Uncertainty Analysis of Piston Gauge

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Abstract. *Piston gauge is typically used for the calibration of pressure gauges and pressure transmitters. The principle of pressure definition is based on the physical pressure definition (known value of force that perpendicularly acts on known size of area). In practice, the uncertainty of the reproduced pressure by piston gauge is mostly determined by the calibration for specific conditions. Uncertainty of reproduced pressure is rarely evaluated on the basis of uncertainty for determination of the piston and balances weights as well as the uncertainty of the effective area of pressure gauge. In the latter case, it is important to analyze the uncertainties caused by the piston gauge conditions of use. The paper presents the analysis of the uncertainties of individual components of piston gauge for pressure measurement, where liquid oil is used as crusher liquid.*

Keywords: Piston Gauge, Uncertainty of Measurements, Uncertainty Analysis

1. Introduction

Now the precision of piston gauges expressed by permissible error is about 0.005% of reading and in some cases even better than 0.002%. Uncertainties of measurement are affected by the measurement conditions. Therefore the accuracy data from manufacturer are uncontrollable without any assumptions of conditions.

This paper presents the uncertainty analysis for pressure determination reproduced by piston gauge in case when we have the data from calibration certificate for piston weight, balances weights, effective piston area and their uncertainties. Analysis is based on the basic relationship for determining of pressure caused by piston gauge on which the law of uncertainty propagation is applied. It is necessary to determine the values of all contributions of influencing factors to the uncertainty of reproduced pressure.

2. Subject and Methods

For the piston oil gauge measuring overpressure the pressure defined by the relation [1, 2]

$$p_{\mathrm{et}} = \frac{m_j \cdot g_{\mathrm{m}} \cdot \left(1 - \frac{\rho_{\mathrm{vz}}}{\rho_{\mathrm{z}}}\right) + \pi \cdot D \cdot T}{A_{\mathrm{ef}} \cdot \left[1 + \left(\alpha_{\mathrm{p}} + \alpha_{\mathrm{c}}\right)\left(\theta - 20\right)\right] \cdot \left(1 + \lambda p\right)} + \rho_{\mathrm{oil}} \cdot g_{\mathrm{m}} \cdot h \tag{1}$$

where

- p_{et} is pressure on the output of piston gauge (Pa),
- m_j is the actual total weight of the loaded balances (kg),
- g_{m} is the local gravitational acceleration (m/s^2),
- ρ_{gas} is the density of gaseous medium (kg/ m^3),
- ρ_{vz} is the density of ambient air (kg/m^3),

- ρ_z is the average density of the loaded balances (kg/m^3),
- ρ_{oil} is the density of oil medium (kg/m^3),
- πDT is the affect caused by surface tension (N/m)
- A_{ef} is the effective piston area at 20 °C and null pressure (m^2),
- α_p is the temperature coefficient of linear expansion of piston (°C^{-1}),
- α_c is the temperature coefficient of linear expansion of container (°C^{-1}),
- θ is temperature of pressure gauge (°C),
- λ is the coefficient of pressure deformation of pressure gauge (Pa $^{-1}$),
- h is the height differences of levels of inputs points (m),
- p is pressure value affecting on pressure gauge (nominal pressure value) (Pa).

The next section describes different uncertainties (in the case described by equation (1)) their evaluation and inclusion into the total uncertainty of defined pressure.

Expected limiting values of environment variables in this analysis are [5]:

- ambient temperature: (19 to 23) °C,
- ambient relative humidity: (5 to 95) %,
- ambient pressure: (70 to 110) kPa.

Calculation of the Standard Uncertainty by the Method A
Evaluation of uncertainty by the method A is determined as the standard deviation of the arithmetic mean when we estimate the output variable as the arithmetic mean of the measured data.
If we do not have enough number of pressure data at one measurement point to be able to evaluate the uncertainty by the method A then we determine the repeatability by the method B.

Calculation of Standard Uncertainty by the Method B
On the basis of the law of uncertainty propagation which assumes the dependence of output quantity p on input quantities in the form $p = f(x_1, ..., x_n)$, there will be for uncorrelated input quantities [4]

$$u(p) = \sqrt{\sum_{i=1}^{m} C_i^2 u^2(x_i)} \tag{2}$$

where

C_i – is the sensitivity coefficient which will be determined as $C_i = \dfrac{\partial f}{\partial x_i}$,

$u(x_i)$ – is standard uncertainty of estimation x_i.

We will assume the value of the component – πDT of the effect caused by surface tension as negligible for corresponding analysis.

For this purpose it is necessary first to determine estimates and uncertainties of the input quantities. According to equation (1) assuming that the piston gauge is used and the same high of reference levels is assured are:

- m_j is the actual total weight of the loaded balances (kg),
- g_{m} is the local gravitational acceleration (m/s^2),
- ρ_{gas} is the density of ambient air (kg/ m^3),
- ρ_{z} is the average density of the loaded balances (kg/m^3),
- A_{ef} is the effective piston area at 20 °C and null pressure (m^2),
- α_{p} is the temperature coefficient of linear expansion of piston (°C^{-1}),
- α_{c} is the temperature coefficient of linear expansion of container (°C^{-1}),
- θ is temperature of pressure gauge (°C),
- λ is the coefficient of pressure deformation of pressure gauge (Pa $^{-1}$),

Individual input variables for pressure determination of the pressure piston gauge can be split into two groups. The first group consists of the base component to determine the pressure (m, A_{ef}, g_{m}) and the second group consists of components that are used for correction of the basic components. If we analyze the relationship from the other point of view then we can include all quantities except (m, A_{ef}, α_{c}, α_{p}, ρ_{z},λ). According to [3] components with the maximal value in the total uncertainty of a piston manometer are A_{ef}, m, T

3. Results

Data from the Slovak Institute of Metrology specified in [5] were used for the uncertainty analysis. All uncertainty contributions of the input quantities were determined as estimates by application of the law of uncertainty propagation on relationship (1) according to [1], [2]. Results of the analysis are shown in Table 1 for the pressure point p_{20} = 20,00464 MPa.

Table1. Uncertainty budget for i = 20 pressure point of piston pressure gauge.

Input quantity	Estimation	Standard uncertainty	Probability contribution	Sensitivity coefficient *	Contribution to the total uncertainty
$m_{\mathrm{z}20}$ (kg)	20,397	4,3.10^{-5}	rectangular	0,98	1,28.10^{-5}
g_{m} (ms^{-2})	9,80873243	1,0.10^{-7}	rectangular	2,034	2,04.10^{-7}
ρ_{vz} (kgm^{-3})	1,192	1,4.10^{-5}	rectangular	0,0025	3,54.10^{-6}
ρ_{z} (kgm^{-3})	7904,721	1,9.10^{-2}	rectangular	3,82.10^{-7}	7,26.10^{-9}
A_{ef} (m^2)	9,9995.10^{-6}	1,6.10^{-10}	rectangular	2000563	3,2.10^{-4}
($\alpha_{\mathrm{p}} + \alpha_{\mathrm{c}}$) (°C^{-1})	1.10^{-5}	1,0.10^{-6}	rectangular	9,002	9,0.10^{-9}
T_{20} (°C)	20,45	2,5.10^{-2}	rectangular	0,0002	5,0.10^{-6}
λ (MPa^{-1})	8.10^{-10}	2,4.10^{-10}	rectangular	400,2	9,61.10^{-8}
$p_{\mathrm{et}20}$ (MPa)	20,00464	1,4.10^{-6}	Gaussian	1	1,4.10^{-6}

* sensitivity coefficients have units based of definition.

Graphical presentation of the uncertainty value of input quantities is in Figure 1.

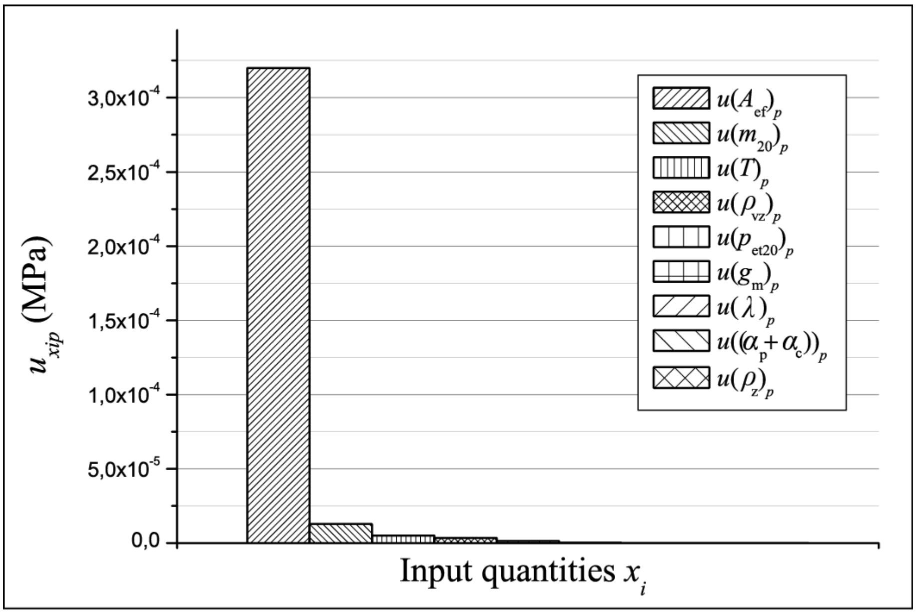

Fig. 1. Uncertainty contributions of individual input quantities.

4. Discussion and conclusions

Detailed uncertainty analysis of piston pressure gauge gives us in particular measurement system a possibility to deteremine correctly the value of individual partial uncertainties, or vice versa after proper consideration some uncertainty neglect. As we can see from Table 1 and from Figure 1 it was cnfirmed that the dominant uncertainty components of piston gauge are A_{ef}, m, T, but component T and m are almost negligible comparing to the impact A_{ef} component.

The impact of tilt piston was nglected in the analysis. In analyzing. For that reason there was necessary to control the vertical deviation piston spirit levels. The effects of sensitivity, stability and linearity was also considered in the analysis.

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