HEAT MEASUREMENT UNCERTAINTIES IN VERIFICATION IN METROLOGICAL LABORATORY

Václav Kubernát

The University of West Bohemia in Pilsen, Plzeň, Czech Republic, gubbi@ket.zcu.cz

Abstract: Heat-meters as a kind of revenue meters are metrologically certified and this certification is executed with some measurement uncertainty. Since these certifications are performed by means of temperatures and flow amounts simulations, it obviously results in some measurement uncertainty. The value of the measurement uncertainty can be seen in the following calculation.

Keywords: uncertainty evaluation, calorimeter verification, metrological laboratory

1. INTRODUCTION

If we want to define uncertainties in a measurement of an amount of delivered and consumed heat, it is necessary to take into consideration this is not a straightforward matter. Heat measurement is an indirect one comprising of measurements of temperature and flow amount. Thus the measurement uncertainties should be defined as a combination of both the temperature measurement uncertainties and the flow amount measurement uncertainties on the basis of which the heat measurement uncertainties will be defined then. [1]

This is, of course, a simplified approach. In addition, a precise calculation of uncertainties in such a complex measurement requires long-time experience in this field, especially practical experience.

2. SENSORS AND CALORIMETER DESCRIPTION

Heat calorimeter (type ETM 1.01) is meant for absolute measuring of an amount of delivered and consumed heat in warm-water systems and for its registration. Calorimeter is suitable for revenue measurement. Is connected to heat pipes or placed in junction exchange stations. Calorimeter has technical and programmable devices, which provide connection to communication channel thereby data processing and evaluation in superior computer.

Heat measuring instruments with calorimeters evaluate and register consumed heat amount using notorious principle of measuring. It means, we measure water volume rate, input and output temperature and subsequently we count the heat rate using following formula:

$$q_t = Q_m \cdot (h_1 - h_2) = Q_v \cdot \rho \cdot (h_1 - h_2) \qquad (1)$$

where

q_t is   heat rate
Q_m massic flow rate of water
Q_v water volume rate
h_1 water enthalpy by temperature ϑ_1
h_2 water enthalpy by temperature ϑ_2
ρ water density.

We measure input and output temperature of the measuring system to get water enthalpies and density. Consumed heat amount Q during time interval t is counted using integration by time of the heat rate. The interval of data logging is 1 s.

$$Q = \int_t q_t dt \qquad (2)$$

From a functional perspective the calorimeter consists of arithmetical unit and input and output circuits. This logical unit is realized using single-board microcomputer. Executes counts of enthalpy and water density in range to 180°C. Resistance temperature devices Pt100 are connected with four-wire cable and signals are modified in input circuits.. Input circuit for signal processing from measured flow is pulse, frequency or current and connecting of different kinds of flow meters is available.

Indicator registers the amount of consumed heat and water. Indications can be displayed on electronic display. There is permanently displayed immediate flow on display. Other indications can be displayed using control buttons.

For water flow measurement is possible to use different kinds of flow meters, for example induction, vortex shedding or ultrasonic one. For revenue use with heat measurement configuration must be these sensors measuring instruments by course of law No. 505/1990 Sb. and must possess design approval appointment and metrological verification.

For water temperature measurement can be used resistance temperature devices Pt100. For revenue use with heat

measurement configuration must be these sensors measuring instruments by course of law No. 505/1990 Sb. (and law No. 119/2000 Sb.) and must possess design approval appointment and metrological verification too.

3. UNCERTAINTY EVALUATION OF THE CALORIMETER VERIFICATION

3.1. Measurement description
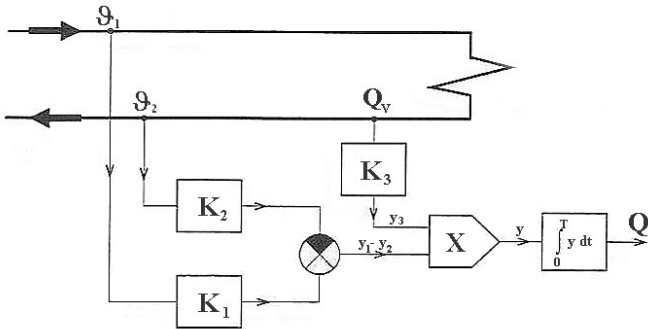Principle scheme of the measurement shows Fig. 1.

Fig. 1. Heat measurement by calorimeter

We measure the heat calorimeter (type ETM 1.01) with resistance temperature devices (Pt100). The flow is measured with ultrasonic flow meter with a pulse output and with the pulse number $Kq = 2,8.10^{-3}$ l/imp. Flow meter is installed in return line. The calorimeter has a frequency output. The heat transfer fluid is the warm water. [3]

We measure the input temperature ϑ_1 (on the admission line) and the output temperature ϑ_2 (on the return line).

The constant temperature in laboratory is 22°C and the relative humidity is $\varphi = 45\%$. That's why we don't reflect the surrounding effect. [5]

We don't reflect any correlation between influencing quantities for the simplification.

Following the directive TPM 3722-93 were simulated temperature differences 10°C, 20°C, 50°C and 100°C.

Signal from the flow meter was simulated for all temperature differences with the frequency $f = 1$ kHz during the time t = 120 s (measured with digital stopwatch), so the volume rate of flow was 120000 imp. $2,8.10^{-3}$ l/imp = 336 l.

3.2. Uncertainty sources
We can define following mathematical model:

$$Q_d = f(Q_V, \rho_{\vartheta 2}, h_1, h_2) \tag{3}$$
$$Q_d = Q_c + \Delta \tag{4}$$
$$Q_d = K_q.n.\rho_{\vartheta 2}.(h_1 - h_2) + \Delta \tag{5}$$
$$Q_d = Q_V. \rho_{\vartheta 2}.h_1 - Q_V. \rho_{\vartheta 2}.h_2 + \Delta \tag{6}$$

Where Qd is amount of the heat measured with calorimeter

Q_c conventionally accurate value
Δ absolute error
K_q pulse number [l/imp]
n count of simulated pulses

Q_V simulated volume rate
$\rho_{\vartheta 2}$ water density
h_1 water enthalpy by temperature ϑ_1
h_2 water enthalpy by temperature ϑ_2.

Uncertainty sources Z_j are:
- uncertainty of the simulated pulses of flow (Z_{j1})
- uncertainty of simulated resistors for input temperature (Z_{j2})
- uncertainty of simulated resistors for output temperature (Z_{j3})
- uncertainty of output pulses owing to stopwatches (Z_{j4})
- uncertainty of the reading from calorimeter (Z_{j5})
- uncertainty owing to mathematical operations (Z_{j6}) [2]

For these uncertainty sources can we evaluate the sensitivity coefficients A_{xzj}:

If we make a partial derivation of (6) with respect to simulated volume rate Q_V, we get:

$$\frac{\partial Q_d}{\partial Q_V} = \rho_{\vartheta 2}(h_1 - h_2) \tag{7}$$

On the input temperature depends only enthalpy h_1. If we make a partial derivation of (6) with respect to input temperature ϑ_1, we get:

$$\frac{\partial Q_d}{\partial \vartheta_1} = \frac{\partial h_1}{\partial \vartheta_1} Q_V \rho_{\vartheta 2} \tag{8}$$

On the output temperature depends enthalpy h_2 a water density $\rho_{\vartheta 2}$. If we make a partial derivation of (6) with respect to output temperature ϑ_2 we get:

$$\frac{\partial Q_d}{\partial \vartheta_2} = -\frac{\partial h_2}{\partial \vartheta_2} Q_V \rho_{\vartheta 2} + \frac{\partial \rho_{\vartheta 2}}{\partial \vartheta_2} Q_V (h_1 - h_2) \tag{9}$$

We make a partial derivation of (6) with respect to time to get uncertainty of output pulses owing to stopwatches:

$$\frac{\partial Q_d}{\partial \tau} = \frac{\partial Q_V}{\partial \tau} \rho_{\vartheta 2}(h_1 - h_2) \tag{10}$$

If we make a partial derivation of (6) with respect to uncertainty of the reading from calorimeter, we get $A_{xz5} = 1$.

The value of the uncertainty owing to mathematical operations is difficult to evaluate and equals to zero.

3.3. Uncertainty evaluation for the minimal temperature difference

In our case is the minimal temperature difference 10°C.

Value Δh = 41,767 kJ/kg (from tables)

Count of pulses = 120 000

Calculation of the sensitivity coefficients:

A_{xz1} = 978,3251*(336,3047-294,5377) = 40861,7 kJ/imp (substitution in the equation (7))

A_{xz2} = 1370,4 kJ/°C (substitution in the equation (8))

A_{xz3} = -1175,6 kJ/°C (9)

A_{xz4} = 0,95 kJ/s (10)

A_{xz5} = 1

Standard uncertainty of type A is calculated in table No. 1, standard uncertainty of type B, combined uncertainty u_c and extended uncertainty U are in table No. 2.

Table 1

Uncertainty type A			
No.	Heat Q [GJ]	ΔQ [kJ]	ΔQ^2 [kJ^2]
1	0,0135842	-17,23	296,87
2	0,0135957	-5,73	32,83
3	0,0136071	5,67	32,15
4	0,0135975	-3,93	15,44
5	0,0136030	1,57	2,46
6	0,0136014	-0,03	0,00
7	0,0136064	4,97	24,70
8	0,0136046	3,17	10,05
9	0,0136055	4,07	16,56
10	0,0136089	7,47	55,80
Suma =	0,1360143	0,00	486,88
Avg. =	0,0136014		
u_{Ax} =	**2,3259**	**[kJ]**	

Table 2

Uncertainty type B					
Source	ΔZ_{max}	Function form	u_{Bz}	A_{xz}	u_{xz}
A	0 imp	normal	0 imp	40861,7 kJ/imp	0,000 kJ
B	0,01 °C	normal	0,005 °C	1370,4 kJ/°C	6,852 kJ
C	0,01 °C	normal	0,005 °C	-1175,6 kJ/°C	-5,878 kJ
D	0,0056 s	uniform	3,233.10^{-3} s	0,95 kJ/s	0,0031 kJ
E	0 kJ	normal	0 kJ	1	0,000 kJ
u_{Bx} =	**9,028**	**[kJ]**			
Standard combined uncertainty					
u_{cx} =	**9,323**	**[kJ]**			
Extended uncertainty					
U =	**18,645**	**[kJ]**			
U =	**0,137**	**[%]**			

4. CONCLUSION

The greatest influences are caused by resistance reference standards and by uncertainty of type A. Other sources are insignificant.

Standard combined uncertainty is u_{cx} = 9,323 kJ.

Extended uncertainty U = 18,645 kJ (U = 0,137%).

6. REFERENCES

[1] Hesse, J. a kol.: *Sensors (A Comprehensive Survey)Vol. 4 – Thermal Sensors*.VCH Weinheim,1990. ISBN 3-527-26770-0.

[2] Jenčík, J.: *Nejistoty v měření*. Pragoregula 99, page 95- 100.

[3] *Calorimeter ETM 1.01*. Manual of the Elis Plzeň a.s.

[4] Ďaďo, Kreidl: *Senzory a měřicí obvody*. ČVUT Praha,1996. ISBN 80-01-01500-9.

[5] Beran, Vl., Tůmová, O.: *Měření veličin životního a pracovního prostředí*. ZČU Plzeň, 1996. ISBN 80-7082-248-1.