table 1, through the DPS data processing system, obtained the regression equation ofsurface waviness.

Y_1=12.3286-1.0833X_1-2.3667X_2-4.5X_3-0.525X_4-0.1405$X_1 \cdot X_1$+1.0845$X_2 \cdot X_2$+5.622$X_3 \cdot X_3$-1.003$X_4 \cdot X_4$-0.55$X_1 \cdot X_2$-2.0625$X_1 \cdot X_3$-1.65$X_1 \cdot X_4$+2.3125$X_2 \cdot X_3$-0.2$X_2 \cdot X_4$ -0.7875$X_3 \cdot X_4$(1)

In the SPSS nonlinear regression analysis results, founded that 95% of confidence interval which in the regression coefficients containing no zero, showed that the estimate value of 15 parameters is statistically significant. On the basis of the results of variance analysis for inspection formula(1), to analyze its reliability. Waviness value data of variance analysis are shown in table 2.

Tab.2 The Variance Analysis Table Based on Experiment Results Waviness

	Sum of Squares	Degrees of Freedom	Mean Square	Partial Correlation	Value of p
Linear Regression	1869.8192	14	133.5585	F_2=5.43540	0.0014
Surplus Variable	393.1518	16	24.5720		
Lack of fit	349.1775	10	34.9178	F_1=4.76430	0.0029
Average error	43.9743	6	7.3290		
Summation	2262.9710	30			

Lack of fit and regression equation Test. From table 2, $F_1 > F_{0.05\,(10,\,6)} = 4.06$, $F_2 > F_{0.01\,(14,16)} = 3.7$, $F_3 = 18.2233 > F_{0.01\,(14,\,6)} = 4.46$, all reached very significant level, indicating that arc radius, speed, feed,and turning back four dependent variable has significant impact on the surface waviness of KDP crystals.

According to the sum of squares regression models available in table 2establishedthe determination coefficient $R^2 = 0.8263$, shown that the variable effects on surface waviness is 82.63%, meaned the experimental sample points fitting effect is of good and high reliability.

Durbin-Watson Test. Itwas carried out on the regression equation,obtained DW = 2.2392, proving surface waviness model residual error did not exist autocorrelation, obeied the normal distribution. Figure 2 is the waviness regression plot of surface waviness, the scatter did not show obvious regularity, showed that the regression equation is reliable.

Analysize the influence factors of KDP crystal surface waviness. For the surface waviness,the influence degree of order is feeding quadratic coefficient, feeding, speed, the interaction of speed and feeding, other items at the 0.1 level was not significant. Waviness in the regression equation of the interaction of the rotation and feed X_2X_3 has significant effects on the dependent variable. Using multiple factor method and MATLAB software to analyze the influence rule, as shown in figure 3. In the Figure 3, X, Y axis level expressing speed and feed value respectively, and the Z axis is surface waviness value.

The figure 3 shows that,when feeding increases, speed increases, the surface waviness larger,Speed decreases, and surface waviness smaller. When reducing feeding,speed increases, the surface waviness gets smaller, Speed decreases, and surface wavinesslarger. When the rotating speed at 660 r/min to 800 r/min, and feeding in 7.4 um/r to 10.6 um/r changes, smaller values

changing of the surface waviness. By using lingo software to optimize the model, obtained arc radius as 9 mm,speed as 633 r/min,feeding 11.8 um/r,turning back as 21 um.

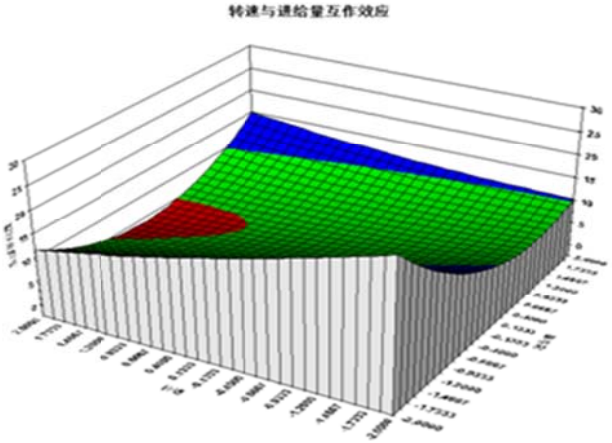
2.3.The Analysis of the influential factorsof KDP crystal surface

Research on the effects through the same rough forthe surface roughnessof KDP crystal , first established a thematical model of surface roughness of quadratic regression.

$$Y_2=42.1429-5.75X_1-0.1667X_2+15.25X_3+0.3333X_4-4.8691X_1\cdot X_1-2.7441X_2\cdot X_2+3.256X_3\cdot X_3-3.1191X_4\cdot X_4-0.75X_1\cdot X_2-6.875X_1\cdot X_3-0.125X_1\cdot X_4+1.125X_2\cdot X_3+0.125X_2\cdot X_4+0.5X_3\cdot X_4 \quad (2)$$

Then tested and analysed the coefficient of regression equation and found that the interaction effect of the cutting tool arc radius and feed had big influence on surface roughness of KDP crystals. Finally, using the multi-factor analysis as shown in figure 4, it is concluded that,when the feed is larger: tool arc radius , the surface roughness value decreases,Tool arc radiusdecreases, the surface roughness valueincreases. When reducing feeding ,tool arc radius increases, the surface roughness value become larger,Tool arc radius, roughness value decreases, and the feeding and cutting tool arc radius are the most hours roughness values reach the global minimum. The interaction relationship is in large feeding, the cutting tool arc radius increases, the surface roughness value is smaller, with the decrease of feeding, cutting tool arc radius increases, the surface roughness value become larger [9].

Finally, optimizating to get the optimal parameter combination, tool arc radius as 5 mm,the speed of 800 r/min,feeding as 1 um/r,turning back as 21um .



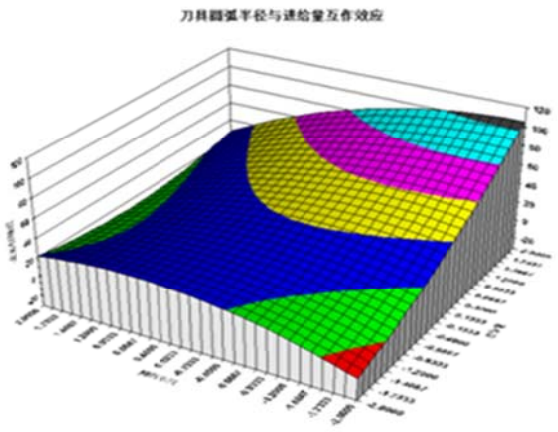


Fig.3 The Combined Effect of Speed and Feed Fig.4 The Combined Effect of Tool Arc on Surface Waviness Radius and Feed on Surface Roughness

At last,partial least squares method and lingo software were used to obtain optimal processing program， the tool radius of 9mm; speed of 800 r / min; feed rate of 9.184 μ m / r; turning back of 21 μ m.With these process parameters to machine KDP crystal,make a series of process test,surface waviness can be achieved 0.020 μ m, and surface roughness can be achieved 0.017 μ m.

3 Summary

(1) Through the regression equation fitting test, significant loss inspection, determination coefficient R2, Durbin -Watson statistics test,significance test of regression coefficients,found surface waviness and roughness of the quadratic regression model Y1 and Y2 is reliable.

(2) Using factors analysis method acquired when the rotating speedwithin the range of 660 ~ 800 r/min, feeding between 7.4 ~ 10.6 um/r changes, the surface waviness is in smaller values. When feeding increases, tool arc radius increases, the surface roughness value decreases,with the decrease of feeding, cutting tool arc radius increases, the surface roughness value become large.

(3) Draw a conclusion by nonlinear method and lingo software optimize method,when the cutting tool radius of circular arc as 9 mm,the speed as 633 r/min,feeding as 11.8 um/r,turning back as 21 um, surface waviness value reach the minimum.When the cutting tool radius of circular arc as 5 mm,the speed as800 r/min,feeding as 1 um/r; turning back to 21um , surface roughness valuereach

the minimum.

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