On the dead volume of a Standard Small Volume Prover

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Abstract: The calibration procedures of compact provers, which are used as standards to calibrate volumetric meters, are well known. However, the reduction of uncertainty of measurement in a prover calibration or when using a prover as standard depends on several factors, among them, the way of controlling some quantities, the kind of valves in the hydraulic circuit and how they are operated, the kind of liquid totalizer in calibration etc. In general, position sensors installed close to the initial and final ends of the cylinder ruler of the prover indicate the useful displacement along the tube. Such sensors limit the dead volume in the cylinder ends, which is not defined by the equipment user. On the other hand, if these dead regions, which are affected by the dynamics of the prover operation were evaluated by the user, the result could be different from that indicated by the supplier. The present work discusses that matter and, based on experimental data, analyzes the useful length for the cylinder of a small prover (09 L) which belongs to Inmetro (the Brazilian National Metrology Institute). A system for controlling and acquiring data has been created and adapted to the prover, and it is able to score pulses in two distinct counters, improving the equipment resolution. Besides making possible to investigate the size of dead spaces of the cylinder, such system could eliminated sensors at the final and initial positions of the tube ruler. The prover was calibrated by gravimetric water draw method under multiple samples along the cylinder length and using the two distinct pulses counters.

Keywords: Compact prover, Volumetric meters, Flow rate, Dead volume

1. Introduction

The fluid flow measurement is necessary within a large field of activities, as such as in the industry, in the scientific and technological developments, in activities related to the environmental monitoring and controlling, among others. It is crucial to accomplish such measurements in a reliable way and, in order to reach the right expected result or to allow a correct evaluation of a flow phenomenon. These facts drive the seeking for new measurement methods or development of new experimental procedures, and they also drive the investigation on procedures or methods largely known. It can generate improvements in the measurement results, or still, identify fragile aspects or limitations of an equipment or measurement instrument. When dealing with moving fluids, the flow rate, total volume (or total mass) quantities in a certain process plays an important role, and the pursuit for narrow ranges of uncertainties in the measurements is an unceasing task, as well as for making reliable measurements. All standards instruments which are used must be calibrated, as well as traceable [1-3]. The compact prover is an equipment used to calibrate volumetric totalizators. The Brazilian National Institute of Metrology - Inmetro has a compact prover for using with liquids in low flow rate. While in time, this equipment has been used for researches. Its data acquisition system was modified and it is being studied in the present work.

2. The purpose

The main goal of this work is to discuss, based on experimental data, aspects on the useful length of the cylinder of a compact prover. The sizes of the dead volumes marked by the prover manufacturer were confronted with that one estimated through the use of a system which was created by Inmetro. The knowledge of this length is very important for the statement of the limitations when using the compact prover to calibrate a certain kind of volumetric meter, because the limit of flow rate range that really could be set to perform such calibration will also depend on the response time and the sensitivity[4] of the meter which is being calibrated. In this work, a previously calibrated electromagnetic flowmeter (and volume totalizer) was connected to the prover, to initiate an investigation.

To evaluate the system, it was necessary to identify the total volume of the prover´s cylinder and to confront it with that useful delineated by the manufacturer equipment. The calibration of the prover was made by water draw.

2.1 The water draw method

Figure 1 shows the schematic of the compact prover used for this work.

The water draw calibration of a compact prover can be made in two ways: by gravimetric or volumetric methods. The volumetric method consists basically on to relieve a certain volume of liquid from the cylinder of the prover to a container where the collected volume can be directly

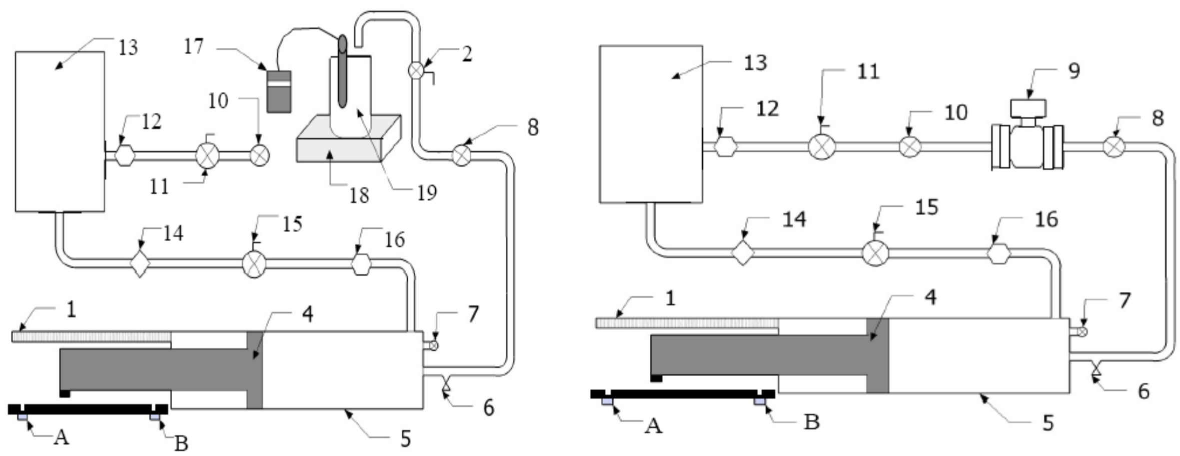

Fig. 1 Schematic of the compact prover (on the left, scheme for water draw calibration; on the right, scheme for volumetric meter calibration): 1- translator linear encoder, 2 and 11- throttle valves, A-upstream sensor, B-downstream sensor, 4- piston, 5- flow tube (cylinder), 6 and 17- temperature sensors, 7- drain valve, 8 and 10 - air bleed, 9-flow meter, 12 and 16- check valve, 13- tank, 18-balance, 19 - flask.

measured. The gravimetric method, figure 1, consists into collecting such liquid in a container and, after weighing it, to convert this value to the respective volume by using the density of the fluid. In both methods, the calibration can be made by displacing the total liquid of the cylinder at once or partially collecting it until the prover cylinder is completely empty. In the calibration process, all the quantities that affect the results must be considered to make corrections. The main goal of the prover calibration process is to determine the *K* factor of the prover and its uncertainty. The *K* factor indicates the pulses number of the prover cylinder ruler (while the piston inside the cylinder moves) past for each unitary volume of fluid displaced.

In this work, after attaching the new system to count pulses in the prover, this standard was calibrated and thus, it was possible to calculate the volumes for the discussion proposed in this article. During the gravimetric water draw measurements, the total cylinder length was considered, instead the useful volume stated by the prover supplier (it was done due to the new system characteristics for evaluating the dead volume).

3. The new system

3.1 The pulses counter of the prover

The prover has a system of pulses counting which is linked to two optical position sensors. Such sensors are placed aligned to the cylinder and the rule (there is a linear encoder), each one close to the cylinder extremities (figure 1). The function of such optical sensors is to indicate the start and the stop points of pulses counting referred to the displacement of the piston moving inside the cylinder, so, delimiting its useful volume (or the dead volumes) stated by the prover manufacturer.

In analyzing the dead volumes, this work shows a system that permits estimating these volumes by counting pulses along all cylinder length, i.e., including the number of pulses upstream the first settled optical sensor and downstream the second one and then, registering the amount of pulses that passed before reaching the first sensor and after passing the second one. In this system, the pulses were counted through a PCI-CTR10 (Measurent Computing) board. The encoder signal has low amplitude (about 2mV), and it has been conditioned to pulses signal from 0 to 5 volts, in a TTL standard, which is sent to the board. The detection of the position sensors signal is made by two opto-couplers. This signal has two voltage levels (one low and other high). The conditioner circuit is supplied with a 5V source, and a PC receives those signals through two channels (one for each position sensor) of a NI -6014 (National Instruments) board. With this system, instead of simple counting of pulses, a secondary counter was added allowing to improve the resolution.

3.1.1 Experimental procedure

An electromagnetic flowmeter was connected to the prover (figure1) to register the flow rate in each test run, being its signal sent to a PC trough a 4-20mA signal, which is converted to volts by a resistor. A NI -6014 board captures these signals. The data were acquired by a program developed with the LabView ™ tool, and the acquisition frequency was determined by the acquisition rate of the board (1kHz). So, the flow rate was calculated by linear correlation between the 4-20mA and the range of flowmeter capacity. Such meter also indicates the total volume passed inside it. The flowrate levels stated were chosen within the calibrated range of the flowmeter, and the measurement were made as follows.

After fitting the valves opening in accordance to the wanted flow rate range , the cylinder piston was returned to its initial end. Then, the test run was started. For each flow rate, it was automatically acquired: the amount of pulses read until passing the sensor A, the amount of pulses just before the entrance and just after crossing the region of activity of the sensor B, and the amount of pulses until the piston stops. Thus, to calculate the total volume run in a part or in the total length of the cylinder, the sum of two pulses indication number could be done. This way, it was possible to identify the sum of passed pulses (consequently, the volume of displaced liquid) and the time spent to go from zero to the flow rate range set up and, also, the time interval to decelerate from the mean flow rate set up until stopping the piston. These were fundamental parameters to evaluate the useful volume of the cylinder by using the system which was developed to the compact prover. Simultaneously, during each run it was registered the flow rate indicated on the display of the flow meter, in a different instant of time for a same run, as it will be shown ahead.

Each series of measurement was composed of five runs executed in a same flow rate.

3.2 Results

After determining the *K* factor of the prover, the useful and dead volumes of the cylinder were determined as follows.

3.3 Evaluation of the dead volume

The dead volume at the beginning of the cylinder corresponds to the volume until reaching the sensor A. The sensor B indicates the beginning of the dead volume at the cylinder ending. In this study, the electromagnetic flowmeter connected to the piston prover has 16,92L/min in nominal capacity. Table 1 shows the mean values for the measured quantities. For each mean flow rate, the figures 2 to 4 indicate the flow rate as a function of the time.

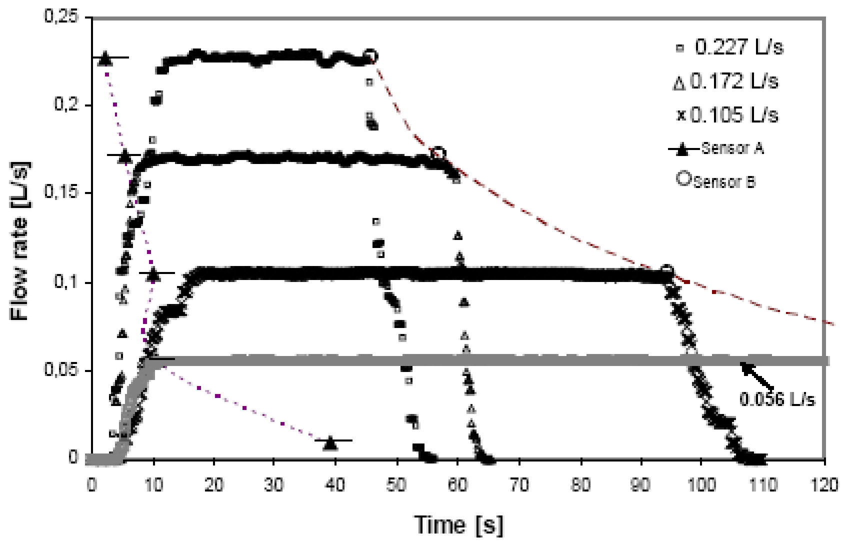

Fig. 2 Time spent until the piston arrives to positions of sensors A or B, for several mean flow rate

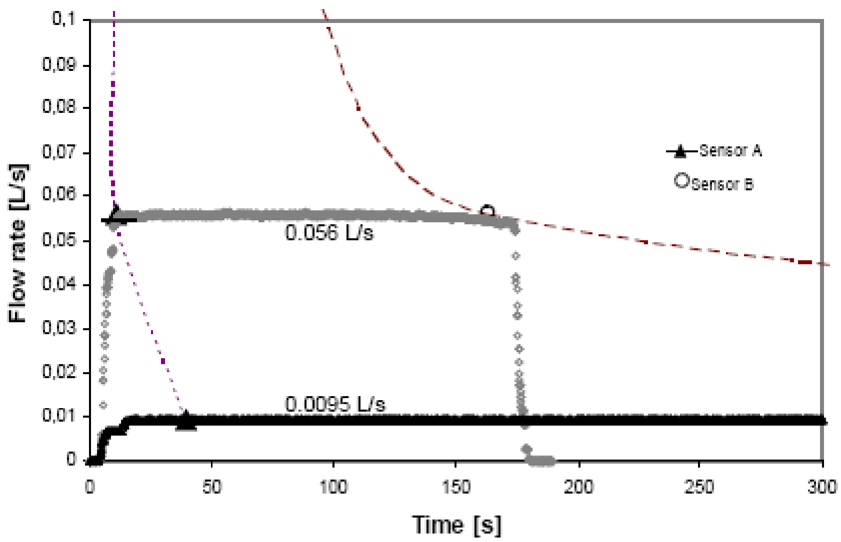

Fig. 3 Time spent until the piston arrives to positions of sensors A or B , under low flow rate

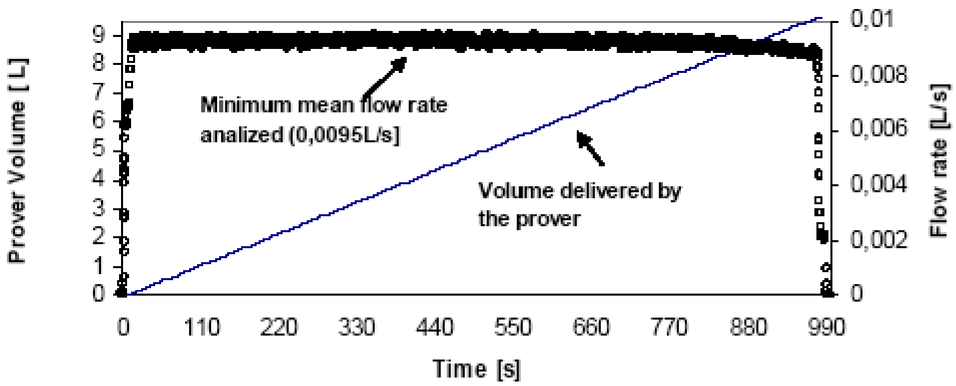

Fig. 4 Time spent until the piston runs the total cylinder length, under lowest flow rate measured

Table 1- Data reduction

Flow rate [L/s]	Volume upstream sensor A (dead volume at the beginning) [L]	Time spent until sensor A [s]	Volume upstream sensor B [L]	Time spent until sensor B [s]	Volume downstream sensor B (dead volume at the ending) [L]	Total volume of the cylinder [L]	Time spent to run all cylinder length [s]	Time spent from Sensor B to the end [s]	Total volume (indicated in the flowmeter) [L]
0,0096	0,343	39,20	9,297	944,6	0,368	9,665	991,0	46,4	9,24
0,0056	0,341	10,70	9,295	163,4	0,369	9,664	177,3	13,9	9,44
0,1050	0,336	10,10	9,291	94,4	0,373	9,664	104,0	9,6	9,47
0,1720	0,331	5,30	9,288	57,1	0,375	9,663	61,0	3,9	9,49
0,2270	0,339	5,10	9,285	45,9	0,379	9,664	51,0	5,1	9,52
Average	**0,338**		**9,291**		**0,373**	**9,664**			**9,43**

4. Discussion

Table 1 shows the time spent for the piston to reach both the beginning and the final dead volumes in the cylinder, for several flow rate. In figures 2 and 3, the circles with dashed line mark the instant where the sensor B was reached (in the intersection between those circles and the flow rate curves), for different flowrates. The triangle plus line detaches the time when sensor A was reached by the piston, when the requested mean flow rate was established. In those pictures, each triangle (plus line) is positioned at the same level of the flow rate to which it is related to.
According to the pictures, at the cylinder ending, the time when the piston finds the sensor B is almost the same when starts the deceleration of the piston movement (suddenly diminishing the instantaneous flow rate). However, at the cylinder beginning, there is no coincidence between the time to get the mean flow rate level and the time spent for the piston to arrive sensor A. In this last case, the higher the flow rate, the higher the difference between such time intervals (figure 2).
As mentioned before, the dead volume values were related to the sensors position set by the the equipment supplier. Nevertheless, as one of the function of the dead volume is to contribute to result in minimum effects due to transient on flow rate during a calibration of a volumetric meter (as that due to the acceleration and deceleration of the piston), the figures 3 and 4 show that dead volume in the beginning should be larger than that had been set previously by the prover manufacturer. So, this is an example of limit for using the prover for calibration. The results can be affected by the flow rate range and the kind of volumetric meter.

5. Conclusion

In this work a brief analysis of the dead volume in a cylinder of a compact prover was presented. After the prover was calibrated through gravimetric water draw method, an electromagnetic flowmeter (and totalizer) was connected to this prover in order to be observed its response. For that, a system to account pulses related to the piston displacement was created and attached to the prover. Besides improving the prover resolution, the new system allowed to compare the dead volume previously stated to the prover with that estimated by experimentally investigating the response of the volume totalizer when it is calibrated using that compact prover as standard.

In daily tasks of a laboratory for calibration, it is known that it is impossible to verify in detail each instrument response before calibrating it using a compact prover as standard. The results of this work, although still an assessment to the treatment of the subject, evidence that the settlement of the provers dead volumes deserves to be more deeply studied. More investigations should be made on this subject, including measurements with other volumetric meters and evaluation of the impact on totalizers calibration. Also, the ranges of uncertainties of measurements must be investigated, in order to clarify the critical situations.
The use of the double accounting for pulses of the prover presented here was very important to make the analysis above, because it permitted to scan and deal with a smallest volume of the cylinder.

Acknowledgments

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