Scholar Publishing Group
Kinetic Mechanical Engineering
https://doi.org/10.38007/KME.2023.040204
ISSN 2790-2676 Vol. 4, Issue 2: 27-37

Research on Quality Control of Arrow Shaft Based on SPC

Xirui Yang*

School of Business Administration, Henan Ploytechnic University, Jiaozuo 454000, Henan, China
2432195028@qq.com
**corresponding author*

Keywords: Statistical Process Control, Shaft Deflection, Process Capability Analysis, Orthogonal Experiments

Abstract: Based on statistical process control (SPC), the arrow shaft product was analyzed, and after fully understanding the quality processing status of the product, it was found that the change range of the deflection of the arrow shaft product exceeded the process requirements, resulting in insufficient process capacity. Normality test is carried out, and the mean-standard deviation control chart is drawn to find out the anomalies, and then the causes are analyzed from the original error, and then the fishbone diagram is used to analyze other causes of the abnormalities and make quality improvements. Data is collected again and control charts are used to verify the effect of the improvements, thereby increasing the pass rate of the product and further increasing customer satisfaction

Outdoor Products Co., Ltd. for a variety of arrow shaft production is the main standard of customer demand, the company has been in the industry for many years, has a lot of production and processing experience, but the company still uses traditional post-inspection, which will produce multiple processing errors superimposed, increase the rate of unqualified. In view of the case of shaft rupture, SPC technology [1] is used to study this, hoping to enhance the quality of the shaft, reduce the number of shaft breaks, and improve the utilization rate of the shaft.

In practice, the data recorded and sorted from each process is mainly used for recording and traceability, and it is rarely used in post-event analysis, and the data recorded and sorted out consumes a lot of resources, if these data are not fully applied, not only cause unnecessary waste of quality costs, but also the value of data has not yet been reflected. In addition, for the product, post-event analysis is not sufficient, if you can achieve advance quality control [2], will greatly enhance the efficiency of quality, the use of statistical process control, can make the data analysis accurate, rapid characteristics of more full use, and timely response to the abnormal situation of production and processing, so as to achieve quality abnormal alarm.

1. Quatitative analysis of SPC Technology on Arrow Shafts

1.1. The Main Parameters of the Arrow Shaft

Outer diameter: 7.6mm; Inner Diameter: 6.2mm; Length: 30" (76.2cm); Straightness: +/-0.006; Deflection: 350; Weight: 28g.

1.2. Quality Characteristics of the Shaft

(1) Deflection

Deflection is the "soft and hard" of the arrow shaft, and whether it will fly in an "S" shape in flight, which is closely related to the deflection of the arrow shaft. The smaller the deflection, the harder the shaft, the smaller the shaft is not easy to deform, but it is not easy to repair when damaged, in addition, there may be friction with the bow in flight, resulting in slower arrow speed. The larger the deflection, the softer the shaft, and during flight, the shaft is easy to deform, making the "S" too large, and occasionally there will be a broken rod, which will bring great danger.

(2) Weight

When the weight of the arrow is too light, it is easy to damage the bow blade. Usually the traditional bow range is 8-15 grains per pound, when using the same bow, when using light arrows, the penetration force, kinetic energy and parabola of the bow and arrow are smaller, the flight is straighter, and there is a greater distance tolerance rate. When using heavy arrows, the penetration, kinetic energy and parabola are large, but the flight speed is slow, at this time, the arrow path is relatively curved, the flight distance is not easy to be too far, and there are higher requirements for distance. In actual production, the weight of the arrow can be adjusted by the weight of the arrow and the tail of the arrow.

(3) Straightness

When the straightness error of the arrow shaft is large, the situation of scattered flowers will be formed in flight, so the straightness of the arrow shaft has a great impact on the accuracy, but usually the straightness of the arrow can also be adjusted by sticking the screw feathers in the later stage.

2. Qualitative analysis of SPC Technology on Arrow Shafts [4]

2.1. Establish Control Points

In the process requirements of the arrow shaft, the straightness only needs to reach the ordinary standard of 6/1000, in actual production, there is generally no problem with straightness, and the problem of straightness can sometimes be corrected later by sticking the spiral feathers. The weight index of the arrow shaft is 28g, the allowable error range is ±3, the weight is well controlled, and the impact on the failure rate of the arrow shaft is small. The deflection requirement is 350 and the deflection tolerance range is ±20. In the process of processing to control the straightness, the weight is easier, however, the incoherent carbon brazing dimension, so that the adhesive distribution and strength are not easy to control, in the deflection/strength, the stability is not high, the size fluctuation range is wide. In actual production, the quality problem of the arrow shaft is mostly formed because of the unqualified deflection, the change range of the deflection of the arrow shaft exceeds the specified range is also the main reason for the unqualified factory, when the use process, the deflection is too small will form the arrow shaft rupture, therefore, the arrow shaft deflection as the analysis object of this paper, monitor the production process of the arrow shaft, judge whether the deflection is abnormal.

2.2. Select Control Chart

In this paper, the deflection of the shaft was selected as the control point and studied using a metered value control chart[5]. Metered charts typically use mean-standard deviation (Xbar-S) and mean-range (Xbar-R) charts. The standard deviation of the mean requires large data to provide more accurate feedback on the characteristics of the data. Therefore, this paper chose to use a mean-range (Xbar-R) chart to monitor the production process of the product.

2.3. Measurement System Analysis

The company uses a deflection meter to measure shaft deflection, and since the deflection is continuous data, GR&R analysis of the measurement system is performed to examine repeatability and reproducibility [7]. 3 surveyors were randomly selected, one arrow shaft was selected every 30 minutes, a total of 10 arrow shafts were selected for measurement, and each arrow shaft was measured 3 times per person, and the analysis results were shown in Table 1 and Table 2

Table 1. Gage for deflection R&R

Source	DF	SS	MS	F	P
Operator	2	5.76	2.878	0.018	0.982
Shaft	27	4202.87	155.662	389.154	0.000
Repeatability	60	24.00	0.400		
Total	89	4232.62			

Table 2. deflection R&R

Source	Variance component	Variance component contribution rate	SD	Study variation	%SV
Total gage R&R	0.4000	0.77	0.63246	3.7947	8.76
Repeatability	0.4000	0.77	0.63246	3.7947	8.76
Reproducibility	0.0000	0.00	0.00000	0.0000	0.00
Between parts	51.7539	99.23	7.19402	43.1641	99.62
Total variation	52.1539	100.00	7.22177	43.3306	100.00
Distinguishable number of categorical variations=16					

According to the above figure, the repeatability contribution rate of the R&R variance component of the gage is 0.77%, the reproducibility is 0, and SV/Toler = 8.76% <10%, indicating that the measurement system is excellent. In addition, the number of distinguishable classes is 16, indicating high accuracy and can be used to measure shaft deflection.

2.4. Initial Competency Test

Processing data is collected at the processing site, and five samples of continuous production are randomly selected every day. The deflection of the shaft was measured using a deflection measuring instrument with a total of 25 subgroups of 5 data in each group, and the mean and standard deviation were 350.4 and 10.27, respectively. P=0.108>0.05, it can be seen that the data follow a normal distribution. After drawing a control chart, analyze whether the production process is stable. Plot the mean-range (Xbar-R) chart as shown in Figure 1. Initial process capability is detected, as shown in Figure 2.

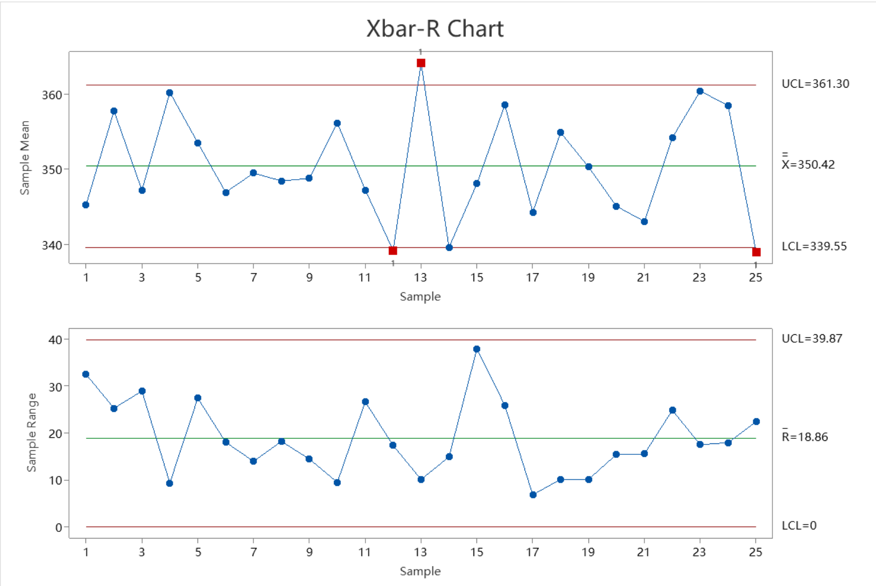

Figure 1. Figure 1 mean-range control chart

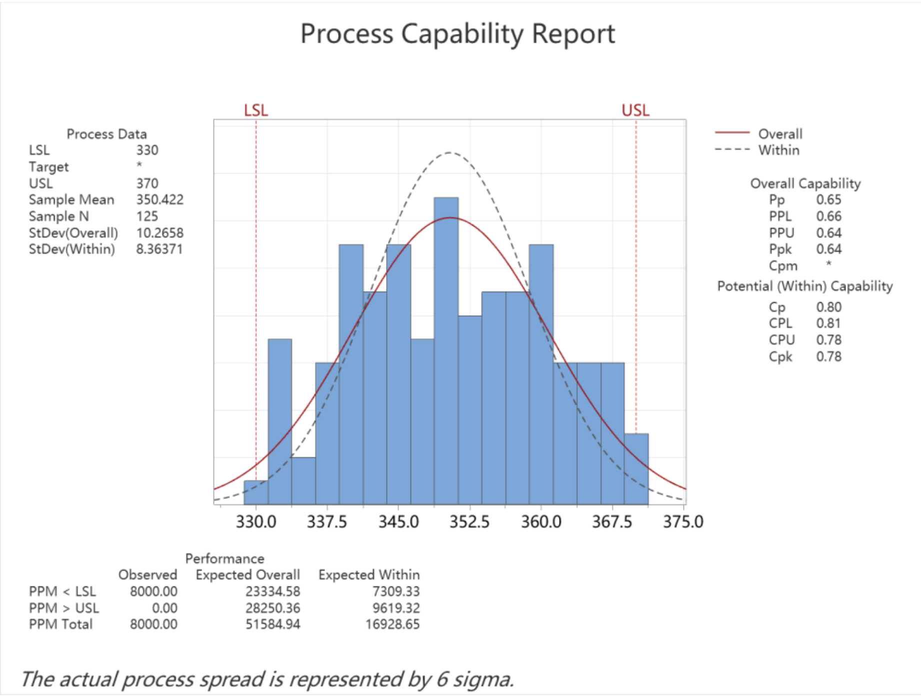

Figure 2. Initial process capability detection

According to the stability criterion of the control chart, it can be seen that the data points of the deflection have no arrangement law, and only the sample mean of 13 points in the graph exceeds the upper control boundary, and the remaining points are within the boundary. Therefore, analyze the reasons for the occurrence of the abnormal appearance of point 13. The original error that caused the abnormality is analyzed, and the principle error in the process of shaft machining is the same, however, only point 13 is out of bounds, indicating that it is not an abnormality caused by the processing principle, and the same is true, nor is it an anomaly caused by the geometric error of the machine tool. After observing the data of the processing process, it can be seen that the main reason for the abnormality of point 13 is the error caused by the force heating of the process system, and the production of this batch of workpieces is not controlled well, and the temperature in the furnace will be too high in the case of long-term use of the curing oven. Therefore, when heating and curing, it is necessary to reasonably arrange the heating time and reasonably use the curing time of the curing oven, so as to improve the product qualification rate.

Because of the large processing volume and long processing time of arrow shaft products, long-term process capability monitoring is required, so the long-term process capability index (PPK) is used to analyze whether the production capacity meets customer requirements. From Figure 2, it can be seen that PPK=0.64, the process capability level is grade C, and the process capability is insufficient.

3. Analysis and Improvement

3.1. Factors that Affect Shaft Deflection

The fishbone diagram in 5M1E [9](man, machine, method, material, measurement, environment) is used to analyze the factors affecting the deflection of the arrow shaft, and the analysis results are shown in Figure 3.

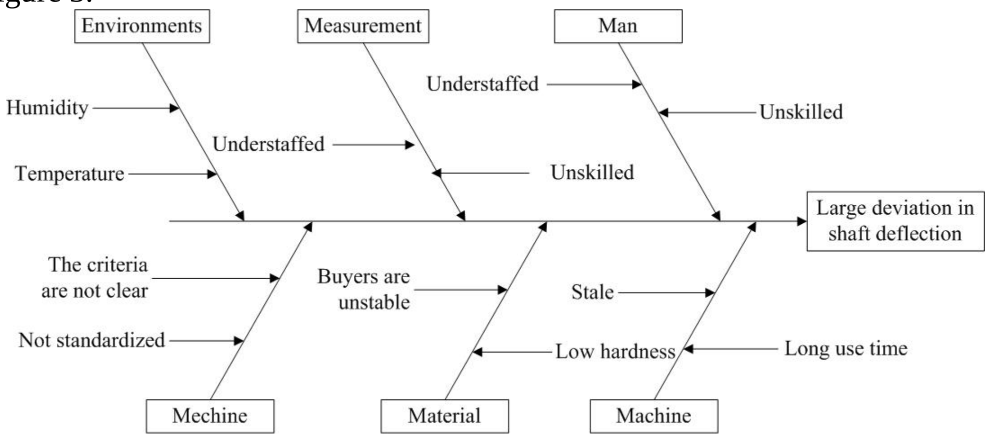

Figure 3. Factors affecting shaft deflection

3.2. Develop Improvement Measures

3.2.1. According to the Actual Production Situation and the Influencing Factors of Figure 3, the Following Improvement Measures are proposed

(1) Since the company has 10 laborers, 2 management personnel, 8 workers, the number is small, so the professional ability requirements of employees are higher, it is necessary to carry out professional training for operators, strengthen the professional knowledge and quality awareness of operators, standardize their operating procedures, before production, to formulate a clear policy for each position, implement the post responsibility system.

(2) The number of the company's tape wrapping machine is 4 sets, 2 curing ovens, 2 tube reel machines, 2 core removal machines, 1 cutting machine, 2 fabric cutting machines, 2 coreless grinding machines, because of less equipment, and long-term operation, so in production, it is necessary to strengthen the management of equipment, and replace some old equipment in time, as well as excessive wear equipment, to ensure the normal operation of the equipment.

(3) In the high-temperature curing process, it is necessary to calculate the temperature range of the high-temperature curing furnace in advance, and the temperature can be set between 110 degrees and 130 degrees according to previous experience, but the debugging temperature during

processing not only wastes materials, but also delays time, if the temperature is established to predict the model, it will greatly improve production efficiency, this paper uses multivariate analysis to establish a deflection and temperature prediction model. Similarly, when reeling, the pressure range of the reel machine should be controlled. When cutting and grinding rods, it is necessary to adjust the reasonable concentration of cutting fluid.

3.2.2. Range Control of Factors

The main factors affecting the deflection in the production process of arrow shaft are temperature, cutting fluid concentration, pressure, in the past processing process, workers often through the debugging of the workpiece to determine the parameter range, this practice is commonly used in the production process, but there is a certain irrationality, it is not only easy to cause the waste of the workpiece, increase the production cost, but also according to the experience of the parameter range lack of theoretical basis. The deflection required by the arrow shaft product is 350, the tolerance range is ±20, according to the deflection data obtained by the previous processing experience, it can be known that the temperature parameters can be adjusted between 110 ℃ and 130 ℃ according to the actual situation, the pressure parameter range is 2.5MPa-3.0MPa, the cutting fluid concentration range is 3%-10%, based on the above analysis, to determine the reasonable parameters must establish a reliable mathematical model, obtain a reasonable value range.

3.3. The Deflection Prediction Model Based on Multivariate Analysis is Established [10]

In the production process, there are many factors that affect the deflection of the shaft, and the three factors of temperature, cutting fluid concentration and pressure have a significant impact on the deflection. From the current experimental study, it is known that the biggest factor affecting the deflection is temperature. In production, the determination of the temperature range has a significant impact on the quality of the shaft.

The temperature range has a great influence on the deflection of the shaft, and in production, the relationship between deflection and temperature can be established with a mathematical model, so as to reduce the number of temperature debugging times in production and quickly optimize the temperature parameters. In this paper, multiple regression analysis is used to determine the mathematical model of deflection, so as to predict and control the deflection.

(1) Experiment preparation

Purpose of the experiment: To measure the deflection obtained by different parameter combinations, reflect the influence of various factors on deflection, and obtain a prediction model of deflection by regression analysis.

Test conditions: machine tool and mold are determined; Production environment conditions are steady state.

Test protocol: univariate experimental design, multivariate orthogonal experimental design.

Multivariate orthogonal experiments [11][12]

Multivariate orthogonal test contains test purpose, test index and determining factors and levels, and arranges and combines factors and levels according to the set factor level table, this method can reduce the number of tests and find the appropriate horizontal combination of test factors, so as to achieve the optimization of the system.

According to the test indicators, the selection of factors and levels is the basis for the design of multivariate orthogonal experiments, because the factor level table is the only basis for the development of orthogonal tables, so before making orthogonal tables, the factor level table should be made, this paper takes the arrow shaft deflection as the test index, temperature, pressure, cutting fluid concentration as the influencing factors of deflection, and the factor level is shown in Table 3.

Table 3. Table of factor levels

Factor / level	1	2	3
Temperature	90	110	130
Cutting fluid concentration	0.03	0.07	0.10
pressure	2.7	2.8	2.9

According to Table 3 set the orthogonal table, this experiment is 3 factors and 3 levels, so the typical orthogonal table L9 (34) is selected, where "9" represents the number of rows, indicating that 9 different conditions of the test are done, "4" represents the number of columns, that is, there are no more than 4 factors that can be arranged when doing the experiment, "3" means that each factor can take 3 different levels during the test.

(2) Establishment of multiple regression model

The three elements that affect the deflection in the processing process mainly include temperature (t), cutting fluid concentration (q), pressure (p), in the case of consistent raw materials and equipment stability, there is a relationship between deflection and temperature, cutting fluid concentration and pressure, such as Equation 1.

$$Y=cp^{b1}t^{b2}q^{b3} \tag{1}$$

Y—deflection; c—correction factor; p—pressure; t—temperature; q—cutting fluid concentration; b1, b2, b3—regression coefficients

Take the logarithm on both sides of the nonlinear function of Equation 1, which is converted into a linear function, and take the logarithm to obtain Equation 2:

$$\lg Y=\lg c+b_1\lg p+b_2\lg t+b_3\lg q \tag{2}$$

make:$\alpha=\lg Y$, $\gamma=\lg c$, $\beta 1=\lg p$,$\beta 2=\lg t$,$\beta 3=\lg q$. Get Equation 3.

$$\alpha=\gamma+ b_1\beta_1+ b_2\beta_2+ b_3\beta_3 \tag{3}$$

This multivariate linear equation, β_1, β_2, β_3 and α have some inevitable linear relationship. The regression analysis is shown in Table 4. The ANOVA analysis is shown in Table 5

Table 4. Regression analysis table

Regression equation: deflection = 0.129 + 1.32 temperature -0.0151 cutting fluid concentration -0.582 pressure					
Argument	0.4000	0.77	0.63246	3.7947	8.76
Variable	0.4000	0.77	0.63246	3.7947	8.76
Temperature	0.0000	0.00	0.00000	0.0000	0.00
Cutting fluid concentration	51.7539	99.23	7.19402	43.1641	99.62
Pressure	52.1539	100.00	7.22177	43.3306	100.00
S=0.0427983R-Sq=97.6%R-Sq(adjusted)=96.1%					

Table 5. ANOVA analysis

Source	DF	SS	MS	F	P
Regression	3	0.36606	0.12202	66.62	0.000
Residuals error	5	0.00916	0.00183		
Total	89	0.37522			

The significance test of the regression equation was carried out by the F test method, and when the α = 0.01 was known, 66.62> $F_{0.99}(3,5)=12.06$ from the F distribution table. It is known that the regression equation is significantly effective, and the significance test for the regression coefficient is shown in Table 6.

Table 6. Multivariate ANOVA table

Source	DF	F
Temperature	2	326.52
Cutting fluid concentration	2	2.14
Pressure l	2	11.48
Total	6	

It can be seen from Table 6 that when α=0.10, $F>F_{0.90}(2.2)=9.0$ of pressure, and α $F>F_{0.99}(2,2)=99.01$ of temperature, temperature and pressure are significantly effective at significance levels of 0.01 and 0.1, while the concentration of cutting fluid is not significant.

Equation 3 is: Y=100.129p-0.582t1.32q-0.0151. It can be obtained that temperature and deflection are positively correlated, the greater the temperature, the greater the deflection, it can be seen that when the value of one of the two parameters is determined, the approximate value range of the other parameter can be obtained.

3.4. Verification of improved performance

When the processing process is stable, the deflection measuring instrument is used to measure the deflection of the arrow shaft, and 5 measurement data are continuously extracted every day for 25 days, and a total of 25 sets of data are measured. The mean-range chart is shown in Figure 4.

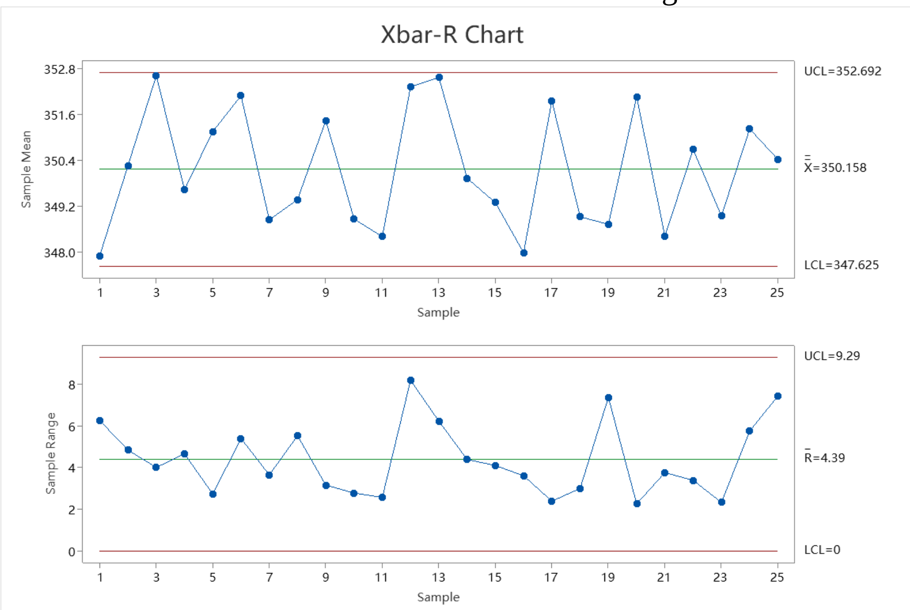

Figure 4. Mean-range control charts

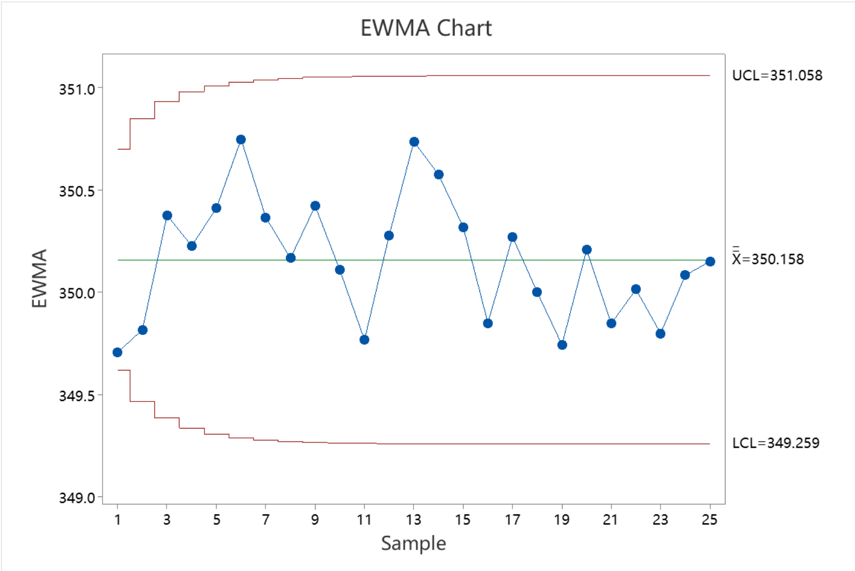

Figure 5. EWMA control chart

It can be seen from Figure 4 that there are no anomalies in the mean and standard deviation plots of the improved shaft deflection, indicating that the production process of the shaft deflection is stable. The EWMA chart has better sensitivity than the mean chart and can reflect the small band of the process, so the EWMA chart [13] is plotted on the shaft deflection, as shown in Figure 5.

It can be seen from Figure 5 that the production process of the shaft deflection is stable, and the upper and lower control lines have a certain contraction when monitored by the EWMA control chart, which is closer to the target value

3.5. Process Capability Test[15]

From Figure 6, it can be seen that Cpk=2.59 and Ppk=2.81, both of which are larger and the gap is small, indicating that the production process is very stable. Ppk also increased from 0.64 to 2.81, reaching grade A.

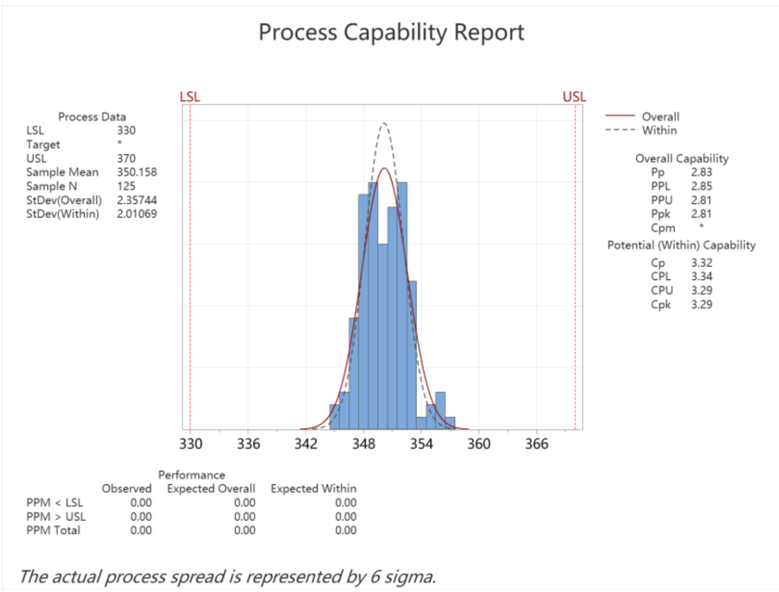

Figure 6. Process capability detection

4. Summary

In this paper, SPC technology is applied to the quality control of the shaft, and the quality control of the shaft deflection is carried out through SPC technology, so that the process capacity of the shaft deflection is increased from 0.64 to 2.81, reaching the A level of the evaluation standard and meeting the needs of customers. First, the shaft production process and the quality characteristics of the shaft are analyzed, and the original error is analyzed, and then, according to the experimental experience, the factor that has the greatest impact on the quality of the shaft is the large fluctuation range of the deflection, and the fishbone diagram in the 5M1E method is used to analyze the cause of the deflection problem, so as to propose reasonable improvement measures. And the most important factor affecting the deflection of the shaft is temperature, and the multiple regression model on temperature and deflection is set up, so as to facilitate the debugging of temperature parameters. Finally, the improved deflection data were collected, and the improvement results were verified by means-standard deviation chart and EWMA chart to verify the improvement results, and found that the process was stable and in line with customer requirements.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

References

[1] HanyAbdel-Motaleb. (2022). Statistical process control. Cutting Tool Engineering (5), 74.

[2] Faouzi, S. (2022). Quality control of wool during industrial processing.

[3] Hanna, M. E., & Publishing, S. Introduction to management science: mastering quatitative analysis.

[4] Williamon, A., Ginsborg, J., Perkins, R., & Waddell, G. (2021). Qualitative analysis.

[5] Bedane, I., & Jima, T. (2021). Contemporary quality management control chart. Science Publishing Group(2).

[6] Shrestha, N. (2021). Application of Statistical Process Control Chart in Food Manufacturing Industry.

[7] Hazmi, Ahmad Syafiq AhmadAbd Maurad, ZulinaNoor, Mohd Azmil MohdDin, Nik Siti Mariam Nek MatIdris, Zainab. (2021). Measurement system analysis on the external standard using an azeotropic mixture of ethylene glycol and detailed uncertainties. Journal of separation science. 44(7).

[8] Oncul, K. (2021). Quality optimization and process capability analysis of ring spun supima cotton yarn. Materialpruefung: Werkstoffe und Bauteile, Forschung Prufung Anwendung(10), 63.

[9] Yang, L. (2018). Practical effect analysis of 5m1e analysis on improving sterilization quality in disinfection supply room of hospital. Smart Healthcare.

[10] Lachowski, K. J., Vaddi, K., Naser, N. Y., Baneyx, F., & Pozzo, L. D. (2022). Multivariate analysis of peptide-driven nucleation and growth of au nanoparticles. Digital Discovery, 1.

[11] Liu, Z., & Narayan, A. (2022). A stieltjes algorithm for generating multivariate orthogonal polynomials.

[12] Arsenault, F. J., & Brooks, B. E. (2021). Conducting Multivariate Experiments. US20210319471A1.

[13] Mohammed, Z. M. (2022). Modelling time-series process of an agricultural crop production process by ewma quality control chart. International Journal of Mathematics in Operational Research, 23.

[14] Knoth, S., Woodall, W. H., & VG Tercero-Gómez. (2021). The Case against Generally Weighted Moving Average (GWMA) Control Charts. 10.48550/arXiv.2107.00224.

[15] Ranjan, N. (2022). Process capability analysis for fabrication of high elongated pvc polymer using extrusion process - sciencedirect.

[16] Anis, M. Z., & Bera, K. (2022). Process capabilitycpassessment for auto-correlated data in the presence of measurement errors. International Journal of Reliability, Quality and Safety Engineering, 29(06).