JOURNAL OF ENGINEERING annals OF FACULTY OF ENGINEERING HUNEDOARA
TOME VI (year 2008), FASCICULE 2, (ISSN 1584 – 2665)

CAPABILITY OF DIMENSIONS MEASUREMENT

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ABSTRACT:
The capability by Measurement Systems Analysis and uncertainty of dimensions measurement by three various gages were evaluated. Used measurement process is not capable and is affected by gages resolution. Low capability correlate with high uncertainty and high value of Z-score.
KEYWORDS:
Dimension, measurement, gage, capability, uncertainty, Z-score

1. INTRODUCTIONS

The requests for measurement qualitative characters of products, services, trades and processes increase in connection with the natural pressure towards to the quality. The measurement is important in manufacturing for its all phases. May be said: "What you can not to measure, you can not to make" [1].

The requirements for the present quality measurements, as well as requirement of always new measurement methods are not actual only in the industry. They interfere with all branches of human activities – for example ecology, developed biotechnology, nanotechnology, all forms of medicinal and veterinary diagnostics, food control, defensive and security structures. This process is dynamic phenomenon. The growth of measurement quality brings new knowledge as a rule and their application forces the improvement of measurement.

The quality of measurement process can be evaluated in the same manner as it of any manufacturing (but also informative or diagnostic) process. The measurement process takes place pursued in measurement system. The system involves measurement equipment, used method, appraisers and conditions of environment, which affect particular elements of the process. The application of the standards (e. g. ISO 9000, ISO 10 012, ISO 17 025) has positive influence on the quality of measurement process. The analysis of the capability provides an operative evaluation of the measurement process quality with its quantification.

The aim of measurement management system according to standard STN EN ISO 10012:2004 [2] is to regulate the risk that the measurement equipment or measurement process could provide incorrect results. Incorrect results as a rule negatively affect the final quality of products with consequential economic or moral damages. The incorrect results of measurement can eventually affect the health (and in an extreme case human life) in the case of diagnostic verification, but also safeness, property, human environment, governmental interests. Although we, from experience, can suppose that confirmed (calibrated and verificated) measurement equipment will be accurate also at the end of calibration interval, there is obvious danger of equipment misdirection. The probable consequence of measurement equipment misdirection is measuring of incorrect values even with the most accurate and the most true (without bias) measurement equipment. The misdirection can be result of incorrect measurement method, the conditions (environment) of measurement or incompetent appraisers.

2. THE CAPABILITY OF MEASUREMENT PROCESS

The capability can be evaluated by two methods as a rule. The first one, based on the analysis of control processes according to standard VDA 5 (or DIN EN V 13005) [3] regards to the uncertainty of measurement. The disadvantage of this method is its restriction for geometric values.

The second method based on the analysis of measurement system is not standardized yet. Various reference manuals are used instead of the standards, the first of all in the automotive industry. The most important of them is reference manual MSA – Measurement Systems Analysis. MSA helps conform to ISO/TS 16 949:2002 requirements as well as AIAG standards.

Measurement system analysis (MSA) is an experimental and mathematical method of determining how much the variation within the measurement process contributes to overall process variability. MSA involves GRR (gage repeatability and reproducibility) studies to evaluate measurement systems. It is a system designed to help engineers and quality professionals assess, monitor, and reduce measurement system variation. It teaches how to conduct measurement system studies including linearity, stability, repeatability, and reproducibility. Analysis of variance (ANOVA) is other used technique of MSA. The advantages of ANOVA as a compared with GRR are that it is capable of handling any experimental set-up, can estimate the variance accurately and extracts more information from the experimental data. The disadvantages are that the numerical computations are more complex and users require a certain degree of statistical knowledge to interpret the results. If the analyzed measurement system is capable, it is likely that the measurement process, taking place in it is capable as well. In regard to more simply approach and suitable software the technique GRR was used for estimation of capability of measurement process [4][5, p. 117].

3. EXPERIMENTAL

The aim of the work is to analyze results of ten samples – parts (iron nails with diameter 4 mm ± 0.11mm and length 115 mm according to STN 02 2825) diameter measurement by evaluation of measurement process capability by MSA, technique GRR, as well as to determine uncertainty and Z-score of analyzed process.

Three measurement equipments - gages were used for measurement:

1. Slide caliper "Somet" (according to DIN 862). The gage was calibrated at last at VIII/06. The expanded uncertainty U = 17.0 μm (coverage factor k = 2). The bias for 5.1 mm standard is 0 mm. The discrimination (the smallest readable unit of the scale) of the equipment is 0,05 mm. The standard uncertainty u_B = 0.01681 mm.
2. Screw micrometer „Somet" (according to DIN 863). The micrometer was calibrated at last at VII/2007. The expanded uncertainty U = 1,0 μm (coverage factor k = 2). The bias for 5,1 mm standard is +0,0004 mm. The discrimination of the equipment is 0,01 mm. The standard uncertainty u_B = 0,002943 mm.
3. Digital micrometer "Kinex" (according to DIN 863) was not calibrated. Maximal permissible error, guaranteed by producer is 0,002 mm, the distribution is rectangular, divisor is 1,73. The discrimination of the equipment is 0,001 mm. The standard uncertainty u_B = 0,001192 mm.

Two appraisers A and B (the method recommend 2-3 appraisers) measured diameter of the randomly chosen samples. The appraiser B is more skilled. The sequence of appraisers and samples in the measurement was random (by lot), the each appraiser measured the diameter of nail three times (the method recommends 2-5 trials). The results of measurement for individual samples are on the figure 1.

Grubbs' test (with significant level 0.05) detected no outliers. The statistical outliers would indicate that the process is suffering from special disturbances and is out of statistical control. The normality was estimated by Freeware Process Capability Calculator software, using Anderson – Darling test. The standard methods of MSA assume normal probability distribution. In fact, there are measurement systems that are not normally distributed. When this happens and normality is assumed, the MSA method may overestimate the measurement system error.

Therefore, before use, the data should be checked to confirm that its distribution is approximately normal. Whereas normality of the statistical files of values measured by both appraisers and all gages was not confirmed, the measurement system error is partly overestimated [5, p. 48].

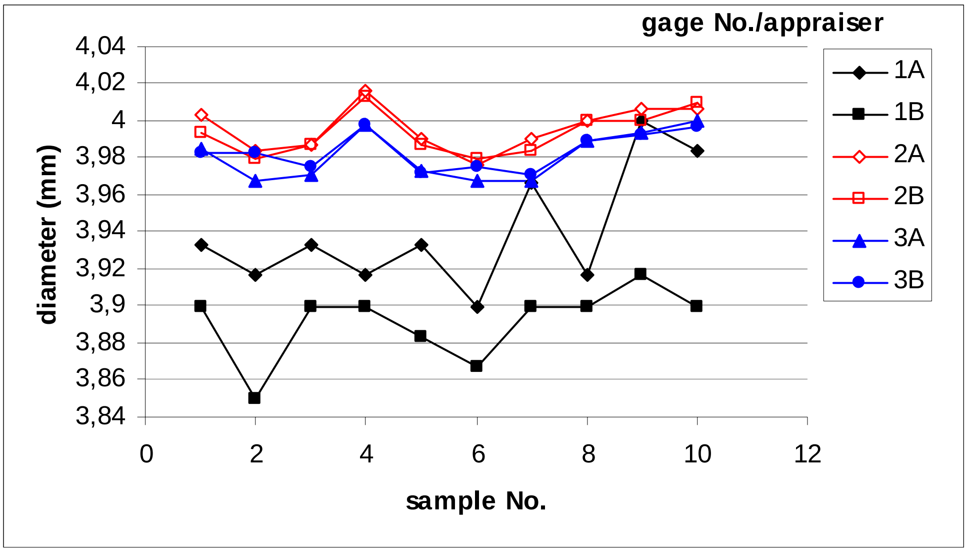

FIGURE 1. THE AVERAGE DIAMETER OF SAMPLES.

The GRR technique of MSA method - combined estimate of measurement system repeatability and reproducibility, described in [5, p. 99-117] with confidence level 99 % (5.15 σ) was used for capability evaluation. The software Palstat CAQ was used for calculation.

Table 1.: The average diameter, standard deviation and discrimination of measurements by gages No. 1, 2 and 3 for all samples.

Gage No	AVERAGE	STDEV	Discrimination	% of X values out of control limits
1	3.916 mm	0.0396 mm	0.05 mm	25
2	3.995 mm	0.0126 mm	0.01mm	65
3	3.982 mm	0.0119 mm	0.001 mm	80

The first step of analysis is to estimate whether the discrimination - the value of smallest scale division (graduation) of measurement equipment is sufficient. A general rule of thumb is the discrimination ought to be at least one - tenth the process variation. Looking at table 1, we can see that only gage No. 3 fulfils this condition [5, p. 74].

The measurement system ought to be in statistical control before capability is assessed, the range control chart is used. The process is in the control, if all ranges are between control limits. This condition was satisfied for gage No. 1, but not for gage No. 2 (5 % of measurements - one value of appraiser B out of control limits) and gage No. 3 (10 % of measurements - one value of appraiser A and one for B out of control limits). If one appraiser is out of control, the method used differs from the others. The statistic control of the process can be reached by some techniques, but by reason of repeatability was not possible to use them in this case.

The area within the control limits of the X-bar control chart represents measurement sensitivity („noise"). Since measurements used in the study represents the process variation, approximately one half or more of the averages should fall outside the control limits. If the data show this pattern, then the measurement system should be adequate to detect (sample - to - sample) variation and the measurement system can be provide useful information for analyzing and controlling the process. If less than half fall outside the control limits then either the measurement system lacks adequate effective resolution (discrimination) or the sample does not represent the expected process variation [5, p. 102]. As can be seen in table 1 (the 4th column), the condition of sensitivity was satisfied for gages 2 and 3.

The number of distinct categories ("ndc", based on Wheeler's discrimination ratio) is connected with the question of the resolution of measurement equipment. It indicates the number of various categories, which can be distinguished by the measurement systems. It is the number of non-overlay 97 % confidence intervals, which cover the range of expected variability of product. The "ndc" is greater than or equal to 5 for capable processes, results with "ndc" values between 2 - 5 may be conditionally used for rough estimations [5, p. 117]. The "ndc" value for gages 2 and 3, tab. 2, is satisfactory only for rough estimations.

Table 2.: The the capability indices.

Gage No.	ndc	%EV	%AV	%PV	%GRR
1	0.88	36.5	76.6	53.0	84.8
2	3.85	31.3	14.3	93.9	34.4
3	3.26	36.2	16.2	91.8	39.7

The %EV index represents the cumulative influence of measurement equipment, used measuring method and environmental conditions on the variability. It is a function of average range of trials of all appraisers. The value of %EV is similar for all gages (between 31.3 % and 36.5 %). Whereas standardized measurement method was used and the measurement equipments 1 and 2 were in valid (not expired) calibration interval only the low equipment's resolution (resolution) for gages 1 and 2, the sensibility on the environment and missing calibration of gage 3 could affect the % EV index.

The % AV index represents the influence of appraisers on the variability, for example their liability (responsibility) and competence. It is a function of the maximum average appraiser difference. As can be seen from tab. 2, this value is markedly affected by gage (low resolution of gage 1 make possible noticeable subjectivity of scale reading).

The %GRR index refers to contribution of measurement instrument to the variability. Its value represents the process capability in practice. The capability decreases with increasing of this index. % GRR<10 % is generally considered to be an acceptable measurement system, % GRR > 30 % is considered to be not acceptable. The analyzed measurement process is not capable, because the values of %GRR run over 30 %. The worst capability has gage 1.

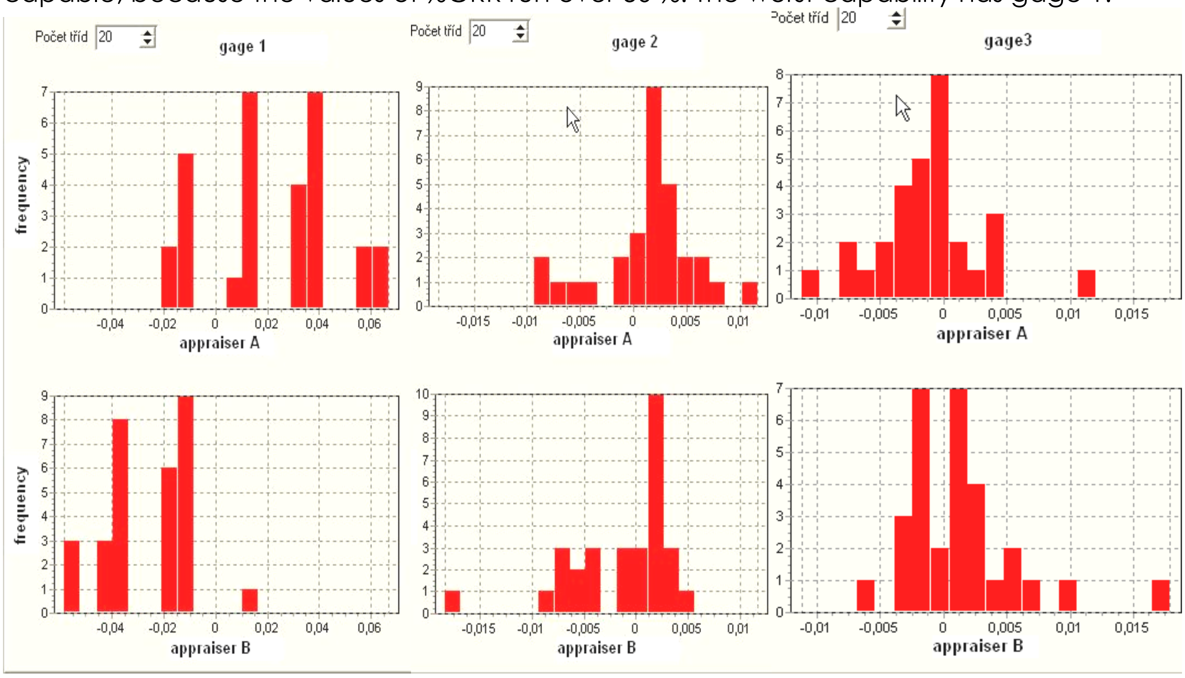

FIGURE 2. NORMALIZED HISTOGRAMS FOR THE GAGES 1, 2 and 3.

The %PV is a function of the range of individual samples - parts (nails). It is sensitive to influence of variability between variations of the nails diameter. The values of % PV indirectly describe suitability of used measurement equipment for specific measurement. The value of %PV above 99 % is for very accurate equipment, above 90 % for suitable, above 70 % for satisfactory and above 50 % for inaccurate one. The equipment with value up to 50 % is unsuitable [6, p. 29]. The value of %PV was 86.9 %. The gage 1 is inaccurate, gages 2 and 3 are suitable in respect to variability between the measured samples.

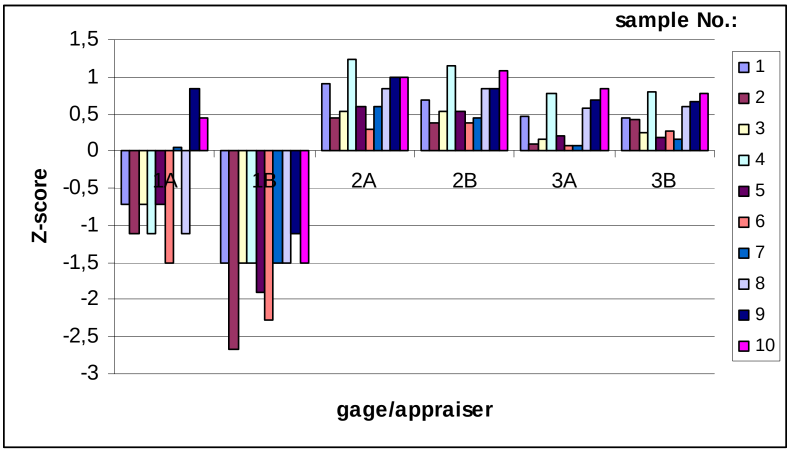

FIGURE 3. Z-SCORE

Normalized histogram – histogram plot (fig. 2) is a graph that displays the frequency distribution of the gage error of appraisers who participated in the study. The graph provides a quick overview how the error, i.e. difference between observed value and reference value (samples average) is distributed. The asymmetric form of histograms indicates that both appraisers are introducing a systematic source of variation which is resulting in the biases [5, p. 109].

The measurement process with the smallest bias has gage 2 for both appraisers. The results of appraiser A are more perfectly centered as they of appraiser B.

Z-score method, routinely applied in interlaboratory comparison tests was used for validation of above mentioned results. The value for individual sample is:

$$z_i = \frac{x_i - \bar{x}}{s} \qquad (1)$$

x_i is the average diameter of all trials on one sample, measured by one appraiser with one gage, $\bar{x}$ the average diameter of all measurements and „s" is standard deviation of all measurements. The results $| z_i | \leq 2$ are satisfactory and $| z_i | \geq 3$ are unsatisfactory [7]. As can be seen on the fig. 3, the results are satisfactory for appraiser and gages with warning for gage 1 and appraiser B. All results of slide caliper have negative bias.

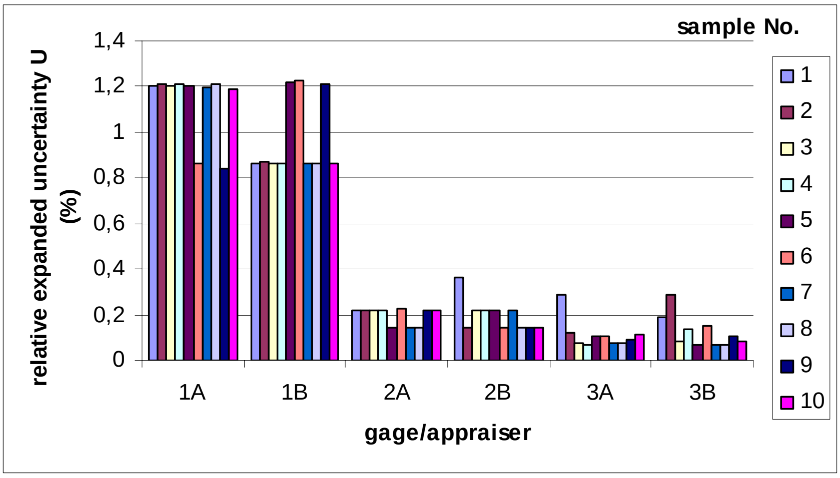

FIGURE 4. THE RELATIVE EXPANDED UNCERTAINTY OF THE MEASUREMENT.

As can be seen from fig. 4, relative expanded uncertainty has ultimate values for the slide caliper, they for micrometers are similar. The influence of appraisers on the uncertainty is low.

4. DISCUSION

Because the values of % GRR are above 10% results, analyzed process of diameter measurement is not capable, eventually in compliance with "ndc" they can be conditionally used for rough estimations. The value of % GRR for micrometers (34.4 % and 39.7 %) are less than they for Vickers hardness tests capability (66.4 %) [8]. Even less process capability was observed at Brinell hardness measurement of wrought brass (%GRR between 62.7 and 88.7 %) [9] and it of cast brass (between 63.7 and 89.4 %) [10]. The capability of microhardness measurement process is also low (% GRR between 61 % and 86 %) [11]. Low capability has also the process of blood pressure measurement (% GRR between 35 % and 75 %) [12][13].

5. CONCLUSIONS

1. Analyzed processes of diameter measurement by slide caliper, screw micrometer and digital micrometer are not capable.
2. The insufficient resolution of slide caliper and screw micrometer and absence of calibration of digital micrometer are reasons of non – capability.
3. Slide caliper has higher values of Z-score and uncertainty as micrometers.
4. Observed non-capability of measurement process is valid only for used model.

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