Application of Statistical Process Control in Engineering Quality Management

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Abstract. The control of the statistical process is to apply statistical techniques to monitor each stage of the production process and to achieve the purpose of improving and ensuring the quality of the product. The basic element of quality control is the control chart. Control chart is a statistical tool to control product quality in the production process, and is the most important method in quality control. Statistical process control is widely used in the quality management of energy, environment, chemical engineering and other fields, and plays a vital role in improving the process and product quality in related fields.

1. Introduction

In the process of production, the fluctuation of product quality characteristics is inevitable. It is caused by the fluctuation of basic factors such as human, machine, material, method and environment. There are two kinds of fluctuations: normal fluctuations and abnormal fluctuations. Normal fluctuations are the result of accidental causes (unavoidable factors), which have little impact on product quality, are difficult to eliminate technically, and are not worth eliminating economically. Abnormal fluctuations are caused by systematic reasons (abnormal factors), which have a great impact on product quality, but measures can be taken to avoid and eliminate them [1]. Statistical process control is a real-time process control technology using mathematical statistics method, which can scientifically distinguish the normal fluctuation and abnormal fluctuation of the process. It studies the ability and stability of the process by analyzing the state changes of the process, finds out the symptoms of systemic factors in time, and takes measures to eliminate the effects, so as to achieve the purpose of controlling and improving the quality of the process. The process is maintained in a in control state only influenced by random factors [2].

Statistical process control technology focuses on the effectiveness and systematicness of quality control. In recent years, as an effective quality control technology, statistical process control technology has been widely used in many industries at home and abroad [3].

The effective implementation and application of statistical process control technology helps quality management develop from passive after-checking to active pre-prevention in the process, which greatly reduces the production cost of the enterprise, and at the same time improves the competitiveness of the enterprise. This article will mainly discuss the relevant theoretical knowledge of statistical process control in quality management and the statistical tools used.

2. Relevant theories of statistical process control

The theoretical basis of statistical process control is probability theory and mathematical statistics. According to the probability theory and mathematical statistics knowledge, we know that the quality characteristic values measured in the stable state of the process, that is, the quality indexes roughly obey
the normal distribution. The characteristic of the normal distribution is that they all tend to a certain value, but there is a range. The normal distribution has a property that is often used in quality control, and regardless of how \( \mu \) and \( \sigma \) are taken, the probability of falling within the range of \([\mu-3\sigma, \mu+3\sigma]\) is 99.73%. This is the exact value obtained through strict probability calculation, see Figure 1,

![Fig. 1. Properties of normal distribution.](image)

Therefore, the probability of falling outside the range of \([\mu-3\sigma, \mu+3\sigma]\) is 1-99.73%=0.27%, and the probability of falling on the side greater than \((\mu+3\sigma)\) or less than \((\mu-3\sigma)\) is 0.27%/2=0.135%. Shewhart constructed the Shewhart control chart based on this property of the normal distribution, also known as the conventional control chart.

When using statistical process to control quality characteristics, manufacturing enterprises introduce a concept called CPK to directly judge whether the actual process meets the requirements of tolerance,

\[
CPK = \min\{(USL-\mu)/(3\sigma), (\mu-LSL)/(3\sigma)\},
\]

(1)

where the USL and USL are the upper and lower specification limits for quality characteristics, respectively.

The larger the CPK is, the more stable the production process is and the more sufficient the capacity is. Process quality control is the premise and guarantee to achieve product quality. It is usually measured by process capacity, which refers to the actual process capacity of the process under stable statistical control state, and is often expressed by process capacity index \( CP \). \( CP \) represents the ability to predict the process, which indicates the degree to which the entire process meets the specification.

\[
CP = (USL-LSL)/(6\sigma).
\]

(2)

When \( CP < 1 \), the process capability is insufficient; when \( 1 \leq CP < 1.33 \), the process capability is acceptable; when \( 1.33 \leq CP < 1.67 \), the process capability is sufficient. But in the economic prosperity, the rapid growth of the number of products, high-tech flourishingly developed today, the original quality standards can no longer apply to the current demand. If the process quality level reaches \( 6\sigma \), the process capability index \( CP=2 \) is required. As an evaluation index of process quality, there is no doubt that the higher \( CP \) value is, the higher the processing quality is, but the higher the requirements on equipment, operators and other aspects are, and the higher the manufacturing cost is. Therefore, an appropriate \( CP \) value should be determined based on a comprehensive analysis of technology and economy. When the deviation degree parameter is 0, \( CPK = CP \), the smaller the deviation degree, the smaller the variation between sample data, and the better the \( CPK \) index. On the contrary, the \( CPK \) indicator is worse.

It should be particularly emphasized that \( CP \) and \( CPK \) are determined by the size and mean deviation of the process fluctuations in a statistically in control state. Therefore, it is necessary to first determine whether the process is in a controlled state. This requires the use of statistical tools such as control charts.

3. Control chart

3.1 Basic theory of control charts

Quality management is the central link of enterprise management, and the implementation of statistical process control is an important tool for realizing quality management focusing on effective prevention. The first introduction of statistical mathematics in management science is quality management. Due to
the needs of the change and development of quality management, the role and status of statistical technology have been continuously strengthened. The basic element of statistical quality control is the control chart. Control charts are statistical tools to control the quality of products in production process, and are the most important methods for quality control. In the 1920s, Shewhart invented the control chart, which was promoted and applied in industries such as industry and service, and became the main tool for statistical process control. With the in-depth study of control chart theory, special control charts for monitoring small shifts have been introduced, such as exponentially weighted moving average control chart and cumulative sum control chart. The control chart not only has the analysis function, but also has the control function. It can not only make a reliable assessment of the process and judge whether the process is capable, but also provide an early warning system for the process to monitor the process in time to prevent the occurrence of drift. It is precisely because of the above-mentioned advantages of control charts that more and more companies are beginning to pay attention to statistical process control and use control charts to monitor the production process in order to achieve the purpose of improving quality.

There are many ways to classify control charts [4]. According to the quality indicators and the nature of the data, they are divided into measurement control charts and count control charts; according to the number of quality indicators, they are divided into unary control charts and multiple control charts; according to the fluctuation status of quality indicators, it is divided into small fluctuation control chart and normal fluctuation control chart; according to the size of the product, it is divided into small batch control chart and large batch control chart. No matter what kind of control chart, there are three basic control lines: UCL is called the upper control limit, CL is called the centre line, and LCL is called the lower control limit, as shown in Figure 2. To make a control chart, we must first determine these three control lines, and then plot the statistics of a sample into a control diagram to determine if the process is in the statistical control state.

![Fig. 2. Formation of control chart.](image)

| Sample number | observations |
|---------------|--------------|
|               | a     | b     | c     | d     | e     |
| 1             | 3.5065 | 3.5086| 3.5009| 3.5144| 3.503 |
| 2             | 3.4882 | 3.5085| 3.4884| 3.525 | 3.5031|
| 3             | 3.4897 | 3.4898| 3.4995| 3.513 | 3.4969|
| 4             | 3.5153 | 3.512 | 3.4989| 3.49  | 3.4837|
| 5             | 3.5059 | 3.5113| 3.5011| 3.4773| 3.4801|
| 6             | 3.4977 | 3.4961| 3.505 | 3.5014| 3.506 |
| 7             | 3.491  | 3.4913| 3.4976| 3.4831| 3.5044|
| 8             | 3.4991 | 3.4853| 3.483 | 3.5083| 3.5094|
| 9             | 3.5099 | 3.5162| 3.5228| 3.4958| 3.5004|
| 10            | 3.488  | 3.5015| 3.5094| 3.5102| 3.5146|
| 11            | 3.4881 | 3.4887| 3.5141| 3.5175| 3.4863|
| 12            | 3.5043 | 3.4867| 3.4969| 3.5018| 3.4784|
| 13            | 3.5043 | 3.4769| 3.4944| 3.5014| 3.4904|
According to the statistical process control theory, product quality fluctuation is the root cause of quality problems, and this kind of fluctuation has statistical regularity. The statistical process first needs to select the object, that is, the in control quality characteristics, and then obtain the sample data of the in control quality characteristics, and use the method of mathematical statistics to make its control chart. If there are abnormal fluctuations in the control chart, the reasons can be found out and eliminated. In practical application, there are many criteria for judging the condition that the production process is under statistical control, such as:

1) The points are randomly scattered around the centerline;
2) The point is within the control limits;
3) No chains, trends or other patterns;
4) The process is stable and predictable.

The control chart is designed with the principle of $3\sigma$, so the event with an occurrence probability of 0.0027 is defined as a small probability event, that is, an event that does not occur, and the acceptance risk at this time can be accepted by everyone. Therefore, when the acceptance risk of multiple consecutive points is close to or less than 0.0027, the process is regarded as stable, and if the probability of multiple consecutive points is close to or less than 0.0027, it is regarded as an abnormal process [5].

### 3.2 Application of control charts

This article will use a simple operation example to illustrate the specific steps and analysis methods of the control chart. According to the above, there are many types of control charts and it is not appropriate to explain them in detail. The mean-range control chart is the most widely used pair of charts. Therefore, this article takes the mean-range control chart as an example to give an illustration.

The specific steps of drawing the control chart are as follows:

1) Collect data with subgroups as a unit, and determine the size, number and interval of subgroups.
   In this case, the subgroup size is 5, the number of subgroups is 20, and the subgroup interval is 1, as shown in Table 1[2];
2) Calculate the mean and range of each subgroup;

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|   | 14   | 15   | 16   | 17   | 18   |
|---|------|------|------|------|------|
|   | 3.5004 | 3.4846 | 3.5145 | 3.5004 | 3.4959 |
|   | 3.503  | 3.4938 | 3.4832 | 3.5042 | 3.4823 |
|   | 3.5082 | 3.5065 | 3.5188 | 3.5188 | 3.4966 |
|   | 3.5045 | 3.5089 | 3.4935 | 3.4954 | 3.4964 |
|   | 3.5234 | 3.5011 | 3.4989 | 3.502  | 3.5082 |
|   |        |        | 3.4989 | 3.4985 | 3.4871 |
|   |        |        | 3.4964 | 3.4966 | 3.4856 |
|   |        |        | 3.4964 | 3.4964 | 3.4856 |
|   |        |        | 3.4964 | 3.4964 | 3.4856 |
|   |        |        | 3.5053 | 3.4985 | 3.4885 |
Note: Select a reasonable scale on the mean control chart and range control chart to make the points as far as possible in the middle of the chart.

1) Draw the mean and range value on the control chart, and then connect the polylines;
2) Calculation of control limits;
   - Calculate the mean value of the k subgroups means as the center line of the mean control chart;
   - Calculate the mean value of the ranges of k subgroups as the center line of the range control chart;
   - Calculate the upper and lower limits of mean control chart and range control chart.

1) Draw the center line and upper and lower control limits of the mean control chart and range control chart.
   - Note: the range control chart should be analyzed first and then the mean control chart should be analyzed because the range control chart will be affected if the range control chart is out of control.

The control chart drawn according to this case is shown in Figure 3.

First of all, it can be clearly seen from the range chart that all points are in between the upper and lower control limits and fluctuate up and down around the centerline without obvious change trend or chain. Therefore, according to the control chart, all observed values can be known to be in control. The same conclusion can be obtained from the mean control chart, so we can get the final conclusion that the production process is in a in control state.

4. Conclusion
Statistical process control is mainly to monitor the stability of the process in real time with the method of control chart, and then gradually replace the inspection of the product. The best way to make the end result satisfying to our customers and ourselves is to control every step involved in the final outcome. Further speaking is to control the formation of the final result related to each step involved in the human, machine, material, method, ring, measurement of these six elements. The tool that can embody this idea centrally is the statistical tool that consists of various control charts - SPC. Control chart is an important basis for scientific management of production process, and one of the important methods to find abnormal process and give early warning. It is of great significance to improve product quality and production efficiency to effectively monitor the production process by using the control chart, find out the abnormal phenomenon in the production process in time and quickly find out the cause of the abnormal phenomenon. The application of statistical technology can make better use of the obtained data to make decisions.

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