Intercomparison of primary high-pressure flow standards

The first intercomparison of the primary standards for high-pressure gas flow measurement of Germany, Denmark and The Netherlands is a success. The differences between the laboratories are smaller than when working standards are used. 95% of the normalized differences are less than unity, which supports the CMC claims of the laboratories.

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Intercomparison of primary standards

In addition to the existing intercomparisons [1], [2], the EuReGa experts' team aims to demonstrate the equivalence of the primary standards. With minor modifications to the pipework, it appears to be possible to make a direct intercomparison of the piston provers using the available DN100 packages. At this point we like to emphasize that the current work is an intercomparison only. Harmonization of the primary standards is not pursued.

Unfortunately, the French colleagues cannot participate as their primary PVTt system [3] operates at a variable pressure. The French PVTt system and the German High-Pressure Piston Prover were used in an earlier primary intercomparison using sonic nozzles [4].

Participants' Piston Provers

All participants use a piston prover as primary reference. The characteristics of these provers are listed in Table 1.

Table 1: Characteristics of the participants' piston provers. All provers are operated on natural gas.

Institute	VSL	PTB	FORCE
Primary device	24" Gas Oil Piston Prover (GOPP)	10" Piston Prover (HPPP)	26" Twin Piston Prover
Piston	Passive	Passive	Active
Nominal diameter	600 mm	250 mm	660 mm
absolute operating pressure	1 – 62 bar	8 – 51 bar	1 – 66 bar
Piston stroke / Effective stroke	12 m / 6.5 m	6 m / 3 m	2.8 m / 0.6-2.7 m
Flowrate range	3 – 230 m³/h	3 – 480 m³/h	2 – 400 m³/h
Maximum piston speed	0.25 m/s	3 m/s	0.17 m/s
CMC	0.070% – 0.086%	0.065%	0.080%

PTB uses a 10" gas-gas Piston Prover (HPPP), it consists of a honed 250 mm diameter in which a piston can travel at a maximum speed of 3 m/s (approx. 480 m³/h) over a length of 6 m with an effective measurement length of 3 m. VSL uses a 24" gas-oil Piston Prover (GOPP). The prover is filled with oil on one side and gas on the other side of the free moving piston. The maximum flowrate is 230 m³/h. Finally, FORCE Technology uses a 26" Twin gas-gas Piston Prover with two parallel cylinders with bidirectional pistons inside them. The actuated pistons can displace up to 400 m³/h.

Transfer meters and test Protocol

Both meter packages used in this intercomparison consist of a G250 turbine meter with a fixed upstream flow conditioner, upstream spool and downstream spool with thermowell. The meter packages are designated EuReGa DN100 M1 and EuReGa DN100 M2. They are normally used in the EuReGa intercomparison every three years, the last time in 2017 and 2018 [2]. The packages are calibrated individually, not in series.

The meters are calibrated at flowrates 25, 40, 65, 100, 160, 250 and 400 m³/h at absolute pressures of 8, 20 and 50 bar. At each flowrate the laboratories report the meter deviation e, which is the average of four or five successive measurements, and its expanded measurement uncertainty. PTB and Force cover the entire range while VSL covers the range up to 200 m³/h. In addition, VSL calibrated only one meter package: EuReGa DN100 M1.

Data processing and results

The processing of the measurement data is done according to [5]. The data analysis is performed in the Reynolds domain. In this way the results obtained at different pressures can be compared. For each combination of pressure and flowrate $\bar{e}$ is the weighted average of the deviations e observed by the labs, which makes $\bar{e}$ the reference level. The small differences between the corresponding Reynolds numbers are ignored. The data were processed for meters M1 and M2 separately. The results are combined in one graph.

The deviations $d = e - \bar{e}$ with respect to the reference level (e=$\bar{e}$ or d=0) versus the Reynolds number are graphically displayed in Figure 1. The deviation uncertainties are indicated by error bars. For most data points these uncertainty bars intersect the reference level with five exceptions for meter M1. With more than 100 calibration points this result agrees to a 95% confidence level. When comparing this result with Figure 3 of [2], the deviations are smaller in the present intercomparison.

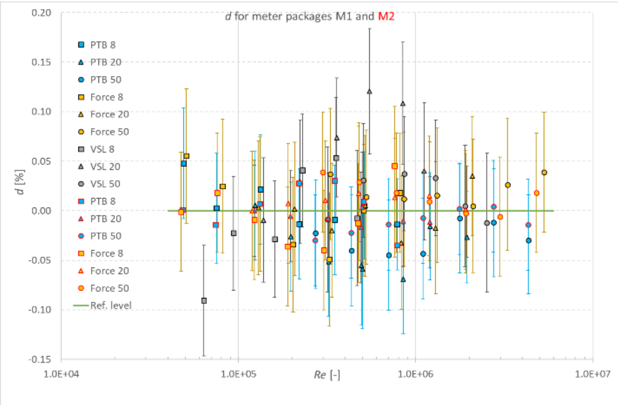

Figure 1: Deviations d [%] versus the Reynolds number Re [-]. The markers for meter M1 have a black outline and the markers for meter M2 a red outline. The symbol colors correspond to the participating laboratory and the symbol shapes to the calibration pressure. The horizontal green line is the reference level d=0.

The normalized deviations $E_n = d/U(d)$ are shown in Figure 2. Here E_n values are plotted versus the Reynolds number Re. Table 2 shows the frequency distribution of the observed E_n values. This table confirms that 95% of the results matches E_n≤1.

Table 2: Frequency distribution of observed E_n values.

Histogram bin	Number	Percentage
$0 \leq E_n \leq 0.5$	70	67%
$0.5 < E_n \leq 1$	29	28%
$1 < E_n \leq 1.2$	0	0%
$E_n > 1.2$	5	5%
Total	**104**	**100%**

Discussion and conclusions

This intercomparison demonstrates that the first intercomparison between primary high-pressure gas flow standards is a success. The differences between the laboratories are smaller than when working standards are used. With less than 5% of the E_n values higher than 1, the laboratories agree with 95% confidence. This result supports the CMC claims of the participating laboratories.

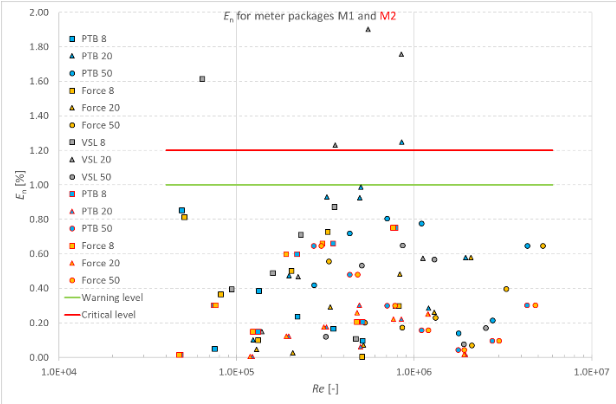

Figure 2: E_n [-] values versus Re number [-]. The green horizontal line is the warning level corresponding to E_n=1. The horizontal red line is the critical level corresponding to E_n=1.2.

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