Flomeko 2000 - IMEKO TC9 Conference
Salvador, Bahia, BRAZIL
4-8 June, 2000

THE NATIONAL STANDARD GAS PROVERS OF THE IMGC-CNR

G. Cignolo, A. Rivetti, G. Martini, F. Alasia, G. Birello, G. La Piana
IMGC-CNR
Istituto di Metrologia "G: Colonnetti" del Consiglio Nazionale delle Ricerche
Strada delle Cacce, 73 - 10135 Torino, Italy

A small bell prover and a piston prover of large capacity recently installed in the new Gas Flow Laboratory of the IMGC-CNR (the national primary standards laboratory in Italy for mechanical and thermal quantities) are described. The provers have been completely revised, automated and equipped with state-of-the-art instrumentation for measurement of temperature, pressure, bell or piston displacement and time.

Both provers have been calibrated again soon after installation in the new laboratory and have been used successfully in two EUROMET comparisons carried out in 1998. The paper describes the adopted calibration methods and their results. The uncertainty budgets are given and discussed. The expanded uncertainty (k = 2) of the bell prover can be as low as 0.1% when its full capacity is used.

Thanks to the design criteria selected when constructing the larger prover (that is equipped with a piston of 1000 mm diameter) the mere "volumetric" uncertainty of the piston prover is an order of magnitude lower than that of any bell prover. Therefore, the expanded uncertainty associated with the volumes of gas delivered at the test point ranges between 0.01% and 0.1%, being almost completely dependent upon the stability of temperatures and pressures.

Keywords: Gas, Prover, Measurement, Standard, Calibration, Flowmeter, Meter

1 INTRODUCTION

The laboratory for measurements of volumes and flowrates of gas was first established at the IMGC in the 1970's. Between 1995 and 1998 it was completely remade and equipped with updated measurement standards and instrumentation. First, the premises of the laboratory were rebuilt and an accurate air temperature conditioning system was installed. A number of radiators, in the shape of thin metal plates, were installed to line completely the walls of the laboratory. The plates (covered by aluminised panels) are fed with water at a controlled temperature of +20 °C. A slow air flow at the same nominal temperature is introduced into the room through its ceiling and let out through grids at the floor level. Typical temperature oscillations at a given spot are within ± 0,3 °C, with a period of about 50 min; vertical gradients across the 6 m useful height of the room are of the same order of magnitude.

The gas flow standards now available at the laboratory are a small bell prover and a large piston prover, both described in this paper. A temperature-controlled, 3 litre-capacity piston prover designed for measurement of gas flowrates between 0.01 L/h and 60 L/h has also been constructed and is now being completed and characterized.

2 THE BELL PROVER

This prover, manufactured by American Meter Co., was the first one adopted at the IMGC, as it was purchased in the mid 1970's. Its nominal capacity is 5 cubic feet, or about 142 L (the scale actually spans 160 L). At the time when the improvement works were undertaken, a long use had clearly shown that a complete remaking of this prover was needed, especially from the point of view of the installed instrumentation.

The upper half of the prover was almost completely reconstructed. The three columns sustaining the top plate and the plate itself were stainless-steel made in a larger size, in order to improve stiffness and to accommodate more apparatuses. New rollers with low-friction ball bearings were fitted to the bell; new stainless-steel rods providing guidance to the bell were installed, accurately adjusted and aligned with those existing inside the oil bath, to make the run of the bell as precise, rectilinear and frictionless as possible.

A large circular hole was cut on top of the copper bell and a blind flange was fitted to it. This flange carries a fitting, through which a platinum resistance thermometer (PRT) protrudes by about 20 cm into the cavity of the bell, to measure directly the temperature of the gas, at least on top of the measuring chamber. Another PRT and a pressure port are installed at the external end of the U-shaped, 75 mm bore inlet-outlet pipe of the prover, close to its main access valve. State-of-the-art temperature measuring instruments, manometers and differential manometers are connected with the PRTs and the port. They are linked to, and scanned by the PC of the gas laboratory.

The most important improvement made to the bell prover, however, consists of a new apparatus designed to accurately measure both displacement and velocity of the bell. A graduated ruler with a pointer were the only means previously available to indicate the position of the bell and consequently to evaluate, by sight, the contained volumes of gas. An automatic, high-resolution reading system was therefore designed and installed. This consists of a rotating encoder coaxially fitted to a large (0.3 m in diameter) and precisely machined wheel installed upon the top plate of the bell prover. When the bell moves, the wheel is caused to rotate by a thin steel tape, one end of which is bolted to the top flange of the bell, and the other to the circumference of the wheel. The tape is slightly stressed by means of a counterweight acting on the wheel through a metal rope. The encoder generates about 280000 pulses during a complete stroke of the bell, which corresponds to a rotation of about 5 rad.

The pulses are fed to a counter and to a purpose-built, microprocessor-based instrument, that is able to compute and display the operation parameters in two different states:

State A) TEST: this initial phase is necessary when the bell prover is used to calibrate flowmeters; it is intended to allow the achievement of steady-state conditions in the whole system before measurements. During this phase, the microprocessor instrument displays (and updates at a programmable refresh rate, usually 1 reading per second) the totalized volume, the elapsed time, the instantaneous flowrate with its deviation (per cent) from the current mean of flowrates and finally the standard deviation of the whole set of instantaneous flowrates. Looking at those parameters, the operator is able to decide when to begin the real measurement run.

State B) MEASUREMENT: the instrument display is reset, then begins to show the same parameters as above, referring to the measurement run. When the operator stops the measurement run, the instrument displays total volume, elapsed time, initial and final pulse number (useful to make calculations about dead volumes), highest, lowest and mean flowrates, together with the standard deviation of the set of measured instantaneous flowrates.

The prover tank is filled with Shell Diala DX oil, selected after consultation with colleagues of EAM-OFMET and NMi, whose courtesy is gratefully acknowledged. Its nominal viscosity at 20 °C is 17 mm^2/s. Its density at 20 °C (as measured at the IMGC for the purpose of the calibration of the bell) is (876.17 ± 0.2) kg/m^3.

The compensation of the variable buoyancy upthrust exerted on the bell is made by means of a counterweight acting upon an evolvent-shaped cam. As the cam was not machined accurately enough, it was slightly modified; after careful adjustment of the counterweight, the pressure during a complete stroke of the bell does not change by more than $\pm$ 1.5 Pa. Before each measurement run a waiting time of at least 3 minutes is left in order to let the largest part of adhering oil to drain down into the oil bath from the wetted walls of the bell.

The prover is more often used to *deliver* than to *receive* measured gas flows. In the first case, a remote blower automatically fills the bell with the necessary amount of filtered air from the ambient. After the slight compression, the temperature of the air flow is brought back to that of the room by passing the flow through a long copper pipe before entering into the prover. When required, another circuit fills the prover with pure, inert gases from bottles.

Two extreme pressure conditions inside the bell are used sometimes in the calibration work. In the former condition the inside pressure equals the atmospheric one, in such a way that the flowrate delivered by small blowers or air sampler pumps under test is not affected by any appreciable back pressure. In the latter condition, an as high as possible relative pressure is required inside the bell, in order to feed and operate directly small flowmeters exhibiting an appreciable pressure drop. Examples of such devices are the subsonic nozzles and some types of variable-area meters. Sets of weights (to be loaded on the top flange of the bell) and supplementary counterweights were provided in order to achieve either condition. As a result, the relative or gauge pressure inside the prover can be set at any required value between zero and 1400 Pa.

The prover is equipped with all necessary valves and position sensors to operate it safely and automatically under computer control.

3 CHARACTERIZATION OF THE BELL PROVER

The proper installation and performance of the encoder with its driving system have been checked by comparison with a laser interferometer. The encoder output has been compared with that of the interferometer at 33 equally spaced positions of the bell. The ratios between the actual bell displacements and the number of corresponding pulses emitted in the 32 intervals range between 2.6090 µm/pulse and 2.6099 µm/pulse, with a relative standard deviation of 0.008%.

The repeatability of the encoder display with constant temperature, pressure and gas volume inside the bell has been checked by slightly displacing the bell by hand about 30 times and examining the scatter of the readings. With displacements of a few millimetres, not involving large changes in the relative position of all moveable parts, nor appreciable oil wetting of the walls, the standard deviation is 2.5 pulses, or about 1.5 mL in any position of the bell.

The manufacturer’s calibration of the prover was first checked at the IMGC in the 1970’s by means of the method of dimensional measurement, or *strapping*. The results showed that the gas volumes read on the scale were about 0.04% higher than those computed by the IMGC. This figure is consistent with the 0.2% uncertainty claimed by the manufacturer. After the remaking of the prover, at the end of 1997 another calibration has been carried out by connecting the bell with the top of a sealed, constant volume tank filled with oil, then drawing some oil out and weighing it, in order to determine its volume and the equal volume of air drawn out of the bell.

Two calibration runs have been made by delivering and weighing in sequence 90 samples of oil (of about 1.6 L each); a third run has been made by weighing 10 samples of about 14 L each. A plot of delivered gas volumes versus number of emitted pulses shows that the data points can be fitted by straight lines with sufficient accuracy. The weighted mean of the three runs provides a new value of the volume corresponding to a single pulse, namely 0.58518 mL/pulse. This figure is 0.0475% lower than the one inferred from the manufacturer’s calibration of the bell prover; therefore, it amply confirms the results of the calibration by strapping made at the IMGC in the 1970’s.

The calibration data referring to the first 20 litres of the scale are different and more scattered than the following ones; therefore, this part of the stroke of the bell is only used to achieve steady-state flow conditions, if required, and not for measurements.

The standard uncertainty associated with the above mean calibration coefficient of the encoder has been computed as the statistical composition of the type B contributions in the calibration process with the experimental standard deviations of the 190 measurements, that were (in terms of gas volumes) about 7 mL, 8 mL and 18 mL respectively in the three runs. The following main type B components [1] of the standard uncertainty have been estimated:

0.005% in oil weighing
0.01% in oil density computation at the actual test temperature
0.02% for uncertainties associated with the measurements of temperature in the gaseous phase
0.01% associated with uncertainties of pressure measurements

As a consequence, the estimated standard uncertainty ranges between 0,05% for gas deliveries of 120 L and 0,15% when gas volumes of just 10 L are measured (Fig.1). The usable flowrate range of the bell prover is between 12 L/h and 25000 L/h. During the longest measurement runs account must be taken of the amounts of gas being stored in (or delivered by) the dead volumes inside the bell prover, as a consequence of temperature and pressure drifts (see paragraph 6).

4 THE LARGE PISTON PROVER

This apparatus was designed and constructed at the IMGC in the mid 1980’s, as described in [2]. The main reasons that lead to the choice of that type of standard and its main characteristics are recalled herein. The aim was to develop a gas prover of the largest size that could be housed in the existing premises at the IMGC, with a main goal to be achieved: the reduction by more than an order of magnitude of the merely “volumetric” uncertainties, those that contribute the largest uncertainty component in bell provers. In this way, it was expected that the accuracy would be greatly increased, remaining affected, in fact, only by the more or less good stability of temperatures and pressures and by the usually little uncertainty of their measurements.

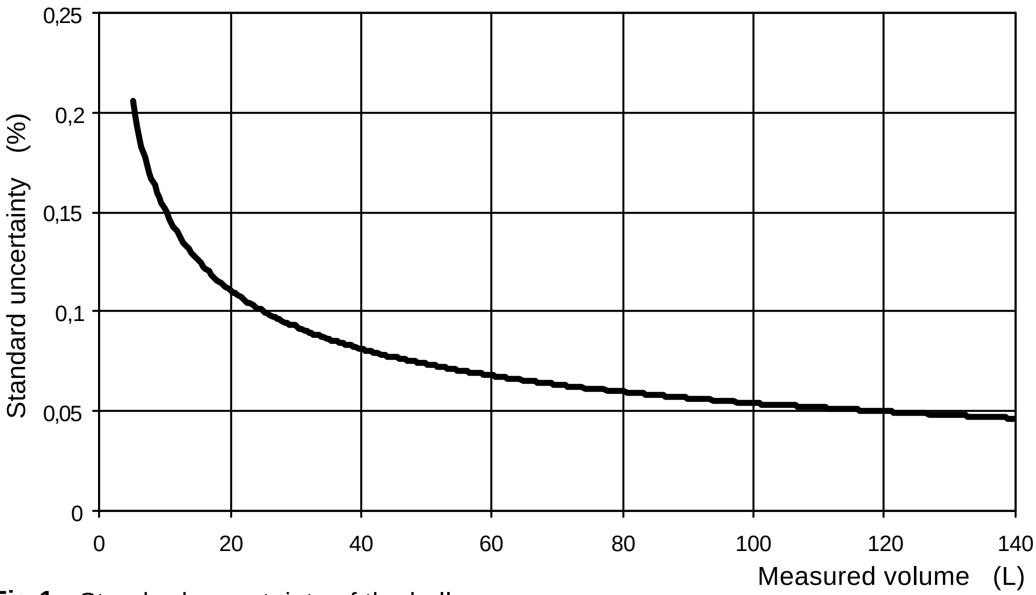

Fig.1 - Standard uncertainty of the bell prover

Two measures had to be taken to achieve the goal: the elimination of the oil bath (whose oscillations, level changes and adhesion to the bell walls are not consistent with the required accuracy) and the adoption of a rigid, precisely machined and measured body to sweep accurately measurable volumes. The most obvious choice, that of a traditional piston-cylinder system was considered. Such a piston with two equal rods affords the interesting opportunity to operate in a closed and possibly pressurized loop. However, a piston of the *plunger* type (namely a long, vertical cylinder forced to sink through a gasket into a slightly larger, rigid but mechanically unfinished chamber containing the gas to be delivered) was preferred because:

- it is much easier and cheaper to machine and polish a large piston than a female cylinder of the same size;
- an external diameter can be measured more accurately than an internal one;
- in the described arrangement, the gasket is fully accessible for inspection or adjustment, and possible gas leaks can be detected promptly;
- in the existing premises, the operation of the prover under pressures significantly higher than 1 bar would be prevented in any case by safety reasons.

The piston prover (Fig.2) is a structure about 6 m high, coming with a top platform where a finely controlled brushless motor drives (through a gear box) the female ball-screw of a lead screw connected with the piston. This apparatus causes the displacement of the piston downwards and the emission of pulses by a rotating encoder applied to the female screw. The trunk piston is made of a 1000 mm nominal diameter, 1630 mm long and 14 mm thick carbon-steel cylinder fitted to a massive bottom flange. The external surface of the cylinder was chromium plated, then ground and polished. Two fans inside the cylinder cavity and one more inside the measurement chamber can be operated at variable speed to ensure temperature equalisation (all motors being housed outside the measurement chamber).

The leak-proof gasket at the top of the chamber is made of a Teflon-coated, 10 mm diameter O-Ring compressed to the necessary and adjustable extent by an upper flange. Alcohol can be poured into an annular groove machined upon the gasket seat to show bubbles in case of gas leakage, either during pressure tests or during normal operation.

The internal diameter of the measurement chamber is 1095 mm; in the clearance between its walls and those of the piston ten PRTs are installed at different levels and positions to accurately measure the average gas temperature. The chamber rests on the 1950 mm diameter base of the prover. At the

Fig. 2 – The piston prover

centre of the base a 100 mm-bore bend and pipe convey downwards and then towards the test line the gas displaced by the piston. There a group of automatically-operated valves (a safety valve; another for admission of air from atmosphere and one more to deliver the gas to the 100 mm-bore test line) are installed. Pressure and temperature sensing ports and a safety disc (designed to break when the gauge pressure in the chamber exceeds ± 30 kPa) are installed there as well.

The operation of the prover is fully automated and controlled by a PC, as a number of hardware and software provisions had to be adopted to ensure a safe operation. The encoder, the timer-counter and the transducers performing the measurements of piston velocity, displaced volumes, local and averaged temperatures, pressures in the chamber, at the test line and in atmosphere are all interfaced to the computer. Their signals are scanned and processed through Lab-View software that, owing to the large number of fast-changing instrument outputs that are available, for the time being is designed on purpose to fit each individual measurement situation. However, as in the case of the bell prover, another microprocessor-based instrument is available at any time to monitor delivered volumes, elapsed times and flowrates.

The mode of operation of the piston prover is as follows. First, the piston is raised up to the top end of its stroke, while filtered air is admitted into the measurement chamber. The initial pressure is normally (but not always) the atmospheric one; a period of about one minute is allowed for the air temperature to stabilize. Then, the electronic controller accelerates linearly and rapidly the motor up to a pre-set constant velocity, while the pressure in the measurement chamber increases and the air begins to flow through the test line. As soon as the pressure and flowrate of the gas, as well as the output of the gas meter or flowmeter installed in the test line are stabilized at their steady-state values, the required and appropriate data acquisitions from both the prover and the instrument under test begin and continue for the longest allowable time. The piston is then gradually decelerated and stopped at a safe distance from a couple of emergency switches.

The highest flowrate that can be measured accurately is about 45 L/s (or 160 m^3/h); thanks to the good performance of the motor speed control and the availability of a reduced-speed drive (1:16) in the gear box, there is no limitation towards very small flowrates, but the excessive length of test runs.

The internal volume of the prover (together with the 100 mm-bore test line) is about 1500 L when the piston is at its upper rest position. The volume of the piston exceeds 1200 L; however, account being taken of the parts of the piston stroke that must be devoted to acceleration, deceleration and to the emergency stop switches installed at both ends, the largest gas volume that can be displaced and measured is about 800 L. This holds true at low flowrates; otherwise, the gas volume that can be delivered and measured in steady state conditions is much less, depending upon the type of the gas meter or flowmeter being calibrated, namely upon its time constant and pressure drop.

5 CHARACTERIZATION OF THE PISTON PROVER

The determination of the cross-section areas of the piston was made a first time in the 1980's, and repeated (with very similar results) in 1998 after the installation of the prover in the renewed laboratory. The process consists in dimensional scanning of six couples of generatrices positioned at an angle of 30° from each other. To this end, two position transducers of the linear optical encoder type (with 100 nm resolution and an uncertainty twice as much) have been installed and accurately centred in opposite housings machined in a steel ring bolted to the gasket flange of the prover. The piston has then been either raised or lowered at a slow speed, the digital outputs of the two transducers being recorded at as many as 190 different levels of the piston.

The absolute value of all diameters has been computed by comparison with a reference standard, an end gage of nominal 1000 mm length. With this type of length standard and position transducers, operating in a differential mode, the uncertainty in the determination of each individual diameter is mainly contributed by temperature gradients and by variable errors in the alignment between the common axis of the two transducers and the actual "diameters" of the quasi-cylindrical piston. The thermal contribution, however, is predominating. An estimated standard deviation of 0.3 °C between the temperature of the end gage and those of the various parts of the piston contributes an uncertainty of 3.6 µm. The composition of all components does not exceed 5 µm, or 0.001% in terms of piston area.

As regards the shape of the piston, the six couples of generatrices have been scanned four times each for a length of over 1200 mm. Both ends of the piston have been found less regular than the central part as regards roundness; however, all measured diameters range between 999.45 mm and 999.57 mm. In the 1 m long central part of the piston that is actually used during measurements of gas quantities the mean diameter at 20 °C varies with a known law between 999.50 mm and 999.53 mm; the associated roundness error never exceeds ± 0.04 mm. The mean cross-section area of the piston in that central part is 0.784644 m^2. The distribution of the diameters is such that, in two extreme measurement conditions, the volumetric errors contributed by the deviations of the piston from the cylindrical shape are + 0.001% and – 0.002% respectively. Restrictions in the choice of the measurement interval have been introduced, in such a way that both these figures now lie within ±0.001%; the associated standard deviation (rectangular distribution) is 0.0006%.

The piston is driven up and down by a ball-screw whose diameter is 100 mm with a nominal pitch of 10 mm. The large coaxial encoder that was installed on the female ball screw body generates 72000 pulses per revolution (electronic multiplication by a factor 4 is not necessary, nor useful). The accuracy of the whole assembly has been checked by means of a laser interferometer that measures the vertical displacements of the top end of the screw. The pulses emitted by the encoder during known displacements of the piston have been counted and the ratios between the two quantities have been computed both in individual parts and in the whole extension of the piston stroke.

The mean value in the whole excursion is 72001.6 pulses/cm, with neither obvious bias nor different trends between the different parts of the screw. Therefore, the mean displacement of the piston corresponding to a single pulse is 0.1388858 µm, and the nominal delivered volume 0.108976 mL/pulse at 20 °C (the number of pulses per litre is 9176.33).

As regards the uncertainty to be attached to the above figures, after proper correction for air refractivity the contribution made by the interferometer is negligible. The standard deviation of the temperature of the screw, when the test was made, is estimated to be 0.3 °C, namely 0.00036% in terms of length. However, the main contribution is made by cyclical deviations caused by small defects in the construction of the encoder, of the male and female screws and in their mutual positioning. A local analysis carried out on several individual threads, as well as on groups of threads distributed along the whole length of the screw, shows that a quasi-sinusoidal deviation (with 10 mm or 1 revolution period) is superimposed upon the theoretically linear relationship between piston translation and number of emitted pulses. The peak-to-peak amplitude of the deviation has been found to be about 25 µm; the absolute standard uncertainty is about 9 µm, corresponding to the delivery of 7 mL of gas.

In the end, when delivering a volume of gas *V* (expressed in litres), the relative standard uncertainty *u(K)* associated with the figure *K* = 0.108976 mL/pulse of volume swept by the piston inside the measurement chamber at 20 °C can be computed as:

$$u(K) = ((1 \cdot 10^{-5})^2 + (6 \cdot 10^{-6})^2 + (36 \cdot 10^{-7})^2 + (0.007/V)^2)^{1/2} \qquad (1)$$

When delivering gas volumes between 150 L and 800 L the above standard uncertainty ranges between 0.0048% and 0.0015%.

6 UNCERTAINTY OF GAS VOLUMES DELIVERED AT THE TEST SECTIONS

The geometrical volumes swept by either the bell or the piston inside each prover must be converted (according to the law of either perfect or real gases) in gas volumes delivered at the temperature and pressure conditions existing at the test sections (delivery points). An accurate determination requires the computation of how much gas is either stored in, or released by the internal free volume of the prover during a test, as a consequence of temperature and pressure changes occurred between the start and stop of each test run.

The method followed at the IMGC consists in the computation (based upon the relevant measurements of displacement, temperature and pressure) of the *difference* between the two masses of gas existing in a prover when each measurement run is started or stopped. That difference of masses is converted into a volume of gas computed at the average temperature and pressure measured at the delivery point.

The method clearly requires not only the usual accurate determination of the volume swept either by the bell or by the piston, but also an evaluation of the total volume of gas left inside the prover and in the test lines at the end of each test run. That *dead* volume is computed as:

- about 40 L plus the undelivered volume as regards the bell prover;
- about 1500 L minus the total delivered volume as regards the piston prover.

The influence of dead volumes on the computation of delivered gas volumes and on their associated uncertainty is very different in the two provers. In the bell prover the influence is very little, because the dead volume is only a fraction of the capacity of the prover; moreover, the basic uncertainty of the prover is comparatively high. There is a real need for the most accurate computations only when measurements at low flowrates involve the delivery of small volumes in very long test runs, during which the atmospheric pressure may change considerably.

As regards the piston prover, on the other hand, the intrinsic uncertainty of the piston is extremely small and the measured volumes of gas are at most equivalent, but very often smaller than the dead volume. For instance, when measuring 350 L towards the end of the piston stroke, the dead volume is about 700 L, therefore the effects of temperature or pressure drifts inside the prover are very important. However, the computation of the influence of dead volumes is unaffected by any constant errors connected with temperature and pressure measurements in the prover, because only the *differences* between initial and final readings are relevant to the said effect.

All temperature probes used in the gas laboratory are calibrated to a standard uncertainty of 0.01 °C at the IMGC Temperature Dept. All the electronic manometers, of both absolute and differential type, are calibrated against the HG5 or MM1 interferometer mercury manometers of the IMGC [3][4] to a standard uncertainty never exceeding 2 Pa. Therefore, the necessary multiple measurements of *stable* temperatures and pressures add almost nothing to the uncertainty of the bell prover and very little to the uncertainty of the piston prover. Very stable conditions can be achieved with some types of meters in a limited range of flowrates, and in such cases an expanded uncertainty (k = 2) of about 0.01% can actually be achieved with the piston prover.

However, in most cases (very fast or very long test runs) the measurement uncertainty of temperatures and pressures is by far dominated by the effects of comparatively large changes or oscillations of both atmospheric and relative pressures, as well as by temperature drifts. The evaluation of the relevant uncertainty components can only be made in each individual measurement situation, having recorded and observed the dynamic behaviour of temperatures and pressures. In the most critical working conditions, namely during short tests at the highest flowrate with meters of the rotary type (that exhibit a variable pressure drop in a cycle) uncertainties as high as 0.1% are possible, even in the favourable case where no resonance is excited. However, the most typical expanded (k = 2) uncertainties of the piston prover of the IMGC are less than 0.05%.

The temperature increase in the measurement chamber, caused by quasi-adiabatic compression and friction at the gasket, was a major concern when designing the piston prover. The measured effect of the two causes, during measurement runs with overpressures up to a few hPa (long enough to let the PRTs to get in equilibrium with the gas) is usually of a few hundredths of kelvin, with a maximum observed value of + 80 mK. This has been also the largest drift observed so far in tests at flowrates higher than 40 m^3/h, in spite of the fact that in such tests the PRTs are not allowed to achieve a really satisfactory thermal equilibrium. Indeed, the gas temperature decreases quickly, owing to the large area of metal surfaces exposed to heat transfer. However, in case of measurements with large overpressures (up to the maximum design value of + 30 kPa) the chamber will be pre-loaded, and its temperature will be stabilized before starting any test runs.

7 INTERNATIONAL COMPARISONS

The very first calibration jobs in which both provers were used after their characterization happened to be two international comparisons in 1998. The EUROMET 425 Project was intended to compare a dozen of small bell provers within Europe, by circulating a specially made Instromet G16 rotary gas meter. The four selected flowrates ranged between 0.4 L/s and 1.6 L/s. The draft of the Report by the pilot Laboratory (NEL, UK) [5], shows the IMGC results in the middle of the ± 0.3% wide band including the results of all participants. The standard deviations of the sets of 5 data points obtained by the IMGC at each flowrate range between 0.003% and 0.013% and the stated expanded uncertainty of 0.14% is confirmed fully.

The piston prover was tested later in 1998 during the EUROMET 419 Project, a comparison of calibrations carried out on an Instromet G 250 rotary meter. The meter was calibrated at the IMGC up to 160 m^3/h, with stated uncertainties of each individual calibration point ranging between 0.025% and 0.1%. Although the criteria for the selection of the reference curve of the transfer standard have not been decided yet, the preliminary results shown by the pilot Laboratory (Force Instituttet, DK) confirm that the piston prover, too, performed well in its comparison exercise.

8 CONCLUSIONS

After their completion and successful comparison with many other standards in Europe, the two gas provers installed in the new gas flow laboratory of the IMGC are now available as Italian national standards for gas flowrates up to 160 m^3/h at near atmospheric pressure. The ease of use and accuracy of the bell prover have been greatly enhanced and are now fully adequate to the needs. The large piston prover, on the other hand, constitutes a unique standard apparatus with remarkable design characteristics and extremely low uncertainties.

As regards the next work items and developments in the IMGC gas flow laboratory, a small piston prover of sophisticated design is currently being completed and characterized; it will extend soon the measurement capabilities of the laboratory down to about 0.01 L/h of air or pure gases.

REFERENCES

[1] ISO, Guide to the expression of uncertainty in measurement, Geneva, 1995.

[2] F. Alasia, G. Cignolo, Design criteria for a 1200-litre capacity piston prover for primary gas volume and flowrate measurements, *Proc. of FLOMEKO Int. Conf. on Flow Meas. (*Melbourne, August 1985), E.A. Spencer ed., H.S. Stephens & Ass. publ., Bedford, UK, 1985, pp. 123-128.

[3] F. Alasia, G. Birello, A. Capelli, G. Cignolo, M. Sardi, The HG5 laser interferometer mercury manometer of the IMGC, *Metrologia,* **36** (6), 1999, 5 pp.

[4] F. Alasia, A. Capelli, G. Cignolo, R. Goria, M. Sardi, The MM1 laser interferometer low-range mercury manometer of the IMGC, *Metrologia*, **36** (6), 1999, 5 pp.

[5] C. Probert, An inter-comparison of bell prover facilities at twelve European Laboratories using a rotary gas meter, to be published as: A Report for NMSPU, Dept. of Trade and Industry, 151 Buckingham Palace Rd., London, 2000.

Acknowledgement: the authors are indebted to their colleagues Roberto Goria and Dr. Salvatore Lorefice for their valuable help.

AUTHORS: Dr. Giorgio Cignolo, Dr. Antonio Rivetti, Gianni Martini, Franco Alasia, Giancarlo Birello, Gaetano La Piana, Mass & Volume Dept., Istituto di Metrologia “G. Colonnetti” del Consiglio Nazionale delle Ricerche (IMGC-CNR), strada delle Cacce, 73 – 10135 Torino, Italy.
Phone: +39 011 3977448; Fax: +39 011 3977437; E-mail: g.cignolo@imgc.to.cnr.it