On the Appropriate Preparation and Realization of Production Process Quality Attribute Measurement

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Abstract. In this paper we are dealing with the methodology of design, preparation and implementation of quality features measurement of the production process. The aim is to develop a methodology for measuring parts in the structure. This article describes the procedure of the sample process management methodology.

1. Introduction

The manufacturing plant produces products that are expected to be of required quality and the producer should be able to determine and maintain the desired price of the product. In order to achieve the required or higher product quality, it is necessary to have a well-organized and technically mastered production process. Furthermore, it is necessary to eliminate unnecessary downtime in the production process, e.g. to avoid wasting time in moving the workpiece on the production line, etc. In some cases it might be appropriate to replace human labor with machines to increase the production efficiency, reduce costs and eliminate errors eventually introduced by human factor. However, the quality of the final product is usually determined in a fundamental way by the pre-production stages, especially by the design. At this stage it is essential to take into account the environmental conditions, resources and the capabilities of the contractor (manufacturer). Already when creating the technical documentation and technical drawings, a suitably designed measuring basis for quality verification must already be taken into account.

2. Description of pre-production stages

Before starting the production process, it must always be clear what will be the final product and who are customers that will be buying it. It should be a-priori known when (how often) the product will be innovated, to keep the customer satisfied with the product. The producer must be sure that the product will be still in demand. Therefore, it is necessary to set in advance the production objectives and the procedures leading achieve and verify them (process monitoring). First, let’s take a look on the prerequisites for a good quality and efficient production process:

ISO documentation: The benefit of the established and effective ISO documentation according to the standard ČSN EN ISO 9001: 2016 (Quality Management System) lies in the formalization of the company's internal processes, which results in the use of approved and verified procedures.

Properly maintained metrological order: All measuring devices must be in accordance with legal metrology, i.e. a controlled process according to the Act on Metrology No. 505/1990, Coll. as amended. The aim of this disposal is to minimize influence of the measuring device, environment, used measurement methods, operator and used software equipment. The measurement process defined
in this case is in some cases subject of analysis of the measurement system (accuracy, repeatability, linearity, ...), which provides us with information on whether the measurement system meets the intended purpose, is objective, or whether our measurements will be accepted by the customer. The measurement process is also influenced by professionally qualified staff and the environment.

**Customer requirements:** The customer enters the design process both by defining required product properties (parameters, tolerances,...), but also requirements for verifying quality of the production process (indicators of competence, performance, management of control diagrams, etc.).

**Recording of measurement data:** Before data collection begins, it should be specified which data will be monitored, recorded and how frequently. Moreover it is necessary to decide whether to check every piece or every $x$-th piece. [1]

Scheme of the procedure before the analysis of the production process is described in Figure 1. According to [4] it is possible to set other possible approaches of the methodology of complex design of the control diagram. Here we follow the division of data into continuous and discrete.

![Figure 1. Scheme of the procedure before the analysis of the production process](image_url)

3. **Process analysis**

There is an increasing need to use new and faster technologies to measure and control parts in the mechanical engineering. Calibrated gauges are used for higher production quality and more accurate production. Inspection jigs are used in mass production for the inspection of manufactured parts. Inspection jigs are single-purpose devices without evaluation electronics, which enable cheap, fast and simple inspection of manufactured components with minimal demands on the operator. The jig operator verifies for example that the inserted inspected part has shape and dimensions that conform to specifications. The inspection elements are fixed on the base plate of the jig, so that they correspond to the model of the inspected component within the specified tolerances. The devices should meet basic important parameters, such as the handling given device, quick and easy inspection of parts and assemblies, reliability and accuracy of the measurements. When designing the product, 3D construction programs are used, guaranteeing high productivity and clarity. The use of products...
reduces scrap and increases accuracy in the production process, further increases labor productivity
and reduces the price of the product.

Serial production has an effect on the design of fixtures. In the production of a large number of
manufactured pieces, a better preparation is required for a small number of pieces, a simpler and
cheaper preparation. If workpieces of similar size and shape are produced at a given point in time, they
can be combined into one jig. In terms of technological feasibility, it is necessary to study the
production documentation, including production processes. These are, for example, the quality of the
machined surfaces, the prescribed dimensions, the size of the machine tool, the number of operations,
sequences and operations, etc. The design of the jig must not allow the reverse insertion of the object.
Positioning and clamping of the workpiece and its release and removal from the jig must be possible
in a short time. All sharp edges must be rounded due to possible injury to the operator. When using
delimiting mandrels with the same line diameters, it is necessary to distinguish them (by color, mark).
In practice, the POKA-YOKE method is used.

When analyzing the production process, we use basic statistical methods, which include, among
others:

1) Calculation of the sampling characteristics. These characteristics (sampling mean, range,
standard deviation, ...) are used for the analysis of measured values (data). It is important to realize
that the resulting value of the selection characteristic is its point estimate and depends on the method
of data collection, unlike the process parameters, which we estimate through the selection
characteristics.

2) Histogram and box plot belong among the most important graphical tools for the basic process
analysis. It provides us with the information about the shape of the probability distribution, process
settings, variability, etc.

3) Control chart is a graphical representation of a (typically sequential) test with the value of a
controlled variable or its parameter. The scope for continuing process monitoring is the band defined
by the LCL (lower control limit) and UCL (upper control limit), while the scope for stopping the
process is the areas outside these limits. Using appropriately selected control diagrams, we can obtain
information (signal) that a detectable cause of variability has started to act in the process, which needs
to be identified, eliminated and such measures taken so that it cannot be repeated. We usually monitor
the selected process parameters at specified time intervals, when we perform so-called inspections.
Inspection consists of one or more measurements. From these measurements we calculate the
sampling characteristics, most often the sampling mean and the sampling standard deviation. These
statistical characteristics provide us with information about the changes of parameters of the studied
process quality feature as shown in Figure 2.

![Figure 2. Shewhart control chart (left CL = 50 and σ = 0,5) and right diagram extended by
warning limits.](image-url)
- process changes;
- occurrence of correlated data;
- number of quality characteristics monitored simultaneously;
- correlation between monitored quality characteristics.

The best known type of control diagram is the Shewhart control diagram, as shown in Figure 2. In practice, this type alone is not sufficient, so many other types of control diagrams have been invented. Control diagrams can be divided into one-dimensional and multidimensional, where each type is best suited for a different process. Control diagrams can be divided into groups according to various aspects:

- according to the nature of the monitored quantity to:
  - control measurement diagram for quantitative (measurable) data obtained by measuring and recording numerical values of the characteristics for each unit in the considered group during inspection
  - a control chart by comparison for qualitative data plotting the number of discrepancies between the observed units and the standard.

- according to the number of monitored variables to:
  - one-dimensional, always following only one characteristic. This includes, for example, the classical Shewhart plot for the mean or variance
  - multidimensional, monitoring several characteristics simultaneously in a single graph. When displaying them, the so-called Hotelling distances are often used.

- according to the number of inspections needed to calculate the last value:
  - classical, using data found only during the last inspection (always drawing only the last measured value of the monitored characteristic)
  - using k previous inspections (measurements) to calculate the actual evaluation value. This includes control charts of moving totals, either unweighted (MA diagram) or weighted (EWMA diagram)
  - using the entire measurement history in a given cycle to calculate the last characteristic. This includes so-called CUSUM diagrams or zone diagrams.

- according to the frequency of inspections
  - classic with a constant time between individual inspections,
  - adaptive, in which the frequency of inspections changes based on the last value.

Before analyzing the process itself, it is necessary to answer the following questions:
- which quantity / quantities need to be monitored?
- Which properties of the production process are influenced by this quantity and vice versa, how are they influenced by this process?
- What exactly does it mean from an operational point of view that the "process is under control"?
- What are the risks when the process is "out of control"?
- Can the process continue during the identification of the identifiable cause (signal verification)?
  What is the risk?
- Can the process continue during maintenance operations? What is the risk?
- What are the cost items (losses) and their quantification?

Only after answering these questions can we continue to design a regulatory diagram, which should be implemented in the following steps:
1) Analysis of the production process. In the first step, we will perform an analysis of the production process, the result of which will be the determination of a controlled variable, the behavior of which we will monitor. We should focus on the influences that affect it and how it affects this process. From an operational point of view, we should determine when the process is under control and when out of control. Whether it is necessary to stop the process in case of finding a detectable cause or not, and whether the production process continues during maintenance or not.

2) Stochastic analysis. In the second step, we analyze the process in terms of its stochastic properties, i.e. we determine the probability distribution of the controlled variable and its time to failure. We find out the probability distribution of the repair or maintenance time. Using the (auto) correlation function in time, we analyze the dependencies of controlled variables.

3) Selection of control diagram. The third step is the most important point of the whole design, where we select the most suitable type of control diagram, which signals the detectable cause in time and minimizes the occurrence of false signals. Individual control diagrams have different sensitivities to different types of deviations (changes). For example, the Shewhart control diagram is able to very effectively capture a large shift (sudden changes) in the monitored process level. On the other hand, CUSUM is much more suitable when the process change is gradual or there has been a small shift. They can be used in various conditions, which also depend on the technical equipment and the complexity of the calculation of the individual control diagrams. We choose the control diagram according to the nature of the controlled variable, if we monitor more characteristics at the same time, we choose according to the number of controlled variables. We take into account the dependence structure of the observed (stochastic) process. When choosing a control diagram, we emphasize not only its ease of use in operation, but we also take into account economic aspects.

4) Selection of the optimal maintenance strategy. In the fourth step, we select the optimal maintenance strategy. Preventive maintenance can significantly reduce production costs and increase its quality. To do this, it is necessary to determine the optimal intervals and ranges of scheduled maintenance. From the point of view of the economic-statistical design of the control diagram, we will continue to consider complete maintenance, which is performed either at predetermined regular intervals or always after signaling by the control diagram.

5) Economic-statistical optimization. The economic-statistical design takes into account both economic parameters and statistical properties of the control diagram. The statistical properties of the control diagram include the ARL value. This serves primarily to optimally set the parameters of the control diagram, by which we reduce the costs not only of statistical control, but also of the loss of quality of the controlled process. Optimized parameters include the sampling range, the length of the interval between inspections in hours, and the width of the control limits, which are usually reported in multiples of the standard deviation of the observed steady state process in which the process is under statistical control.

From the point of view of the economic design of the control diagram, we assume that there are costs for measurement (inspection), which can be divided into variable and fixed costs. At an unknown moment \( v \), a detectable cause occurs that moves the process out of statistical control. If the process is in a state under statistical control, it means that a false signal has occurred, we only count on the cost of finding a false signal. If the signal is justified, we count on the cost of finding and removing the detectable cause.

6) Rules for implementation. In the last step of the control diagram design, we focus on the correct way of its application, where we set the rules of use and ensure their compliance in an appropriate manner. We will introduce rules for the use of control diagrams in the organizational rules of the given production company, by which we will determine the conditions of measurement and sampling, we will assign the powers and responsibilities of individual workers for the correct measurement and evaluation of samples. We will reserve space for the analysis of samples and ensure timely intervention in the detection of an authorized signal.

Average Run Length (ARL) is the average run length of a process, often just the average number of inspections that take place before signaling that a process has reached a statistically unmanageable
state. This quantity depends on the probabilistic behavior of the process. The ARL should be maximal if the process is in a statistically controlled state.

Figures 3 and Figure 5 schematically show the procedure to be followed in the case of data with a normal distribution. [2], [3], [4].

**Figure 3.** Scheme for continuous data the analysis of the production process

**Figure 4.** Scheme for discrete data the analysis of the production process
Figure 5. Scheme continuation for continuous data the analysis of the production process (with $C_p$)

4. Eligibility and performance indicators process
A number of statistical software tools is used to evaluate the competence and performance of the production process. Unfortunately, they are not always used completely correctly, it is always necessary to verify the assumptions so that their conclusions and interpretation are not misleading. In the case of a normal division of the quality mark, the formulas below are used. If there is no normal distribution of the quality characteristic, a different formula will be used to calculate the eligibility and performance indicators. It can be, for example, the Weibull distribution, the log-normal distribution, etc. If the values of the monitored quality trait are not normally distributed, the Johnson transform can be used so that the newly transformed data is then distributed normally $N(0; 1)$.

Figure 5 shows at which stage of the production process the calculation of competence and performance indicators is performed.

- The $C_p$ competency indicator does not take into account the issue of process centering, but characterizes only what we are able to achieve.
- The $C_{pk}$ competency indicator, on the other hand, takes into account degree of centering of the process achieved, and characterizes what we have actually achieved.
- The performance indicators $P_p$ and $P_{pk}$ are based on variability over a longer period of time, assessed by the total standard deviation for this period.

The parameters $C_p$ and $P_p$ do not consider the position parameter. Thus, the process may have a high $C_p$ and $P_p$ value while producing a high percentage of mismatched pieces. If the process is centered, the proportion of non-conforming pieces decreases, which is achieved by the indicators $C_{pk}$ and $P_{pk}$. The introduction of these indicators is based on the assumption of a normal distribution, where $\mu$ is the location parameter, i.e. the mean value of the normal distribution.
$$C_p = \frac{USL - LSL}{6\sigma}, \quad P_p = \frac{USL - LSL}{6s_{TOT}}; \quad C_p \geq P_p$$

$$C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}; \frac{\mu - LSL}{3\sigma}\right); \quad P_{pk} = \min\left(\frac{USL - \mu}{3s_{TOT}}; \frac{\mu - LSL}{3s_{TOT}}\right); \quad C_{pk} \geq P_{pk}$$

If the value of $C_p < 1$, the process is not eligible, $C_p = 1$ the process is close to eligibility and $C_p \geq 1.33$ the process is eligible. [5]

**Figure 6.** Probability density for Shewhart’s control chart with normal distribution $X \sim N(\delta_0, \sigma^2)$

Assuming normality we have:

- In the interval $< \delta_0 - \sigma; \delta_0 + \sigma>$ lies 68.26% of all observations, outside this interval lies 2 * 15.87%, i.e. 31.74%.
- In the interval $< \delta_0 - 2\sigma; \delta_0 + 2\sigma>$ lies 95.44% of all observations, outside this interval lies 2 * 2.28%, i.e. 4.56%.
- In the interval $< \delta_0 - 3\sigma; \delta_0 + 3\sigma>$ lies 99.73% of all observations, outside this interval lies 2 * 0.135%, i.e. 0.27% (2,700 ppm).
- In the interval $< \delta_0 - 4\sigma; \delta_0 + 4\sigma>$ lies 99.994% of all observations, outside this interval lies 2 * 0.003%, i.e. 0.006% (60 ppm).
- In the interval $< \delta_0 - 5\sigma; \delta_0 + 5\sigma>$ lies 99.99994% of all observations, outside this interval lies 2 * 0.00003%, i.e. 0.00006% (0.6 ppm).
- In the interval $< \delta_0 - 6\sigma; \delta_0 + 6\sigma>$ lies 99.999999999% of all observations, outside this interval lies 2 * 0.00000001%, i.e. 0.000000002% (0.002 ppm).

Mismatch rate - ppm (parts-per-million) expresses the number of mismatched pieces in a million series. The number 10-6 ppm then expresses the probability of occurrence of a mismatched piece. [5]

**5. Conclusions**

Each measurement in design case specific. Whether it is a classic measurement of lengths or the measurement of geometric tolerances, e.g. throwing, etc., it is always necessary to verify the assumptions for the use of statistical methods to avoid erroneous conclusions. As mentioned earlier, it is necessary to verify the assumptions of normality for the use, whether of control diagrams or for the use of competence and performance indicators. In many cases, in practice there is no theoretically pure solution, often because of inability to meet certain assumptions. The practitioner, however, must always find a solution, must decide in a specific case and give the best possible answer to the question asked. He has to intuitively choose the optimal, practically possible solution from all that are offered to him.
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