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ASSESSMENT OF STABILITY OF MANUFACTURING PROCESS AIDED BY *AVERAGE DIFFERENCE CHART*

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ABSTRACT
Paper presents a novel method for evaluating measuring system in on-line way, which implies that its analysis can be implemented in SPC. In article is description of the Average Difference chart which allows to estimate the variability between operators by identifying differences in results obtained by their measurements on the same samples. The study showed that skilful interpretation of graph line (points) on AD-chart can be an effectively support of evaluation of manufacturing process.
Keywords: statistical process control, measurement system analysis, control chart, range method

1. INTRODUCTION
In the statistical process control (SPC) there is used the theory of stochastic processes, in which the process model is a function of the variability of its measurement and distribution of its location. Basic tool of SPC are control charts. The idea of the charts is to assess the stability of manufacturing process – stable process is a process, which monitored statistics are kept within control limits *LCL-UCL* [3,5]. The essence of observation of image on process chart lies in its skilful interpretation. However, it should be borne in mind that **the plot on the chart shows the total variation in both the manufacturing process and the measurement process**. If on the chart there will be a symptom of uncontrolled situation, it is difficult to clearly and immediately find out which of them has been destabilized – point outside the control limits may means deregulation of the manufacturing process, but also, for example, operators error. The basis of inference is not only operator`s knowledge about manufacturing process, but also his knowledge about the properties of the product, used technology and the measuring method.

2. *ON-LINE* METHOD FOR MEASUREMENT SYSTEM ANALYSIS
Usage of the *on-line* method allows for an analysis of the measurement system during the manufacturing process (a detailed description of method is in [1]). This method allows for ongoing monitoring of quality state of measurement system, which makes it possible to monitor the current precision (the total of repeatability and reproducibility) and trends. Measurements taken from the manufacturing process within the SPC are also used also for measurement system *on-line* analysis – operator (for example on a first shift) measures parts for SPC and then set aside them on prepared field. The second operator (for example, on the second shift) starts his work from the measurements on those parts (using the same instrument as first operator) [1].
As a result of these actions are obtained two trials of measurements for *n*-element sample (sample size and frequency of its collection by operator for *on-line* analysis are adequate for the sample for SPC). In the evaluation of *on-line* method there are used two control charts – *AD-chart* (Average Difference chart) and the *% R&R index chart*. The second chart graphically presents results of the *%R&R* index

in relation to the measurement system acceptance criteria (0, 10% and 30%) [4] – each point on the chart represents (on the basis of a sample) an estimation of quality of measurement system (evaluation is carried out by range method [3, 4]) (fig. 1).

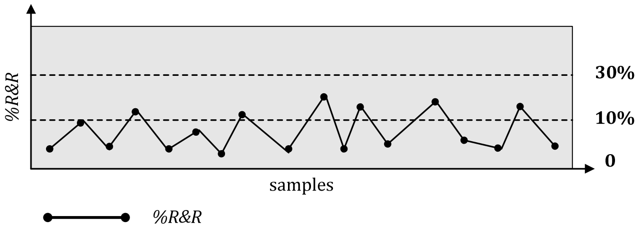

Figure 1. %R&R index chart – an example. Source: [1]

3. *AD-CHART* – AVERAGE DIFFERENCE CHART

AD-chart is used to illustrate (in the form of chart) usefulness of the measurement system which is monitored ongoing. Axies of chart are: the number of samples on the X and on the Y – monitored statistic. It is difference between the averages values on samples calculated from the results obtained by two operators – $Diff_{\overline{Ap1,2}}$ (fig. 2):

$$Diff_{\overline{Ap1,2}} = \bar{x}_{iAP1} - \bar{x}_{iAp2}, \qquad (1)$$

where:

$\bar{x}_{iAP1}$ – the average from the measurements on *i*-sample made by *Ap*1 (*Ap* is *Appraiser*) within the confines of measurements for manufacturing process control charts – data from Shewhart data sheet „prescribed" as data to the *on-line* data sheet; $\bar{x}_{iAP2}$ – the average from the measurements on *i*-sample made by *Ap*2, making second trial (set of measurements) for *i*-sample.

$Diff_{\overline{Ap1,2}}$ contains information about the total variation which results from impact of the measuring process environment, gauge and operators influences.

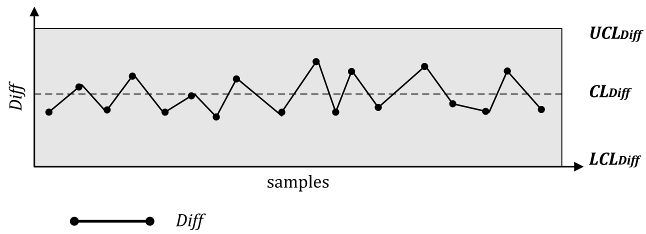

Figure 2. AD-chart – an example. Source: [1]

$Diff_{\overline{Ap1,2}}$ is a random variable that can be written as follows: $Z:(\bar{x}_{iAP1} - \bar{x}_{iAp2}) = Z:(Diff_{\overline{Ap1,2}})$ and characterized by a Normal Distribution with parameters $N(\mu, \sigma_{Diff})$. Theoretical distribution of $Diff_{\overline{Ap1,2}}$ for the two operators are the same and it is: $N\left(\mu, \frac{\sigma_{Ap1}}{\sqrt{n}}\right) = N\left(\mu, \frac{\sigma_{Ap2}}{\sqrt{n}}\right) = N\left(\mu, \frac{\sigma_{Diff}}{\sqrt{n}}\right)$.

The difference between the operators calculated from the averages of samples should be zero because theoretically we strive for ideal situation in which both operators measure the sample accurately and in the same way, so their results do not differ from each other – expected value: $E(Z) = E(Diff_{\overline{Ap1,2}}) = 0$ [2].

In stable conditions (when the measuring system is acceptable) range of points on *AD-chart* should be symmetrical, random on both sides of center line CL_{Diff} (expected value) and within the control limits. Point outside of the control on *AD-chart* is the basis for supposing that the measurement system is instable. In this way the chart can detect the deflection of the measuring process.

Control limits of *AD-chart* are calculated based on 30 consecutive differences $Diff_{\overline{Ap1,2}}$ and determine them $\pm 3\sigma_{Diff}$ values, where σ_{Diff} is the standard deviation of the random variable $Diff_{\overline{Ap1,2}}$:

$$\sigma_{Diff} = \sqrt{\frac{\sum_{i=1}^{N} Diff_{\overline{Ap1,2i}}^{\ 2}}{N-1}}\,, \tag{2}$$

therefore:

$$LCL_{Diff} = -3 \cdot \sqrt{\frac{\sum_{i=1}^{N} Diff_{\overline{Ap1,2i}}^{\ 2}}{N-1}}\,,\ UCL_{Diff} = 3 \cdot \sqrt{\frac{\sum_{i=1}^{N} Diff_{\overline{Ap1,2i}}^{\ 2}}{N-1}}\,,\ CL_{Diff} = 0\,, \tag{3}$$

where:
LCL_{Diff} – lower control limit on *AD-chart*; UCL_{Diff} – upper control limit on *AD-chart*; CL_{Diff} – central line on *AD-chart*; $Diff_i$ – *i*-difference between operators averages; N – number of differences $Diff_{\overline{Ap1,2}}$.

4. STATISTICAL EVALUATION OF THE MANUFACTURING PROCESS AIDED BY *AD-CHART*

Average Difference chart allows to estimate the variability between operators by identifying the differences in the results obtained by their measurements on the same samples. Skilful interpretation of the image may also aid the evaluation of the manufacturing process. Figure 3 shows three examples of situations (A, B and C) where use of *AD-chart* can aid the evaluation of the stability of the manufacturing process.

Situation A on figure 3:

a) Description of situation: image of the manufacturing process (image on $\overline{x}$ chart) indicates deregulation (points outside the LCL_X); image on the *AD-chart* indicates temporarily deregulation of measurement process (points outside the LCL_{Diff}).
b) The interpretation of a situation: obtained by operators of the measurement results differ significantly from each other (results of one of them were probably affected by temporary disturbance of the process). On the basis of images interpretation for both charts can be put forward a proposal that the source of the observed irregularities (disruptions) is a way of measurement used by *Ap*1 (set: SPC measures).
c) Decision: manufacturing process is stable, measurement process is temporarily unstable (corrective actions are needed).

Situation B on figure 3:

a) Description of situation: image on $\overline{x}$ chart indicates deregulation (point outside the UCL_X); image on the *AD-chart* does not indicate any changes in measurement process – point is near to CL_{Diff} line.
b) The interpretation of a situation: within the sample operators took measurements and obtained similar averages.
c) Decision: manufacturing process is temporarily unstable (corrective actions are needed), measurement process is stable.

Situation C on figure 3.:

a) Description of situation: image on $\overline{x}$ chart does not indicate any changes in manufacturing process; image on the *AD-chart* indicates temporarily deregulation of measurement process (points outside the UCL_{Diff}).
b) The interpretation of a situation: operators have obtained different results of measurements in the same sample. Results of one of them were probably affected by temporary disturbance and measurement process became temporarily deregulated. Can be put forward a proposal that irregularity occurred when measurements were made by operator *Ap*2 (set: repeated measures).
c) Decision: manufacturing process is stable, measurement process is temporarily unstable.

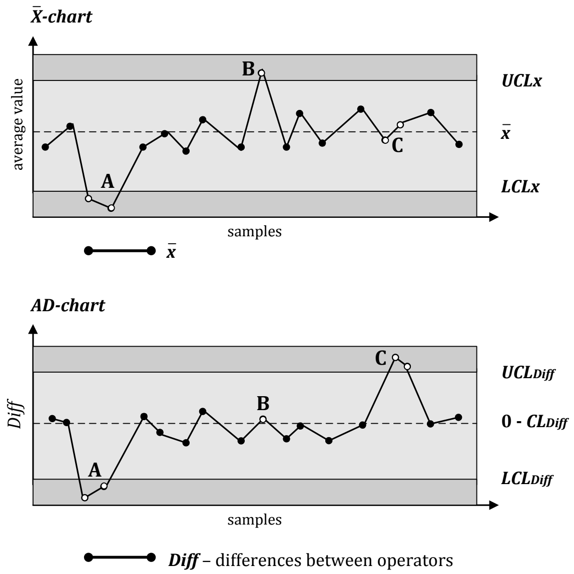

Figure 3. Use of the AD-chart to support of the evaluation of the manufacturing process. Source: own study

The study showed that skilful interpretation of the plot on *AD-chart* can be an effectively support an assessment of the manufacturing process. The possibility of ongoing exclusion or confirmation impact of the operators on the image of manufacturing process variability on the basis of simultaneous observation of average chart and *AD-chart* is undoubtedly the advantage of use graphical tool which is *AD-chart*.

5. CONCLUSIONS

AD-chart allows to estimate the variability between operators. Skilful interpretation of the *AD-chart* image may also aid evaluation of manufacturing process. To recapitulate, the main advantages of this chart are:

- ease of handling and simplicity of interpretation of the chart emerging image of the differences in the behavior of operators (graphical interpretation of the differences in use by operators of the same measuring method),
- possibility to monitor the differences between operators, indicating the reproducibility of the qualitative state of the measuring system (directly at the operators working position and during their daily work),
- and possibility to ongoing exclusion or confirmation impact of the operators on the image of manufacturing process variability on the basis of simultaneous observation of Shewhart chart and *AD-chart*.

6. REFERENCES

[1] Diering M., Pająk E.: Bieżąca ocena przydatności systemów pomiarowych. Część I: metodologia (The current evaluating of the suitability of the measurement system in the manufacturing process. Part I: methodology), Journal of Enterprise Management, No 1/2010, PTZP, Poland.

[2] Funk W., Dammann V., Donnevert G.: Quality Assurance in Analytical Chemistry. Second, Completely Revised and Enlarged Edition, Wiley-VCH Verlag GmbH & Co. KGaA, Wienheim, Germany, 2007.,

[3] Hamrol A.: Zarządzanie jakością z przykładami (Quality management with cases), Warsaw, Poland, 2008.,

[4] Measurement Systems Analysis, MSA-Third Edition – Reference manual. AIAG-Work Group, Daimler Chrysler Corporation, Ford Motor Company, General Motors Corporation, 2002.,

[5] Statistical Process Control (SPC). Reference Manual, DaimlerChrysler Corp., Ford Motor Company and General Motors Corp., AIAG, Second Edition, 2005.