A Technique and software of analysis and control for measurement process

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Abstract

In this paper, a two-section method for measuring is introduced and the variation sources of measurement process are analysed. Measuring is a special process in general process. Various variation source must be firstly decomposed so that the statistical distribution law of measuring process can be established, and then implement monitoring control of the measuring process. A special method to obtain the measuring variation is discussed, and a monitoring control technique for measuring process is studied based statistical distribution. Towards the end, we briefly introduce software design for the analysis and control of a measurement process.

Key Words : Measuring Process, Variation Source, Monitoring Control

1. Introduction

During production and scientific experiments, we often collect data in order to analyse and improve processes and experiments. For example, data obtained from a manufacturing process can be used to improve product quality and to modify the production process. Since the data are obtained from the measurement process, the measured data might not reflect the true status of the production process if errors caused by the measurement process are not small enough compared with the variation of the production process [7].

Like any production process, the variation and its ditribution law of a measurement process is also dominated by both common causes and special causes [2]. The accuracy and precision of a gauge, the skills of operators, the accuracy of calibration etc. are the system factors, which determine the capability of the measurement process. When the measurement process is in a state of statistical control, it has an inherent variation. In engineering, if this variation, compared with the variation of the production process output, is less than 10%, we consider that the measurement process has enough capability and the measured data is relative accurate. We can use the measurement process to measure the output of the production process. Otherwise we have to study the measurement process and reduce the variation caused by measuring process. It is therefore very important to analyse and diagnose the measurement process. On the other hand, the measurement process may be influenced by some special causes such as the wear of a gauge, errors from operators and changes of environment.

It is therefore also important to control the variation of measurement process in order to find special causes. In this paper, the sources of variation in a measurement process are analysed and a metrical approach for the capability of a measurement process is introduced. To detect the special problems of a measurement process, we introduce a method, two-section, to monitor its performance. Finally, we briefly describe software design for the capability analysis and control of the measurement process.

2. The Variation Source Of Measurement Process

A stable measurement process is characterised by its accuracy and precision 6~8).

The distance from the true value of a measured property to the mean value, m, of a measurement distribution is the accuracy of the measurement process. The precision of a measurement process, is the dispersion of the distribution of the measurements.

While the concept of precision is of supreme importance in the evaluation of a measuring process, the concept of accuracy has been gradually diminishing in recent years.

There are two reasons for this: first, a measurement is a related quantity, second, a measurement can not be accepted as valid unless the equipment used in obtaining it has been calibrated 6).

Measured data are obtained by using a measurement process to measure products (the output of a production process). If the true value of a product is known, it is easy to determine the measurement error by subtracting the true value from the measured data. Unfortunately, we do not know the true value of a product, so it is impossible to determine the measurement errors and to use these errors to analysis and control the measurement process.

A measurement process consists of parts to be measured, gauges, operators, and a defined methodology that is used to obtain the measurement. When a measurement is obtained by a measurement process, it will not be the true value of parts, because there are a number of causes of variation in a measurement process 8). The two main sources of variation, that is repeatability and reproducibility, were studied using an analysis of variance (ANOVA) model 3~8).

The repeatability is the gauge variation of a measurement process when the same operator uses the same gauge during a short time to measure the same product a number of times. The reproducibility is the operating variation of a measurement process when different operators use the same gauge to measure the same product a number of times.

The stability is the variation of a measurement process over time and in different places. The control charts, as introduced by Shewhart (1931), are excellent tools for studying stability in time. As for the place, in most cases, we measure the data to insure the stability of our measurement process, the measurement takes place in the same laboratory.

The synthetic variation from gauge, different operators, and even interaction of parts and operators is the total variation of the measurement process.

3. Two-section Measuring and Variation Analysis

Before analyzing the variation of a measurement process, we must decide a gauge, operators and parts. In order to eliminate the influence that the operators remember the measured value of the same parts, we use a two-section method. In the first section, the selected parts are arranged in order and for each part, an empty sheet is prepared to record the measurement. Each time, the person who works in the first section selects a part, and sends the part to the second section. Here, the operator uses the measurement process to measure the part and take down the data. After measuring, the operator returns the part and the measured data to the first section. The person in first section then puts the data into the corresponding sheet. This procedure is repeated until enough data have been gathered for every part.

Using the two-section measuring method for every part, we can get a data collection sheet. In Table 1, we combine all the measured data together.

In table 1, n is the number of parts which we choose randomly; J is the number of operators and K is the number of measuring replications. Generally, n is more than ten and, if resources permit, it should be large[8].

Similarly, K should not be less than 5[3]. Now, we use a dot to denote means as follows.

$$y_{i..} = \frac{1}{JK}\sum_{j=1}^{J}\sum_{k=1}^{K} y_{ijk},$$

$$y_{.j.} = \frac{1}{nK}\sum_{i=1}^{n}\sum_{k=1}^{K} y_{ijk},$$

$$y_{ij.} = \frac{1}{K}\sum_{k=1}^{K} y_{ijk},$$

According to the means and the data in table 1, we can calculate the mean square for operators and replication error.

(1) Mean square for replication error, repeatability

The repeatability of a measurement process is the variation when the same operator measures a chosen part for many times during a short period of time. According to the data in Table 1, we have mean square for replication error (MS_E) as following

$$MS_E^2=\frac{1}{nJ(K-1)}\sum_{i=1}^{n}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}-y_{ij.})^2$$

(2) Mean square for operators, reproducibility

The reproducibility of a measurement process is the variation of the group mean values when different operators use the same gauge to measure the same part for many times. For the data in Table 1, we have mean square for operators (MS_O) as following

$$MS_O^2=\frac{1}{n(J-1)}\sum_{i=1}^{n}\sum_{j=1}^{J}(y_{ij.}-y_{i..})^2$$

(3) Total variation of measurement process

The total variation of a measurement process is the combination of all the above variations that are in group and between groups for one parts. It is the variation when different operators, using the same gauge to measure the same part for many times.

According to the data in Table 1, we have Total variation of measurement process (MS_T)

$$MS_T^2=\frac{1}{n(JK-1)}\sum_{i=1}^{n}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}-y_{i..})^2$$

4. Capability analysis and diagnosis for measurement process

Table 1 The Summary Table Of Data Sheet

PARTS	OPERATORS	VALUE 1	VALUE 2	···	VALUE K
1	1	y_{111}	y_{112}	...	y_{11k}
	2	y_{121}	y_{122}	...	y_{12k}
	...	···	···	...	···
	J	y_{1J1}	y_{1J2}	...	y_{1Jk}
2	1	y_{211}	y_{212}	...	y_{21k}
	2	y_{221}	y_{222}	...	y_{22k}
	...	···	···	...	···
	J	y_{2J1}	y_{2J2}	...	y_{2Jk}
n	1	y_{n11}	y_{n12}	...	y_{n1k}
	2	y_{n21}	y_{n22}	...	y_{n2k}
	...	···	···	...	···
	J	y_{nJ1}	y_{nJ2}	...	y_{nJk}

The capability of measurement process is calculated by the ratio of the variation of the measurement process to the tolerance of the measured product. It is often noted by PT (Percent Tolerance). Here, the tolerance is the difference between the upper limit UCL and the lower limit LCL of measured process[8].

The capability of measurement process PT_T is the percentage of total variation MS_T to the engineering tolerance of measured characteristics of products.

$$PT_T = \frac{MS_T \times 6 \times 100}{\text{Tolerance}} \%$$

Here, the value 6 is used because an interval of length 6 standard deviation centered on the mean of a normal distribution covers 0.9973 of the probability. In[8], the value 5.15 was chosen, which covers 0.99 of the probability.

If $PT_T < 10\%$, no improvement is necessary.

With $10\% < PT_T < 30\%$, the measurement process seems satisfactory, but some improvements may be necessary if the requirement is stringent (Engel and Vries, 1997). For other larger PT_T value, the measurement process has a large variation and the measurement process has not enough capability to measure the production process. If this is the case, we have to study every kind of variation and find out the largest sources of variation and reduce the impact of these.

(1) Repeatability, PT_E

PT_E is the percentage of MS_E to the engineering tolerance of measured characteristics of products.

$$PT_E = \frac{MS_E \times 6 \times 100}{\text{Tolerance}} \%$$

If PT_E is large, we have to determine:

- Is the gauge suitable?
- Is the operating approach right?
- Does the environment influence the measured part greatly?
- Are there some interactions between the operator and the parts measured?
- Does the environment influence the accuracy of gauge?

(2) Reproducibility, PT_O

PT_O is the percent of MS_O to the engineering tolerance of measured characteristics of products.

$$PT_O = \frac{MS_O \times 6 \times 100}{\text{Tolerance}} \%$$

If PT_O is large, we have to determine:

- Do the operators use the same operating approach?
- Is the operating approach standardized?
- Is the measure method easy to master?

Here, we do not compute the interaction between parts and operators because the two-section measuring method can minimize such kind interaction. If the measurement process is complicate and the interactive effect is significant, more complicated methods should be used for analysis[2~8].

5. The distribution of measurement and its control

In the experiment and analysis, if we would like to verify that the measurement process has enough capability, then we can use this measurement process to measure the production process and use the SPC techniques to control the production process. In the control chart, if we find that the plotting points are out of control according to statistical rules, we generally think that the measurement is stable and pay most attention to the production process. But the measurement process may also change if some special causes occur, making it also necessary to control the measurement process.

A measurement process is a kind support process. We can not get the variation of measurement process directly from the measured data because the true values of products are unknown.

In order to obtain the distribution and parameters of a measurement process, we can measure the same part two times at a fixed interval and take down the data. Table 2 is an example of the data collection table.

Suppose that the true values of products $p_1, p_2, \dots, p_n$, are $T(p_1), T(p_2), \dots, T(p_n)$ respectively. Then the following relationships exist

$$X_{i1} = T(P_i) + \varepsilon_{i1}$$

$$X_{i2} = T(P_i) + \varepsilon_{i2} \qquad i = 1, 2, \dots, n$$

Here, ε_{i1}, ε_{i2} ($i = 1, 2, \dots, n$) are the measurement errors, which are determined by the capability of measurement process. Generally, the measurement error $\varepsilon \sim N(0, \sigma^2)$, where σ is the standard deviation of measurement process.

If we determine the measurement errors, we can use control charts to monitor the measurement process. Unfortunately, we can not get the ε_i for product p_i because the true value $T(p_i)$ is unknown. In order to eliminate the $T(p_i)$, we can form the following transformation:

$$y_i = x_{i2} - x_{i1} \qquad i = 1, 2, \dots, n$$

Table 2 Data collection table for measurement process control

Product No.	First measurement		Second measurement		Difference
	Time	Value x_1	Time	Value x_2	$y_i = x_{i2} - x_{i1}$
p_1		x_{11}		x_{12}	y_1
p_2		x_{21}		x_{22}	y_2
…	…	…	…	…	…
p_n		x_{n1}		x_{n2}	y_n

Since $\varepsilon \sim N(0, \sigma^2)$, it is easy to prove that $y \sim N(0, \sigma^2)$. So we can use $y_1, y_2, \ldots, y_n$ to build up control chart. According to the data in table 2, we can construct individual moving range charts (IX-MR) to control the measurement process. The following steps are the procedure to construct IX-MR charts:

(1) calculate the mean value

$$\overline{X}_E^2 = \frac{1}{n}\sum_{i=1}^{n} y_i$$

(2) calculate the moving range MRi

$$MR_i = | y_{i+1} - y_i | \qquad i = 1, 2, \ldots, n-1$$

(3) calculate the average moving range

$$\overline{MR}_i = \frac{1}{n-1}\sum_{i=1}^{n-1} MR_i$$

(4) calculate the control limits of IX chart

$$UCL = \overline{X} + 2.660\,\overline{MR}$$
$$CL = \overline{X}$$
$$LCL = \overline{X} - 2.660\,\overline{MR}$$

(5) calculate the control limits of MR chart

$$UCL = 3.267\,\overline{MR}$$
$$CL = 0$$
$$LCL = 0$$

(6) plot points in IX-MR charts

In the IX Chart, the plot value is $y_1, y_2, \ldots, y_n$. In the MR chart, the plot value is $MR_1, MR_2, \ldots, MR_{n-1}$.

6. The analysis and control software for measure process

According to the methods that we discussed above, the first author has designed a program for variation analysis and control for measurement process (ACMP). This software includes the functions of File management, Data edit and input, Parameter set, Data statistical analysis and transformation, Analysis charts and control charts, Data reports and Control charts printing out. Fig. 1 shows the data process and function structure of ACMP.

1) Data File Management

The file management function consists of data file creation for measurement process analysis and for measurement process control, file opening, saving and erasing etc.

2) Data Edit

The software provides an editor that is used for data input. For different file type, thereare different editors. The user can easily edit data, append rows and columns, copy and delete. The validation and correctness of data are checked automatically.

3) Parameter set

Parameter set consists of the process

settings and plotting settings. In plotting settings, the user can set printer types, the range of data for analysis and control etc..

4) Data analysis

According to the data in the editor and range settings, the software can do some basic statistical calculations, such as mean value, maximum, minimum and deviation.

5) Plotting analysis charts and control charts

In the software, there are three analysis charts are designed to map data on charts to analysis the distribution of data. These charts are histogram chart, probability chart and run chart. The control charts are IX chart and MR chart as we discussed above.

6) Data report

Charts plotted on the screen can be printed on the printer and the data in editor can be printed in report format.

7) Help

The software also provides a hotkey F1 for

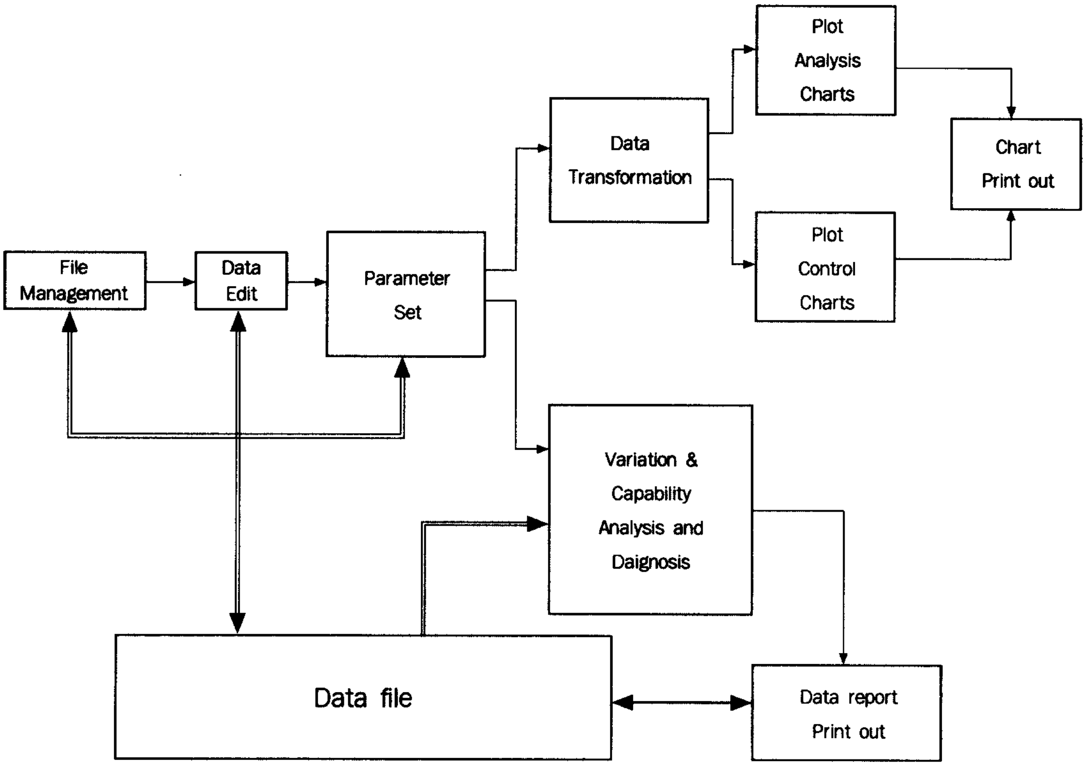

Fig. 1 The Data Process And Function Structure of ACMP.

the help. Whenever needed, press F1 and a help window will pop up.

7. Conclusion

A measurement process is a support process, which is influenced by common causes and special causes. The measurement process itself has it intrinsic capability.

Before we use a measurement process to measure the production process, we first have to analyze the repeatability, reproducibility, stability and total capability of the measurement process. Only when these capabilities meet the engineering requirement, can we use the measurement process to measure the production process.

In this paper, a two-section measurement method to collect data is suggested and a simple analysis method for measurement process is presented. In order to control the measurement process, we developed a simple approach for a dynamic control. The software makes the analysis, diagnosis and control much easier to use in industrial practice.

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