MEASUREMENT SYSTEM ANALYSIS COMBINED WITH SHEWHART'S APPROACH

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Abstract:

The paper presents new procedure of methodology for statistical assessment of measurement systems variation (methodology known in the literature as Measurement Systems Analysis, MSA). This procedure allows for calculation and monitoring in real time (that is on-line) of measurement system (MS) characteristics which determine its usability for manufacturing process control. The presented solution pointed out the gap in process control, which consists in lack of methods for monitoring measurement processes in the on-line way. Their key point consists of taking samples that are also needed for the process control chart for the needs of the MSA method. This means that the samples are taken directly from the production line and during the production process. The method is combined with the standard procedure of statistical process control (SPC) with the use of process control charts. It is based on two control charts. The first one is called AD-chart (Average Difference chart) and it allows to estimate the variation between the operators and stability of the monitored measurement system. The second control chart illustrates the *%R&R* index (Repeatability and Reproducibility) and allows to monitor the MS capability.

The paper also presents authors' proposal of guidelines about the reference value for the *%R&R* index calculation and assessment. Recommendations and guidelines for choosing the reference value are based on two criteria: information about sample and manufacturing process variation and the purpose of using MS (product or process control).

Keywords: Repeatability and Reproducibility, Control Chart, Measurement, Reference Value

1. INTRODUCTION

Measurement system is one of the most important components of production systems – if it is not capable enough, may have a significant influence on the quality of managers decisions made about the production process. It should be stable, predictable, capable and lean. It means that MS capability should be monitored and managed. Also, the measurement uncertainty of the obtained results should be known.

In the Shewhart's approach there is used a theory of stochastic processes, in which the process model is a function of the variability of its measurement and distribution of its location [1]. Basic tool of this approach, that is of statistical process control (SPC), to monitor process 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. 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 [2]. Thus, variation of the measurement system (MS) should be known and much smaller than the natural variation of the manufacturing process, to ensure that decisions about the process (decisions such as: the process is stable/unstable in the statistical sense) and the product (decisions: good item/bad item) is accurate. Thus, the aim of MS assessment is to gain information whether it is adequate for controlling the production process and the manufactured product.

2. THE ON-LINE PROCEDURE OF MSA

2.1 *%R&R –Repeatability and Reproducibility index*

R&R (Repeatability and Reproducibility) is variation which is equal to the total variation of intra-and inter-system and it is total measure of these components of the measurement system. Most of MSA procedures lead to *%R&R* calculation, to gain information about MS capability. Symbol % in *%R&R* represents the measured process variation expressed as a percentage in relation to the known values of reference figure (*RF*). In other words, *%R&R* is equal to the proportion of the variation caused by the measurement system (characterized by *R&R*) to the total variation. Evaluation is represented in Eq. (1) and Eq. (2) [3].

$$\%R\&R = \frac{R\&R}{RF} \cdot 100\% \,, \qquad (1)$$

where:
R&R – standard deviation describing the variation of the measurement system (combined repeatability and reproducibility),
RF – accepted reference value (reference figure); in most of cases it is : total process variation *TV* or 1/6 of process tolerance *Tol*,
and / or:

$$\%R\&R = \frac{\sqrt{\sigma_e^2 + \sigma_o^2}}{\sqrt{\sigma_p^2 + \sigma_m^2}} \cdot 100\% \,, \quad \sigma_m = \sqrt{\sigma_e^2 + \sigma_o^2} \,, (2)$$
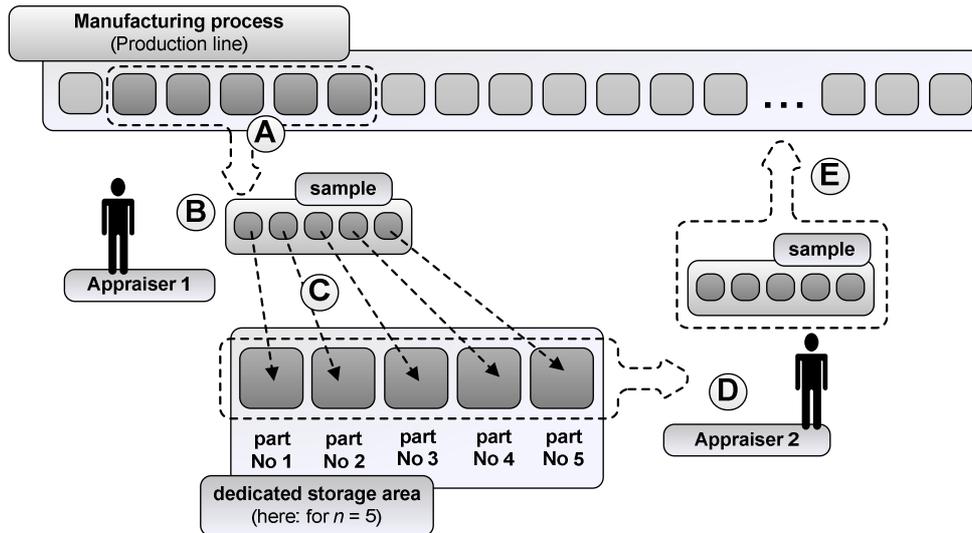
where:
$\sigma_m = R\&R$ – standard deviation of MS,

Fig. 1: Illustration of the on-line procedure for two appraisers. Source: own study based on [2]

σ_e – standard deviation of measuring device,
σ_o – standard deviation of MS operator,
σ_p – manufacturing process standard deviation.

In the automotive industry there are standing acceptance criteria as follow:

%R&R under 10% – the measurement system is acceptable (capable for the task for which is being used),

%R&R between 10 and 30% – may be acceptable for some applications,

%R&R is over 30% – unacceptable, system needs improve.

2.2 Basic assumptions of the MSA on-line procedure

On-line procedure allows for the on-line calculation, that is during the manufacturing process, and to monitor the measurement system (MS) characteristics which determine the MS usability for the manufacturing process control. Figure 1 shows procedure for two Appraisers [2]. Is starts by taking a sample from the production line by the first process operator (Appraiser 1) (A). Appraiser 1 measures the defined characteristic and after performing the prescribed set of measurements on the controlled sample (B), puts it aside in an assigned place (C). After a certain time predetermined in the procedure, second operator (Appraiser 2) repeats on the shifted sample the prescribed measurements (D). Next, Appraiser 2 returns the parts into the production line (E).

Samples are taken directly from the production line and during the production process. The method is combined with the standard procedure of statistical process control (SPC). The procedure is based on two control charts. The first one is called AD-chart (Average Difference chart) and it allows to estimate the variability between the MS operators. In other words, it monitors the stability of the measurement system. The second control chart of the on-line procedure reflects the *%R&R* index (*R&R* means repeatability and reproducibility and it is a measure of quality level and capability of MS) and it allows to monitor the capability of MS.

2.3 Average Difference and %R&R-index charts

The AD-chart monitors the statistic $Diff_{\overline{Ap1,2}}$ (*Diff*) which denotes a difference between average values on samples calculated from results obtained by two appraisers (it is represented in Eq. (3)) [2].

$$Diff_{\overline{Ap1,2}} = \overline{x}_{iAp1} - \overline{x}_{iAp2}, \qquad (3)$$

where:
$Ap1$, $Ap2$ – Appraiser 1, Appraiser 2,

$\overline{x}_{iAp1}$ – the average from the measurements of *i*-sample made by first appraiser $Ap1$,

$\overline{x}_{iAp2}$ – the average from the measurements of *i*-sample made by second appraiser $Ap2$.

Diff contains information about the total variation (with the impact of the measuring process environment and the gauge and appraiser influence). This difference between operators should be zero and thus the central line on the AD-chart equals 0 ("zero" means the ideal situation in which both appraisers measure each sample in the same way).

The control limits are calculated on the base of $\pm 3\sigma_{Diff}$ values where *Diff* is a standard deviation from 30 consecutive *Diff* random variables. A point on AD-chart outside of these limits is the basis for making a supposition that the measurement system lost its stability.

Information about measurement system usefulness is being "refreshed" with taken each new sample from the manufacturing process to analyze – *%R&R* is being calculated every time anew and within one sample. Skilful interpretation of the AD-chart image may also aid evaluation of manufacturing process.

Calculation of the *%R&R* index is based on the short-range method [3]. The total MS variation is estimated on the ground of the statistic average range $\overline{R}$ from ranges of

Table 1: Calculating the %*R&R* index depending on the chosen reference value – a case study. Based on [2]

EV *	0,066
AV *	0,002
R&R	0,066
PV	0,146
TV *	0,160

T *	4
StDev *	0,448

RF	TV	Pp	TVstdev	1/6 T
%R&R	41,2%	1,6%	14,7%	9,9%
Evaluation of the usefulness of the measurement system:	Incapable / Not accepted	Capable / Accepted	Capable of conditionally	Capable / Accepted

* calculations are made on the example taken from [2] for Average Range Method with 3 appraisers, 10 parts and 3 trials of measurements, parts for the study were taken from the process in a short period of time; EV – repeatability; AV – reproducibility; PV – part variation; TV – total variation, TVstdev – total variation based on standard deviation; StDev – known standard deviation of manufacturing process, T – tolerance, Pp – performance process index

measurement values on the same parts obtained by two appraisers.

$$R \& R_i = \frac{\overline{R_i}}{d_2^*},\qquad(4)$$

where:

$\overline{R_i}$ – average of ranges within sample i,

d_2^* – Hartley's index (for sample with $n=5$, the value of d_2^* is 1,19) [1, 4, 5].

On the *%R&R* chart the successive *%R&R* values are plotted. Their positions are related to the measurement systems' acceptance criteria, which are classically set at the levels of 0, 10% and 30%. Based on this, a decision about the MS usability is made.

Information about the current measurement system usability – the same as with *Diff* chart – is being "refreshed" with every new sample taken from the manufacturing process.

3. GUIDELINES ON THE REFERENCE FIGURE FOR CALCULATING *%R&R*

%R&R index is being calculated in the final phase of the evaluation of the measurement system. In the literature on the subject there are given different options of reference value to choose from to calculate it. The newest 4th edition of "MSA – Reference manual" [3] gives few approaches to determine *%R&R*: using total process variation *TV* (on condition that parts represent the full range of variability of the manufacturing process), surrogate process variation (from similar process) or total variation based on known standard deviation (for example from previous studies), *Pp* target value (when manufacturing process is new) or part from specification tolerance *Tol* (or *T*) (to sort the process).

To obtain useful information about measurement system's quality level, it is important to choose appropriate denominator (option as the *RF*) for the calculation of *R&R*
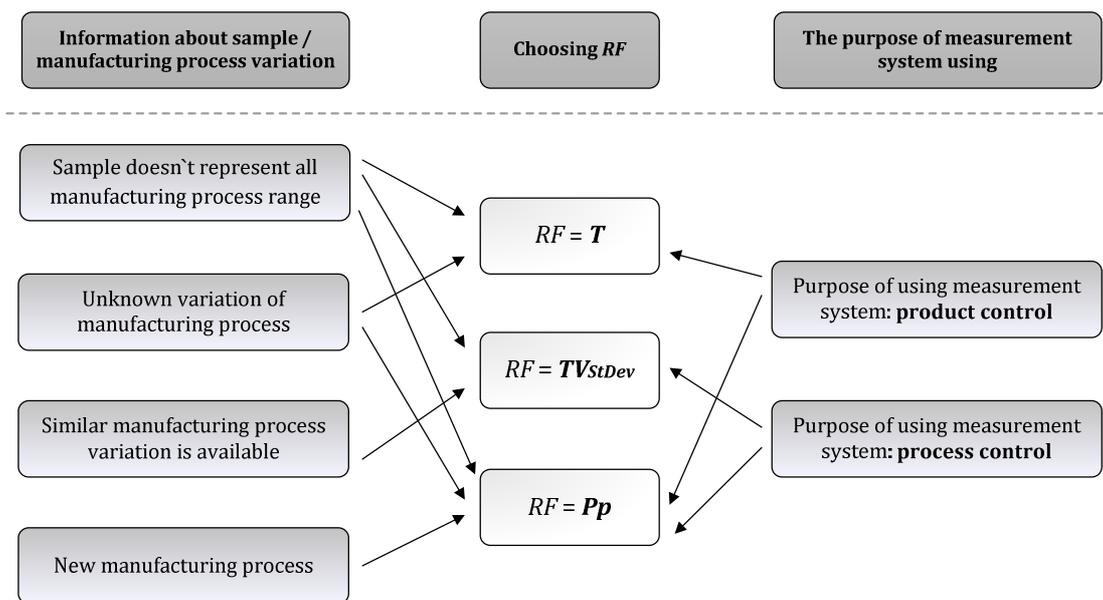

Fig. 2: Choosing the reference value for calculating the %*R&R* index – guidelines. Based on [2]

in a percentage.

Table 1 shows results in calculating the *%R&R* with using different *RF* – depending on the *RF* the same measurement system twice were accepted (for *Pp* and *T* as RF – *%R&R* is under 10%) and with other *RF* calculation was recognized as conditionally accepted (for *TVstdev*) or even incapable (*TV* – *%R&R* exceeds 30%). Poor result for *TV* as *RF* can be explained by organization of study – parts for the study were taken from the manufacturing process in a short period of time and they probably didn't represent the entire range of that process [3]. Thus, Figure 2 presents in general recommendations and guidelines for the choosing the reference value.

In practical applications, that is in a dynamic production conditions authors recommend to use the tolerance as reference figure for calculating *%R&R* in on-line method [2]. The tolerance usually remains constant over a long period of time – it is well known, written in the specification and it is an important part of the contract with a customer. In other cases (in other procedures) – if it is possible – authors recommend to use *TV* as it the best "picture" of actual manufacturing process state.

4. FINAL CONCLUSIONS

The presented MSA procedure pointed out the gap in the statistical process control, which consists in lack of control methods for monitoring measurement processes in the *on-line* way. The *on-line* procedure devised and described in this paper allows assessment the variation between appraisers and the actual capability of the measurement system. The procedure is combined with the classical process stability monitoring with usage of control charts (e.g., *x-R* chart), that is with Shewhart's approach.

The main characteristics of the procedure are:
- conducting MSA simultaneously with a running process control chart;
- analyzing MSA results in graphical form on two control charts;

- information about the current measurement system usability is being "refreshed" with every new sample taken from the manufacturing process.

Authors also showed that criteria for measurement systems acceptation should take into account the chosen reference value for the calculation of *%R&R* index. They also explained how to choose the reference value, depending on available information about sample and variation of manufacturing process and on the purpose of usage of measurement system.

REFERENCES

[1]   "Statistical Process Control", SPC 3rd Edition – Reference Manual, AIAG-Work Group, Daimler Chrysler Corporation, Ford Motor Company, General Motors Corporation, 2005.

[2]   M. Diering, "The method of the current evaluating the suitability of the measurement system in the manufacturing process" (in Polish: "Metoda bieżącej oceny przydatności systemu pomiarowego w procesie wytwarzania"), doctoral thesis, Faculty of Mechanical Engineering and Management, Poznan University of Technology, Poland, 2010.

[3]   "Measurement Systems Analysis", MSA 4th Edition – Reference manual, AIAG-Work Group, Daimler Chrysler Corporation, Ford Motor Company, General Motors Corporation, June, 2010.

[4]   Aczel A.D., "Complete Business Statistics" (in Polish: „Statystyka w zarządzaniu"), 2008.

[5]   A. Hamrol, "Quality management with cases" (in Polish: „Zarządzanie jakością z przykładami"), Warsaw, 2008.