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Comparative analysis of methods of hardness assessment

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ABSTRACT

Purpose: The aim of this paper is to show how it could utilize the statistical methods for the process management.

Design/methodology/approach: The research methodology bases on a theoretical analysis and empirical researches. A practical solution is presented to compare measurements methods of hardness and to estimate capability indices of measurement system.

Findings: Measurement system analysis (MSA), particularly theory of statistical tests brings correct results for the analysed case.

Research limitations/implications: Comparative analysis of measurement methods – interlaboratory studies, delivery control etc. is necessary in the interpretation of results.

Practical implications: Described methodology and results can be employed in the industrial practice.

Originality/value: The complete statistical comparative analysis of methods of hardness measurement with the help of a stationary and mobile hardness tester.

Keywords: Quality management; Statistical methods; Measurement system capability; Measurements of hardness

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1. Introduction

Quality is a challenge that must be taken up by producers and other organisations. A formal requirement of quality are among others ISO 9000 standards, specific branch requirements e.g. ISO/TS 16949 (the automotive industry), HACCAP system (the food industry), AS 9000 standard (the aircraft industry) and the organizational culture Six Sigma [1-8].

Among many quality instruments, statistical methods have the elementary meaning which are first of all the following: statistical process control (SPC), measurement system analysis (MSA), statistical acceptance plans and statistical methods in process improvement (ANOVA, DOE etc.) [9-14].

It should be stated that the basis of each good statistical analysis are good data i.e. a good measurements. Only on this condition the statistical methods allow to assign the significance to the data and to make their physical interpretation.

The assessment of measurement quality is the subject of measurement system analysis (MSA).

From the point of view of a methodology the MSA requires application of many different statistical methods – descriptive statistics, statistical tests, tests of hypotheses, the analysis of variance, regression and correlation. The MSA's tasks do among others as follows: a comparative analysis of methods, gage repeatability and reproducibility studies, assessment of capability of measurement system (capability indices Cg, Cgk) [10, 15].

2. Quality of measurement data

Without a good measurement there are no good statistics, and first of all statistical properties of measurement systems decide about their advantages and usability.

The good measurement should be correct and precise. Measurement correctness means no systematic error, and precision is connected with dispersion of measurement results: the smaller dispersion of measurement results, the more precise measurement is.

Qualification of a measurement system for the sake of correctness should comprise an assessment of systematic error, linearity (linearity – variation of systematic error depending on a location in a measurement system) and stability (stability – variation of systematic error in time) [15].

Qualification of a measurement system for the sake of precision comprises an assessment of repeatability (repeatability – variation from a measurement device) and reproducibility (reproducibility – variation for which an operator is responsible, in other words innocent systematic error of an operator).

The simplest method of measurement system assessment for the sake of precision is the range method (so-called R method), but it does not allow to isolate components as for reproducibility and repeatability from a total variation of a system. Therefore, the most often method of a measurement system assessment as for correctness and precision is the average and range method (it is so-called R&R method) or – more seldom – the method of analysis of variance (ANOVA) [10,11,15].

The following criteria of assessment of measurement system suitability are valid [15]:

- If variation of a measurement system is not more than 10% of the process variation (or the variation declared by specification limits), the measurement system is suitable without any restrictions
- If variation of a measurement system is between 10% and 30% of the process variation (or the variation declared by specification limits), the measurement system is suitable conditionally (e.g. for the sake of costs)
- If variation of a measurement system is more than 30% of the process variation (or the variation declared by specification limits), the measurement system is not suitable to control the process.

Let us consider the matter that in given criteria the variation of the measurement system relates to the process variation or the variation declared by specification limits. It is a very rational approach: the point is to have not a very good measurement system (because surely it is very expensive) and not bad one (because it does not "see" the process variation).

The standard PN-ISO 5725 (volume 1 to 6) describes the problem of repeatability and reproducibility.

3. Assessment of capability of measurement system

Estimation of a capability of the measurement system consists, similarly to the estimation of process capability, in a comparison of variation of measurement system capability with client's expectations defined by specification limits.

In case of two-sided limitation (the upper and lower specification limit) the capability indices of measurement system are determined the most often as follows [10, 15]:

- index Cg

$$C_g = \frac{k/100 \cdot T}{6 \cdot s} \quad (1)$$

- index Cgk

$$C_{gk} = \frac{k/200 \cdot T - \left| \bar{x} - x_0 \right|}{3 \cdot s} \quad (2)$$

where: LSL – lower specification limit
USL – upper specification limit
T – tolerance (T=USL-LSL)
$\bar{x}$ - mean of n measurements
k – percent of the tolerance, default=20
s – standard deviation of measurement results
x_o – reference value (value of a standard)

In case the value x_o is not known, the index Cgk (equation (2)) is not evaluated.

4. Measurement of hardness

Hardness evaluation belongs to the basic tests of mechanical properties of materials. There is a relationship between the hardness and other material's characteristics, e.g. a tensile strength. This type of relationship is settled on the basis of comparative measurements.

Nowadays the hardness measurement can be made with the help of very precise stationary and mobile testers. The mobile measurement instruments are more and more popular because of the opportunity for their application in hard-to-reach places or regarding big complicated elements. The choice of the tester, first of all, depends on a size of the element to be measured, a size of the formed imprint, a load being imposed, a condition of surface and thickness of the tested element [16].

Among stationary hardness testers we have, first of all, the Brinell (PN-EN ISO 6506-1:2002), the Vickers (PN-EN ISO 6507-1:1999) and the Rockwell (PN-EN ISO 6508-1:2002) hardness testers [16].

The hardness measurement using mobile devices is made with the static UCI (Ultrasonic Contact Impedance) method, the dynamic rebound hardness testing method or the optical TIV (Through-Indenter-Viewing) method. To dynamic methods belong among others the Poldi hardness test, the Leeb hardness test (it is a modern version of the scleroscope), the Shore hardness test etc...

5. Experimental procedure

The aim of tests was a comparative analysis of hardness assessment using a stationary Vickers/ Brinell (WPM) hardness tester and a mobile hardness tester MIC 20 of the Krautkramer Company. The MIC 10 is a versatile, "two-in-one": tester

Table 1.
List of descriptive parameters

Descriptive Statistics	Mean	Standard deviation	Minimum, min.	Maximum, max	Skewness	Kurtosis
Vickers/Brinell	139.19	4.65	130.9	153.0	0.49	0.03
MIC20 sounder 2050, loading 50 N	155.09	5.98	138.0	168.0	-0.09	-0.04
MIC20 sounder 201L, loading 10 N	149.97	6.29	137.0	168.0	-0.34	0.05

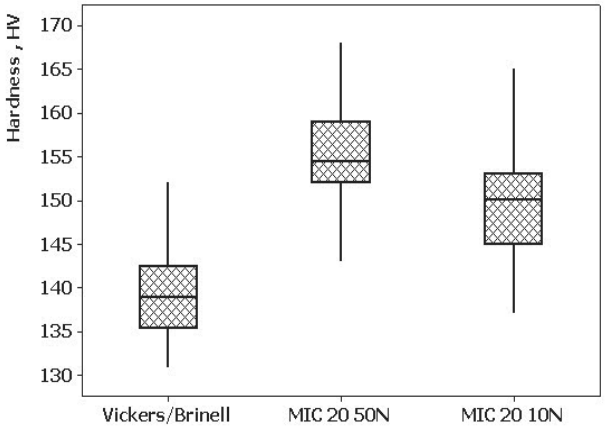

Fig. 1. Boxplots for analyzed measurement methods

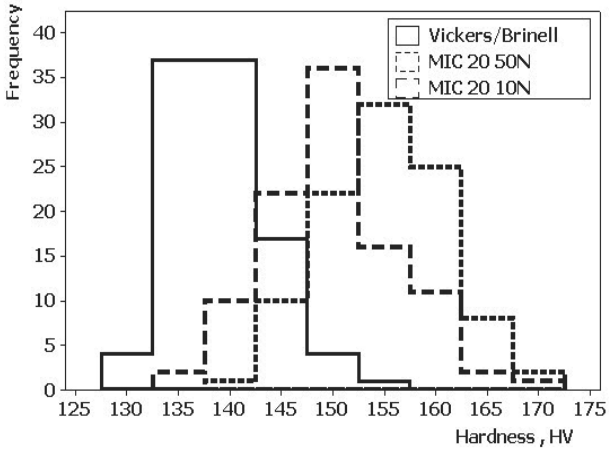

Fig. 2. Histogram for analyzed measurement methods

combining the UCI (Ultrasonic Contact Impedance) and rebound test methods. The UCI method tests, small and complex shaped parts comprised of fine-grained metals, while the rebound method is preferred for larger, coarse-grained forgings and castings.

The measurements were carried out on a tool steel C80U (PN-EN ISO 4957:2002) sample after isothermal annealing. The surface on which the measurements are performed was in the after-polishing state. 100 measurements were carried out using each method. The effects of a preliminary statistical analysis of measurement results are presented in Table 1 and in Figures 1, 2. No unusually large or small outliers have been observed (Fig.1), the values of shape parameters i.e. skewness and kurtosis, very close to the zero, preliminarily indicate that for each measurement method the results - as for the variation - are the subject to a normal distribution, as it could be expected.

The preliminary assumptions regarding a normal distribution on the basis of skewness and kurtosis, proved the graphical test of normality (Fig. 3) and the Anderson – Darling test [8, 10, 12]. In the meaning of the Anderson – Darling test (Vickers/Brinell – p-value = 0.057, MIC 20 (sounder 2050, loading 50 N) – p-value = 0.245, MIC 20 (sounder 201L, loading 10N) – p-value = 0.099) there is no basis for rejection of the hypothesis that it is the normal distribution.

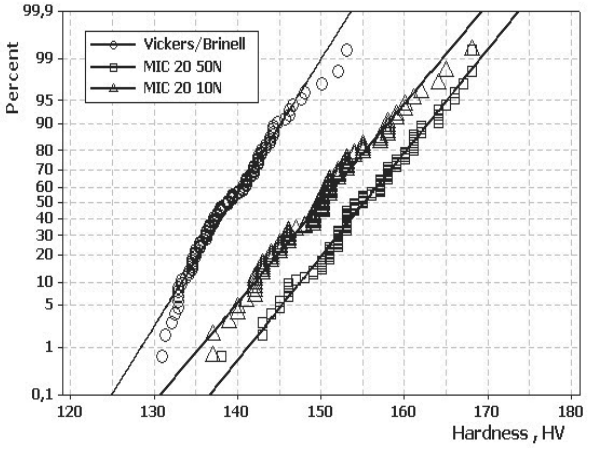

Fig. 3. Graphical test of normality (normal probability plot)

In the meaning of the Bartlett's test (a test for the comparison of many variances) [8, 10, 12] (p-value =0.009) there is a basis for rejection of the hypothesis on equality of variances.

However, in the meaning of the Fisher test (a test for the comparison of two variances) there is no basis for rejection of the hypothesis that variances for MIC 20 (sounder 2050, loading 50N) and MIC 20 (sounder 201L, loading 10N) are equal (p-value = 0.692).

On the basis of tests executed it can be stated, that the MIC 20 method is characterized by a larger, statistically significant dispersion of results comparing to the Vickers/Brinell method; in other words, it is less precise.

For comparison of average values it was no possible to use multiple comparisons tests (post-hoc tests) like in ANOVA, because the variances turned out to be different in the meaning of the Bartlett's test. Hence, for comparison of average values in the Vickers/Brinell method and two MIC 10 methods, the t test was applied. In the meaning of the t test there is a basis for rejection of the hypothesis that the mean values for MIC 20 methods (sounder 2050, loading 50N and sounder 201L, loading 10N) are equal (p-value = 0,000), and there is the basis for rejection of the hypothesis that the mean values for MIC 20 and Vickers/Brinell methods are not equal (Vickers/Brinell vs. MIC 20 (sounder 2050, loading 50N) – p-value =0.000, Vickers/Brinell vs. MIC 20 (sounder 201L, loading 10N) – p-value = 0.000).

On the basis of t tests carried out it can be stated that the MIC 20 and Vickers/Brinell methods differ as for the correctness.

6. Discussion of results

Two applied methods (Vickers/Brinell and MIC 20) give statistically different results both from a correctness and precision view-point. As it could be expected, the measurement executed with the help of the Vickers/Brinell stationary hardness tester is more precise than the measurement made using the mobile hardness tester. The differences in precision are obviously reflected as the values of capability indices Cg. But the differences in correctness of both the methods are the subject of larger consideration. It can be observed that the results of the measurements achieved with the help of a mobile hardness tester clearly move towards the higher values comparing to the results obtained with the help of a stationary one. This problem requires a more technical analysis.

7. Summary

The assessment of quality of measurement system should be preceded by all further statistical analyses of data. Acquaintance with the measurement system from a correctness and precision view-point is significant in case of laboratory tests as well as statistical process control (SPC), delivery control and process improvement. Because of this, the methods of measurement systems analysis (MSA) are the subject of a great interest from the theoretical and practical point of view, and they are intensively developed. The reason for that situation is also the fact that we have contact with still better and better processes i.e. the processes that are characterized by less and less variation and this generates a need for the better measurement.

The hardness belongs to the basic parameters of material. Because the application of hardness testers is larger and larger, it is necessary to get to know well their measurement potential and quality comparing to classical stationary hardness testers. This study presents that kind of analysis.

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