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UNCERTAINTY ANALYSIS IN PISTON PROVER CALIBRATION

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ABSTRACT

This paper presents main uncertainties sources, differential equations analysis and the estimation of combined uncertainty in the calibration of a compact piston prover of the IPT Flow Laboratory.

The piston prover is used mainly for calibration of liquid flow meters as turbine meters, positive displacement meters and rotameters. Calibration of other types of liquid flow meters can also be performed provided its particularities are taken into account.

The procedure used was the gravimetric method with static weighing using water (Water Draw) as described in ISO 4185/80 Measurement of liquid flow in closed conduits - weighing method. The uncertainty analysis was made according to the ISO GUM - International Standard Organization - Guide to the Expression of Uncertainty in Measurement.

1.INTRODUCTION

Several new designs of pipe provers have been introduced within the last years, and are gradually coming into widespread use. They are generally referred to as “compact pipe provers” or “small volume pipe provers”, because they are much smaller than conventional pipe provers designed for the same flow rate. All types operate on a common principle, namely the precisely measured displacement of a volume of liquid in a calibrated section of pipe. The displacement is measured by counting pulses, by means of a displacer being driven along the pipe by the liquid stream being metered.

Calibrations are usually carried on following recommendations of *API – American Petroleum Institute _ Manual of Petroleum Measurement Standards, ISO – International Organisation for Standardisation - Proving systems for volumetric meters* and OIML R119 *Pipe provers for testing measuring systems for liquids other than water.* The calibrating of a pipe prover must determine its swept volume, referred to a standard condition of pressure and temperature, with a recommended total uncertainty not exceeding ± 0.05 % [4].

Water is the better medium to be used for the draw method, considering the volumetric references that have been certified to deliver a given quantity of water and the effect of viscosity and surface tension on the drain time of a certified volume reference.

2. OPERATION PRINCIPLE OF THE PISTON PROVER

The calibrator consists of a precision honed measurement flow tube, a flow piston and shaft, a photoelectric sensor/encoder, associated valves, supply tank, and an electronic console to interpret and display the data, which can be connected with the pulse output of the meter under calibration and the liquid temperature measurement device.

Air under pressure is introduced in upstream side of the piston to provide fluid power for calibration. Downstream of the piston, the system is flooded and fully bled with the fluid used to calibrate the flow transducer. The flow rate is controlled by the operation of throttling valves. The displacement velocity is controlled by valves installed downstream of the meter to be calibrated, named high flowrate, medium flowrate and low flowrate valves, associated with a pressure control valve installed in the air compressed entry.

When the piston displacement starts, a linear electrical pulse sequence that comes from the encoder is sent to the data collecting system. Each pulse represents a small but very precise volume of fluid.

The piston movement pushes the fluid through the flowmeter to be calibrated, and the piston velocity is directly proportional to the flow rate.

At the beginning of the piston prover operation, it is necessary to enter informations regarding the meter: calibration range, internal diameter, sensor type, viscosity and density specification as a function of fluid temperature which is being used. This information is stored in a table form by the system software.

After the definition of variables, the software calculates the various parameters as function of this set-up information. A fluid temperature transmitter is used to correct the moved volume value by the steel thermal expansion and to calculate the fluid density and viscosity that will be used in the calibration.

The system runs only in one-way: when the piston reaches the final course, the return is made using manually operated valves. Downstream of the meter to be calibrated, there is also installed a check valve that does not allow flow in the opposite way.

3. DESCRIPTION OF THE PISTON PROVER CALIBRATION (WATER DRAW)

The calibration of the compact piston prover of IPT Flow Laboratory was carried out on the own place and the experimental assembly is described below on the figure 1.

The compact prover has a capacity of 90 liters and is used as a reference meter in calibration of liquid flow meters, mainly turbine meters, positive displacement meters and rotameters for oil and other liquids than water.

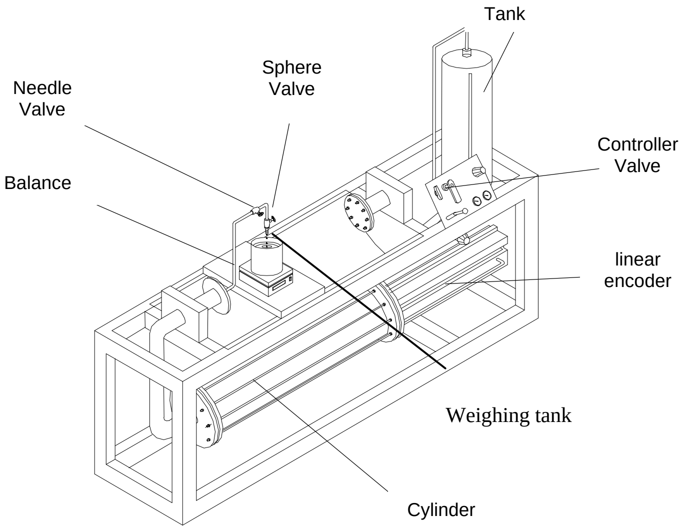

Figure 1- Experimental arrangement for the piston prover calibration

The aim of the calibration is to determine the K factor (pulses / liter) which is the parameter that correlates the number of pulses produced by the equipment with a determinate water volume displaced by the piston.

The water-draw calibration was carried out by a gravimetric method that consists essentially of passing water through the prover to a weighing device. The indication of the mass of water from the prover during the calibration (one travel) is divided by the density of the water to found the volume.

The reference standard used on the calibration of the piston prover was a digital balance traced to a national standard mass laboratory at RBC[1] with an uncertainty of 1.3 in 5000 gram and a weighing capacity adequate to the water mass collected for one measurement.

The software supplied with the prover includes a calibration procedure that count the number of pulses emitted by its encoder during the collection on the weighing tank.

Three temperature measurement were made: fluid temperature inside the prover, fluid temperature inside the weighing tank and ambient temperature.

It is important to keep the ambient conditions stable. Ambient temperature and prover temperature cannot differ more than 0.5^{o}C.

After the flow is in permanent conditions, the samples collected must have approximately the same number of pulses and consequently the same mass . The calibration has to be repeated five consecutive times, and the results can not differ more than $\pm$ 0.05%.

After each run, one sample of water was collected to determinate the water density.

The calculation of the volume must considerate some important corrections like thermal expansion and contraction of prover.

4. UNCERTAINTY ANALYSIS

The uncertainty, for this case, will be expressed on terms by K factor. The general equation that express the uncertainty is:

$$u_c^2(Y) = \sum_{i=1}^{n} \left[\frac{\partial f}{\partial x_i}\right]^2 u^2\left(x_i \right)$$

where Y is a output quantity that is a function of x_i , and

$$u_i(Y) \equiv |C_i| u(x_i)$$

is defined as the uncertainty on the quantity Y due to the variable x_i where

$$C_i \equiv \frac{\partial f}{\partial x_i}$$

that is defined as the sensitivity coefficient.

The global uncertainty can be expressed as:

$$u_c^2 = \sum_{i=1}^{n} [C_i u(x_i)]^2 \equiv \sum_{i=1}^{n} \left[u_i^2(Y)\right]^2$$

To calculate the final uncertainty one must known the uncertainty generated by each term that were presented in the expression. It is important that the final expression of the desired variable contain all necessary corrections.

It is important to verify its correct estimation and by what form its value was obtained, if is a historic data or a data from the statistics works.

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[1] Rede Brasileira de Calibração – Brazilian net of certified calibration laboratories.

The uncertainty sources are :

- Standard for meter calibration (balance)
- Balance reading fluctuation
- Lost pulses
- Effect of encoder thermal expansion
- Effect of cylinder thermal expansion
- Effect of water density variation at the calibration temperature
- Effect of ar density variation at the calibration temperature
- Variability of prover temperature
- Variability of encoder temperature

The equation that defined the process to determine the K factor is:

$$K_{20oC} = \frac{Np}{\frac{m_{ind}}{\rho_{water} - \rho_{ar}} * \rho_{water}} * \rho_p \left[\left(1 + 2\alpha_1 \left(T_{prover} - 20\right)\right)\left(1 + \alpha_2 \left(T_{encoder} - 20\right)\right)\right]$$

Where

K	factor (pulses/liter)
N_p	pulses number (pulses)
ρ_p	water density using the prover temperature (kg/m^3)
ρ_{water}	water density using the weighing tank temperature (kg/m^3)
ρ_{air}	air density using the ambient temperature (kg/m^3)
T_{prover}	average between the input temperature and the output temperature in the prover (^oC)
$T_{encoder}$	encoder temperature (^oC)
α_1	encoder thermal expansion coefficient (mm/mm^oC)
α_2	cylinder thermal expansion coefficient (mm/mm^oC)
m_{ind}	mass indicated by the balance (kg)

Must be note that the encoder material is different from the material of the cylinder of the prover, so the coefficients α_1 and α_2 are different.

4.1 Description of individual uncertainties

- **Uncertainty from lost pulses**

The volume is calculated from the number of pulses obtained from the signal conditioning unity for the sensor element. During the calibration pulses can be lost due to the start and finish moments without pulse emission from the signal conditioning unit.

Admit that one pulse can be lost or gained in the beginning of the counting and one pulse can be lost or gained in the finishing according on the figure 2.

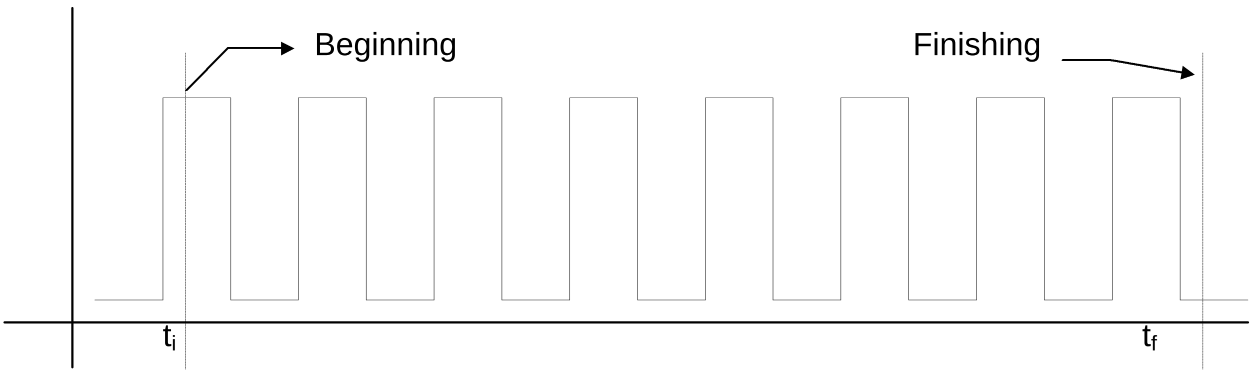

Figure 2 - Detail of pulses lost in the beginning and in the finishing of counting process

- **Uncertainty of encoder thermal expansion**

The encoder calibration was made on 20 ^{o}C then exists the possibility to occur a error due to different ambient temperature. The ambient temperature may vary up to 1^{o}C during the calibration.

- **Uncertainty of cylinder thermal expansion**

Such as the encoder, the cylinder volume must be corrected to 20^{o}C. It can be admitted that the cylinder temperature at the beginning of calibration is the same as ambient temperature.

Supposing a maximum variation of 1^{o}C in ambient temperature and in variation between the fluid and the ambient temperature, the combined uncertainty of the two effects of thermal expansion results ±0.005%.

- **Effect of density variation due to temperature variation in the weighing tank**

To quantify the effect of temperature variation during calibration, were carried out a comparison between the values of density obtained from the equation presented by the International Association for the Properties of Water and Steam (IAPWS)[2] and values obtained from some water samples used to determinate the density. This comparison was made by temperature intervals and it is shown on the table 1.

Table 1 - Water density variation in function of the temperature variation

Temperature (°C)	Deviation from samples water density (kg/m^3)	Deviation from PTB equation (kg/m^3)
20-25	1.3	0.907
25-30	1.4	1.649
30-35	1.6	1.616

- **Uncertainty of the standard of mass meter and thermometers and barometers used on test**

It is necessary to include the effect of the standard meter calibration on the reading and reading fluctuation of the calibration mass of the tank weighing just as for thermometers and barometers used on the test. The uncertainty of the reading is obtained by the certificate meter calibration and the uncertainty of the reading fluctuation must be observe during the test for after be estimated.

5 RESULTS

Table 2 presents the uncertainty calculation according to ISO GUM.

After identification of uncertainty sources, the uncertainty were evaluated, quantified and combined to determine the final uncertainty. It was obtained a final uncertainty around 0.07% or 0.447 liters, based on the standard combined uncertainty multiplied to a coverage factor of 2.02, under a confidence level of 95%.

[2] Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, IAPWS, 1995

Table 2 - Evaluation of the uncertainty in the volume determination on the prover calibration.

Variable Quantity	Estimate x_i	Standard uncertainty u (xi)		Degree of freedom	Probabilities distribution	Sensitivity coefficient	Uncertainty	Individual Contribution (%)
Mass (calibration meter) (g)	5000	$u_m/2$	0,65	30	Retangular	-1,3577E-01	-0,088249014	15,80163
Mass (process variation) (g)	5000	$(m_{máx}-m_{mín})/\sqrt{3}$	0,0230 94	infinito	Normal	-1,3577E-01	-0,003135421	0,01995
Water density (kg/m^3)	998,3	$(\rho_{máx}-\rho_{mín})/\sqrt{3}$	5,8E-02	infinito	Normal	6,7970E-01	0,039242303	3,12458
Ar density (kg/m^3)	1,08	$u_p/2$	0,005	infinito	Normal	5,028E-03	2,7151E-05	0,00000
Encoder temperature (calibration meter) (^oC)	21,29	$u_T/2$	0,05	30	Retangular	9,78E-04	4,88763E-05	0,00000
Encoder temperature (process variation) (^oC)	21,29	$(T_{máx}-T_{mín})/\sqrt{3}$	1,443	infinito	Normal	9,78E-04	0,001410937	0,00404
Prover temperature (calibration meter) (^oC)	19,56	$u_T/2$	0,05	30	Retangular	1,52E-02	0,000760308	0,00117
Prover temperature(process variation) (^oC)	19,56	$(T_{máx}-T_{mín})/\sqrt{3}$	0,59	infinito	Normal	1,52E-02	0,00904266	0,16591
Lost pulse	3400	$u_p/2$	1,00	30	retangular	2,00E-01	0,199658032	80,88272

6 CONCLUSION

As the uncertainty calculation is based on the judgement of the person is making the evaluation, the main influence factors may vary depending on the considerations and observations of the technician is carrying on the calibration. In the presented case, the factor of most influence in the final uncertainty of the calibration was the loose of pulses that can happen in the beginning and finishing of the calibration.

By the presented method, to assure that the results of two consecutive calibrations are within 0.02% of difference from the total volume, it is request an enviromental control. It can be particularly problematic in field calibration.

7. REFERENCES

[1] ISO 5168-1978 “Measurement of fluid flow - Evaluation of uncertainties”;

[2] API – American Petroleum Institute Manual of Petroleum Measurement Standards, First edition October 1988

[3] BIPM/IEC/IFCC/ISO/IUPAC/OIML (1993) “Guide to the expression of uncertainty in measurement”, 1ª edição, ISO 1993.

[3] Alan T. J. Hayward , *Pipe provers – a user’s manual,* Cambridge University Press, 1991

[4] Methods and Equipment for Calibration of Variable Area Meters (Rotameters). Instrument Society of America - ISA RP 16.6, 1961.

[5] Flow Measuring Engineering Handbook *R. W. Miller McGraw Hill*