Dynamic Quality Control Method

Summary of the Invention

The present invention relates to methods and systems for quality control of a production process in which multiple products are produced and samples of the produced product are inspected. Specifically, the invention relates to determining, by measurement of the samples, whether a detailed inspection of the production process is required and/or whether the production process should be modified.

Background to the Invention

A known method of quality control for a production process is based on one or more numerical "quality values". The quality values can be evaluated for any of the products by measurement, and each quality value is indicative of a corresponding property of the product. For example, one such quality value may be a particular dimension of one of the products. The production process aims to ensure that every product produced has a quality value which is within a predetermined range between a lower limit value (LL) and an upper limit value (UL). The values of LL and UL are fixed at the time of designing the products by the specification of the products.

It is impractical to measure the quality value(s) for each product produced, so instead a percentage (normally a low percentage) of products of the production process are sampled, and the quality value(s) are measured for each sample product. It is determined whether any of the sampled products have a quality value which is above an "upper control limit" (UCL), which is lower than UL. It is further determined whether any of the sampled products have a quality value which is below a "lower control limit" (LCL), which is higher than LL. If any of the sample products has a quality value outside the

range LCL to UCL then the production process is checked in more detail. Often this involves a "freeze" in which the production process is interrupted while a check occurs.

The values of UCL and LCL are chosen to be sufficiently spaced from UL and LL respectively that if no sample products have quality values outside the range from LCL to UCL then it is highly likely that none of the products of the production process (i.e. including those products which were not taken as samples, here referred to as the "unsampled products") have quality values outside the range LL to UL.

Thus, the gaps between UCL and UL, and between LL and LCL, constitute "buffer zones" which compensate for the risk that the measured quality values of the sample products differ from the quality values of the entire population of products.

Summary of the Invention

The present invention is motivated by the following analysis of the situation described above, in relation to figures 1 and 2. Figure 1(a) is a graph having axes of time (t) and a single quality value (x). The values of LL, LCL, UCL and UL are marked on the vertical axis. Each of the small crosses in the figure indicates quality value x from a corresponding sample product. The sample products taken from the first process at time intervals. The dashed line drawn between these samples is provided to guide the reader's eye. Note that none of these samples is outside the range LCL to UCL, so the prior art method would not instruct this process to be checked and/or modified.

By contrast, in the corresponding points for a second production process shown in fig. 1(b) the mean of the points is close to the limit value LCL, and

one point (shown by an arrow) is actually less than LCL. Therefore, the prior art would instruct that the second process should be checked and/or modified.

However, supposing that the quality values x shown in figs 1(a) and 1(b) are drawn from respective Gaussian probability distributions, those probability distributions are as shown in fig. 2. The probability distribution (a), which could have generated the points of fig. 1(a) is "unstable", that is broad. It includes a significant proportion which is lower than limit LL or higher than limit UL. Therefore, a significant proportion of the unsampled products are likely to be outside the specification, and the first production process should be checked and/or modified accordingly.

By contrast, the distribution (b) which could have produced the set of samples shown in fig 1(b) is "stable", that is narrow. It contains no significant proportion outside the range defined by LL to UL, and accordingly all the products of the second production process are within this specification. This is true even though distribution (b) includes a small proportion lower than LCL, which resulted in the point marked by the arrow in fig. 1(b). Thus, it is not necessary to check the second production process.

In summary, the prior art technique discussed above recommends no check of the first process (although in fact it is unreliable), and recommends a check of the second production process (although in fact it is satisfactory).

The present invention aims to provide a new and useful method for controlling a production process, and specifically for determining whether the production process should be checked and/or modified.

In general terms, the present invention proposes that quality values from recent sample products are used to derive a numerical estimate of the

variation in the quality values (e.g. a standard deviation of the quality values) in the population of products, and that this variation is taken into account to vary the values of UCL and LCL. The dynamically varying values of UCL and LCL are referred to here as DUCL and DLCL.

When the variation in products is low, then the values of DUCL and DLCL are updated to be closer to UL and LL respectively, because in this case the quality values of the samples provide an accurate estimate of the quality values of the rest of the population of products, and the "buffer zones" do not need to be so wide. Thus, the present invention makes it possible to avoid unnecessary checks of the production process.

When the variation in products is higher, the values of UCL and LCL are set further from UL and LL, because the samples provide a less accurate estimate of the quality values of the rest of the products and wider "buffer zones" are required. Thus, the present invention makes it more likely that a check of the production process will be carried out when it is required, and thus reduces the risk that products outside the range LL to UL will be produced.

Specifically, the present invention proposes a method of controlling a production process producing products, the method comprising repeatedly performing the steps of:

(i) inspecting a sample of the products to determine a quality value for that sample product;

(ii) determining whether the quality value of the sample product is outside a range defined by one or more variable control limits, and in this case instigating a modification and/or check of the production process;

(iii) using recent quality values to derive a variability value for the quality value; and

(iv) updating the variable control limits in accordance with respective predefined limit values, the variable control limits becoming closer to or further from the respective predefined limit values according to whether the variability value becomes respectively higher or lower.

Preferably, there are variable upper and lower control limits, and in step (ii) the determination is positive if the quality value of the sample is above (below) the variable upper (lower) control limit. In step (iv), the variable upper (lower) control limit is updated to be equal to the predefined upper (lower) limit value minus (plus) a positive value which is a function of the variability value.

This positive value may a linear function of the variability value, with a positive linearity constant A. For example, if the variability value is the standard deviation σ of the quality value of the sample, the variable upper (lower) control limit is updated to equal the predefined upper (lower) limit value minus (plus) $A\sigma$.

The value of A thus influences the width of the buffer zones. It may be selected based on the proportion of the produced products which are inspected.

For example, suppose that each product of the production process is treated as an independent sample from a Gaussian distribution having a mean value and a standard deviations, then if a very large number of products are produced a few of those products will be several standard deviations from the mean, according to known statistical rules. For this reason, if a very small proportion of the products produced by the process are inspected, there is a correspondingly high chance that one of the products which was not expected will depart very far from the most outlying of the samples. Accordingly, in this case the buffer zone (which as in the prior art compensates for the possible

discrepancies between the sampled products and the rest of the population) should be wider.

Specifically, the value of A may be selected to ensure that, if the determination in step (ii) is negative, the probability that any product produced during a predefined period (e.g. the sampling interval) is outside a range defined by the predefined limit values, is less than a predefined probability value, such as 0.5.

Although the invention has been described above in terms of a method, alternatively the invention may alternatively be expressed as a system for controlling a production process.

Brief Description of the Figures

An embodiment of the invention will now be described in detail with reference to the following figures in which:

Figure 1, which is composed of figures 1(a) and 1(b), illustrates a prior art control method;

Figure 2 shows quality value distributions leading to the results shown in figure 1;

Figure 3 is a figure for explaining an embodiment of the present invention;

Figure 4 is a control system according to the present invention;

Figure 5 shows a process monitored by a prior art system; and

Figure 6 shows the process of figure 5 monitored by the embodiment of figure 4.

Detailed Description of the Embodiments

Referring firstly to figure 3, a graph is shown of the presumed frequency distribution of the quality value x at a time at which the quality value x_s of a

sample product has just been measured. It is supposed that the distribution is a Gaussian distribution having a mean value x_s and a standard distribution σ. If this distribution is correct, then the proportion of the products which will have a quality value x higher than the upper limit UL is C, which is proportional to the area under the distribution to the right of UL on fig. 3.

Suppose that we are considering a production process which is producing sixty products per hour, and that one sample is measured every hour. In other words, our one sample, having quality value x_s, is one of sixty products produced in the same hour. We define P_c as the probability that x is greater than UL (which as mentioned above is proportional to the area C). Thus, the probability that at least one of the sixty products produced during the hour has a quality value above UL is $1 - (1 - P_c)^{60}$, which we can proximate as $P_c \times 60$.

If this value is less than 0.5, then it is likely that none of the sixty products have a quality value above UL. We define the value of x such that $P_c \times 60$ is equal to 0.5 as x_{UL}. In other words, if $x_{UL} < UL$, then there will probably be no faulty ("No good" – NG) products in the population of 60 products.

Thus, we can define the maximum value of x_s for which we can be confident that there are no faulty products (in other words the dynamic UCL) as equal to UL – m where m is equal to $x_{UL} - x_s$. Specifically, if $P_c \times 60 < 0.5$, then $P_c < 0.00833$. Referring to a standard table of the cumulative probabilities under a normal distribution, this gives us that m is equal to 2.39σ.

More generally, i.e. even if the number of products is not 60, or if we require a certainly level different to (e.g. above) 0.5, then the dynamic UCL can be written as UL – $A\sigma$ for some value of A which can be derived from the standard normal distribution cumulative probability table.

Referring to figure 4, a monitoring system 1, which is embodiment of the present invention, is shown monitoring a product production process 3. The output of the production process 3 is products. A sample of these products are transmitted to an inspection device 5 of the monitoring system 1, which outputs the quality value for each sample product. The quality value is fed to a derivation unit 7 which derives the standard deviation of the last few quality values (e.g. the last five or ten values). For example, writing the last N quality values as $\{x_n\}$ for $n=1,\ldots,N$, the mean of recent values $\bar{x}$ can be written as

$$\bar{x}=\frac{1}{N}\sum_{n=1}^{N}x_n, \qquad (1)$$

and the standard deviation σ can be written as

$$\sigma=\frac{1}{N}\sum_{n=1}^{N}(x_n-\bar{x})^2. \qquad (2)$$

The derivation unit 7 sends the standard deviation to an update unit 9. The update unit 9 also receives information from an interface unit 11. Using the interface unit 11 a user is able to input into the monitoring system 1 the values of LL and UL, together with information informing the monitoring system 1 of the proportion of the products which are being sampled and a probability value indicating the certainty with which the user wishes to ensure that none of the unsampled products are outside the range defined by LL and UL.

Using this input data, the update unit 9 is able to produce an updated value for the dynamic upper control limit and the dynamic lower control limit, by the manner described above in relation to figure 3. It feeds these two dynamic control limits to a determination unit 13 which also receives the quality value from the inspection device 5. Thus, the determination unit 13 is able to compare each quality value with dynamically-varying control limits.

Optionally, following an updating of the control limits by the update unit 9 caused by a new quality value, the updated control limits may be fed to the determination unit 13 in time for the determination unit 13 to compare whether that same new quality value falls between them.

The output of the determination unit 13 is a warning signal which indicates to a user that the production process 3 should be check and/or monitored because there is a significant risk that some products produced by it will be outside the range defined by LL and UL.

Referring now to figures 5 and 6, a comparison is made of the operation of the prior art monitoring system described above and a monitoring system according to an embodiment of the present invention. Both of these monitoring techniques are applied to the same set of "quality data" which is a series of quality values at different times. These quality values at different times are shown as the waving line in fig. 5, which is also present in fig. 6. Fig. 5 shows the prior art case in which the UCL and LCL are constant. Fig. 6 shows the case in which the UCL and LCL are dynamic, according to an embodiment of the present invention. These dynamic UCL and LCL are shown as the uppermost and lowermost varying lines on fig. 6.

Referring to fig. 5, at a time A the prior art system registers that the quality values are above the constant UCL, and thus issues a warning indicating to the user that the production process should be checked and/or adjusted. At a time B, however, the prior art system notes that the quality values are between the constant UCL and LCL, so no warning signal is issued.

By contrast, referring to fig. 6, at time A, the embodiment notes that although the quality values are high, they are nevertheless below the dynamic UCL. This is because the variability of the quality values is low, and therefore the

dynamic UCL is high. Thus, no unnecessary warning signal is generated by the determination unit 13.

At time B, however, although the quality value is not particularly high, it is nevertheless higher than the dynamic UCL, since the variability in the quality value indicates that the quality values of the sample products are not necessarily a good indication of the quality values of the unsampled products. Thus, at time B the monitoring system issues a warning signal from the determination unit 13.

Note that the process shown in figures 5 and 6 is one for which the quality value is expected to be symmetrically distributed about 0. This leads to the dynamic UCL being simply the negative of the dynamic LCL. In such a case, it is unnecessary to treat these two control limits as separate variables, and a single dynamic control limit can be used instead.

Although the invention has been explained above with reference to particular embodiments, many variations are possible within the scope of the invention as will be clear to a skilled reader. For example, an embodiment of the invention may be contemplated in which only one of the control limits is dynamically modified, and the other control limit is constant, as in the prior art.

Furthermore, the invention may be applied in the case that there are a plurality of different quality values for each product (e.g. one quality value may be the weight, another may be the height dimension, and another the width dimension). In this case, dynamic (upper and/or lower) control limits may be provided for each of the quality values, all varying dynamically as a function of the variability of the corresponding quality variable. The production process may be frozen, for checks and/or modifications, when any of the quality

values of any sample moves out of the range defined by the corresponding dynamic control limits.

Claims

1. A method of controlling a production process producing products, the method comprising repeatedly performing the steps of:

(i) inspecting a sample of the products to determine a quality value for that sample product;

(ii) determining whether the quality value of the sample product is outside a range defined by one or more variable control limits, and in this case instigating a modification and/or check of the production process;

(iii) using recent quality values to derive a variability value for the quality value; and

(iv) updating the variable control limits in accordance with respective predefined limit values, the variable control limits becoming closer to or further from the respective predefined limit values according to whether the variability value becomes respectively higher or lower.

2. A method according to claim 1, in which:

the variable control limits include an variable upper control limit and the predefined limit values include an predefined upper limit value;

in step (ii), the determination is positive if the quality value of the sample is above the variable upper control limit; and

in step (iv), the variable upper control limit is updated to be equal to the predefined upper limit value minus a positive value which is a function of the variability value.

3. A method according to claim 2 in which the variability value is the standard deviation σ of the quality value of the sample, and in step (iv) the variable upper control limit is updated to equal the predefined upper limit value minus $A\sigma$, where A is a positive constant.

4. A method according to claim 1, in which:

the variable control limits include an variable lower control limit and the predefined limit values include an predefined lower limit value;

in step (ii), the determination is positive if the quality value of the sample is below the variable lower control limit; and

in step (iv), the variable lower control limit is updated to be equal to the predefined lower limit value plus a positive value which is a function of the variability value.

5. A method according to claim 4 in which the variability value is the standard deviation σ of the quality value of the sample, and in step (iv) the variable lower variable control limit is updated to equal the predefined lower limit value plus $A\sigma$, where A is a positive constant.

6. A method according to claim 3 or claim 5 in which the value of A is selected based on the proportion of the produced products which are inspected.

7. A method according to claim 6 in which the value of A is selected to ensure that, if the determination in step (ii) is negative, the probability that any product produced during a predefined period is outside a range defined by the predefined limit values, is less than a predefined probability value.

8. A method according to claim 7 in which the predefined probability value is 0.5.

9. A system for controlling a production process producing products, the system comprising:

(i) inspection means for inspecting a sample of the products to determine a quality value for that sample product;

(ii) determination means for determining whether the quality value of the sample product is outside a range defined by one or more variable control limits, and in this case instigating a modification and/or check of the production process;

(iii) derivation means for using recent quality values to derive a variability value for the quality value; and

(iv) updating means for updating the variable control limits in accordance with respective predefined limit values, the variable control limits becoming closer to or further from the respective predefined limit values according to whether the variability value becomes respectively higher or lower.

10. A system according to claim 9 in which:

the variable control limits include an variable upper control limit and the predefined limit values include an predefined upper limit value;

the determination means makes a positive determination if the quality value of the sample is above the variable upper control limit; and

the updating means updates the variable upper control limit to be equal to the predefined upper limit value minus a positive value which is a function of the variability value.

11. A system according to claim 10 in which derivation means is adapted to derive the variability value as the standard deviation σ of the quality value of the samples, and the updating means updates the variable upper control limit to equal the predefined upper limit value minus $A\sigma$, where A is a positive constant.

12. A system according to claim 9 in which:

the variable control limits include an variable lower control limit and the predefined limit values include an predefined lower limit value;

the determination means makes a positive determination if the quality value of the sample is below the variable lower control limit; and

the updating means updates the variable lower control limit to be equal to the predefined lower limit value plus a positive value which is a function of the variability value.

13. A system according to claim 12 in which the variability value is the standard deviation σ of the quality value of the sample, and the updating means updates the variable lower variable control limit to equal the predefined lower limit value plus $A\sigma$, where A is a positive constant.

14. A system according to claim 11 or claim 13 n which the value of A is selectable to ensure that, if the determination in step (ii) is negative, the probability that any product produced during a predefined period is outside a range defined by the predefined limit values, is less than a predefined probability value.