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THE *%R&R* INDEX – PROPOSALS AND GUIDELINES ON THE REFERENCE VALUE AND ACCEPTANCE CRITERIA

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ABSTRACT
The paper presents authors proposal regarding the guidelines about calculation of %R&R index (Repeatability and Reproducibility in percentage) when using procedures of MSA (Measurement Systems Analysis) which allow to calculate the precision of measurement system.
Keywords: repeatability and reproducibility, measurement system analysis, standard deviation, capability indices

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. The paper presents authors' proposals and guidelines on the reference value for the calculation of *%R&R* index. Also, authors discuss in the paper about acceptance criteria for the measurement systems procedures (in general) in according to the choice of the reference figure (*RF*).

2. 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. 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* equals to the proportion of the variation caused by the measurement system (MS) (characterized by *R&R*) to the total variation (*RF*), which is usually the sum of the measurement system variation and the manufacturing process variation or process tolerance [1,2,3] (1):

$$\%R\,\&\,R = \frac{R\,\&\,R}{RF}\cdot 100\% \quad , \tag{1}$$

where:
R&R – standard deviation describing the variation of the measurement system (combined repeatability and reproducibility),
RF – accepted reference value (reference figure)
or (2):

$$\%R\,\&\,R = \frac{\sqrt{\sigma_e^2+\sigma_o^2}}{\sqrt{\sigma_p^2+\sigma_m^2}}\cdot 100\%\,,\;\; \sigma_m = \sqrt{\sigma_e^2+\sigma_o^2} \tag{2}$$

where:
σ_m = *R&R* – standard deviation of MS,

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

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; *Pp* wasn't an option in previous edition of that manual) or part from specification tolerance *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* in a percentage.

Table 1. Calculating the %R&R index depending on the chosen reference value – a case study / an example. 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*

Table 1 shows results in calculating the %*R&R* with using different RF – depending on the RF the same measurement system twice time is accepted (for *Pp* and *T* as RF – %*R&R* is under 10%) and with other RF calculation is 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.
Figure 1 presents in general recommendations and guidelines for the choosing the reference value.

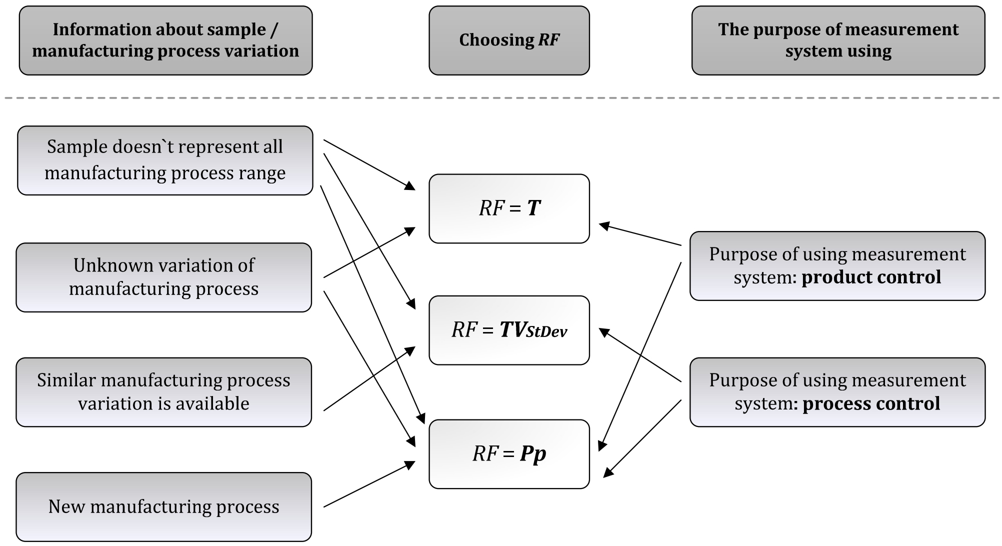

Figure 1. Choosing the reference value for calculating the %R&R index – guidelines

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. PROPOSALS ON THE ACCEPTANCE CRITERIA FOR MEASUREMENT SYSTEMS

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.

Authors conducted an analysis of whether the standing acceptance criteria for measurement systems are reasonable. The purpose of that research was to determine the measurement systems acceptance criteria for *on-line* method, but results can be also used for other MSA methods. The influence of *%R&R* on the process capability index *Cp* was analyzed. In this regard, information contained in [5] and the known relations for calculating process capability indices, the variance of the manufacturing process and the *%R&R* index were used to lead numerical analysis. It was carried out for two situations – when the *RF* is total variation based on the known process standard deviation and second when as the *RF* is taken process' tolerance. Calculations led to the results – respectively equations (3) and (4) (detailed numerical analysis can be found in [2]):

$$Cp_{proc} = \frac{Cp_{obs}}{\sqrt{1 - R\&R_{StDev}^{2}}}, \tag{3}$$

and:

$$Cp_{proc} = \frac{Cp_{obs}}{\sqrt{1 - (Cp_{obs} R\&R_{T})^{2}}}, \tag{4}$$

and (4) is true when $Cp_{obs} \cdot R\&R_T < 1$,
where:
Cp_{proc} – real (unknown) process' *Cp* index,
Cp_{obs} – observed (calculated) process' *Cp* index,
$R\&R_{StDev}$ – *R&R* based on the known process standard deviation,
$R\&R_T$ – *R&R* based on the process tolerance.

Interpretation of the influence of the *%R&R* index on *Cp* index allows to answer the question of what may be the maximum range of the measurement system that the difference between the observed and real variations of the manufacturing process to make about it a reliable decisions – the higher is *%R&R* (that is the less capability of measurement system) the greater is a difference between Cp_{obs} and Cp_{proc}. For *%R&R* under 15% the difference between Cp_{obs} and Cp_{proc} is not significant. When *%R&R* is more than 30% then deviation of Cp_{obs} from Cp_{proc} is too large to be accepted. It means that when the reference value is tolerance, then acceptance criteria for measurement system should be as follow:
– *%R&R* under 15% – the measurement system is acceptable (capable for the task for which is being used),
– *%R&R* between 15 and 30% – may be acceptable for some applications,
– *%R&R* is over 30% – unacceptable, system needs improve.
Considering these it can be concluded that the acceptance criteria for measurement system should include the chosen reference value to calculate *%R&R*.

5. CONCLUSIONS

Authors 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. They described a piece of results of their research in this area.

6. ACKNOWLEDGMENT

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