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UPGRADING OF A BELL PROVER

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Abstract – Bell provers have a wide usage for calibrating various types of flow meters by timing the bell ascendance. They are often used as a working standard. Known area of the bell along with measured displacement of the bell produce, with some measurement uncertainty, volume generated by the bell. This volume with measured time gives the flow generated by the bell.

The temperature and the pressure of the gas in the bell are not constant. Further more the temperature and the pressure at the flow meter are not equal to those in the bell due to losses in pipes. Because of that it is imperative to measure all of them. When those measurands are stored in database entire measurement can be analyzed at referent conditions.

In order to automate measurements with the bell prover, to improve the measurement uncertainty of the results, and to obtain some additional quantities like velocity and acceleration of the bell, computerized measurement equipment has been installed on the bell prover.

Keywords: bell prover, flow measurement

1. INTRODUCTION

The bell prover (Fig. 1) consists of: two cylindrical tanks, one open at the top (filled with oil) and the other open at the bottom with a dome-shaped top (the bell), motion system with the counterweight, regulation valves and the ventilator for the bell filling. The bell is moveable and performs the function of generating gas flow while the outer tank is fixed and serves for the oil storage. The outer tank with his inner part serves for the gas displacement. The oil serves as a sealant between the outer and the inner tank. The bell prover RKA 1000 of the company Rombach also has measurement scale calibrated in litres installed at the front side. Normally there are three regulation valves. One valve is located on the pipe coming out from the bell, and it releases the gas from the bell into measurement system. Second valve is located at the end of the measurement system and through it the gas is released to atmosphere. Third valve is electromagnetic and it is located between the first and the second one. This electromagnetic valve serves as a prevention from damaging the bell and at the same time it slows down the bell at high flows. The second valve is essentially the system of rotameters. This system of rotameters consists of three rotameters which regulate the flow in the range 0,00002-26 m^3/h, see [1].

Fig.1. The bell prover RKA 1000 (Rombach)

Flow measurement with the bell, is performed under following assumptions:

- the velocity of the bell is constant,
- the oil level is constant,
- the gas pressure and the density in the bell are constant, see [2].

Since in the real situation the above mentioned assumptions are not completely satisfied, calculation errors are generated. By installing parallel measurement equipment for the pressure, temperature and displacement, continuos acquisition of all above mentioned quantities is made possible by using measurement amplifier and PC.

2. MEASUREMENT SYSTEM

The turbine meter G 65 (Elster) is used as a flowmeter (Fig. 2). It is used for flow measurement of the following gases: natural gas, propane/butane, nitrogen, etilen, and air in the flow range 10 - 100 m^3/h (Table I). Common type of G-65 has the installed mechanical rate counter. In this case we are dealing with modified version of G-65 without the mechanical rate counter. Inductive pick up on the G-65 provides measurement signal which is acquired by the measurement amplifier Spider 8 and PC.

Pressure transducers P11 (Table II) are used for gauge pressure measurement in the bell, while the PD1 are used for gauge pressure measurement at the turbine meter (Table III). PTX610 is used for absolute environmental pressure measurement (Table IV). Thermometer Testo 9600 with

TABLE I. Characteristics of turbine meter G 65

Measurand	flow
Manufacturer	Elster
Type of measurement instrument	turbine meter
Range	10 – 100 m^3/h
Measurement uncertainty	0,88 m^3/h

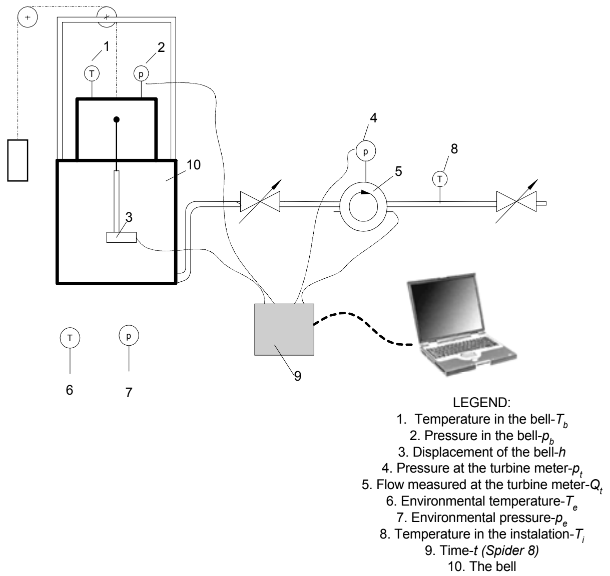

Fig.2 Measurement system

TABLE II. Characteristics of pressure transducer P 11

Measurand	pressure in the bell
Manufacturer	Hottinger Baldwin Messtechnik
Type of measurement instrument	inductive
Range	0 – 100 mbar
Measurement uncertainty	0,5 mbar

TABLE III. Characteristics of pressure transducer PD 1

Measurand	tlak u instalaciji
Manufacturer	Hottinger Baldwin Messtechnik
Type of measurement instrument	inductive
Range	0 – 100 mbar
Measurement uncertainty	0,5 mbar

NTC sensor is used for temperature measurement in the bell (Table V).

For temperature measurement in the installation liquid-in-glass thermometer Tlos is used and another one is used for environmental temperature (Table VI).

Inductive displacement transducer W 100 (Table VII) is used for measurement of the bell displacement.

TABLE IV. Characteristics of pressure transducer PTX 610

Measurand	environmental pressure
Manufacturer	Druck
Type of measurement instrument	piezoresistive
Range	0 – 1500 mbar
Measurement uncertainty	1,5 mbar

TABLE V. Characteristics of liquid-in-glass thermometers

Measurand	temperature
Manufacturer	Testo
Type of measurement instrument	NTC
Range	-40-130°C
Measurement uncertainty	0,231°C

TABLE VI. Characteristics of liquid-in-glass thermometers

Measurand	temperature
Manufacturer	Tlos
Type of measurement instrument	filled with Hg
Range	10-30°C and 0-50°C
Measurement uncertainty	0,058°C

TABLE VII. Characteristics of displacement transducer W100

Measurand	displacement
Manufacturer	Hottinger Baldwin Messtechnik
Type of measurement instrument	inductive
Range	±100 mm
Measurement uncertainty	1 mm

TABLE VIII. Characteristics of measurement Spider 8

Manufacturer	Hottinger Baldwin Messtechnik
Sampling rate	1-9600 Hz
Measurement uncertainty	0,1 %
A/D conversion	16 bit

The turbine meter, pressure transducers and displacement transducer are connected to the measurement amplifier Spider 8. PC using software Catman 3.1 controls spider 8 (Table VIII).

3. MEASUREMENT PROCEDURE

The flow rate was set with rotameters and the following measurands were acquired:

1. temperature in the Bell-T_b,
2. pressure in the Bell-p_b
3. displacement of the Bell-h
4. pressure at the turbine meter-p_t
5. flow measured on the turbine meter-Q_t
6. environmental temperature-T_e
7. environmental pressure-p_e
8. temperature in instalation-T_i
9. time-t

Simultaneously with the release of the gas into pipe installation, the Catman was started and p_b, p_t, h, Q_t and t were stored in database with the measurement period 11,0 seconds and the sampling rate of 10 Hz. Other measurands were taken manually at the beginning and at the end of the measurement period and after the measurement these data were added to the database. The measurement range of the displacement transducer was a serious limitation for the measurement time.

Four measurements were carried out in total at the flow rate of 40 m^3/h with the air at 21°C. The minimum, the maximum and mean values of all conducted measurements are presented in Table IX.

4. RESULTS OF MEASUREMENTS

4.1. *Air at referent conditions*

Generated volume of air under working conditions V_{bWi} consists of measurand Δh and the bell area for every sample interval

$$V_{bW_i} = \Delta h \cdot A_B \tag{1}$$

The volume of the air under referent conditions (15°C, 1013,25 hPa) V_{bR}, for the entire measurement period, is calculated from the following expression

$$V_{bR} = \sum_i \left[V_{bWi} \cdot \left(\frac{288,15}{273,15 + T_{b_i}} \cdot \frac{p_{a_i} + p_{b_i}}{1013,25} \right) \right] \tag{2}$$

The volume of the air under working conditions, which passed through the turbine meter V_{tWi}, is given by the expression

$$V_{tW_i} = Q_{tW_i} \cdot \Delta t \tag{3}$$

Total volume under referent conditions V_{tR} is given by

$$V_{tR} = \sum_i \left[V_{tW_i} \cdot \left(\frac{288,15}{273,15 + T_{t_i}} \cdot \frac{p_{a_i} + p_{t_i}}{1013,25} \right) \right] \tag{4}$$

The deviation e is calculated, see [3], from the following formulae

$$e = \frac{V_{tR} - V_{bR}}{V_{bR}} \cdot 100\% \tag{5}$$

4.2. *Measurement uncertainty*

Measurement uncertainty is classified as:
- *type* A, the standard deviation (based on data) of average for uncertainty source,
- *type* B, the standard deviation (based on an estimate, not data) of average for uncertainty source.

Total uncertainty U is noted by the equation

$$u = \sqrt{u_A^{\,2} + u_B^{\,2}} \tag{6}$$

4.2.1. *Combined standard uncertainty*

Combined standard uncertainty u_c is obtained by root-sum-square method

$$u_c^{\,2}(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 \cdot u^2(x_i) \tag{7}$$

Multiplied by the coverage factor *k=2 for the* confidence level 95%, the relative expanded uncertainty U_c, see [4], is given by

$$U_c = k \cdot u_c \tag{8}$$

5. ANALYSIS OF RESULTS

The results of measurements of displacement point to the fact that the velocity of the bell is not constant. The velocity is oscillating due to transient behaviour of the bell (Fig. 3). This phenomenon is caused by the fact that the influence of the additional forces acting on the bell are present. These forces are set up by the masses in motion, the viscosity of the oil, and the adherence of the oil.

The results have also shown that the pressure in the bell is not constant, but has a tendency to attenuate as the bell approaches the end of measurement period (Fig. 4). The reason for attenuation lies in fact that the compensation of buoyancy is not working completely, but it is within manufacture's specified limits.

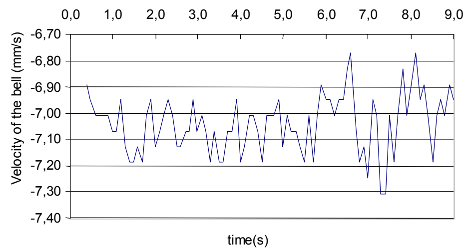

Fig. 3. Velocity of the bell

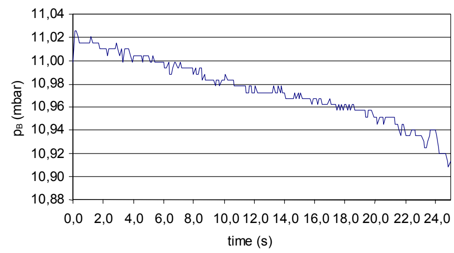

Fig. 4. Pressure in the bell during the measurement

6. CONCLUSION

Upgrading of the bell prover by installing computerised equipment has shown many benefits. First of all we can obtain additional information about motion of the bell. Some faults in the motion system have been revealed. Friction in the motion system has fluctuating values. In other words the friction coefficient in the motion system is definitely not evenly distributed along the path of the bell. This can be a subject of further studies which should also include experimental determination of less known bell characteristics: hydrodynamical characteristics of the installation, the influence of the ventilator, dynamics of the bell and waves generated on the oil surface. The results point out the reasonably accurate behaviour, of the proposed procedure for the measurements with the bell, with respect to the measurement uncertainty.

TABLE IX. Results of measurements at all measuring points

Measurement	M. Point	1	2	3	4	5	6	7	8	9
	Measurand	T_b [°C]	p_b [mbar]	h [mm]	p_t [mbar]	Q_t [m^3/h]	T_e [°C]	p_e [mbar]	T_i [°C]	t [s]
M1	Min	21,4	10,9138		4,4269	41,2880	21,0	1018,75	21,4	
	Max	21,4	10,9990	126,2686	4,5083	41,5191	21,0	1018,75	21,4	11,00
	Average	21,4	10,9635		4,4744	41,4185	21,0	1018,75	21,4	
M2	Min	21,4	10,9085		4,4331	41,2926	21,0	1018,74	21,4	
	Max	21,4	10,9936	126,7238	4,5083	41,4868	21,0	1018,74	21,4	11,00
	Average	21,4	10,9604		4,4781	41,4072	21,0	1018,74	21,4	
M3	Min	21,4	10,9032		4,4394	41,2834	21,0	1018,73	21,4	
	Max	21,4	10,9990	126,1308	4,5208	41,5191	21,0	1018,73	21,4	11,00
	Average	21,4	10,9642		4,4774	41,4200	21,0	1018,73	21,4	
M4	Min	21,4	10,9085		4,4331	41,3111	21,0	1018,76	21,4	
	Max	21,4	10,9936	125,9512	4,5333	41,5099	21,0	1018,76	21,4	11,00
	Average	21,4	10,9629		4,4774	41,4157	21,0	1018,76	21,4	

TABLE X. Deviations and the uncertainty of deviation

Measurement	Deviation *e* [%]	Uncertainty of deviation *U(e)* *k*=2
M1	-0,266451	0,030624
M2	-0,211305	0,030647
M3	-0,347656	0,030596
M4	-0,348294	0,030599

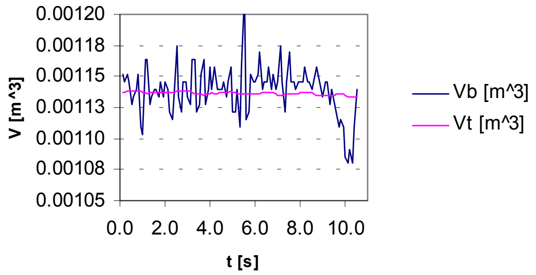

Fig. 6. Measurement 2

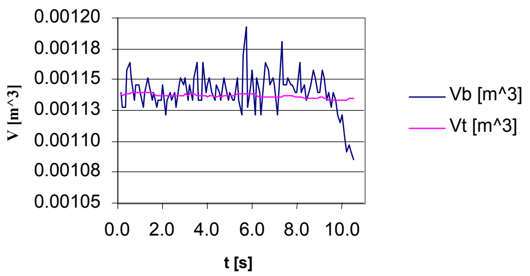

Fig. 5. Measurement 1

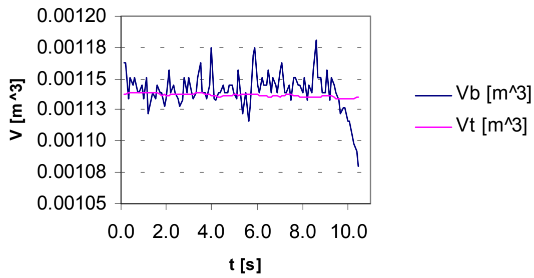

Fig. 7. Measurement 3

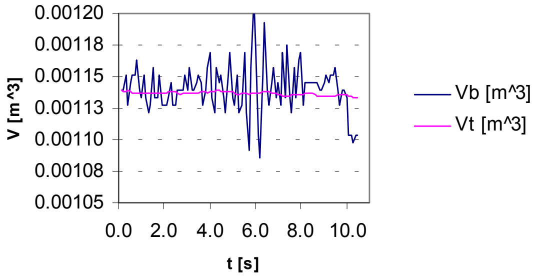

Fig. 8. Measurement 4

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[5] Figliola S. R., Beasley E. D., Theory and design for mechanical measurements, John Wiley&Sons, USA, 1991Fig. 8. Measurement 4

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