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GAUGE AND PROCESS CAPABILITY METRICS

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Abstract: *Capable process is a process that is able to produce items within the specification limits. In order to have an accurate estimation of process capability, quality management system is required. If measurement system is not repeatable or reproducible relatively to the variability between items, then that measurement system is not sufficiently precise to be used in product capability analyses. This Paper presents the effects of gauge R&R variation on process capability index* C_p.

Key words: *process capability, gauge R&R*

1. INTRODUCTION

Estimation of process capability together with statistical control and design of experiments are statistical methods that have been used for years in an attempt to reduce variability of production process and their final products (Dietrich & Schulze, 1999). Process is capable if requirement range *T* is greater or equal to process range 6 σ which represents 99,73% of surface below the normal distribution curve used to approximate the process. Process capability is estimated by calculating, process capability indices. In order to estimate quality of the measurement system it is necessary to identify and quantify sources of variability, define stability and determine measurement system capability. In case whan measurement system variation is significant in comparison to established variation of the item that is measured in a production process, system may not provide valid information on process control. For this reason, prior to establishing process stability and capability, it is necessary to analyze measuring system and determine whether measuring system will be able to consistently, accurately, and precisely differentiate between parts of the process.

2. ESTIMATION OF PROCESS CAPABILITY

The most common indices used are those for calculating potential process capability C_p and demonstrated excellence index C_{PK}. C_p index describes tolerance field range in reference to actual data dispersion, while C_{PK} index defines the process position in reference to requirement limits. Process capability indices are provided in the expressions (1) i (2).

$$C_p = (USL - LSL)/6\sigma = T/6\sigma \quad (1)$$

$$C_{pK} = min\left((USL - \bar{x})/3\sigma; (\bar{x} - LSL)/3\sigma\right) \quad (2)$$

USL - upper specification limit
LSL - lower specification limit
T - tolerance area
$\bar{x}$ - arithmetic mean (central line of the control chart)
6σ - observed process range

In the expressions (1) and (2) standard deviation has been estimated on the basis of data from control chart. Various control charts are used for detection of variations in the process and determining amount of process standard deviation (Juran, & Gryna,1993).

3. ANALYSIS OF MEASUREMENT SYSTEM IN PRODUCTION ENVIRONMENT

Requirement for estimating quality of measurement systems stems from a very simple fact that measurements are in no way perfect. Variations in the measurement system result from random and systematic effects. **(**Breyfolge, 1999). Main sources of measurement system variability are the item that is measured, equipment, operator and environment. Significance of elements in the measurement system is expressed by the amount of dispersion of measuring results obtained in defined measurement conditions. Influences of individual elements of measurement system can be classified in three main categories:

Repeatability *EV* is defined as the influence of measuring equipment in the measurement system variation. Repeatability represents dispersion of measurement results obtained by one appraiser during multiple measurements of identical characteristics on the same parts (samples), while using the same instrument.

Reproducibility *AV* is defined as the influence of appraisers conducting in the measurement system variation. Reproducibility represents dispersion of measurement results obtained by several appraisers during multiple measurements of identical characteristics on the same parts (samples), while using the same or different instrument.

Part variation *PV* is defined as the influence of parts (items) in the total variation of measurement system *TV*.

Measurement system variation R&R depends on the total dispersion of measurement results due to mutual effect of repeatability and reproducibility R&R. Calculation of the measurement system variation R&R is given with the expression 3.

$$R\,\&\,R = \sqrt{EV^2 + AV^2} \quad (3)$$

Total variation *TV* (expression 4) depends on the variation of measurement system *R&R* and parts variation *PV.*

$$TV = \sqrt{(R\,\&\,R)^2 + PV^2} \quad (4)$$

Measurement system capability represents share of measurement system variability *R&R* expressed as percentage of total variation *TV* or tolerance field *T*, i.e. share of measurement system variance in the total variance. Expressions for calculating measurement system capability are as follows:

$$\begin{aligned} &Measurement\ system\ capability = R\,\&\,R/TV \cdot 100\% \\ &Measurement\ system\ capability = R\,\&\,R/T \cdot 100\% \end{aligned} \quad (5)$$

$$Contribution = \sigma^2_{R\,\&\,R} / \sigma^2_{TV} \cdot 100\%$$

Criteria for assessing quality of measurement system *R&R* in the tolerance field *T* or total variation *TV* are provided in Table 1, and criteria for assessing quality of measurement system *R&R* for contribution percentage are provided in the Table 2.

% *T*, %*TV*	Gauge *R&R* is
< 10	Acceptable
10 – 30	Borderline
> 30	Unacceptable

Tab. 1. Criteria for assessing quality of gage *R&R* in the tolerance field *T* or total variation *TV*

Contribution %	*Gauge R&R is*
< 1	*Acceptable*
1 – 9	*Borderline*
> 9	*Unacceptable*

Tab. 2. Criteria for assessing quality of gauge *R&R* for contribution percentage

4. EFFECT OF GAUGE R&R VARIATION ON PROCESS CAPABILITY INDEX C_p

When analyzing process capability the most significant is C_p index based on process dispersion (Mudronja, 2006). In order to be able to provide notion on actual process capability, gauge *R&R* must be able to detect any deviation in monitored process or product. Further analysis shows the relationship of the observed process capability index C_{pTV} that results from total variability *TV* and actual index C_p, based on variation of parts in *PV* process.

$$C_{pTV} = C_p \times \sqrt{1-(R\&R)^2}$$

Relationship between process capability indices C_{pTV} and C_p that depends on quality of gauge *R&R* and on contribution to *R&R* is illustrated on Figures 1 and 2, and in Tables 3 and 4.

C_p	Gauge *R&R*, %				
	90%	70%	50%	30%	10%
	C_{pTV}				
0,5	0,22	0,36	0,43	0,48	0,50
1	0,44	0,71	0,87	0,95	0,99
1,5	0,65	1,07	1,30	1,43	1,49
2	0,87	1,43	1,73	1,91	1,99
2,5	1,09	1,79	2,17	2,38	2,49
3	1,31	2,14	2,60	2,86	2,98

Tab. 3. Relationship between process capability indices C_{pTV} and C_p depending on quality of gauge *R&R*

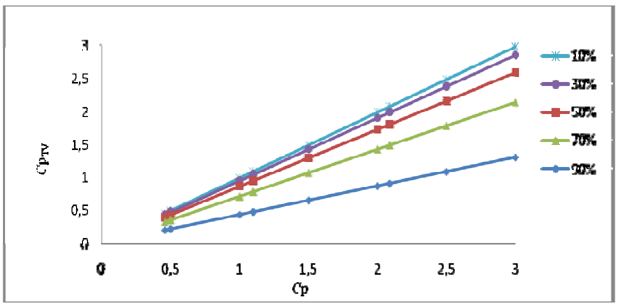

Fig. 1. Relationship between process capability indices C_{pTV} and C_p depending on quality of gauge *R&R*

C_p	Contribution *R&R*, %				
	90%	70%	50%	30%	10%
	C_{pTV}				
0,5	0,16	0,27	0,35	0,42	0,47
1	0,32	0,55	0,71	0,84	0,95
1,5	0,47	0,82	1,06	1,25	1,42
2	0,63	1,10	1,41	1,67	1,90
2,5	0,79	1,37	1,77	2,09	2,37
3	0,95	1,64	2,12	2,51	2,85

Tab. 4. Relationship between process capability indices C_{pTV} and C_p depending on contribution to R&R.

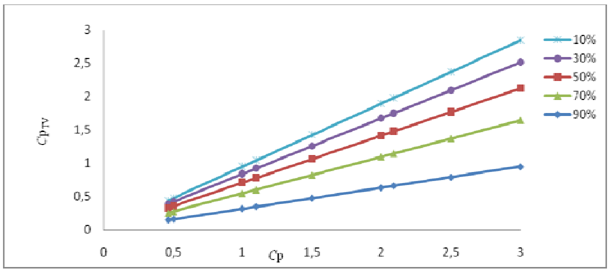

Fig. 2. Relationship between process capability indices C_{pTV} and C_p, depending on contribution to R&R

From the presented results it may be concluded that quality of measurement system significantly affects process capability index C_p. If the observed process capability index $C_{pTV} = 1{,}73$, and gauge *R&R* uses 50 % of total variation or tolerance field, actual process capability index will be $C_p = 2{,}0$. However, if gauge *R&R* uses 10 % of total variation or tolerance field, the observed process capability index will be $C_{pTV} = 1{,}99$, meaning that process capability estimation is significantly better. Also, it needs to be emphasized that in case whan gauge *R&R* variation is significant in comparison to the established variation of the parts *PV*, measurement system will not be able to give an accurate estimation of process capability (Bass & Lawton, 2009).

5. CONCLUSION

Based on conducted analysis it may be concluded that high quality measurement system is essential for detection and monitoring of process variations. Higher percentage of *R&R* means geater error in estimating the process capability index C_p. Furthermore, it was determined that the error in estimation increase as the index C_p increases. Only high quality measurement system will be able to provide accurate and precise estimation of process capability.

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