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THE QUALITY OF TEMPERATURE MEASUREMENT WITH VISUAL PYROMETER

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ABSTRACT: *A temperature is a fundamental parameter in metallurgical operations. Reliable and continuous measurement of temperature is essential for effective control of the operation. Thermocouples were the traditional devices used for this purpose, but they are unsuitable for continuous measurement because they rapidly dissolve. Pyrometers are suited especially to the measurement of moving objects or any surfaces that can not be reached or can not be touched. The quality of temperature measurement with pyrometer with a vanishing filament was evaluated using the analysis of uncertainty and the measurement systems analysis (MSA).*
KEYWORDS: *temperature, pyrometer, uncertainty, MSA*

INTRODUCTION

The demands on the measurement of the qualitative characters of products, services, trades and processes increase in connection with the pressure towards to the quality. The measurement is important in all phases of production. It starts in the research, goes on in development, monitoring of raw materials as the inputs, semi-finished products, process of production, environment and the final check-out. May be said "What you can not measure, you do not know to product". The growth of measurement quality yields new knowledge as a rule and its application forces the improvement of the measurement.

The aim of measurement management system according to standard STN EN ISO 10012:2004 [1] is to regulate the hazard of incorrect result of measurement equipment or measurement process. Incorrect results negatively affect the final quality of products with economic or moral damages. They can affect the health, safeness, property, environment, governmental interests. We can suppose that confirmed (calibrated and verified) equipment is accurate also at the end of calibration interval. But there is obvious danger of equipment misdirection (incompetent appraiser, environment or inappropriate method). The probable result of misdirection is incorrect values measured with accurate and true equipment.

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EQUIPMENT AND METHOD

A pyrometer is a non-contacting device that intercepts and measures thermal radiation. This device can be used to determine the temperature of an object's surface. The disappearing filament pyrometer principle of measurement is a thin, heated filament over the object to be measured and relied on the appraiser's eye to detect when the filament vanished. The object temperature was then read from a scale on the pyrometer. The appraiser's eye as a sensor brings subjective influence (quality of appraiser, for example his or her competence, perception, skill discipline and vigilance) into measurement process. The range of measured temperatures is between 800 and 2200°C as a rule.

The thermoelectric equipment TESTOterm 9010 was used as check (working) standard. Its exploring element with cased chromel – alumel (K) thermoelectric couple touched the body surface. The standard uncertainty of calibration (the equipment with exploiting element) u_{kal} = 1,516°C for temperatures up to 900°C and u_{kal} = 2,086°C for upper ones. The uncertainty includes recommended sources for calculation of B type uncertainty [2].

Two identical pyrometers – Pyromet 1 (PVS and PJP) were used as measurement equipments. The discrimination (effective resolution) - the value of the smallest scale graduation (range 700 – 1500°C) d = 10°C, the maximal permissible error guaranteed by producer is ± 22°C (maximum permissible bias error as ± 1.5 % of the upper limit of measuring range 1400°C is recommended by OIML for ordinary accuracy class of pyrometers [3]).*

EXPERIMENTAL

The measurement was carried out on ten levels of temperature between 800 and 1000°C. The measured body - grey-black cube of SLI (natural iron magnesia) *was heated in a resistance furnace. Its surface temperature was measured with standard. Once the standard indicated stabilized temperature, two appraisers (A, B) measured the surface temperature of body with two pyrometers in random order. Each of appraisers carried out three trials with one pyrometer (12 measurements at one temperature level in common). The temperature of body, measured with standard was read six times at one level. The result of imperfect furnace regulation and heat removal throughout the measuring aperture was some variation of the body surface temperature. This fact became one of the sources of uncertainty of temperature.*

The distance between objective of pyrometer and measured body was 1.3 m, the ambient temperature was 22.9 – 24.1°C, the relative humidity 40.3 – 52.4 % with absence of any dust, vapor, smoke and external magnetic field apart from that of the earth. Their presence could to absorb thermal radiation with decreasing of measured temperature.

Total standard uncertainty of temperature, measured with standard:

$$u_{et} = \sqrt{u_A^2 + u_{kal}^2} \qquad (1)$$

$$u_A = \frac{s}{\sqrt{n}} \qquad (2)$$

s = standard deviation, n = 6 is number of trials (3 trials each of appraisers).

The uncertainty of average temperature $\bar{T}$, measured with standard at one level was expressed as a relative expanded uncertainty U_{rel} (coverage factor k = 2). The values of $\bar{T}$ and U_{rel} for particular levels illustrate Figure 1 and 2 (“standard”).

The temperature measured with the vanishing filament pyrometer is dependent on the emissivity of the object. With greater use of brightness pyrometers, it became obvious that problems existed with relying on knowledge of the value of emissivity ε. Emissivity was found to change, often drastically, with surface roughness, bulk and surface composition, and even the temperature itself.

A true black body would have an ε = 1 while any real object would have ε < 1. The scales of pyrometer match with temperature of true black body. Because of real bodies radiate less energy, their measured temperature is constantly less. For calculation of correction the value of ε = 0.6 (for fire-clay or chamotte and wave-length l = 0.65 μm). The correction, add to measured temperature was calculated by equation (3), regarding the recommendations of producer

$$T_k = 0.0575\, T - 19.45 \qquad (3)$$

T = measured temperature

Corrected value of temperature

$$T_{kor} = T + T_k \qquad (4)$$

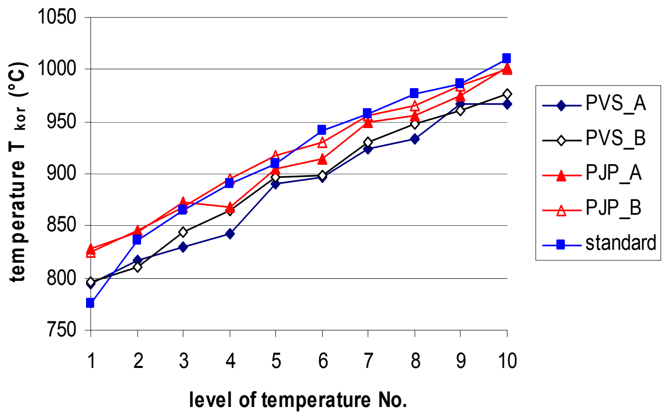

Figure 1. The average values of temperature measured with pyrometers and standard

The average corrected values of temperature T_{kor} measured by particular appraisers with both pyrometers illustrates Figure 1. According to unpaired t-test to compare two means (α = 0.05) the differencies between the values of temperature, measured by appraisers A and B (p = 0.7137) and with pyrometers PVS and PJP (p = 0.1852) by conventional criteria are considered to be not statistically significant.

The standard uncertainty of temperature measured by pyrometer was calculated using equation (5):

$$u_{pyr} = \sqrt{u_A^2 + u_{res}^2 + u_{et}^2 + u_{sys}^2} \qquad (5)$$

Uncertainty u_A was calculated by equation (2): s = standard deviation, n = 3 is number of trials (one appraiser with one pyrometer), u_{res} = 0,29 x d = 2,9 uncertainty resulting from discrimination d*, u_{et} is standard uncertainty of temperature measured by standard at given level, calculated by equation (1) and u_{sys} is standard uncertainty of bias error, calculated from difference between temperature measured with pyrometer and with standard to [4] using equation (6).*

$$u_{sys} = 0{,}6 \cdot \left|\left(T_{kor} - \bar{T}\right)\right| \qquad (6)$$

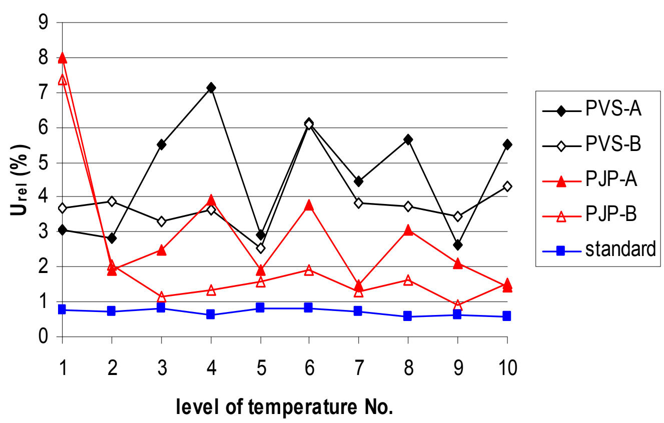

Figure 2. The relative expanded uncertainty U_{rel} of temperatures

The values of uncertainty of average corrected temperature T_{kor}, measured with pyrometer at one level, expressed as relative expanded uncertainty U_{rel} (k = 2) illustrates Figure 2. The uncertainty of pyrometer is 3 to 6 times more than uncertainty of standard.

MEASUREMENT SYSTEMS ANALYSIS

In addition to analysis of uncertainty the quality of measurement process was evaluated by "Measurement systems analysis" (MSA). This method is not standardized yet, but is recommended in the reference manuals, used the first of all in the automotive industry. MSA helps conform to ISO/TS 16 949:2002 requirements as well as AIAG standards. It is an experimental and mathematical method of determining how much the variation within the measurement process contributes to overall process variability. The measurement process, running in capable measurement system (consists of measurement equipment, samples, environment, method, appraisers...) is capable as well.

The computation of capability by GRR method MSA (analysis of repeatability and reproducibility) was carried out in accordance with [5] using the software Palstat CAQ with significance level $\alpha = 0.01$ and confidence level $\alpha = 0.01$ ($5.15\ \sigma$). The values of capability indices are in tab. 1.

The first step of analysis is to estimate whether the discrimination is sufficient. A general rule of thumb is the discrimination ought to be at least one - tenth the process variation [5, p. 44]. If we compare the variability is expressed by standard deviation (s) which does not run over 18.3°C (level No. 4, measured by appraiser A with pyrometer PJP) and the discrimination of equipment (10°C), the resolution is not sufficient. Because average value of standard deviation is 3.88°C, the discrimination (0.1°C) of standard is sufficient.

The measurement system ought to be in statistical control, the range control chart was used. Analyzed process is in the control, all ranges (for pyrometers and standard) are between control limits. If one couple (appraiser and equipment) is out of control, the method used or (and) metrological characteristics differ from the others. The area within the control limits of the X-bar control chart represents measurement sensitivity („noise"). 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 variation between the levels of temperature and the measurement system can be provide useful information for analyzing and controlling the process, or else system lacks adequate effective resolution. The analyzed system has high resolution: 80 - 90 % of measurements with pyrometer and 90 % with standard are out of control limits (tab. 1).

The number of distinct categories ("ndc", based on Wheeler's discrimination ratio) is connected with 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 over 5 for capable processes, the values over 2 may be conditionally used for rough estimations.

Table 1. The indices of MSA

equipment	PVS	PJP	Standard
appraisers	A/B	A/B	A-B
%R	0	0	0
%X	90	90	90
%EV	11.5	14.7	6.0
%AV	7.7	9.4	0.7
%PV	99.0	98.5	99.8
%GRR	13.8	17.4	6.1
ndc	10.13	7.99	23.3

The %EV index represents the cumulative influence of measurement equipment, measuring method and environmental conditions on the variability. It is a function of average range of trials of all appraisers. Because standardized measurement method was used and the measurement equipments were in valid calibration interval only the condition of environment 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. Low value of index confirms good competence of appraisers. The value of index is significantly affected by equipment.

The %GRR index represents the process capability in practice. %GRR < 10 % (the rate of the manufacturing production process variability that is „consumed" by measurement system variation) is generally considered to be an acceptable – capable measurement system, %GRR > 30 % is not acceptable. Analyzed measurement process by standard is capable. The processes using pyrometers are conditionally capable.

The %PV is a function of the range of temperatures. It is sensitive to variability of particular levels of temperature. The values of %PV indirectly define suitability of used measurement equipment for specific measurement. The value of %PV for accurate equipment is between 90 and 99 %. Because %PV of standard is 99.8 % the equipment is too sensitive for analyzed system and therefore uselessly expensive.

Normalized histogram – histogram plot is a graph that displays the frequency distribution of the gage error of subjects who participated in the study (a couple appraisers – equipment). The graph provides a quick *overview how the error, i.e. difference between observed value and reference value (samples average) is distributed.*

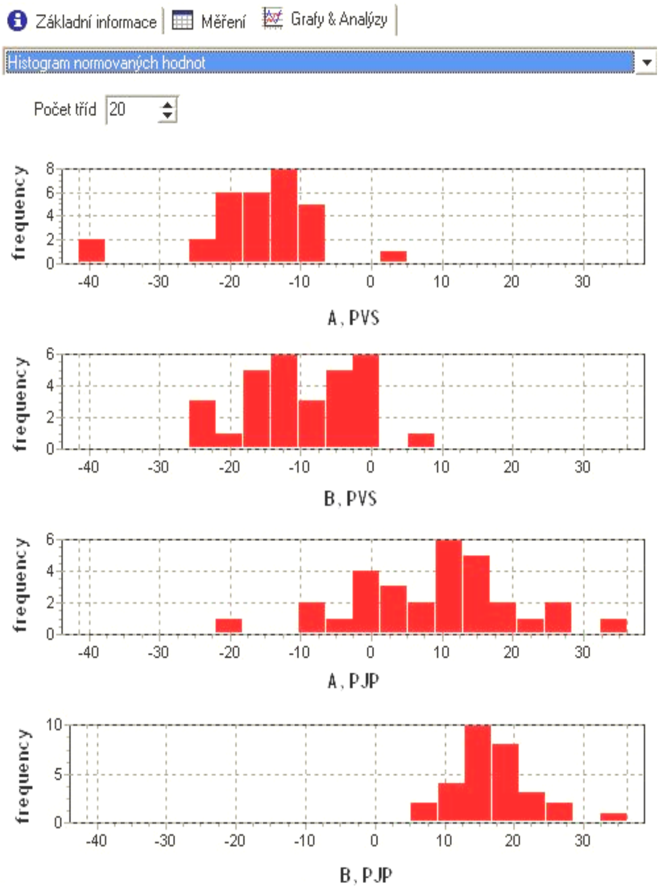

Figure 3. The normalized histogram for temperatures

As illustrates Figure 3, the differences of bias (systematic error – the difference between histogram's peak and 0) and variability (random error – the width of histogram) between subjects are significant.

CONCLUSIONS

The results obtained are summarized as follows:

- *The measurement of temperature with pyrometer has more significant uncertainty than measurement with thermocouple.*
- *The capability of temperature measurement process, with pyrometer by MSA method is conditionally acceptable.*
- *The equipments affected the quality of measurement process more significantly than appraisers.*
- *As for uncertainty the best conjunction is appraiser B and pyrometer PJP (average uncertainty U_{rel} = 2.07 %).*

ACKNOWLEDGEMENTS

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