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Application of Six Sigma Method in Improving the Quality of the Spiral Bevel Gear

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Abstract: According to the quality problems in one gear enterprise, the DMAIC method which is the core application of the six sigma theory is used to improve the quality of the spiral bevel gear, and the quality data is analyzed by using Minitab software. Firstly, the quality problem is defined in accordance with the DMAIC procedures and the main reasons for quality problems in spiral bevel gears are determined. Secondly, measurement systems and process capability are analyzed. Then, we set a specific program for the improvements for the main causes of quality problems. Through the successful implementation of this project, the quality of spiral bevel gears is greatly improved, and the production cost is greatly reduced. The effect is very significant.

Introduction

The product quality is the major focus of competition in enterprises, the six sigma method is a new management concept, which focuses customers as its center, and data as foundation, pursuing perfect service as its target. It means only 3.4 opportunities for error in one million opportunities and qualified rate is 99.99966% above.It advocates of process management and its core is DMAIC method, it is based on systematic and can enable the operation ability of enterprise to achieve the best state through five structured process which includes definition (D), measurement (M), analysis (A), improvement (I) and control(C)[1]

In the gear industry, the spiral bevel gear is the basis component which can achieve the cross-axis motion transmission. Because of its advantages of the coincidence degree, smooth transmission and carrying capacity, it is widely used in the various machinery and equipment with the intersection and drive shaft, such as motor vehicles, engineering machinery, machine tools and so on. A gear enterprise in Tangshan city has the advanced management ideas and the better technology to ensure the company to provide users with high quality products, despite the remarkable achievements have been made, the company in pursuit of excellence, it decided to implement the six sigma method to complete further quality improvements.

In this paper, as for the quality problems in spiral bevel gears, the DMAIC method in the six sigma is used in the systematic study of quality issues through the definition, measurement, analysis, improvement and control in order to improve quality and lower defect costs.

Project definition

Spiral bevel gears are processed in pairs, divided into gears and gear shafts, as shown in figure 1, active tooth material is 20MnCr5 and is the application of cold extrusion processing, driven gear material is 16MnCr5, and it is the application of heat after the isothermal forging process made normalizing. The hardness of the two organizations is uniform rough, and the quality is stable with good mechanical processing and deformation stability after heat treatment. Heat treatment requirements: using of a heating carburizing quenching and tempering to improve the fatigue strength, the requirement of tooth surface hardness is 58 HRC-62HRC, the penetration depth is

1.0-1.3, the requirement of gear meshing with the gear shaft: the lateral clearance value is 0.175 ± 0.025, the gears required to achieve the national standard GB11365-89's 8. The spiral bevel gears general process route is as follows.

Figure 1 Spiral bevel gear

Gear processing route: forging →rough turning → heat treatment →precision turning →milling →check →heat treatment →coarse grinding bore→grinding surface →grinding cylindrical → grinding teeth→check→cutting keyway→precision grinding bore → final inspection → storage.

Gear shaft processing route: forging→drilling→rough turning→heat treatment →precision turning →milling →check →heat treatment→grinding center hole→precision turning→milling keyway→grinding cylindrical→grinding teeth→check→ final inspection → storage.

In order to improve product quality, the six sigma project team in the enterprise checks 1365 spiral bevel gears, and finds unqualified products of 133 pairs, about 10% of nonconforming product. Therefore, in order to improve customer satisfaction from the company's strategy and start to determine the quality improvement goals: the failure rate to spiral bevel gears which is 10% currently is reduced to 2%, DPMO is down to 20,000 or less. Project team finds the main reasons are the failed gear lateral clearance and hardness failed which accounts for 78.0% of all quality defects in these non-conforming products. Therefore, the project team will focus on the main quality problems which are the lateral clearance value and surface hardness.

Project measurement

Measurement system analysis. The main task of measuring stage is ensuring the capability of measure system is enough and improving measurement system if necessary[2].

In order to ensure gear measurement system accurate and make it has good repeatability and reproducibility, the specific method is as follows: firstly, choose 3 operators recorded as A, B and C, and then select 10 saw blades, numbered from1 to 10. In order to get the lateral clearance value, each gear is tested twice by three operators. Time lag is necessary between two measurements to ensure that the testers can’t be affected by previous results. The repeatability and reproducibility are analyzed by Minitab, and the results are shown in table 2. We can see the results in table 2, gage repeatability and reproducibility can contribute 4.79% for the total rate, while the fluctuations between parts can reach 95.21% for the total rare. According to the evaluation criteria of measurement system, When%%R&R≤30%, measurement system is acceptable.

Table 1 MSA data

Testers	Measurements									
	1	2	3	4	5	6	7	8	9	10
A	0.169	0.179	0.166	0.178	0.177	0.193	0.178	0.167	0.173	0.179
	0.171	0.180	0.165	0.178	0.176	0.190	0.176	0.168	0.173	0.181
B	0.168	0.178	0.165	0.176	0.177	0.192	0.175	0.169	0.172	0.182
	0.170	0.181	0.165	0.177	0.175	0.189	0.177	0.168	0.163	0.182
C	0.168	0.180	0.165	0.178	0.178	0.190	0.176	0.168	0.174	0.179
	0.168	0.180	0.164	0.176	0.176	0.191	0.177	0.166	0.173	0.180

Table 2 Variance components of gear measurement system

Source variance	Components	Contribution rate
Total Measure R&R	0.00000028	4.79%
Repeatability	0.00000028	4.76%
Reproducibility	0.00000000	0.04%
Operator	0.00000000	0.04%
Between Parts	0.0000566	95.21%
Total variation	0.0000594	100.00%

Similarly, the measurement system of hardness and personnel must also be validated to ensure its reliability.

Process capability analysis. Process capability analysis of gear lateral clearance. The value of gear lateral clearance is a key size, the lateral clearance values which are relatively large gap are too small will affect the transmission of results. The spiral bevel lateral clearance datas are got from 2009 continuous 5 day, and the number of sample was 60, the data is shown in table 3 and analysis of the data is shown in figure 2.

Table1 3 The value of gear lateral clearance

	First	second	Third	Fourth	Fifth	…	Eleventh	Twelfth
1	0.156	0.153	0.169	0.172	0.176	…	0.175	0.163
2	0.163	0.180	0.181	0.160	0.175	…	0.175	0.186
3	0.143	0.183	0.168	0.176	0.197	…	0.150	0.176
4	0.187	0.172	0.177	0.174	0.186	…	0.180	0.192
5	0.175	0.162	0.157	0.178	0.180	…	0.193	0.164

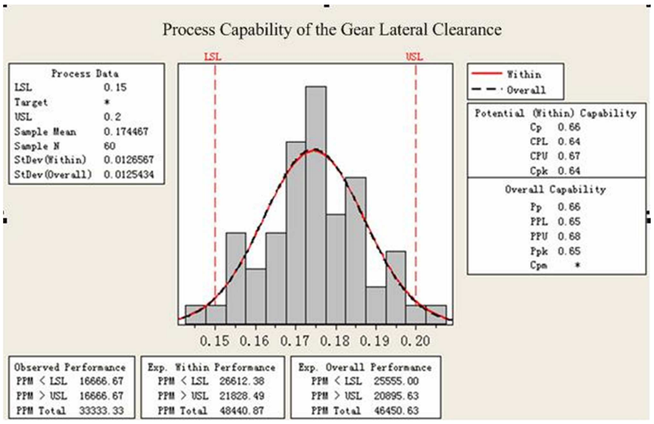

Figure 2 Gear lateral clearance process capability

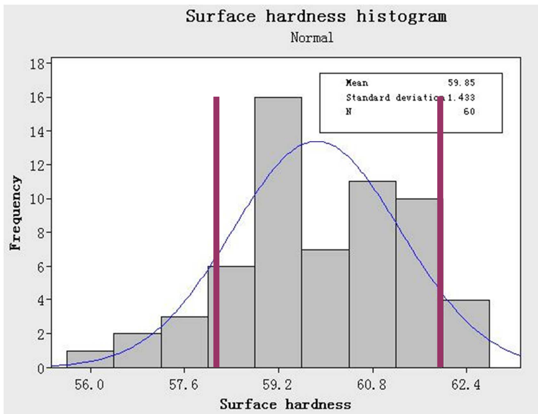

Figure 3 Gear surface hardness histogram

The process capacity of gear lateral clearance is shown in figure 2, we can also clearly see the process capacity of the gear lateral clearance is 0.64, and the level of sigma is less than 3 sigma levels. So improvement is needed urgently.

Process capability analysis. Process capability analysis of gear surface hardness. Gear surface hardness is determined by the heat treatment, the requirements of heat treatment are carburization quenching and tempering, the range of tooth surface hardness is 58HRC-62HRC. In 2009, every day we collected 5 consecutive hardness until the number of data was 60. We made histogram with Minitab software, shown in figure 3.

We can see a large number of substandard products in fig 3 and instability of the production process can be determined and production capacity is insufficient, it should immediately be improved.

Analysis and Improvement

Process capability improvement of the gear lateral clearance. In order to find the reason for the low processing capacity of the gear lateral clearance, we focus on the actual gear production process using brainstorming, and make the cause -effect diagram to analyze the reasons of insufficient process capacity, the diagram is shown in figure 4.

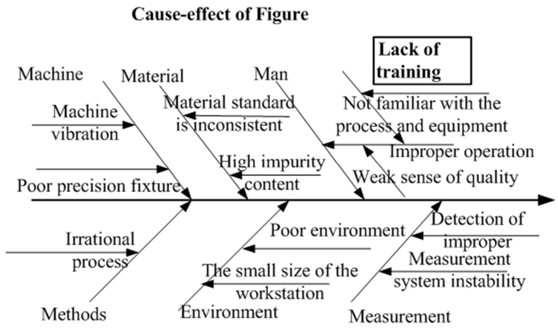

Figure 4 The gear lateral clearance cause-effect chart

According the results of analysis, we find that skill of staff is the main reason which leads to the low processing capacity of the gear lateral clearance. So companies need to enhance staff training, establish and complete training plan.

Gear tooth surface hardness improvement. The factor analysis of Influencing tooth surface hardness. With the actual production process, we find the main factors which influencing processing capacity of tooth surface hardness by brainstorming, such as carburizing temperature, carburizing holding time, quenching temperature, back annealing temperature, tempering time. Through access to relevant information and data we can find there is a range of the best in the heat treatment parameters, as shown in table 4.

Table 4 Heat treatment parameters

carburizing temperature	carburizing holding time	quenching temperature	tempering temperature	tempering holding time
920°-940°	4-8	820°—850°	190°-230°	4-10

To study the relationship between the gear surface hardness and the factors, we use multiple regression analysis. Multiple regression analysis is used to study the relationship between the response variable and multiple predictor variables. Some of the data between hardness and the various factors are shown in table 5.

Table 5 Relationship between hardness and the factors

surface hardness	carburizing temperature	carburizing holding time	quenching temperature	tempering temperature	tempering holding time
58.4	920	4	830	220	4
59.5	925	4	830	210	4
58.6	920	6	830	220	10
61.6	935	6	850	190	6
60.5	930	8	835	200	8
…	…	…	…	…	…
56.7	920	6	820	230	8

The results of multiple regression analysis using Minitab software are shown in table 6.

Table 6 Multiple regression analysis table

variables	coefficient	coefficient standard deviation	T	P
constants	-53.17	24.37	-2.18	0.039
carburizing temperature	0.09429	0.02138	4.41	0.000
carburizing time	-0.0514	0.1051	-0.49	0.629
quenching temperature	0.04088	0.01581	2.59	0.016
tempering temperature	-0.03867	0.01379	-2.80	0.010
tempering holding time	-0.02399	0.08034	-0.30	0.768

S = 0.412556 R-Sq = 92.3% R-Sq（adj）= 90.6%

Regression equation:

hardness = - 53.2 + 0.0943 carburizing temperature - 0.051 carburizing time + 0.0409 quenching temperature - 0.0387 tempering temperature - 0.0240 tempering holding time

From table 6, we can see that P value of carburizing temperature, quenching temperature and tempering temperature are less than 0.05, the rest are greater than 0.05 from the results, and therefore, the main factors influencing heat treatment are carburizing temperature, quenching temperature and tempering temperature. So we mainly aimed at the three factors for designing experiment

Gear tooth surface hardness improvement. The design of experimental scheme and improvement. As for the improvement of hardness of tooth surface, we use the full factorial experimental design approach. The full factorial experimental design is refers to all combinations of all levels of all factors to have to at least conduct a test, because it contains all the combinations, the number will be required to test more, but its advantage is the method can estimate main effects and all interaction between the factors[3]. So we carry out the full factorial experimental design to the main factors which influence gear surface hardness, such as carburizing temperature, quenching temperature and tempering temperature.

Table 7 Test data

operation sequence	standard sequence	center points	block	carburizing temperature	quenching temperature	tempering temperature	surface hardness
3	1	1	1	920	850	190	61.5
9	2	0	1	930	835	210	59.5
8	3	1	1	940	850	230	60.1
10	4	0	1	930	835	210	60.1
2	5	1	1	940	820	190	61.4
4	6	1	1	940	850	190	62.1
6	7	1	1	940	820	230	58.3
11	8	0	1	930	835	210	60.0
5	9	1	1	920	820	230	57.3
7	10	1	1	920	850	230	58.5
1	11	1	1	920	820	190	58.4
12	12	0	1	930	835	210	60.1

We design an experimental table using Minitab software, it is shown in table 7, and do experiments in accordance with the test plan matrix, and fill the results in the surface hardness column in table 6. At the same time, the main effect chart is output (figure 5) and interaction effect chart (figure 6) is output using Minitab software. The main effect figure 5 shows that the surface hardness increases with carburizing temperature and quenching temperature increasing and reduces with the tempering temperature decreasing, but we can't take the peak of carburizing temperature, quenching temperature and the lowest tempering temperature, because we can also see whether there are interaction effects between factors. Through figure 6 the interaction effect chart, we can see the interaction effect between carburizing temperature and the quenching temperature, because the two lines are not parallel, we get the output of optimization results using the response optimization in Minitab software, it is shown in figure 7. Because the range of tooth surface hardness is 58 HRC -62HRC, we consider the quality and processing costs and expect the target is 60 HRC. Therefore, we can get the best treatment plan for tooth surface hardness: the carburizing temperature is 930℃, quenching temperature is 840℃ and tempering temperature is 210℃.

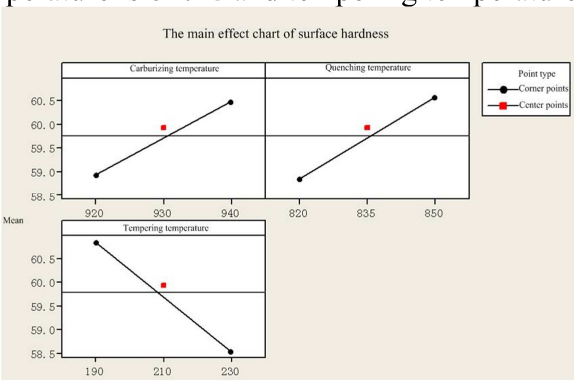

Figure 5 The main effect chart of surface hardness

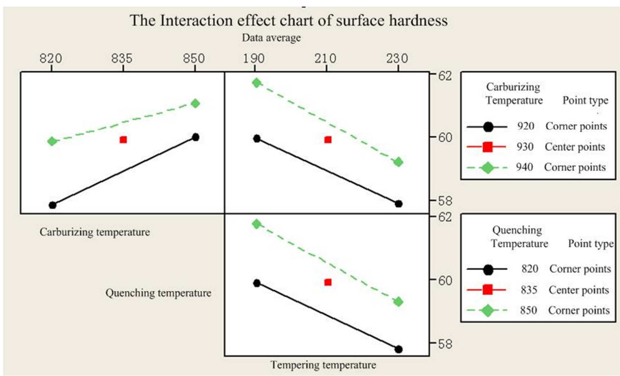

Figure 6 The interaction effect chart of surface hardness

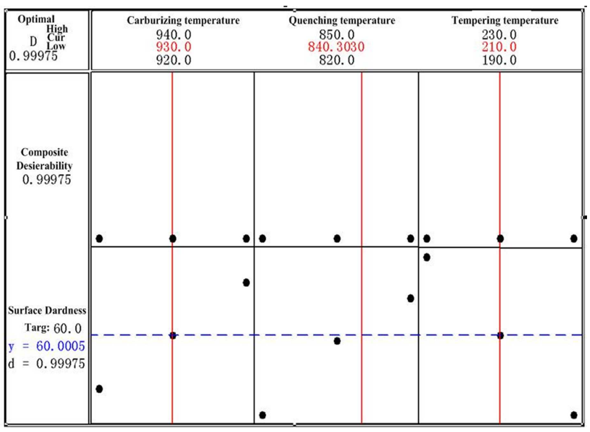

Figure 7 Optimization chart

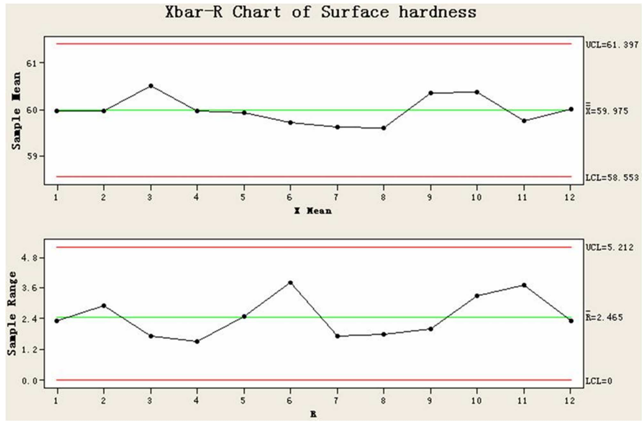

Figure 8 Xbar-Rchart of surface hardness

Quality control

As for the problem of the gear tooth surface hardness, Project team designs a set of improvement scheme. Through application in gear enterprise, the scheme is proved feasible. As long as the production process is controlled properly, the quality of hardness gear will be protected. In order to control the production process, we select some quality characteristic data in the critical control points and analyze the quality data. For example, the control chart is established by the data of the hardness of the tooth surface , it is shown in figure 8, all the data points fall within the control limits in figure 8, It indicates that the gear surface hardness is controlled after improvement. The improvement effect is remarkable.

Conclusions

Through the project selection, we have a systematic improvement on spiral bevel gears in accordance with the DMAIC procedures. The effect is remarkable, and nonconforming rate reduces greatly. The six sigma method for the spiral bevel gears production process quality control is very important, it makes workers on analyzing quality problem more scientific and reasonable[4].The program also can be generalized to the related to other projects, the six sigma method has better guidance significance in improving product quality.

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