‘GAS OIL PISTON PROVER’, PRIMARY REFERENCE VALUES FOR (HIGH- PRESSURE) GAS-VOLUME, RESULTS

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Abstract

The paper describes the design, measurement results and uncertainty analyses of the hydraulic driven piston-prover system which is in operation at VSL since 2008. The 12 meter long, 0.6m bore piston-prover is used for the realization of Reference Values for Gas-Volume at pressures between 1 and 65 bar(a) and ‘any’ type of Gas. The principle is based on the displacement of a piston acting as a Gas-Oil separator. The standard has a flow-rate range from 5 to 230 m3/h. The system is designed to calibrate reference meters. The Calibration and Measurement Capability (CMC) of the system is proven smaller than 0.1% (k=2). The paper also explains the coherence between the Gas-Oil Piston-Prover and other traceability generators and ‘flow rate bootstrapper systems’

Introduction

The Gas Oil Piston Prover, (GOPP) was designed in 2000 and built in 2003. The first results, shared on Flomeko 2003 [1] underpinned the metrological feasibility of the system. It took another lustrum to get the system into satisfactory operation. In 2010 the system and its uncertainty claim was approved under ISO17025 and accepted by PTB and LNE. It was important to ‘have PTB and LNE on board’ as these entities are partners in the ‘Eurega’[3] consortium for the Harmonized Reference Values of gas volume [4]

Working Principle

The working principle is based on the displacement of a piston acting as a Gas-Oil separator. (See figure 1). The piston travels at a relative low speed. A speed-controlled centrifugal pump generates an oil flow rate that moves the piston with a uniform velocity towards the left side of the cylinder, passing sensors indicating boundaries of discrete volumes. The oil & gas container at the top-side of the configuration, works also like a displacement system and the gas is forced towards the open outlet of the container flowing back into the cylinder.

During the gas transport from the container to the cylinder, the mounted gas-meter will indicate a passed actual volume that is matched with the known volume of the displaced piston. Obviously it is a process with two strokes, after the active measuring stroke (piston moves to the left end) the pump will be stopped and the oil returns (caused by a slight natural hydrostatic over-pressure) to the cylinder and forces the piston back to its starting terminal. Proximity switches take care of the comparison process. The HF pulses coming from the Meter- or Device under-Test (a Travelling Reference Meter) are compared with the reference LF pulses of the several reference volumes of the primary cylinder.
In [1] a more extensive description of the design considerations was given.
The advantage of the concept is the closed circuit

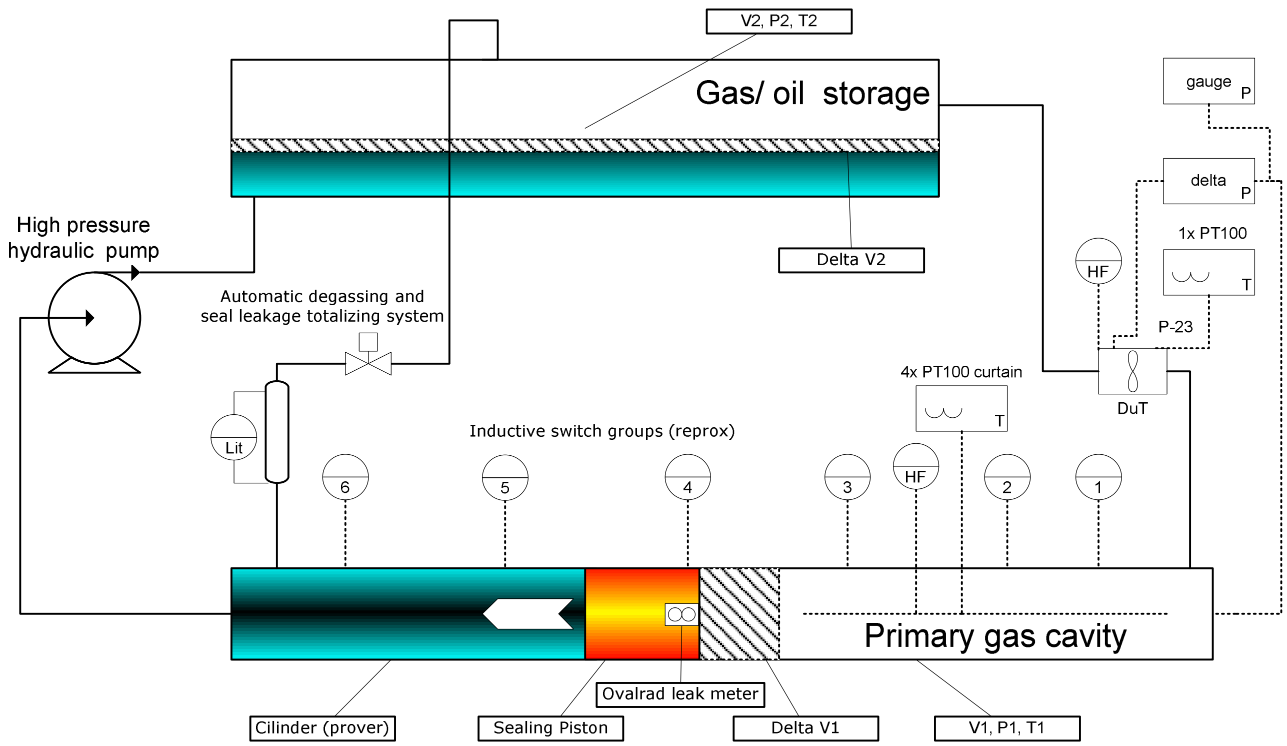


Figure 1, schematic diagram GOPP

approach where the amount of high-pressure gas as the transported fluid can be maintained at a stable temperature, isolated from 'the outer world' such as a gas supply or gas grid. The system includes a hydraulic oil flow-rate controller to maintain constant speed of the piston.
The developed primary standard has a flow-range of 5 up till 230 m3/h at actual conditions. The system is designed for the calibration of Travelling Reference Meters and has a direct relation to the 'meter' and the 'second'. Consequently, 'GOPP'-calibrated gas-meters are available with reference values at various pressures to disseminate traceability at junctions with similar conditions as the Dutch traceability-chain.
Some details, see previous diagram:

- 6 groups of reprox-timing/cross checking sensors that are triggered at each passage of the piston;
- 1 High frequency sensor output signal of the DuT;
- 4x PT 100 element-curtain sliding over a string, equally distributed measuring the average temperature in the centre line of the gas cavity of the prover;
- 1x High frequency sensor output signal of the 'Oval' leak meter in the piston;
- 1x PT 100 element embodied in the DuT;
- 1x delta Pressure sensor between inlet of the MuT and gas cavity of the prover;
- 1x Gauge pressure sensor attached at the gas cavity
- 1x LF pulse for the degassing and gas leak counter;
- 1x PT 100 sensor for ambient temperature inside the GOPP skid for checking purpose.

Improvements since 2008

Since the first date of operation, the following improvements have been successfully implemented:

- A set of flexible yet 'hard surface' type seals to ensure either leak tight operation and still 'slip-stick-free' piston movement;
- The actual flow rate is increased from 120 to 230 m^3/h by enhancing the pump control;
- A ramp-up pump speed function is added to avoid first 5 seconds start-up pulsations of the rotary gas meter (a so called 'iRPP', or 'Instromet Rotary Piston Prover' [6]);
- A de-gassing and seal-gas-leakage totalizing counter is implemented;
- A thermal insulation fabric is placed around and above the GOPP. Five giant air ventilators inside the tent are placed to ensure low temperature gradient operation of the complete system;
- A re-wiring of the electrical system and ATEX certification was done in order to allow GOPP working at 'EuroLoop'[5] premises;
- A software upgrade for made higher testing efficiency;
- The inner cylinder wall is polished to get a more smooth piston operation. (no 'heavy spots')

Preparations and procedure of operation

In the next section, the preparation and operation procedure of the GOPP is described step by step:

1. The inner diameter between start and stop reprox sensors is calibrated with rotating clock gauges (see next section for details);
2. The representative switch length between the reprox sensors is calibrated with a laser interferometer (see next section for details);
3. All relevant temperature sensors are calibrated at the same time in one bath at 10,15, 20, 25 and 30 °C;
4. The gauge pressure- and dP transmitter are calibrated at process conditions p=1,9,21,36, 51 and 61 bar(a);
5. The Device under Test is mounted and pulse outputs are checked;
6. The system is slowly pressurized starting from lowest to highest pressure level of the test program;
7. The pressure stability is observed, some gas will be absorbed into the hydraulic oil, eventually add some more gas for compensation of pressure decrease;
8. The system is checked on external leakages;
9. Some pre-runs are carried out to test smooth operation of piston;
10. Eventual oil spill inside the cylinder is recorded by emptying the measurement cavity. This could be an indication of leaking seals to the gas side;
11. The hydraulic oil is de-gassed prior to calibration runs with the help of the looking glass manifold (could be an indication of leaking seals to the oil side);
12. About 10 sequential pre-test runs at highest flow rate are carried out to get temperature equilibrium;
13. When all gas temperatures show less than 0.1 °C difference, official calibration runs are initiated;
14. Checking of eventual pulse train output of dynamic seal-leakage flowmeter (Oval-rad meter) during one piston stroke and checking of de-gassing totalizing system;
15. Data analyses and criteria check: standard deviation of test group (<0.02%), average temperature differences inside the prover (<0.10°C), standard deviation of all tests within one piston stroke (<0.02%), permissible difference between crosscheck of reprox sensor timing during one piston stroke (<0.05%);

Determination of base reference volume

Diameter calibration. The inner diameter of the prover is measured with an automatic diameter gauge setup. This setup consists of a rigid rod on which two digital micrometers (gauge clocks) are attached. The rod is fixed on the rotating shaft of a stepper motor reduction gearbox combination. The stepper motor is to bring the digital micrometers into position and transported by a tender rolley. The measurement angle position resolution amounts 4 degrees.

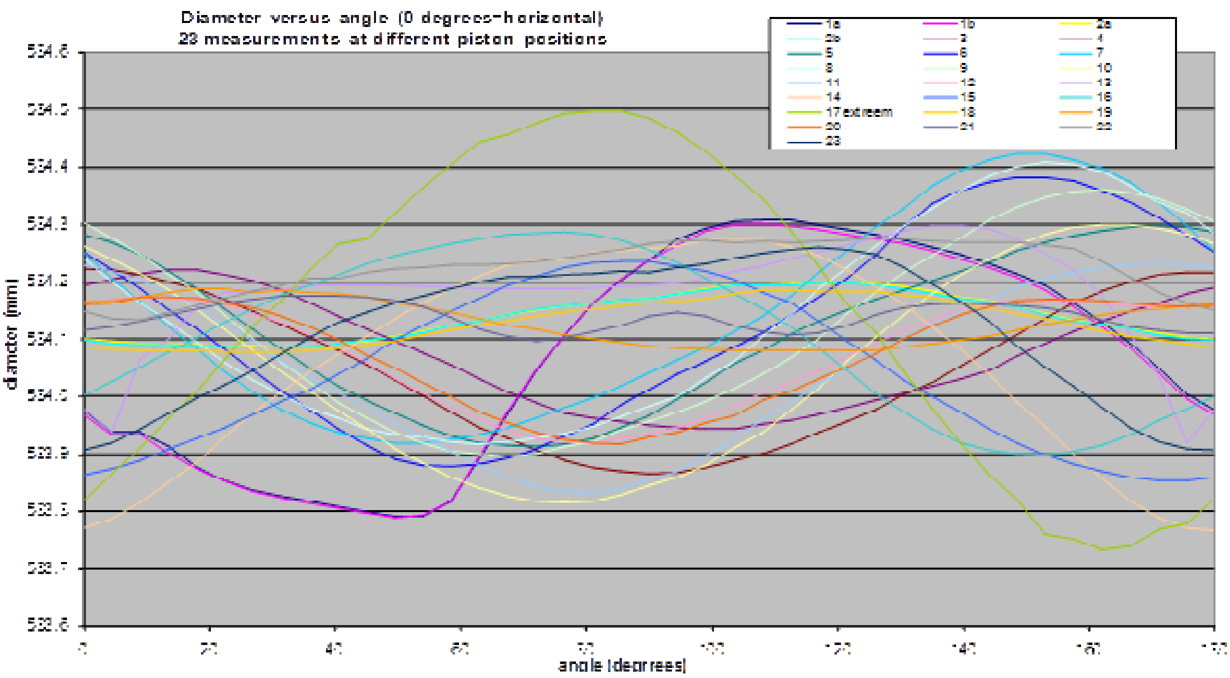


Figure 2, diameter as a function of angle, position

The micrometers are indicating the length difference of the inner prover radius related to a ‘zero’ position of the micrometer. The resolution is 1 micrometer and uncertainty of the measurement amounts 0.01mm. The zero position of the micrometer is determined with a fixed diameter calliper gauge. At any time during the measurements, temperature of the rigid rod and the prover wall is measured with separate temperature sensors.

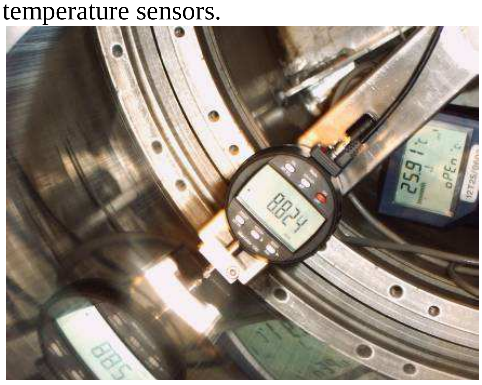


Figure 3, one of the two rotating clock gauges

The repeated tests 1a, 1b, 2a and 2b demonstrate the excellent reproducibility of the test method (see graphs).The maximum and minimum diameter of the complete prover length (12m) amounts: 584.50 resp. 583.73 mm. These extremes are important design values for the maximum piston slide strip diameter to prevent the piston from sticking due to temperature expansion of the aluminium body inside the stainless steel cylinder. While the extremes are outside the calibration stroke, the extremes do not play any role in the reference volumes between the inductive switches.

The representative average diameter between start and stop switches amounts 584.108 mm. The maximum deviation of the individual digital gauges amount 2 µm and while no correction is applied, the uncertainty is 4 µm per gauge (2s). The uncertainty of the certified reference calliper is 1.8 µm (prevailing temperature correction is applied) which adds up to a total uncertainty of 6 µm for a one shot diameter determination. The uncertainty of the representative diameter is based upon RSS of 2*stdev of 697 results (0.082 mm) and 0.006 mm of the gauges which results in 0.082mm, equivalent to 0.014% on diameter and 0.028% on volume. The cylinder is a little elliptic as can be seen on figure 3. The cylinder is divided into three parts that are bolted together. Apparently, the sections are not perfectly mounted ‘in phase’ to each other.

Piston stroke length determination. The representative switch distance from the cylinder end is determined with the original metal switch ring (Carbon steel) which is mounted on a dummy sliding piston. The dummy piston is pulled into position with a hand operated reel and cable. When the inductive sensor under test is triggered by the metal ring, the relative laser position is recorded.

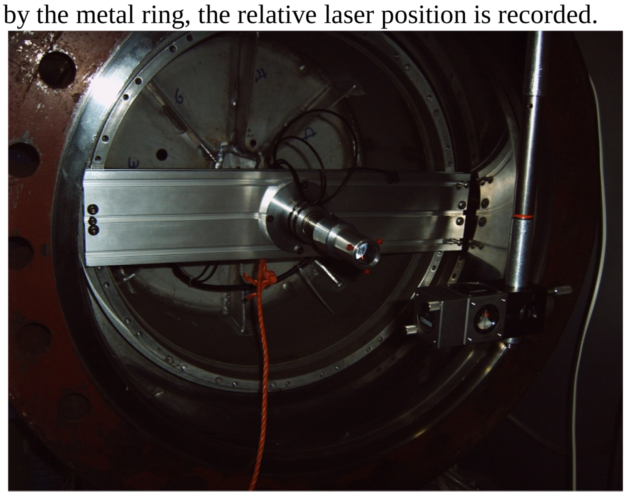


Figure 4. Ferro switch ring, reflector and splitter

The dummy piston is provided with a centre corner cube as reflector for the laser beam (see centre line of piston in figure 3) The laser beam is sent through a beam splitter length measurement of the relative position of the dummy piston. Each switch position is determined 10 times. The resolution of the interferometer system (make Agilent) amounts 0.1 micrometer. However the uncertainty of the length determination amounts ten times larger due to breaking index corrections (temperature, pressure and humidity of the air inside the prover). The representative length between the switches is corrected to a reference temperature of 20 °C.

Physical Model

For the mathematical description it is assumed that in first approach the piping and the meter casing is completely rigid and that the dimensions do not vary with the changes in temperature and pressure as observed during the calibration. Moreover it is assumed that the calibration takes place under quasi-stationary flow-conditions. This implies that the mass flow rate in the pipeline is constant.

The mass balance equation can be written as:

$$\rho_1 Q_1 = \rho_2 Q_2$$

In which ρ is the density and Q is the volume flow rate. The indices 1 and 2 refer to the GOPP and the MuT position respectively.

The densities are obtained using the state equation of a real gas: $p_i = Z_i \ \rho_i \ R_a \ T_i \quad (i = 1,2)$

In which: p is the absolute pressure, T the absolute temperature, R_a the specific gas constant for the gas and Z_i the real gas constant or compressibility factor.

The quantity determined in the calibration process, is the relative deviation of the gas flow meter e_{MUT} is defined as:

$$e_{MUT} = \left(\frac{Q_{MUT}}{Q_{STD\,@\,MuTposition}} - 1 \right)$$

All temperatures are expressed in ºC, so

$$T_i = T_0 + t_i \quad (i = 1,2) \ with \quad T_0 = 273.15\,K$$

The pressure at the TRM (p_{MUT}) is the absolute pressure at GOPP (p_{STD}) plus pressure difference dP over the MuT.

It is assumed that pressure, temperature and compressibility factor readings are corrected for known deviations. Successive substitution of the equations to the mass balance equation leads to the following expression for the deviation of the MUT

$$e_{MUT} = \left(\frac{p_{STD} + dp}{p_{STD}} * \frac{Q_{MUT}}{Q_{STD}} * \frac{T_0 + t_{STD}}{T_0 + t_{MUT}} - 1 \right) * 100\%$$

(While all tests are carried out at nearly the same pressures, all compressibility factors are assumed to be equal).

The indicated volume flow rate of the MuT is calculated as follows:

$$Q_{MUT} = \frac{I_{tot}}{Pf * \tau_{MUT}}$$

In which:

Q_{MUT} =Indicated flow rate of meter under test [m^3/h]
I_{tot} =amount of pulses collected during time τ
Pf = Pulse factor of MuT [pulses/m^3]
τ_{MUT} = time of I collected pulses [s]

The actual volume flow rate Q_{STD} generated by the GOPP is given by:

$$Q_{STD} = \frac{\pi}{4} D_i^2 * (L_i - L_0) * (1 + \boldsymbol{\alpha}(\mathbf{t}_{OC} - t_{Lcal})) * (1 + 2\boldsymbol{\alpha}(\mathbf{t}_{OC} - t_{Dcal})) * (1 + \frac{P * D_i}{W * E}) / \tau_i$$

In which:

D_i = representative (average) inner Diameter of prover for discrete volume i [mm]
L_0 = representative (calibrated) length of start proximity sensor for all discrete volumes [mm]
L_i = representative (calibrated) length of stop reprox , for discrete volume i [mm]
$\boldsymbol{\alpha}$ = linear expansion coefficient for the prover material (stainless steel), $16*10^{-6}$ [1/°C]
T = temperature [°C]
τ_I = switch time between two reprox sensors at beginning and end point of a discrete volume [s]
E = Elasticity modulus of $2*10^8$ [kPa]
W = Wall thickness of prover [mm]
P = operating line pressure (gauge) [kPa]
OC = operating condition
Lcal= at time of the length calibration
Dcal= at time of the diameter calibration

In the model the thermal expansion and pressure expansion of the cylinder due to elasticity are taken into account.

Thermal behaviour

Prior to the actual calibrations of a connected MuT, a set of pre-runs need to be carried out depending on the current ambient temperature stability of the laboratory in which the GOPP is located at that moment.

The process temperature of the GOPP is always controlled by the ambient temperature. No other process temperature set point is possible unless an airco system would be located within the thermal insulation tent (future plans). The temperature range in which GOPP will be operated is between 5~30 °C. Typically some 15 pre-runs need to be carried out to stir the oil in the system and to get equalize out initial temperature gradients inside the cylinder and oil container cavities, especially immediately after pressurizing the system (see figure 4, high temperature peaks). When the temperature variations (amplitudes) and temperature differences become less than 0.1°C then stable operation is guaranteed, see also the example in the second graph below.

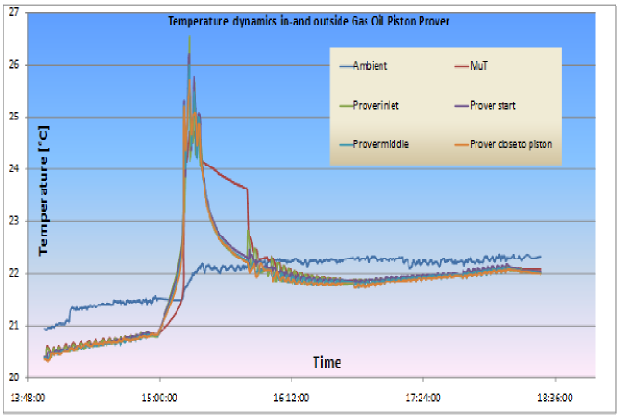


Figure 5, temperature around pressurization

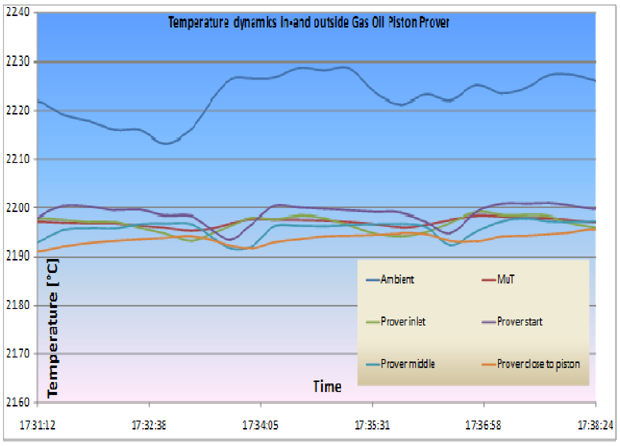


Figure 6, zooming-in at two tests

This second graph zooms in at two piston strokes. The temperature rises during the calibration stroke and sequently the temperature slowly descents slightly when the piston moves back onto start position. The temperature rise is caused by the warmer gas moving from the top of the oil container into the prover cavity through the DuT. In the return stroke, the warmer gas is cooled down a little and send back to the oil/gas container again. This phenomena will probably disappear completely when GOPPwould be placed in an air conditioned housing (future plans) and/or when a higher degree of turbulence is applied in the surrounding air within the insulation tent.

Discussion of results, uncertainty, CMC's

In the next section, the uncertainty sources are given. The analyses is based upon the physical model of the piston prover given before. Table 1 is self explainable and depicts the analyses of the uncertainty of the reference flow rate generated reference flow at the position of the piston itself. The uncertainty at the MuT location will be discussed hereafter.

Quantity	What	Value	Sensitivity		Budget type	u par	unc
Di	Inner diameter	584.10 mm	δQ/δDi	0.3425639 %/mm	Calibration	0.082 mm	0.028 %
L0	Length reprox 0	3791.1 mm	δQ/δL0	-0.0734802 %/mm	Calibration	0.25 mm	0.019 %
Li	Length reprox i	5152.0 mm	δQ/δLi	0.0734802 %/mm	Calibration	0.18 mm	0.013 %
alpha	Thermal expansion	1.60E-05 1/°C	δQ/δα	-1800.2765 %°C	Literature constant	1.60E-06 1/°C	0.003 %
tOC	temperature at operating condition	20 °C	δQ/δtoc	0.0048008 %/°C	Calibration & representativity	0.2 °C	0.001 %
tLcal	temperature during L	26 °C	δQ/δLcal	-0.0016002 %/°C	Calibration & representativity	0.4 °C	0.001 %
tDcal	temperature during D	26 °C	δQ/δDcal	-0.0032006 %/°C	Calibration & representativity	0.4 °C	0.001 %
P	Absolute pressure	51 Bar	δQ/δP	0.0015359 %/Bar	Calibration & representativity	0.2 Bar	0.000 %
W	Wall thickness	19 mm	δQ/δW	-0.0039166 %/mm	As built Tolerances	1 mm	0.004 %
E	Elasticity modulus	2.00E+08 kPa	δQ/δE	-3.561E-10 %/kPa	Literature constant	2.00E+07 kPa	0.007 %
time	Elapsed time	200 s	δQ/δτ	-0.4999998 %/s	Calibration	0.0001 s	0.000 %
	Flow rate STND	**6.57 m³/h**			uncertainty	(2s)	**0.037** %

Table 1, parameter list, sensitivity factors, uncertainty budgets

In the previous paragraph the base uncertainty is discussed. For the CMC, the following sources need to also to be taken into account. The most significant or and/or notable sources will be discussed in more detail:

Line pack: The 'regular' line pack is defined as follows

$$\Delta e = -\left(\frac{\Delta p}{\Delta \tau} * \frac{1}{p} + \frac{\Delta t}{\Delta \tau} * \frac{1}{(T_0 + t_{avg})}\right) * \frac{Avg\ Dead\ volume}{\Delta Volume} * \Delta \tau \ [\%]$$

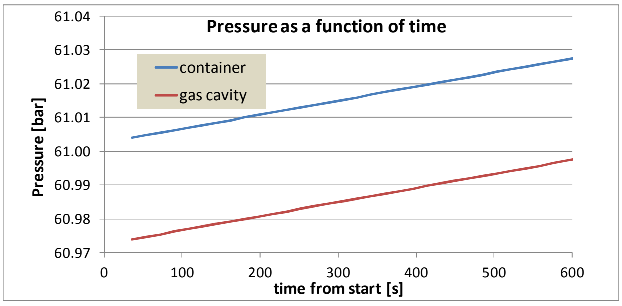
Which is valid for a MuT that is mounted upstream of the primary standard.

(Mind that Δτ could be deducted, however for sake of clearness it is left in the equation.)
Δ*e* is the relative impact on the calibration result in %
Furthermore:

Avg Dead Volume	Average volume between MuT and Piston
ΔVolume	Discrete reference stroke volume of piston inside the prover [m^3]
Δτ	Time interval of the passed piston triggering at start and stop sensor representative for ΔVolume [s]
Δp	Pressure change during time interval Δτ [mbar]
P	Operating pressure in mbar
Δt	Temperature change during time interval Δτ [°C]
t_{avg}	Average temperature of the average dead gas volume [°C]

Calculated impact for GOPP conditions: 0.01%

Specific decreasing volume causing line pack. This is the most remarkable source. Due to the linear decrease of the inner gas container volume related to the increasing cylinder gas volume, both pressures will rise according to the next theoretical graph which is given here without mathematical proof. Although the process pressure at zero flow will be stable, due to the pressure drop between both containers, the process pressure in the cylinder will rise and thus will lead to a line pack error according to the model of the previous source.



For the given 'low pressure drop' rotary meter under test, the pressure rise in the cavity is as follows:

Flow rate	Absolute line pressure [Bar]	
Q m3/h	9	51
	Pressure rise	
	mBar/s	mBar/s
200	0.055	0.34
100	0.006	0.04
20	0	0.0003

The impact on GOPP is negligible for this low dP rotary meter, however for higher dP generating meters the impact (e.g. Coriolis) should be taken into account.
Thermal expansion of DuT. The uncertainty in the rotary meter cartridge thermal expansion correction amounts: 0.005%
Interpolation of deviation curve of DuT. This is not relevant while real data are used at the controlled flow rates points. Typical values are 0.01~0.03%.

Representativity of temperature measurement. For the cavity inside the cylinder this uncertainty is determined at 0.05°C. This performance is typical for a standalone well insulated 'chunk of steel'. Due to the built-in-thermometer design of the MuT, the representativity for the latter is 0.03°C.
Piston seal leakage. The inner measured inner cross-leakage of the seals amount less than 0.005% at 5 m^3/h.
Reproducibility of the data set.
The reproducibility of the measurements at the cardinal flow rate points is caused by the following combined effects:

- Slip stick of the piston;
- Not representative temperature measurements;
- Hysteresis of the inductive switches;
- Variations in temperature of connected volumes (line pack effects);
- Instabilities of the rotors of the MuT;
- Measurement noise in temperature and pressure sensors/ instrumentation amplifiers, A/D converters.

Typical found values are between 0.01~0.3% depending on flow rates and pressures (see table 3 on last page).

Overview CMC's for one device under test
The CMC's for one specific rotary meter (ID# 3.3) is calculated in table 2.

Flow	Pressure stage in Bar(a)					
rate	**1**	**5**	**9**	**21**	**36**	**51**
m3/h	CMC ref. volume in iRPP ID#3.3 [%], *k* =2					
200			0.07	0.06		0.06
150			0.07	0.06	0.06	0.06
100	0.08	0.07	0.07	0.07	0.06	0.06
80						
50	0.08	0.07	0.07	0.06	0.06	0.06
20			0.07	0.12		0.12
10			0.12	0.20	0.12	0.12
5			0.14	0.29		0.19

Table 2, CMC's of GOPP with the 'golden' transfer standard

How to get reference values for higher flow rates?
The multiplication of traceability in flow rates is carried out by the 'bootstrapping' principle. Basically it is done by copying traceability at identical flow rates in a multiple transfer meter set. When putting these meters into parallel operation, a reference value at higher flow rate is generated. Such a system can be designed as standalone 'multiplier-facility' such as VSL TraSys (See detailed discussion in [2]) or as a ad hoc configuration with existing test- and calibration facilities.

Conclusion and future work

VSL-GOPP is a standalone, closed circuit calibration system on a skid, build in 2003 and improved considerably over the past 10 years to generate accurate reference values for low to high pressure Natural Gas or other gases. The system is mainly suitable for the calibration of rotary (primary) standards and can be used for R&D work. Other metering principles can be calibrated as well as long as the meters under test have a reasonable response time (<4 seconds) and low pressure drop (< 200 mbar at 61 bar and 230 m^3/h). The system will be used intensive in the next years to improve the

accuracy of the EuroLoop and other facilities around the world.
It is scheduled to build the system inside a very well insulated housing together with an airco system to have full control over the surrounding temperature to achieve even higher accuracies.

References

[1] M.P. van der Beek et al, “Gas-Oil Piston Prover”, a new concept to realize reference values for High-Pressure Gas-Volume in the Netherlands, Flomeko 2003, Groningen, the Netherlands.

[2] R. van den Brink et al, ‘NMi TraSys, The ultimate carrier & multiplier for the unit of volume for High Pressure Natural Gas’, Flomeko 2003, Groningen, The Netherlands.

[3] B. Mickan et al, ‘EUREGA: EUropean REference for GAs Metering’, Flomeko 2013, Paris, France.

[4]B. Mickan, M.P. van der Beek, I.J. Landheer, R. Kramer, D. Dopheide, 'Unit of volume for Natural Gas at operational conditions, PTB and NMi VSL disseminate Harmonized Reference Values', Flomeko 2003, Groningen, The Netherlands.

[5] M.P. van der Beek, ‘EuroLoop: Metrological concepts for efficient calibrations and primary realization of accurate reference values in flow’, NSFMW 2007, Oslo, Norway.

[6] Dijstelbergen, H.H. ,Beek van der, M.P., 'A new reference meter for gas meter calibration', Flomeko 1998, Lund Sweden

Annex uncertainty analyses table

The several uncertainty sources are depicted in the following table (3). The base uncertainty is found in the top rows which values are root-sum-squared with the repeatability figures for data sets at the specific flow rates to get the final CMC’s. The reproducibility of the calibrated rotary meter is estimated at 0.01% and believed to be less than the reproducibility of the system.
In next calibration stages (like bootstrapping) the interference between parallel operated rotary meters and drift of the meters (per year) are taken into account.

Table Step 0							Uncertainty reference volume at meter location [%], *k* =2					
							Pressure stage in Bar(a)					
							1	**5**	**9**	**21**	**36**	**51**
				Ubasis Q>20m3/h			0.076	0.070	0.066	0.062	0.059	0.058
				Ubasis Q<=20m3/h			0.126	0.122	0.067	0.118	0.116	0.116
Quantity	**What/Source**	**sensitivity**		**budget type**	**u par**	**unit**						
V	Base Prover Volumes	1.00E+00	%/%	calibration	0.037	%	0.037	0.037	0.037	0.037	0.037	0.037
	consistency obo 0.1mm per reprox	1.00E+00	%/%	repeateability	0.0118	%	0.012	0.012	0.012	0.012	0.012	0.012
	Bouncing effects	1.00E+00	%/%	repeateability	0.00	%	0.000	0.000	0.000	0.000	0.000	0.000
P	prover expansion	1.54E-03	%/bar	correction	1	bar	0.002	0.002	0.002	0.002	0.002	0.002
T	prover expansion	4.59E-03	%/°C	correction	2	°C	0.009	0.009	0.009	0.009	0.009	0.009
P	abs Gaspressure	0.00E+00	%/bar	calibration	0.5	bar	0.000	0.000	0.000	0.000	0.000	0.000
	Jet Pressure effects	1.00E+00	%/%	correction	0.00	%	0.000	0.000	0.000	0.000	0.000	0.000
T	abs Gastemperature	0.00E+00	%/°C	calibration	0.2	°C	0.000	0.000	0.000	0.000	0.000	0.000
dT	Temperature difference	3.41E-01	%/°C	comparison	0.03	°C	0.010	0.010	0.010	0.010	0.010	0.010
	Jet flow	3.41E-01	%/°C	representativity	0.05	°C	0.017	0.017	0.017	0.017	0.017	0.017
	Several data sets	3.41E-01	%/°C	type A	0.1	°C	0.034	0.034	0.034	0.034	0.034	0.034
dV/V	Linepack effects			>20 m3/h			0.01	0.01	0.01	0.01	0.01	0.01
	Leakage			>20 m3/h			0.003	0.003	0.003	0.003	0.003	0.003
dV/V	Linepack effects/section			<=20 m3/h			0.1	0.1	0.01	0.1	0.1	0.1
	Leakage			<=20 m3/h			0.01	0.01	0.01	0.01	0.01	0.01
*)	Mind that flowcontrol was carried out in the oil line								*)			
dP	press diff @ 1 bar	1.00E-01	%/mbar	cal,comp, type A	0.5	mbar	0.050					
dP	press diff @ 5bar	2.00E-02	%/mbar	cal,comp, type A	2	mbar		0.040				
dP	press diff @ 9bar	1.11E-02	%/mbar	cal,comp, type A	3	mbar			0.033			
dP	press diff @ 21bar	4.76E-03	%/mbar	cal,comp, type A	5	mbar				0.024		
dP	press diff @ 36bar	2.78E-03	%/mbar	cal,comp, type A	5	mbar					0.014	
dP	press diff @ 51bar	1.96E-03	%/mbar	cal,comp, type A	5	mbar						0.010
Flow rate							1	4	8	20	40	50
200	m3/h			reproducibillity		%			0.02	0.02		0.02
150	m3/h			reproducibillity		%			0.01	0.00	0.01	0.02
100	m3/h			reproducibillity		%	0.02	0.01	0.03	0.02	0.01	0.03
80	m3/h			reproducibillity		%						
50	m3/h			reproducibillity		%	0.01	0.00	0.00	0.01	0.01	0.01
20	m3/h			reproducibillity		%			0.03	0.03		0.02
10	m3/h			reproducibillity		%			0.10	0.16	0.04	0.03
5	m3/h			reproducibillity		%			0.12	0.27		0.15

Table 3, Uncertainty sources used in CMC analyses of table 2