Research on quality evaluation and forecast control in assembly process for complex products

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Abstract. Assembly quality affects complex product's performance in high degree because the assembly is the end of manufacture process. In this paper, a comprehensive evaluation and forecast control of various factors affecting assembly failure is presented based on theory of gray system. Firstly, the absolute correlation degree and relative degree of correlation are calculated by using data from assembly process of complex products. Then, the comprehensive correlation degree and rank analysis are obtained with the gray method. Finally, the gray system theory is used in quality analysis and forecast control of a valve manufacturer. The final result indicates that excess amount of leakage is the main factor affecting product quality in accord with the actual situation.

Keyword: quality engineering, quality control, monitoring method, complex products

1. Introduction

The product quality of complex mechanical products is mainly revealed in assembly quality. And assembly process is the most widely spread and complex production process, which has enormous impact on product quality [1]. Assembly process as the entire production process in the final stage, the highest cost is the quality of the entire product the greatest impact [2]. In the assembly process, the abnormal assembly process will affect the quality of the whole product assembly. Product assembly process involves many factors, and each factor is interrelated and mutually restricting. A number of factors to determine the decisive factors affecting the product are particularly difficult in the manufacturing industry [3]. Because many people are engaged in manufacturing personnel, the technical level and assembly site is different. But for all this, a lot of problems exist in experience of the degree of understanding
of assembly process and accuracy of assembly tools [4]. These factors together determine the overall quality of product assembly, so quality of product assembly process evaluation becomes particularly important.

There is plenty of evidence to show that advanced assembly technology could improve the quality and efficiency of product assembly modeling rapidly. An assembly sequence of different assembly quality has establishment of assembly sequence based on the degree of deviation of the transfer model. So, quality evaluation of complex products were studied in many papers [5]. The assembly product quality is determined by many feature quantities. Because of the importance of each feature, assembly product quality is very different [6]. Based on gray theory, a multi-parameter diagnosis method of rolling assembly process for complex products has been developed. Therefore, gray theory is applied to the assembly of the valve quality of the various factors to evaluate and predict the impact of final quality assembly to determine the most significant factors, and to improve production efficiency.

2. Gray correlation analysis model of product assembly quality

Aimed at the product assembly quality, multiple targets and multiple solutions, according to the gray theory, the analysis model of the gray correlation analysis model is established. Based on quality model and programming and optimizing theory, the criterion of assembly quality judgment is solved in stochastic variable for online inspection. At present, three system research methods of uncertainty are probability statistics, fuzzy mathematics and gray system theory [7]. They all have one thing in common, that is, the research object has certain uncertainty [8]. The main focus of probabilistic statistics is on uncertainty of random events. Fuzzy mathematics focuses on the problem of less certainty. And the gray system theory mainly studies uncertainty of small sample and less information [9]. These areas are difficult to solve the problem of probability statistics and fuzzy mathematics [10].

In general, the study of product assembly quality often cannot provide a large number of assembly data. These data is often difficult to make a reasonable assessment of decision-making, the emergence of gray theory can solve such problems. In the valve assembly quality assessment and forecast, the overall quality of valve assembly and leakage, links, body material quality, valve core and valve seat sealing with the provisions of actuator torque, product storage and transportation are closely related to a number comprehensive enterprise valve assembly fault component composition of the reference sequence. Based on the gray system theory, the influence degree of different variables on product quality was analyzed. So, the calculation procedures of gray system theory are shown as follows:

Firstly, the length of the series \( n \), referred to as:

\[
\varphi_s = \varphi_s(1), \varphi_s(2), \varphi_s(3), \ldots, \varphi_s(n)
\]  

(1)

The number of failure factors by the composition of data comparison sequence. The sequence length is \( q \), denoted as:

\[
\varphi_s = \langle \varphi_s(1), \varphi_s(2), \varphi_s(3), \ldots, \varphi_s(n) \rangle
\]  

(2)

Then, the number of product fault and the comprehensive correlation of the various factors were solved in the following.

(1) Establishing evaluation factor set

The relevant data of assembly quality of product classification, classification indicators, and independent of each indicator for the back of quality assessment were collected.
(2) Dimensional processing of data

In the evaluation, the relevance of indicators of significance, dimensions vary, and difference in the number of poor, cannot be directly calculated, usually on the data dimension of a treatment. In this paper, the actual measured values are dimensioned by using the method of initializing and initializing zero.

The numerical initialization and numerical start zero were shown by the following formula, respectively.

\[ \psi' = \left( \psi_1(1), \psi_1(2), \ldots, \psi_1(n) \right) = \left( \frac{\psi_1(1)}{\psi_1(1)}, \frac{\psi_1(2)}{\psi_1(2)}, \ldots, \frac{\psi_1(n)}{\psi_1(n)} \right) \]

\[ \psi^0 = \left( \psi_1(1) - \psi_1(1), \psi_1(2) - \psi_1(1), \psi_1(3) - \psi_1(1), \ldots, \psi_1(n) - \psi_1(1) \right) \]

\[ = (\psi_1^0(1), \psi_1^0(2), \psi_1^0(3), \ldots, \psi_1^0(n)) \]

(3) Correlation coefficient between the influencing factors

The numbers of correlation coefficient between the influencing factors can be calculated in the following:

\[ |\alpha| = \left| \prod_{k=2}^{n-1} \psi_i^0(k) - \frac{1}{2} \psi_i^0(n) \right| \]

\[ |\alpha'\beta' = \left| \prod_{k=2}^{n-1} \psi_i^0(k) - \frac{1}{2} \psi_i^0(\alpha) \right| \]

\[ |\alpha - \beta| = \left| \prod_{k=2}^{n-1} (\psi_i^0(k) - \psi_i^0(\alpha)) - \frac{1}{2} (\psi_i^0(n) - \psi_i^0(\beta)) \right| \]

(4) Calculating the absolute correlation

The absolute degree of correlation reflects the degree of geometric, and two sequences are not absolutely independent. When the degree of geometric similarity is larger, the absolute degree of correlation is calculated as:

\[ \varepsilon^0 = \frac{1 + |\alpha| + |\beta|}{1 + |\alpha| + |\beta| + |\alpha - \beta|} \]

Next, the gray comprehensive correlation degree not only reflects the degree of similarity, but also reflects the close degree relative to the starting point. This is a more comprehensive characterization of the relationship between sequence is closely linked to a number of indicators, which can be computed as follows:

\[ p_{\theta^0} = \theta \varepsilon^0 + (1 - \theta) r^0 \]

In general, it is preferable that \( \theta = 0.5 \), \( \theta \) is a little larger if the relationship between the absolute quantities, and \( \theta \) may be smaller if the rate of change is heavier.

Thus, correlation analysis of the results was carried out based on above results. So the comprehensive correlation degree of each factor was compared, and the more significant factors were found. With the actual situation, the reasons were analyzed and the improvement measures were proposed in this paper.

3. A case study

Based on the gray system theory, a kind of gray modeling method for valve quality evaluation and forecast control in assembly process was proposed is this paper. These analyzing and calculation processes were characterized by high accuracy and simple algorithm. For a multivariate, nonlinear, disturbed and uncertain mathematic model of
manufacturing system, a simulation model by gray system theory was presented. The main reason of valve core and the valve seat gap is too large, and the problem usually occurs in the valve core or seat manufacturing accuracy is unqualified because assembly workers cannot properly ensure the valve seat and valve core close contact.

Firstly, the data of evaluation factor set for valve assembly process was collected and analyzed. The set of valve assembly quality assessment factors was shown in Table 1.

| Cause number of failures | First day | Second day | Third day | Fourth day |
|-------------------------|----------|-----------|-----------|------------|
| $\varphi_1$             | 205      | 197       | 186       | 214        |
| $\varphi_2$             | 203      | 214       | 197       | 211        |
| $\varphi_3$             | 220      | 203       | 189       | 201        |
| $\varphi_4$             | 195      | 188       | 210       | 207        |
| $\varphi_5$             | 213      | 220       | 180       | 195        |
| $\varphi_6$             | 188      | 202       | 219       | 198        |
| $\varphi_7$             | 1224     | 1224      | 1181      | 1226       |

From the above table it can be seen that the cause number of failures represent total number of failures, valve body leaks, torque failure, leakage exceeded, valve body produces a large number of leakage, connection leak failure, appearance of damage, respectively. And the comprehensive correlation degree is determined by the relative degree of correlation and the absolute degree of correlation. When calculating the absolute degree of correlation, a zero point of the original data is obtained. In the calculation of relative degree of correlation, the original data should be initialized. The quality of the valve assembly quality factor relative to the initial point of zero correlation can be computed by using body assembly quality factor data relative value of the initial correlation.

Then, the valve assembly quality of various factors related to the data point of zero relative to the beginning image is shown in Table 2.

| Zero point indicator | Object of zero point at start point |
|----------------------|-----------------------------------|
| $\psi_1(2) - \psi_1(1)$ | 0.0000 -0.0390 0.0542 -0.0773 -0.0359 0.0329 0.0745 |
| $\psi_2(3) - \psi_2(1)$ | -0.0351 -0.0927 -0.0296 -0.1409 -0.0769 -0.1549 0.1649 |
| $\psi_3(4) - \psi_3(1)$ | 0.0016 0.0439 -0.0394 -0.0864 0.0615 -0.0845 0.0532 |

So, the correlation coefficient between each influencing factor and the valve assembly quality can be determined from the data in Table 1 and Table 2. The correlation coefficient between the absolute and relative degrees of each influencing factor can be presented.

Thus, the absolute association degree correlation coefficient is:

$$|\sigma_0|=42, |\sigma_1|=22.5, |\sigma_2|=9, |\sigma_3|=57.5, |\sigma_4|=14, |\sigma_5|=35, |\sigma_6|=50, |\sigma_1-\sigma_0|=19.5,$$

$$|\sigma_2-\sigma_0|=33, |\sigma_3-\sigma_0|=15.5, |\sigma_4-\sigma_0|=28, |\sigma_5-\sigma_0|=7, |\sigma_6-\sigma_0|=6$$

And, the relative association degree correlation coefficient is:

$$|\sigma'_0|=0.0343, |\sigma'_1|=0.10975, |\sigma'_2|=0.0443, |\sigma'_3|=0.2614, |\sigma'_4|=0.0717, |\sigma'_5|=0.1643, |\sigma'_6|=0.266$$
\[
\left| \sigma_1 - \sigma_0 \right| = 0.07545, \quad \left| \sigma_2 - \sigma_0 \right| = 0.01, \quad \left| \sigma_3 - \sigma_0 \right| = 0.2217,
\]
\[
\left| \sigma_4 - \sigma_0 \right| = 0.0375, \quad \left| \sigma_5 - \sigma_0 \right| = 0.13, \quad \left| \sigma_6 - \sigma_0 \right| = 0.2317.
\]

So we can calculate absolute correlation degree and relative degree of correlation by using comprehensive correlation degree among the influencing factors of valve assembly quality, the absolute correlation degree is as follow:

\[
\begin{align*}
\varepsilon_{01} &= 0.7706, \\
\varepsilon_{02} &= 0.6118, \\
\varepsilon_{03} &= 0.8664, \\
\varepsilon_{04} &= 0.6706, \\
\varepsilon_{05} &= 0.9176, \\
\varepsilon_{06} &= 0.9206.
\end{align*}
\]

The comprehensive correlation degree (\( \theta = 0.5 \)) is as follow:

\[
\begin{align*}
\rho_{01} &= 0.8544, \\
\rho_{02} &= 0.8013, \\
\rho_{03} &= 0.8586, \\
\rho_{04} &= 0.8189, \\
\rho_{05} &= 0.9099, \\
\rho_{06} &= 0.8348.
\end{align*}
\]

Next, the results of the above calculations were sorted as:

\[
\rho_{04} > \rho_{05} > \rho_{06} > \rho_{03} > \rho_{01} > \rho_{02}.
\]

Thus, having analyzed the measured statistics the result is shown below:

\[
\varphi_4 > \varphi_5 > \varphi_6 > \varphi_3 > \varphi_1 > \varphi_2.
\]

This shows that the importance of factors affecting the failure in turn decreased. And the result is very consistent with the actual business. From the perspective of improving product qualification rate, the valve core and valve seat machining accuracy were followed by ensuring the rationality of its installation methods and assembly skills of skilled workers. The quality evaluation model of the valve assembly demonstrates the guidance of gray system theory to the mechanical product quality evaluation and forecast control.

4. Conclusion

There are many methods for evaluating the quality of complex electromechanical products. It is necessary to ensure that the evaluation and forecast method was simple and easy to apply. In this paper, an application of gray system theory for the evaluation of product assembly quality was presented based on the gray of assembly quality with all kinds of influencing factors. The result is more accurate and the gray correlation degree can be compared. The approved method of calculating gray relational grade was somewhat complex, but it can be calculated by computer auto-made software.

In order to improve product assembly quality, the gray system theory was used in evaluation and forecast control for complex mechanical products. With the effective utilization of this machine and other equipments of the assembly line, the reducer assembly quality and the product performance were improved greatly. This assembly machine employs electric drive torque controlled wrench in quality evaluation and forecast control in assembly process for complex products, thus the physical strength of workers is largely decreased and the assembly quality was assured. For the product quality evaluation, this method was also applicable to other complex mechanical products.

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