# APPLICATION OF COORDINATE MEASURING MACHINES IN STATISTICAL CONTROL OF TECHNOLOGICAL PROCESS

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**Abstract**: *The following paper presents the application of coordinate measuring machines in statistical control of technological process. The place of statistical control of the process by means of coordinate measuring machines was shown in the whole area of quality systems as well as in the logistic chain of product's manufacturing. Coordinate measuring machines have statistical modules included in their software, which can be used for statistical control of the process. The demands regarding the increasing quality of products as well as customer's preferences sets new tasks for the software of coordinate measuring machines, regarding power of statistical modules of coordinate measuring machines. Statistical reports of measurements by means of coordinate measuring machine from chosen production cycle were shown.*
***Key words***: *coordinate measuring machines, statistical control, technological process.*

## 1. INTRODUCTION

Customer oriented demands of modern market caused the development of Elastic Productive Systems. More often does the production process take place in short series with prompt delivery to the customer. In such conditions all control operations have to be adapted to the elastic production as well as to various measuring tasks aiming at presentation of complex geometrical specification of the product. Such tasks in days of today's requirements are met by coordinate measuring machines equipped with appropriate software. These machines are used on all stages of production starting from delivery control, on final inspection ending. Therefore on every stage of control there is possibility of exploitation of statistical control of the process. So, on each stage of production process there is possibility of the process follow-up by means of appropriate statistical data.

The coordinate measuring machines have in their basic software, apart from possibilities of basic geometrical volumes' measurements, the capability of shape and orientation deviation measurement as well. Parallelism measurement is practically realizable on measuring machine only. Complex measurement and computational procedures are executed automatically and the results can be represented either in textual or graphical form.

Particular attention in ISO 9000 standards is set on manufacturing process control. Process control includes accuracy control of the product's execution on each possible manufacturing stage when the change of product's characteristics takes place. Logistic co-operation between the sub-supplier, the producer and the receiver in range of control of the product is based on data exchange of individual control stages and on data transfer in form of statistical reports.

It is then here when we meet the special logistic management consisting of the dataflow between the supplier and the recipient of articles and appropriate information transferring aiming at the best adaptation to the customer's needs. The aim of the logistic management is strategic assurance of required level of customer's service. The management also combines distributional functions with production and supply stages [4,5].

TQC - total quality control including statistical quality control is the newest approach in quality shaping. Quality control apart from control also influences the quality of product starting from the project throughout productive processes. The product of expected quality delivered to the customer with its appropriate confirmation is to be the final effect. Care about products' quality concerns whole logistic chains. Logistic processes related control should include product and package design phase. Owe to logistic controlling it is possible to obtain as well as utilize credible information of quality state too. Actions in this sphere should first of all aim at elaboration of complex programs for accurate methods of quantitive determination of quality level as well as for appointment of directions of quality promoting actions in range of the whole enterprise, in the aspect of logistic management [3].

## 2. STATISTICAL PROCESS CONTROL (SPC)

SPC is a widely understood quality control together with utilization of the following statistical methods: statistical control tools, experiments' planning methods used for interfering and influencing the process in order to improve it and hold in specified limits. Quality control by means of statistical methods allows a considerable improvement of qualitative values of products and services. All quality control procedures are based on various conceptions of control cards aiming at the supervision of qualitative parameters on specified stage of technological process. The possibility of process control is important and helpful feature of statistical evaluation of products and processes.

Statistical process control is a series of statistical techniques and methods aimed at continuous improvement of quality of production processes or services. In order to collect process data it is necessary to observe the correct variability of the process. Two types of process variability can be distinguished:

- random (accidental) – caused by changes of temperature, humidity, vibrations etc.; in this case the process is under static control;
- systematic – caused by changes of instrumentation, machine's start-up, deregulation of the measuring-controlling apparatus etc.; the process is then out of static control.

Statistical methods are used in a planned way and in crucial places. They should assure such lowering of prime costs, which will produce a profit in general balance.

For the SPC the following kinds of control cards can be distinguished:

- Real-time quality control cards based on the idea of Shewhart's cards:
  - cards $\bar{X}$ *and R*, $\bar{X}$ *and S*, $\bar{X}$ *and* $S^2$,
  - short series control cards $\bar{X}$ *and R*, $\bar{X}$ *and S or* $\bar{X}$ *and* $S^2$,
  - multi-source grouped control cards
  - alternative characteristic evaluation cards (*C,U,* $N_p$*. i P*),
  - short series control cards with alternative characteristic evaluation *(C, U, Np. i P),*
  - $T^2$ Hotellings card,
  - CUSUM card (relating accumulative sums), MA (relating moving average) and EWMA (relating exponentially weighed moving average),
  - short series control cards for MA and EWMA,
- Regressive control cards,
- Pareto card.

In order to build a typical control card based on Shewhart's idea the selection of results' wey during process course control has to be made at first and then axled perpendicularly in the chart, then it is necessary to:

- select time interval,
- determine tolerance limits by:
  - delimitation of the average called central line – LC. which represents the expected value of the studied parameter in the test or its nominal value.
  - delimitation of standard deviation magnitude, which is usually the upper tolerance limit GLT or else upper control, limit GGK. The GLT is equal to the total of the average and three standard deviations.
  - the delimitation of the lower tolerance limit DLT (the lower control line), which equals the total of the average and three standard deviations,
- marking of the average and tolerance limits on the perpendicular axis and leading the ruled lines to all of these points along the horizontal axis of the chart,
- introduction of data in chronological order,
- designment of the line joining individual data.

Central lines are calculated on the basis of various kinds of data:

- the contribution of inconsistent elements in the sample,
- the number of incompatibility in the selected area,
- the number of incompatibilities for the element,
- the average value in the sample,
- gap in the sample,
- standard deviation in the sample.

Exploitation of the SPC techniques allows making sure whether the process is capable of performing the set requirements and whether it fulfils these requirements at any time. It also allows undertaking appropriate correctory actions when the process does not fulfill the set requirements.

## 3. TECHNOLOGICAL PROCESS CONTROL BY MEANS OF COORDINATE MEASURING MACHINES

The utilization of coordinate measuring machines for statistical process control enables realization of many measurements, i.e.: measurement of cylinder diameter, deviation of cylindricity as well as position in relation to base. By means of CMM indirect measurements are eliminated, which were executed by means of complicated devices or standards demanding additional instrumentation.

The coupling of measuring processes with statistical process control makes it possible to integrate metrological functions of the measuring system with possibilities of graphic representation of repeatable data in the system of various kinds of control cards. During statistical process control by means of CMM there is the possibility of free choice of control cards for the investigated characteristics. The following are generated by means of CMM: R control cards (the gap), S (standard deviation), X (average value) as well as the trend and histogram.

The coordinate measuring machines realize their tasks of product characteristics determination during its initial productive stage as well as on selected stages. At this juncture the determination of lacks formation place and their magnitude is easily performed. The flow chart of technological process with various control places by means of CMM is shown in fig.1.

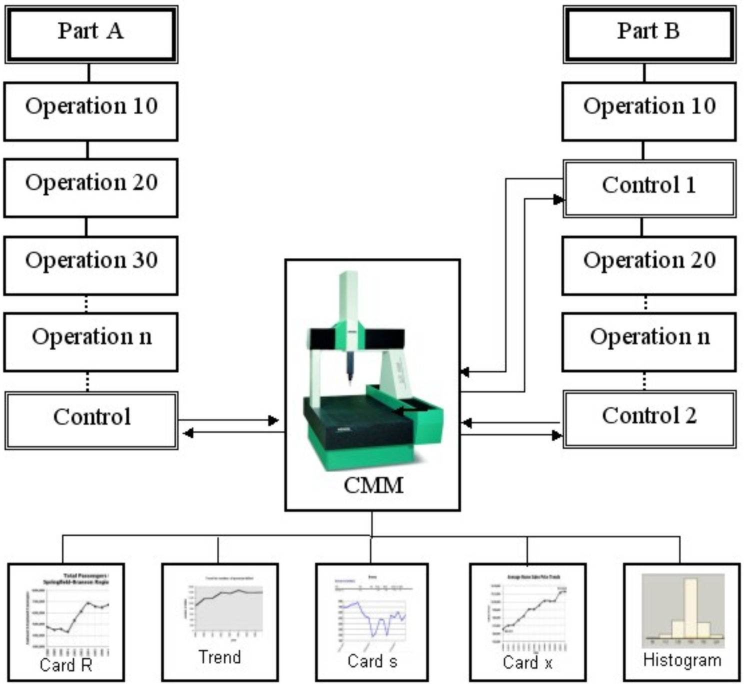



*Fig.1. Course of technological process with use of measuring machine control*

## 4. EXAMPLE OF APPLICATION OF CMM FOR SPC

### 4.1. Methodology of the test

The measurement of the unit shown in fig. 2 was executed for representation of statistical data from coordinate measuring machine. The inside diameter of nominal dimension ∅ 34H9 was subject to process variability analysis. Diameter measurement strategy was taken as measurement of cylinder by 2 circles at sampling depth of 3 and 10 mm from the upper reference plane. 20 measurements of diameters in elements chosen at random from were taken.

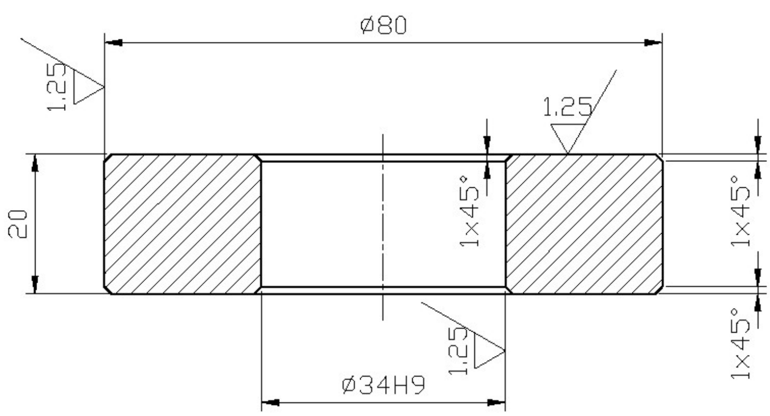



*Fig.2. The element measured on coordinate measuring machine*

The coordinate measuring machine used was Wenzel LH54 equipped with touch-trigger probe and Metrosoft 3.41 software. Measurement uncertainty of machine at $MPE_E$ = 2,5 + L/450. The measurements were taken in automatic cycle in order to minimize the influence of error effecting from service and measuring strategy.

### 4.2. Results of measurement

For the analysis of process variability 20 identical elements were used the measurements of inside diameter of which were taken. The received data enabling the generating the selected Shewart's cards from the program:

- **The $\bar{X}$ cards**

This card is also called the position control card. It is formed by means of location of values of average measurements results for the given sample in fixed and standardized intervals on it. The average values located on the card represent the test of significance for the expected process value, the estimator of which is mean process value, the one which is established on the basis of constructional or technological data. It can be also appointed from pilot test measurements. The X card is usually accompanied by the R card, which controls the dispersion stability of the studied characteristics.

- **The R cards**

These are used for determination of dispersion invariability in time. The position of control limits for the R card is computed from the following formulas:

$$DLK_{(R)} = D_{(1-\alpha/2)}\,\bar{R}\,; \qquad GLK_{(R)} = D_{\alpha/2}\,\bar{R}\,,$$

where: $DLK_{(R)}$, $GLK_{(R)}$ – correspondingly: lower and upper check line for the gap, $D_{\alpha/2}$ *and* $D_{(1-\alpha/2)}$ – the numbers matching conditions: $P(R \geq D_{\alpha/2}\bar{R}) = \alpha/2$ *and* $P(R \leq D_{(1-\alpha/2)}\bar{R}) = \alpha/2$.

- **The S cards**

If the gap becomes a non-effective measure of variability of the given process then it is necessary to use the standard deviation. The control limits in the S card are established by means of standard empirical deviation.

Control cards are based on mathematical statistics. The systematic management of cards is essential for the obtainment of confirmation that the applied process control means warrant stability of this process. In case when deregulation signal appears on the card correctory and repair actions must be taken. Reacting on any signals and elimination of causes of any instability, going beyond the limits of fixed deviation on regular basis contributes to maintaining stability of the process. Control cards are also used for determination whether the given process is adjusted and stays under control as well as whether normal or special variability causes influenced the process.

The preservation of long-term process stability is the main task of complex quality assurance. The analysis of qualitative ability of the process serves this aim; in some cases also the qualitative ability for the machines is used.

Additional requirements for the stable process are set, depending on determination what percentage of measurement values should be found in tolerance limits. Two kinds of qualitative ability coefficients are used:

- $C_m$ - the qualitative capability of the machine. It is used for acceptance of constructively new machines or the ones after repair as well as for selection of machines and devices in design phase of production process;
- $C_p$ – the qualitative ability of process – practical in opinion the efficiency of process near foundation that the process is normally realized The of results contained dispersion is in range × ± 3σ.

Process should match customer's requirements for long and therefore it must have the so-called long-lasting capability which is characterized by two coefficients: $C_p$ *and* $C_{pk}$.

The $C_p$ coefficient defines whether range ± 3σ is smaller than tolerance range:

$$C_p = \frac{pole \quad tolerancji(T)}{6\sigma_p} \geq 1{,}33,$$

where: $T = GLT - DLT$, $\sigma_p$ – standard deviation of value of all process measurements in longer period.

Assumption that $C_p \geq 1{,}33$ value the reliability exists that 99,7 % of the realized production shall match the requirements relating quality, however random variables have in such case to be subject to Gaussian distribution.

The $\boldsymbol{C_{pk}}$ coefficient defines the position of tolerance measurements' value in tolerance range. It is the measure of the process centering this coefficient is used so that the mean value in the received distribution was not too remote from the mid-value of the tolerance range.

$$\boldsymbol{C_{pk}} = \frac{(GLT - \bar{x})}{3\sigma_p}, \ when\ GLT - \bar{x} \leq \bar{x} - DLT$$

or

$$\boldsymbol{C_{pk}} = \frac{(\bar{x} - GLT)}{3\sigma_p}, \ when\ GLT - \bar{x} > \bar{x} - DLT,$$

where: $GLT, DLT$ – the upper and lower tolerance line, $\bar{x}$ – the mean value of the studied characteristic, $GLT - \bar{x}$ or $\bar{x} - DLT$ – distance of the mean process value from the closest tolerance limit.

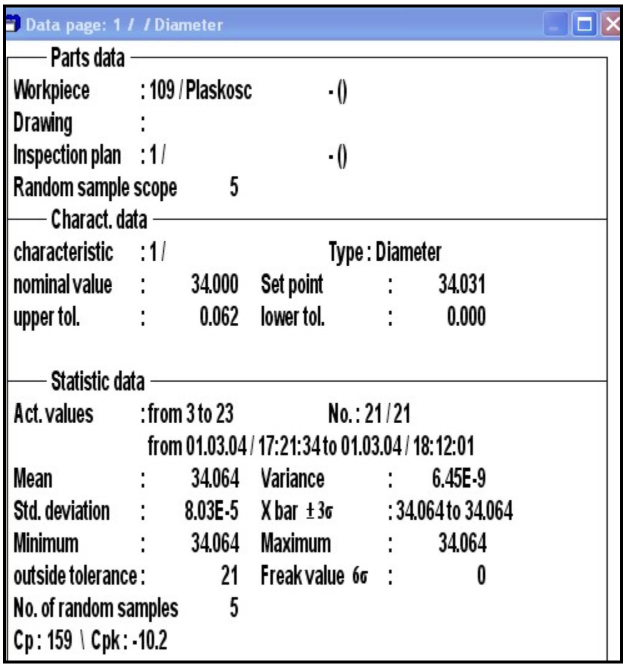



*Fig.3. Ring inside radius measurement statistical data*

Fig. 3 contains data generated by measuring machine relating measured element. For the conducted process the program generated $C_p$ as well as $C_{pk}$. Low $C_p$ = 1,59 value proves good formation of internal cylindrical surface during technological process.

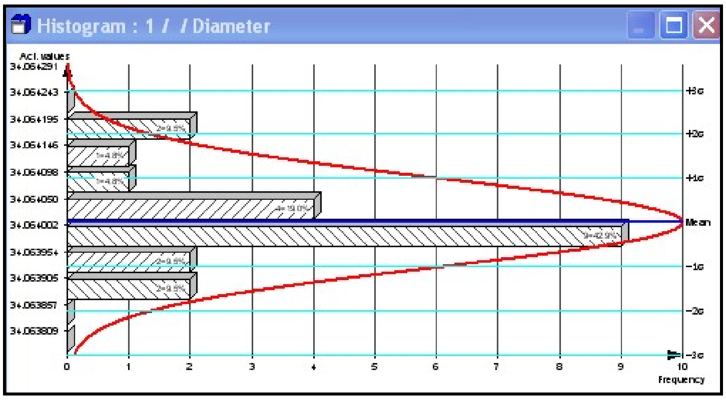
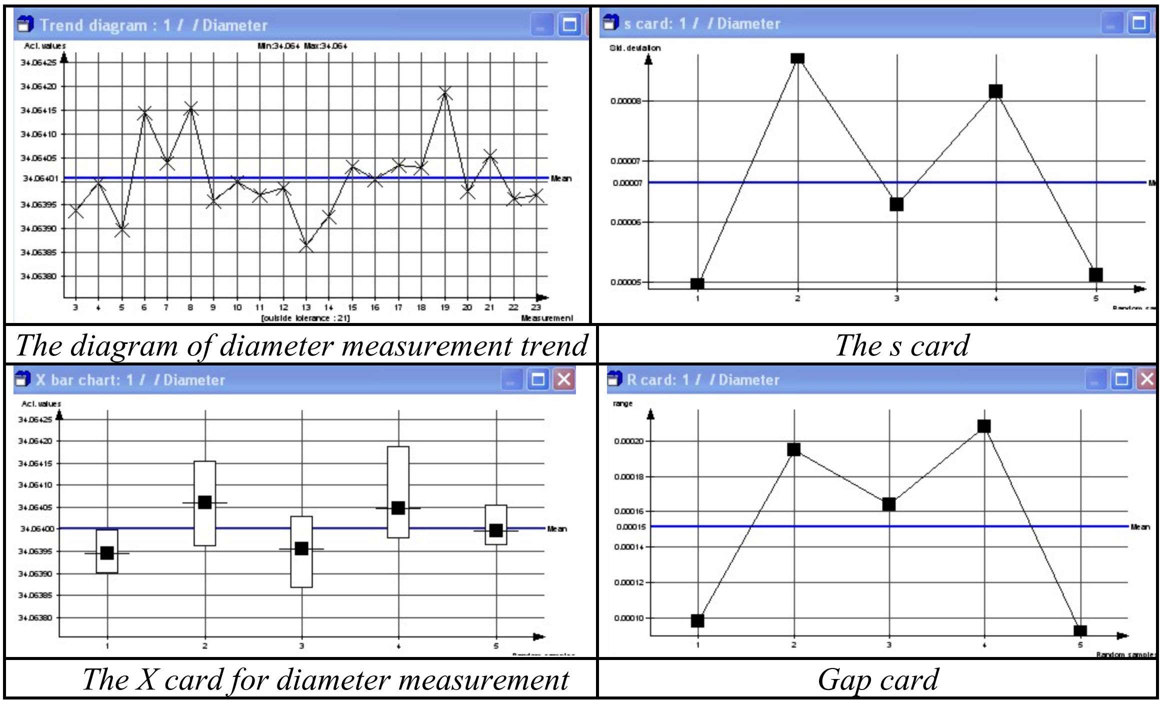



*Fig.4. Histogram for diameter measurement*




*The diagram of diameter measurement trend* — *The s card*

*The X card for diameter measurement* — *Gap card*

*Fig. 5 Control cards generated by coordinate measuring machine*

The histogram shown in fig. 4 illustrates graphic mean value located in the middle of the gap. It represents Gaussian distribution. The frequency of deviation occurrence in definite ranges of value is also illustrated. Measuring process became slightly disturbed, as some points deviate from the central line which is illustrated by X, R, S cards and the trend (fig. 5). The analyzed process behaves stably enough, because points (signals) do not fall out of lower or upper control line, which can be seen, on the trend - the points compose a "wave”. The conducted process has good qualitative capability as well as it is fully controlled.

## 5. CONCLUSION

The use of measuring machine equipped with appropriate statistical module for statistical process control is a suitable tool for the technological process error detection on its all stages. The ineffective detection of deregulations of process can cause considerably larger costs in case of production of small series than in case of large-scale production, as it is often individual custom production usually burdened by the JIT production agreements.

The requirement for continuous improvement of the production process is connected with measuring process improvement. The use of measuring machine owe to which production process will be controllable on each important stage shall enable presentation of full working plan regarding the course, the capabilities and the quality of processes of individual stages of technological process.

The producer is forced by means of ISO 9000, QS 9000 quality standards requirements to employ various types of quality tools. Statistical process control with the use of coordinate measuring machines equipped with statistical modules fulfils all requirements of full processes control thanks to full repeatability as well as stability. Control databases of the individual processes make it possible to reproduce individual reports together with full access to appropriate measured characteristics. The possibility of measuring data relating specific volumes, characteristics or controlling plans also exists. Thanks to SPC data complex cards for individual characteristic, products, machines or processes can be created. The statistical process control by means of measuring machines enables automatic informing about deregulation of the technological process, which requires immediate interference.

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