The Application of the Taguchi Method in the Optimal Combination of the Parameters Design of the Spindle System

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Abstract. The paper combines with the application case in the field of parameter design of main spindle system. Firstly, the relevant parameters that affect the stability of the main spindle system transmission are determined, and then the Taguchi method and Minitab software are used to implement the orthogonal test for multiple factors. According to the experimental data, the analysis of signal to noise ratio and the analysis of variance are performed. Finally, the optimal combination of design parameters with different levels of spindle system is obtained. Case analysis shows that the Taguchi method has a significant effect on improving the transmission stability of the spindle system.

Keywords.the transmission stability of spindle system; Taguchi method; parameter design; Minitab; signal to noise ratio

1 Introduction

The Taguchi method was founded by Dr. Genichi Taguchi of Japan; its central content is regarded as Japan's "national treasure". The Taguchi method is widely used in automobile industry, mechanical manufacturing industry, electronic industry and other fields. In our country, colleges and the national defense science and technology industry have many theoretical researches on Taguchi method. Taguchi method is widely used in automobile manufacturing industry in the foreign countries, such as the U.S. automaker Ford and GM that apply the Taguchi method into practice, the cost of the two companies can be reduced, and the vehicle performance is improved, so Taguchi method gains remarkable achievements. In this paper, the thought of out-line quality control of Taguchi method is applied to the design stage of the spindle system.

2 Taguchi method

2.1 Basic thought

It is different from the traditional definition of quality; Dr. Genichi Taguchi defined the product quality as this [1]: The characteristic of avoiding causing losses to the society after the products get out of factories, the quality of products can be quantified by "quality loss". In order to improve the anti-interference ability of the product itself, Taguchi method can make the function and the property of products no insensitivity to the cause of deviation by adjusting the design parameters. In order to quantitatively describe the loss of product quality, Taguchi proposed the concept of "quality loss function [2]", and he used the signal-to-noise ratio to measure the stable level of designed parameters.

2.2 Parameter design

It means that the parameter design is carried out after the structure of the system is determined; the best combination of all parameters is found by using orthogonal experiment and the method of variance analysis. The so-called best combination is that the signal to noise ratio is introduced as evaluation indicator, the reliability, anti-interference, stability and uniform of products become stronger through the design of the stability.

2.3 Signal to noise ratio

In order to quantify the quality characteristics of the selected equipment, the concept of signal to noise ratio is introduced. Signal to noise ratios have three forms: The signal-to-noise ratio for the characteristic of nominal is best [3], the signal to noise ratio for the characteristic of smaller is best [4], the signal-to-noise ratio for the characteristic of larger is best.

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3 Instance verification

The paper researches on the problem which occurred when a new type CNC machine tool is processing parts in the MX Company, the transmission of the main spindle system is not stable, and the parts' defective rate is also increased.

3.1 Determine impact factors

The experts of the product design department, production operation department and equipment management department determined the main factors affecting the stability of the main spindle system by using the brainstorming method.

3.1.1 Controllable factors

a--bearing support rigidity (N/m): the increase of bearing support rigidity will enhance the stability of the spindle system.

b--spindle support type: The first support type is that the intermediate support bearings arrange in the place where the distance from the intermediate support bearings and the last support bearings is 35mm, the bearing span remains unchanged; the second support type is that one group of bearings selects individual bearing support, the last group of bearings selects three bearings support; the third support type is that there are three groups of bearings that arrange in the front, middle and back of the spindle, each group has two bearings.

c--bearing span (mm): The distance of adjacent two groups of bearings is called bearing span, this paper only considers the span of the first group of bearings and the last group of bearings.

d--pre tightening force (N): Using appropriate methods to make certain pre deformation between the bearing rolling body and the ferrules is called pre tightening force.

e--spindle inside diameter (mm): The inside diameter of high speed spindle is a ladder shape, changing the inside diameter spindle will affect the rigidity of the spindle.

The transmission stability of the spindle system belongs to the dynamic characteristic of the spindle system. For the convenience of the study, this paper gives a simplified schematic diagram of the high speed spindle system.

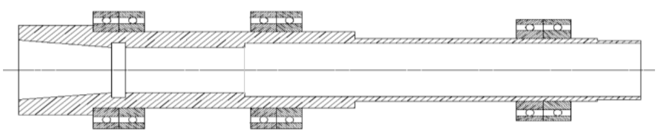

Figure 1. Simplified main spindle system.

3.1.2 Noise factors

M- Spindle materials; N-The cutter point pressure fluctuations when spindles are processed by machine tool (MPa); Q - Cutting fluid type

3.2 Orthogonal test

3.2.1 Determine factors levels

Table 1. Different levels of controllable factors

factors	level1	level2	level3
a(N/m)	8×10^5	8×10^6	8×10^7
b	1	2	3
c(mm)	334	354	374
d(N)	80	150	280
e (mm)	diameter -1	diameter	diameter +1

Table 2. Different levels of noise factors

factors	level1	level2
M	Import	Domestic
N	60	80
Q	Q1	Q2

3.2.2 Make orthogonal table

Table 3. Outer table of orthogonal test

factors	levels			
M	1	1	2	2
N	1	2	1	2
Q	1	2	2	1
combine	S1	S2	S3	S4

Firstly, the orthogonal table is created by the Minitab software, then according to the 27 combinations of different levels in the orthogonal table, the production department performs the on-site experiments, produces CNC machine tools, observes the operation condition of the spindle system of the CNC machine tools, tests the qualified condition of the parts that are processed by CNC machine tools, and records qualified rate of the parts. Finally, the orthogonal test is performed by using Minitab software and the result of the test is shown as follows.

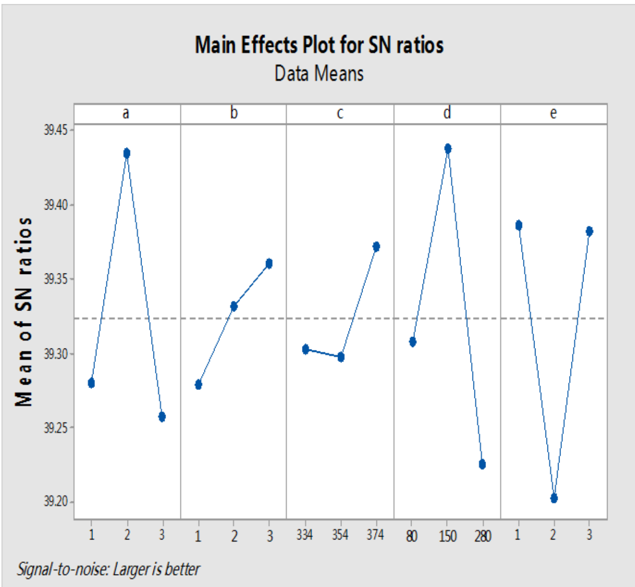

Figure 2. The main effect of each factor on signal to noise ratio.

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	a	b	c	d	e	S1	S2	S3	S4	SN	Mean
1	1	1	334	80	1	90.80	97.44	86.77	90.17	39.1863	91.2950
2	1	1	334	80	2	87.44	85.80	89.00	90.97	38.9134	88.3025
3	1	1	334	80	3	97.75	95.44	91.10	93.47	39.4943	94.4400
4	1	2	354	150	1	96.43	95.44	94.13	93.47	39.5404	94.8675
5	1	2	354	150	2	96.67	97.42	86.46	89.68	39.2951	92.5575
6	1	2	354	150	3	90.61	92.32	93.14	92.55	39.2890	92.1550
7	1	3	374	280	1	88.68	92.46	96.12	93.21	39.3231	92.6175
8	1	3	374	280	2	90.72	90.77	94.11	90.17	39.2193	91.4425
9	1	3	374	280	3	90.35	89.35	95.44	92.35	39.2555	91.8725
10	2	1	354	280	1	97.75	91.79	91.13	91.79	39.3700	93.1150
11	2	1	354	280	2	94.65	92.75	89.79	86.68	39.1632	90.9675
12	2	1	354	280	3	95.48	89.77	91.75	90.75	39.2628	91.9375
13	2	2	374	80	1	92.35	96.44	97.35	95.35	39.5833	95.3725
14	2	2	374	80	2	90.75	91.72	93.31	92.15	39.2728	91.9825
15	2	2	374	80	3	95.35	96.52	93.75	95.20	39.5718	95.2050
16	2	3	334	150	1	96.76	98.59	95.35	97.35	39.7347	97.0125
17	2	3	334	150	2	92.35	93.35	89.88	91.75	39.2574	91.8325
18	2	3	334	150	3	97.38	98.21	96.89	94.20	39.7026	96.6700
19	3	1	374	150	1	90.48	88.68	95.79	97.79	39.3661	93.1850
20	3	1	374	150	2	93.72	87.77	95.01	95.15	39.3471	92.9125
21	3	1	374	150	3	97.79	89.38	98.02	89.68	39.4104	93.7175
22	3	2	334	280	1	97.79	87.52	91.50	88.95	39.1996	91.4400
23	3	2	334	280	2	90.75	90.35	91.13	92.06	39.1871	91.0725
24	3	2	334	280	3	92.13	89.38	87.35	89.76	39.0468	89.6550
25	3	3	354	80	1	92.47	88.68	90.36	92.65	39.1804	91.0400
26	3	3	354	80	2	85.94	95.59	93.50	89.16	39.1630	91.0475
27	3	3	354	80	3	95.44	87.75	95.01	96.35	39.4105	93.6375

Figure. 3 The orthogonal table created by Minitab

3.3 The analysis of signal to noise ratios

The figure.2 shows that the second level of bearing support rigidity is better, the third level of bearing support type is better, the third level of bearing span is better, the second level of pre tightening force is better, the first level of spindle inside diameter is better.

3.4 Variance analysis [5]

Here is the formula for the sum of squares of factors

$$SS = \frac{N}{l}\sum_{i=1}^{n}(\bar{y}_i - \bar{y})^2 \tag{1}$$

In the formula, N is the number of test; l is the value of factor level; $\bar{y}_i$ is the mean of the characteristic value corresponding to the 'i' level of the factor; $\bar{y}$ is the mean of the characteristic value.

The formula for calculating the degree of freedom of factor:

$$DOF = l - 1 \tag{2}$$

The formula for calculating the variance of factor:

$$VAR = SS/DOF \tag{3}$$

This is the sum of squares of factor *a*.

$$SS_a = \frac{N}{l}\sum_{i=1}^{n}(\bar{y}_i - \bar{y}) = \frac{27}{3}\begin{bmatrix}(92.17-92.64)^2 + \\ (93.79-92.64)^2 \\ +(91.97-92.64)^2\end{bmatrix}$$

$$= 17.91$$

The degree of freedom of factor *a*:

$$DOF_a = l_a - 1 = 2$$

The variance of factor *a*:

$$VAR_a = SS_a / DOF_a = 8.954$$

The sum of squares of residuals of the factor *a*:

$SS_{error} = 34.117$ （Derived from Minitab）

The degree of freedom of residual of the factor *a*:

$$DOF_{error} = n - 1 - \sum DOF = 27 - 1 - 2\times 5 = 16$$

The residual variance of factor *a*

$$VAR_{error} = SS_{error}/DOF_{error} = 2.132$$

The variance ratio of factor *a*:

$$F = VAR_a / VAR_{error} = 4.2$$

In the same way, other factors can be calculated and the variance analysis of the mean of the quality characteristic and the variance analysis of the signal to noise ratio are shown as follows

Table 4. Variance analysis of mean

source	df	Seq SS	Adj SS	AdjMS	F	P
a	2	17.91	17.91	8.95	4.20	0.034
b	2	3.006	3.006	1.503	0.70	0.509
c	2	3.419	3.419	1.709	0.80	0.466
d	2	24.37	24.37	12.18	5.71	0.013
e	2	22.71	22.71	11.36	5.32	0.017
error	16	34.12	34.12	2.132		

Table 5. Variance analysis of signal to noise ratio

source	df	Seq SS	Adj SS	AdjMS	F	P
a	2	0.170	0.170	0.085	4.61	0.026
b	2	0.031	0.031	0.015	0.83	0.454
c	2	0.032	0.032	0.016	0.85	0.445
d	2	0.207	0.207	0.104	5.61	0.014
e	2	0.201	0.201	0.100	5.43	0.016

error	16	0.295	0.295	0.018		

From the Table 4, we can see that the value of P is less than 0.05 for the factor *a*, *d* and *e*, so these factors are significant to the mean of the quality characteristic value. From the Table 5, we can see that the value of P is also less than 0.05 for the factor *a*, *d* and *e*, so these three factors are significant to the signal to noise ratio.

According to the variance analysis, we can know that the factors *a*, *d*, *e* have a significant effect on the signal-to-noise ratio and the mean of quality characteristic, so the three factors are important factors, the figure.2 shows that the level of factors *a*, *d*, and *e* should respectively select *a2*, *d2*, and *e1*. The effects of *b* and *c* on signal-to-noise ratio and the mean of the quality characteristic value are not very obvious, so they are minor factors, it indicated that the bearing support type and bearing span are not the main parameters that influence the dynamic characteristics of the spindle system, but it would impact on the flexibility of spindle if the span of the front and the back bearings is too big , so it is better for *c* to select the second level, and according to the signal-to-noise ratio response figure, factor *b* should select *b3*, finally the best combination of factor level is *a2*, *b3*, c2, *d2*, *e1*.

4 Conclusion

This paper has a in-depth study on the problem of unqualified parts that are made by the CNC machine tools of MX company, the research shows that the parameter design of the spindle system is not reasonable, this makes the spindle system transmission is not stable, and the anti vibration property is weak so that the accuracy of processing parts is not high and the qualified rate is low. In this paper, the main parameters affecting the dynamic characteristics of the spindle system and their levels are determined by using the brainstorming method, and the orthogonal experiment, the signal to noise ratio analysis, and variance analysis are carried on by using the Taguchi method and Minitab software, finally the optimal combination of design parameters of the spindle system is determined, then the production department does the production test with the optimal combination of parameters. The test result shows that the qualified rate of parts processed by machine tools is increased from 88.66% to 95.85% compared with before; production efficiency is also increased by 10%.

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