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ADVANCED CHARTING TECHNIQUE FOR QUALITY CONTROL

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3STRACT

An advanced process state testing technique is described. It combines the Neyman - Person Approach to ıtistical Analysis and the Taguchi Loss Function Approach to Quality Assessment. The technique results in ·nificant reduction of the risk of adjustment errors compared with conventional (Shewhart charts) method. A ftware module supporting the suggested technique is available as, an option, considerably increasing the efficiency the automated process control by feedback adjustment.

INTRODUCTION

There are many quality improvement tools, used in manufacturing practice. All these tools, except the control art, represent the so-called 'static' instruments, i.e. they do not yield information in real time. Therefore, 'the tool ɔst generally recommended to controlling the quality during the course of their actual manufacturing is the control art' - Feigenbaum (1983).

The chart suggested by W. Shewhart (1931) involves charting results of repeated sampling on a vertical scale ainst the sample number, plotted horizontally. The sample statistic may be:

ıverage, median, range, standard deviation, etc., if a process is judged by variables,

ıumber of defectives, proportion of defectives, number of defects, etc., if a process is judged by attributes.

The statistic values should cluster about a central line, which represents either a specified standard or the statistic ng-term average of the process. The upper and lower chart limits (UCL and LCL, respectively) represent the ɔundaries of typical statistic variation (so-called 'inherent variability') due to random fluctuations, which are evitable and allowable. If during the course of production a statistic value from one of the samples is recorded ıtside the limits, it would be concluded that a change in the process had occurred and it would immediately be vestigated to determine a cause of the change. In this way many poor production practices have been corrected ;fore the production of large number of defective units. A typical control chart is shown in Fig. 1.

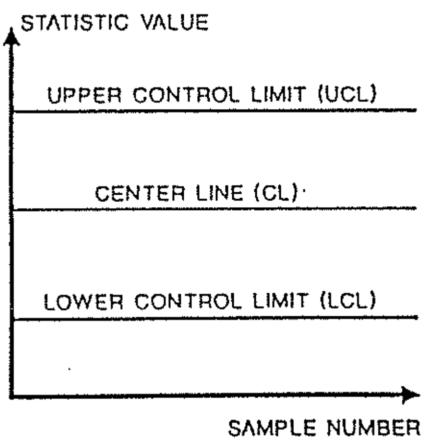

Figure 1. Typical Control Chart

Statistical Behavior

Variables control charts, i.e. so-called 'classical Shewhart charts', solve the problem of process testing by arate assessment of the measures of central tendency and spread. Common practice implies setting up the chart averages ($\bar{x}$) and the chart based on either the sample range (R) or the sample standard deviation (s). Th:e mique is equivalent to construction of a rectangular control region (Shewhart Rectangle) on a two-dimensional ph formed by superimposing the charts. This Rectangle represents boundary of Shewhart control region and is d for testing the Dual Null-Hypothesis concerning the process stability:

$$H_0: \sigma = \sigma_0 \text{ and } \mu = \mu_0$$

$$H_1: \sigma \neq \sigma_0 \text{ or } \mu \neq \mu_0$$

:re σ and μ represent process spread and central tendency estimated by the sample statistics; σ_0 and μ_0 are racterized by the chart centerlines. For all sample points ($\bar{x}_i$; s_i) falling within the Rectangle the process is sidered to be in as state of control, otherwise it is in 'out-of-control' state in terms of process mean or variability ;. 2).

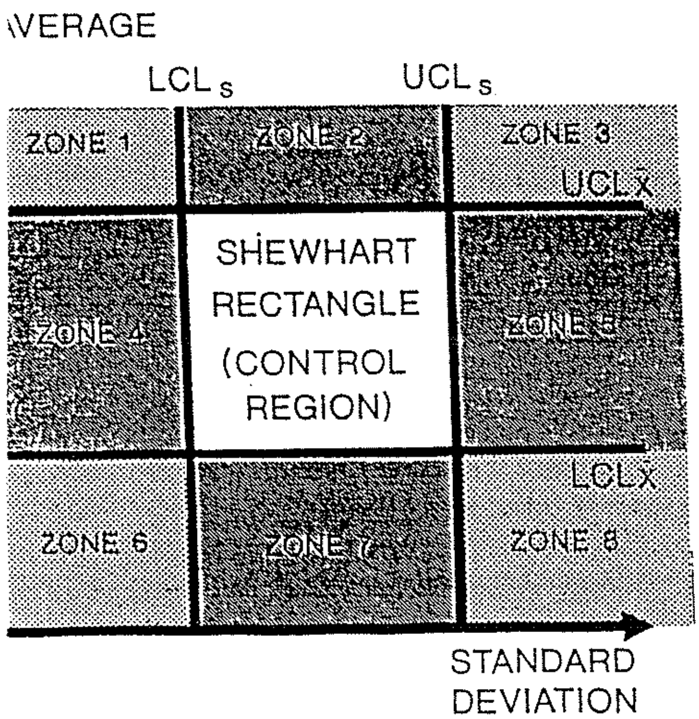

Figure 2. Shewhart Decision Making Method

In contrast to the Shewhart decision making method this work is based on the Neyman-Pearson (1928) approach process testing discussed in their paper preceeding the famous Shewhart (1931) publication. Neyman and Person owed that for the case of simultaneously controlled process mean and variability the control region has an oval ape and represents the results of cutting the joint sampling distribution by a horizontal plane at the height rresponding to the given significance level. Fig.3 presents the Shewhart Rectangle and the oval as well as the sults of sampling (set of 25,000 samples, n=5) from a process with normal random variation N (0;1). One can see it the oval much better fits the shape of the scatter diagram, so the Rectangle represents the rather rough proximation of the true control region.

The oval-shaped control region inevitably leads to rejection of the conception of constant control limits on control arts. Choosing the sample standard deviation as a basis for follow-up analysis, one can set up the chart averages with variable control limits depending on the s-value. Obviously, the dependence corresponds to the ...ation of the oval and the limits dynamics reflect the standard deviation fluctuations. The interested reader can ...d the detailed description of the method theory in our paper (see Bluvband and Grabov (1995)) presented at the ...h ASQC Annual Quality Congress.

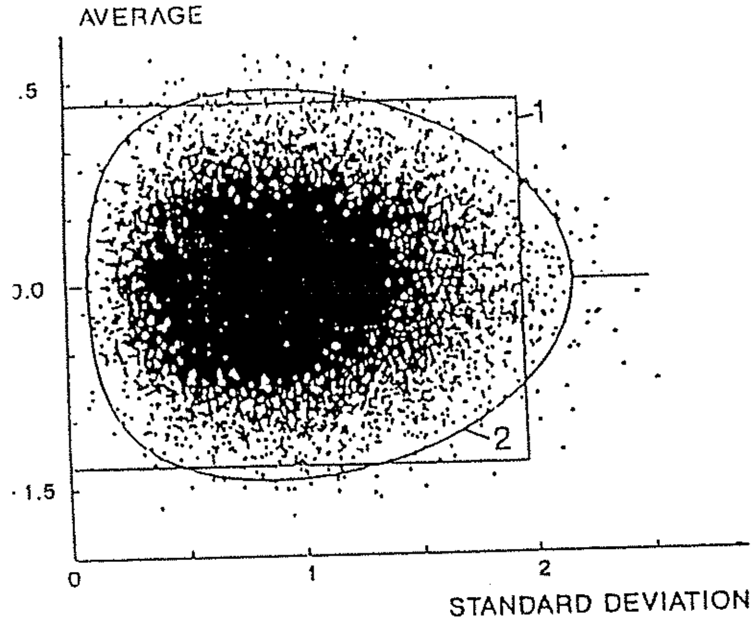

Figure 3. $\bar{X}-S$ Graph presenting the Results of Monte-Carlo simulation:
1 - shewhart Rectangle, 2 - B - over, sampling Data

2 Current Quality Evaluation

Stability evaluation is interesting for manufacturer, whereas what counts for the customers is whether the process ...uality is stable. Therefore, complete continuous process analysis include a feature for on-line quality monitoring. ...or current quality evaluation we proposed a loss estimator (LE-statistic) closely resembling the Taguchi Expected ...oss for a normally distributed product characteristic. On the assumption that samples of size n are drawn from a ...ormal universe with parameters μ and σ, the LE-statistic is given by

$$LE_i = \frac{1}{n}\sum_{j=1}^{n}(x_{ji}-\mu)^2 \qquad \sigma^2\left[\frac{n-2}{n}(s_i^*)^2 + (\bar{z}_i)^2\right]$$

...where x_{ji} denotes the j-th reading of the i-th sample,

$$\bar{z} = \frac{\bar{x}-\mu}{\sigma}; \quad s = \frac{s}{\sigma}\sqrt{\frac{n-1}{n-2}}$$

Thus the LE-statistic value depends on both unit-to-unit variation and process deterioration (wear-out, shift, etc.). The main difference between the LE-estimator and the Expected Loss, is that the former characterizes the on-line quality activity and uses the sample statistic for current loss evaluation. The latter characterizes the off-line quality activity and is associated with the loss computed via the population parameters.

The control limit for the LE-statistic can be established from the extreme loss under process random statistical behavior. Comparison of the losses due to inherent process variability shows that the extreme loss value corresponds to the right vertex of the oval with the coordinates $\overline{z} = 0$ and s^{*}_{rv}.

Thus the 'loss control region' on the $\bar{x}$-s graph is bounded by the iso-loss semiellipse given by

$$\frac{n-2}{n} (s^{*})^{2} + (\overline{z})^{2} \leq \frac{n-2}{n} (s^{*}_{rv})^{2} \qquad (2)$$

and shown in Fig. 4 From Eg. (2) one can easily get the expression for the quality control limits on the $\bar{x}$-chart as a function of the sample standard deviation.

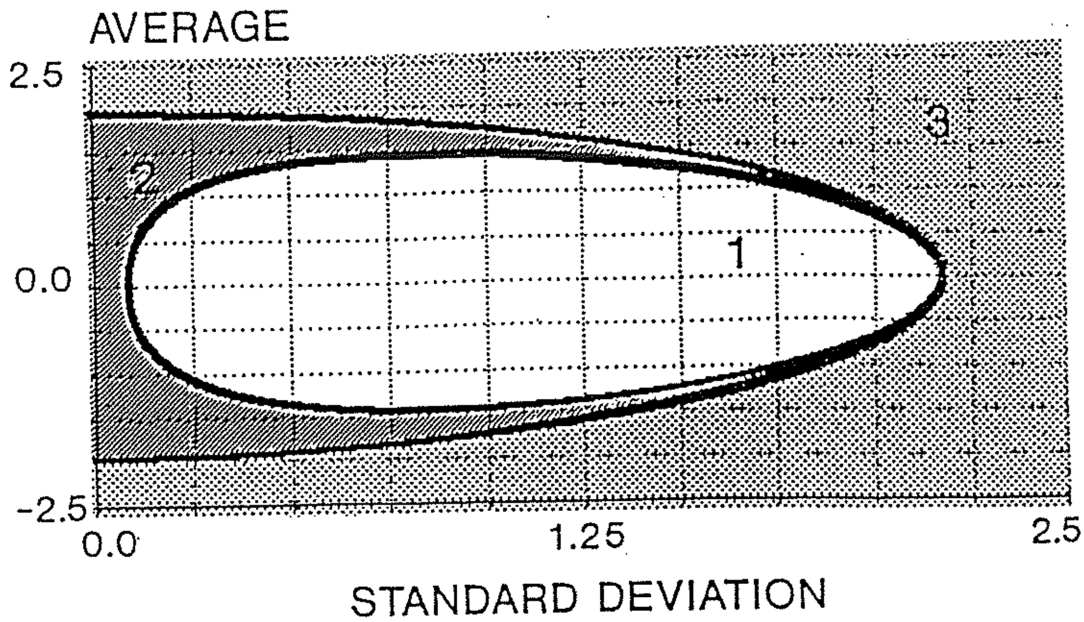

Figure 4. The Area under $\overline{x}-s$ Graph Subdivided by the B - Oval and the Iso - Loss Semiellipse

1 - In - Control State
2 - Warning State
3 - Out - Of - Control State

3. COMPLETE PROCESS ANALYSIS

Combining two couples of variability limits (for stability testing and for quality assessment) on the same chart of averages one can set up a pooled chart intended for complete process analysis. Since the semiellipse contains the oval touching it only at the right vertex, the couple of quality control limits will be outer in relation to the inner couple of stability limits for all sample standard deviation values smaller than the right vertex of the oval. The pooled chart represents a tool for simultaneous visualization of the process central tendency ($\bar{x}$-plot) and spread (control limits) variation.

EFERENCES

luvband, Z. and Grabov, P. (1995). New Approach to Process Control. Proceedings of the ASQC 49-th Annual uality Congress. May 22 - 25, Cincinnati.

:igenbaum, A. V. (1983). Total Quality Control McGRAW - HILL, London.

eyman, J. and Pearson, E. S. (1928). On the Use and Interpretation of Certain Test Criteria for Purposes of .atistical Interference. Biometrica, 20A, 175 - 240.

ıewhart, W. A. (1931). Economic Control of Quality of Manufactured Product. Reprinted by American Society for uality Control. 1981, Milwaukee, WI.

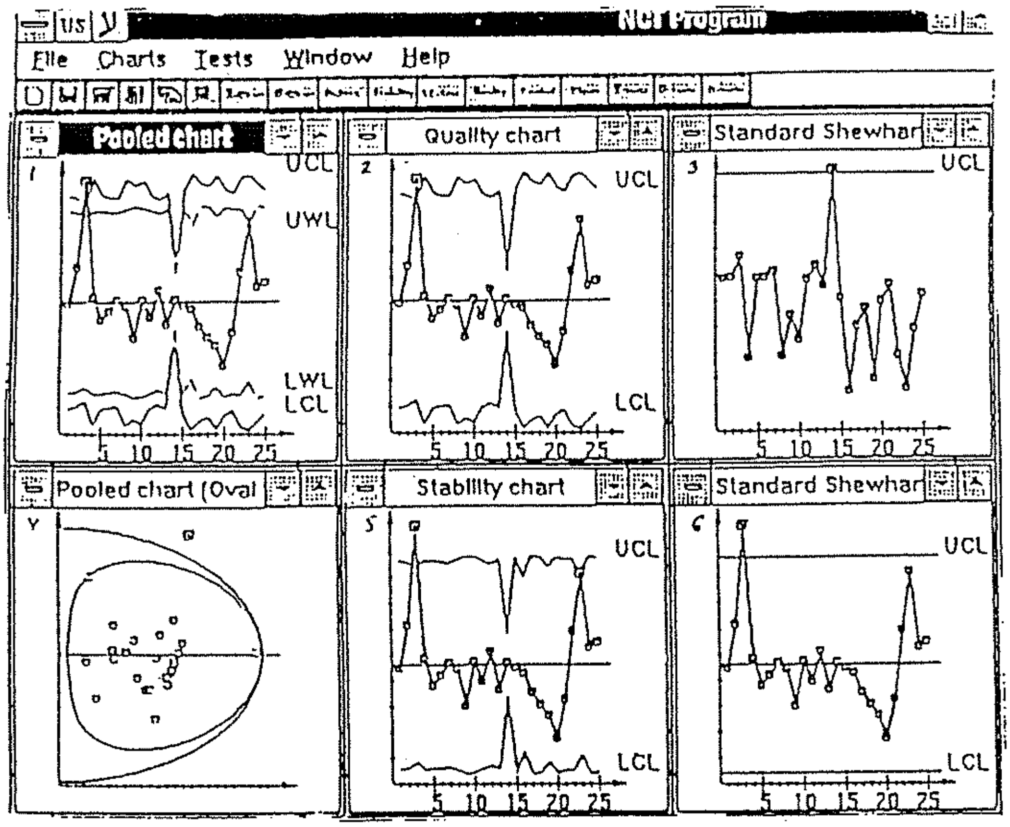

Figure 6. Screens of the Program Supporting the Suggested Approach: 1 - Pooled Chart, 2 - Quality Chart, 3 - Shewhart S - chart, 4 - $\overline{X}-S$ Graph, 5 - Stability Chart, 6 Shewart $\overline{X}$ - Chart

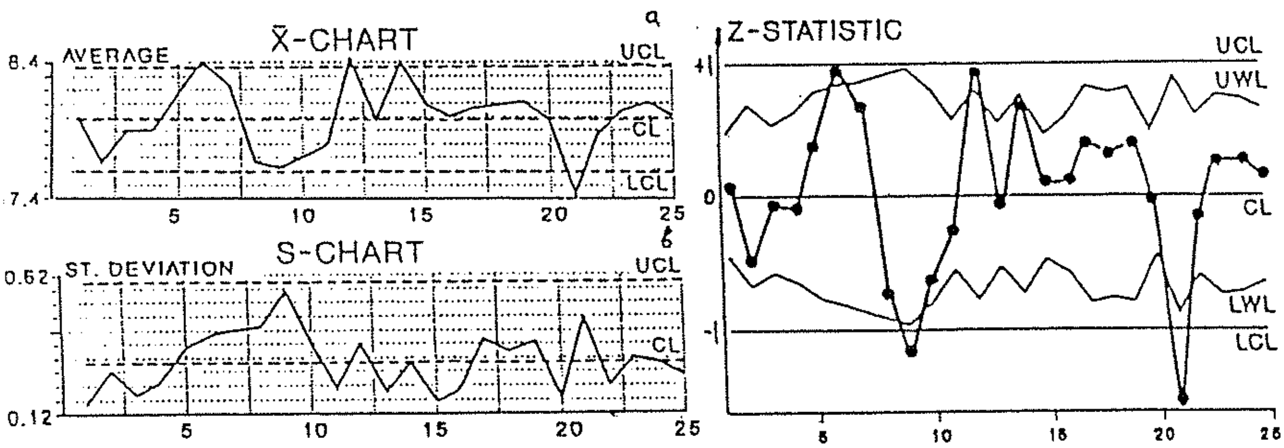

Figure 7. Case Study: a - $\overline{X}$ Chart, b - S. Chart, c - Standardized Pooled Chart

SUMMARY

Despite the fact that customer requirements are the driving force in today's world, the standard charting techniq is oriented only to the evaluation of process statistical behavior over time. This problem has significance for t producer, and not to the customer, who is interested only in the fact that the product quality is stable.

The proposed advanced technique presents a new tool (pooled chart) for Quality - Oriented SPC. Extending t Taguchi Approach activity for on-line quality control, the approach claims that it is unprofitable to adjust a proce characterized quality loss which does not exceed the extreme limit under random statistical behavior (due to proce inherent variability). The proposed quality-oriented pooled chart represents a graphical mean for detecting variati from the quality to be expected in a continuous production line and indicate when a process should be examined trouble. Actually, the chart is intended for performing the test of the hypothesis that subsequently produced ite have essentially the same Quality Characteristics as previously produced ones.

Both setting up and analysis of the pooled chart could be simplified by its normalization, i.e. by procedure elding a standardized chart with zero centerline, the constant (± 1) outer control limits (for quality sessment) and the variable inner ones (for stability testing). The plotting normalized statistic is given by:

$$z_i = [\,(s_i^*)^2 - \frac{n}{n-2}\,(\overline{z_i})^2]\;\frac{sign\,(\bar{x}_i - \bar{\bar{x}})}{(s_{rv}^*)^2} \qquad (3)$$

The suggested technique allows also to perform correct diagnostics of the assignable causes of the process 'out- -control' state. The Shewhart concept of subdivision of the area under the $\bar{x}$-s graph into 9 different zones hewhart Rectangle and 8 'out-of control' zones - see Fig. 2) is logical and is accepted for our approach as well. ıt compared with the Rectangle the zone boundaries represent the curves of the gradients perpendicular to the oval ntour of the control region (see Fig. 5) The gradient equations represent the line of the "steepest descent" to the ntrol region and should be used for optimization of the feedback controllers used for automated process control conjunction with the control charts.

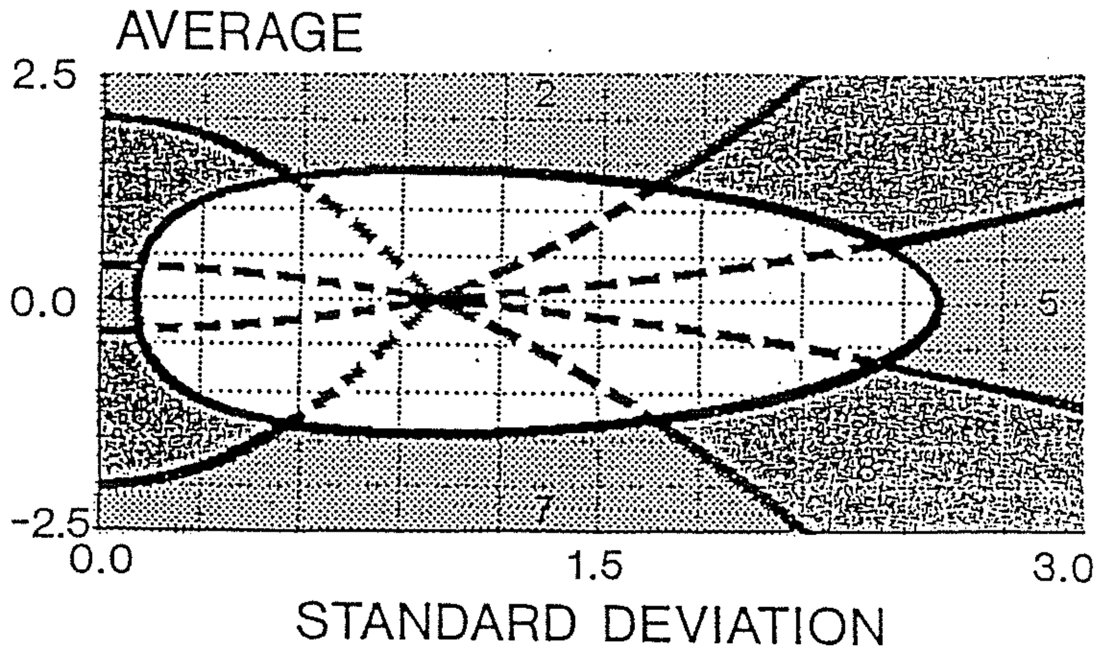

Figure 5. Desision Mapping In the Oval Control Region

The proposed technique is somewhat more complex than the Shewhart charts. However, with the advance of utomated data collection and computerized data analysis the complexity factor is rather insignificant. The end user eed not be overwhelmed by any charting mathematics, as a suitable program performs the statistical calculations nd displays the control chart on a monitor. Some screens of the program supporting the suggested approach are hown in Fig. 6. The program is intended for current process control by collecting data, their treatment and analysis s well as for reporting information. The programs also generates signals for controllers maintaining product roperties at their target values.

. CASE STUDY

the viscosity of the first 25 samples of six was measured during the start-up phase of a new chemical process. he samples were used to set up the Shewhart $\bar{x}$- and s-charts as well as the standardized pooled chart shown in Fig. '. Comparative analysis of the conventional and proposed approaches leads to a conclusion, that the process nanagement according to the Shewhart charts leads to some adjustment rrors: overadjustment - 3 points, underadjustment - 1 point.