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# Combining three independent traceability chains for high-pressure gas flow in Germany

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**Abstract**

Currently all measurement capabilities for high-pressure gas flows in Germany are based on a single traceability chain. However, there are three primary standards available that can be made traceable without mutual dependencies. In this study PTB investigates the benefits of combining three independent traceability chains. The applied method is identical to the harmonization of the high-pressure cubic metre of natural gas [1]. For two G1000 transfer reference meters the measurement uncertainty decreases from 0.110% to 0.089%. For the working standards the CMCs decrease from 0.156% and 0.175% to 0.142% and 0.163% respectively. When only two chains are used the CMCs of the working standards improve with approximately 0.01%. More scenarios are explored. The development of a new primary standard with a CMC of 0.10% has the potential to improve the CMCs of the working standards with approximately 0.02%.

## 1. Introduction

The concept of the harmonized cubic metre of high-pressure natural gas has been in use for 20 years. This harmonized reference value is obtained by combining several independent traceability chains from different countries. Last year the underlying key comparison procedure and the data processing methods were updated and published [1].

The reduction obtained in the measurement uncertainty was the motivation for PTB to study whether this method can also be applied to currently available references that can be made independently traceable. These references are located at the pigsar calibration facility in Dorsten and have the following independent traceability sources:

- a High-Pressure Piston Prover (HPPP), which is directly traceable to length;
- Critical Flow Venturi Nozzles (CFVN), traceable to PTB's airflow facilities in Braunschweig;
- a Laser-Doppler Anemometer (LDA), traceable to a rotating disk that provides a reference velocity.

## 2. Operating ranges

Figure 1 gives a schematic overview of the current pigsar calibration facility. After entering the station inlet, the natural gas is first cleaned in a cartridge filter and then preheated. During the calibration, the preheater also controls the temperature. Between the heater and the pressure regulator two safety shut-off valves protect the test facility against excess pressure. Downstream of the pressure regulator the gas flow is divided into a gas stream which is used for calibration and an internal bypass stream. The flowrate is controlled further downstream in both gas flows, shortly before they join up again ahead of the station outlet. The piping configuration was optimized such that gas volume between the working standards and the test meters is reduced to the minimum, which minimizes the line-pack effect. The gas meters to be calibrated, including upstream and downstream straight lengths provided by the customer, can be installed on a total of six test meter runs with a length of up to 22 m.

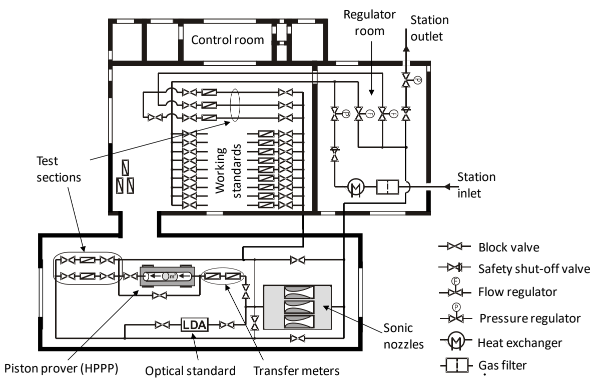


**Figure 1:** Schematic view of the current pigsar facility.

The PTB test installations (piston prover HPPP, optical standard, transfer meters, sonic nozzles), shown in the bottom part of Figure 1 are permanently integrated into the pigsar piping system in a separate metering room. The High-Pressure Piston Prover (HPPP) is described in [2], the sonic nozzles (CFVN) in [3] and the optical LDA standard in [4]. Their measurement capabilities are listed in Table 1.

**Table 1**: Operating ranges of primary standards.

| | HPPP | CFVN | LDA |
|---|---|---|---|
| Pressure [bar] | 8 – 50 | 8 – 50 | 8 – 50 |
| Flowrate [m³/h] | 3 – 480 | 3 – 1600 | 3 – 1600 |
| CMC | 0.065% | 0.15% | 0.21% |

The CMC is the Calibration and Measurement Capability, i.e. the best expanded uncertainty ($k$=2) that can be routinely achieved for a well repeatable meter under test. The CMC of the piston prover [5] is smaller than the CMCs of the other devices. However, its operating range is smaller.

## 3. Combining traceability chains

The three independent traceability chains are graphically depicted in Figure 2. The two G1000 Transfer Reference Meters are calibrated in series up to 1600 m³/h. The piston prover can only be used up to 480 m³/h. For that reason, first two G250 secondary references are calibrated, which are used to calibrate four G250 working standards up to 400 m³/h each. With the four working standards the G1000 meters can be calibrated. This so-called bootstrapping process is performed at 16 bar and 50 bar. Later in the paper the left, middle and right traceability chains in Figure 2 will be denoted as traceability chain 1, 2 and 3, respectively.

The uncertainty $U_{TRM}$ of the G1000 transfer meter is calculated according to [1] using the uncertainties $U_i$ ($i = 1..3$) of the individual traceability chains

$$\frac{1}{U_{TRM}^2} = \frac{1}{U_1^2} + \frac{1}{U_2^2} + \frac{1}{U_3^2} \qquad (1)$$

which results in $U_{TRM}$= 0.082%. As the three traceability chains will produce slightly different values for the deviation an additional uncertainty of 0.05% ($k$=2) for the reproducibility is taken for each meter. As the two meters are calibrated in series the additional uncertainty of the average is $\sqrt{(0.05^2+0.05^2)/2}$, which results in an overall uncertainty of the transfer standards of 0.089% shown at the bottom of Figure 2.

The uncertainty of the transfer standard based on a single traceability chain is 0.110% [6]. So, at this level an absolute uncertainty improvement of 0.021% is achieved.

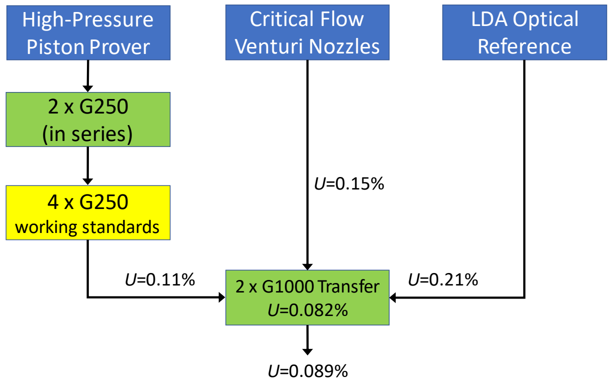


**Figure 2:** Effect on the final uncertainty for the unit of volume flowrate provided by the transfer package based on calibrations with three independent sources of traceability. The combined uncertainty is determined according to [1]. Finally, for the uncertainty of the transfer package, a reproducibility of 0.05 % is considered for each of the two G1000 transfer meters calibrated in series.

## 4. Traceability benefits

How will the rest of the traceability chain benefit from the improved uncertainty of the G1000 TRMs? The traceability chain is schematically depicted in Figure 4. The two G1000 TRMs are used to calibrate four parallel working standards (yellow). These are used to calibrate a new TRM up to 6500 m³/h, which will be used to calibrate the working standards (orange) of pigsar's new closed-loop calibration facility CLP. With these working standards another TRM or MuT can be calibrated.

The calculation of the uncertainties in the entire traceability chain is performed using the method in a previous study [6]. In order to simplify the calculations, the uncertainty contributions have been subdivided in three categories: traceability, process conditions and repeatability. During all traceability steps the same type of instruments are used, of which the uncertainties are practically equal. This means that a single uncertainty value can be assigned to all process-based uncertainty contributions together. As some of the process parameters are mutually dependent, the model was programmed into a Monte Carlo Simulator [7]. The result is that the expanded ($k$=2) uncertainty of all process variables together equals 0.056%. The uncertainty of the MuT due to repeatability of successive measurements is evaluated to be 0.01%.

The evaluation of the uncertainties of the entire traceability chain is depicted in Figure 3. The process starts with the uncertainty of the two G1000

TRMs, shown in the column total. The repeatability and process uncertainties are shown in the columns Type A and Type B, respectively. Subsequently, the uncertainties of all traceability steps are added by root-sum-square summation. In this picture the transfer meters and MuT are at the same level because they are calibrated by the same references. However, in order to achieve the CMC an experience-based additional uncertainty for the long-term stability of 0.075% needs to be added. The CMCs are shown in the rightmost column of Figure 3. The values based on three parallel traceability chains are shown in bold. In italic the CMC values are shown that are based on a single traceability chain. The absolute CMC improvement at the third level in Figure 3 is 0.015% and at the last step 0.012%.

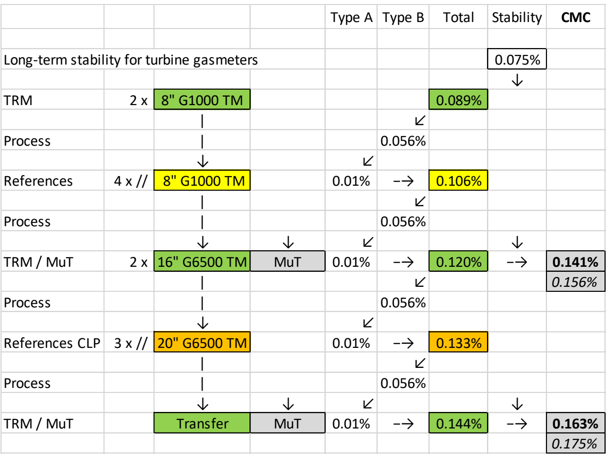


**Figure 3:** Evaluation of the CMCs ($k$ = 2) of pigsar's current (yellow) and new CLP (orange) working standards, based on three independent traceability chains from Figure 2. All uncertainties are added by root-sum-square summation. The boxed value of 0.075% is the additional uncertainty for the long-term stability of the turbine gasmeters and is used to evaluate the CMC at the transfer meter level. The CMC values based on the current single traceability chain are displayed in italic.

## 5. Discussion

After the previous exercise the question rises how many independent traceability chains you want to use in practice and what is the optimum CMC for a standard.

In Table 2 the achievable CMCs of the two G1000 TRMs and the CMCs of the working standards are shown for different combinations of traceability chains. The results for the single traceability chain 1 (row 1, below the header) and the combination of three chains 1, 2 and 3 (row 3) are the same as shown in Figure 3. The LDA optical standard has a much higher CMC than the other two. Omitting this chain results in an uncertainty that is 0.006% higher for the TRMs and 0.004% and 0.003% higher CMCs for the working standards. As uncertainties of a laboratory's measurement capability are generally represented by two decimals, this change is hardly visible.

**Table 2**: Comparison of achievable uncertainties of the two G1000 TRMs and CMCs of working standards in Figure 3 for combinations of different independent traceability chains shown in the leftmost column. Chain 1 – 3 are the HPPP, CFVN and LDA shown in Figure 2, respectively. Chain 4 is introduced as a new standard under development with a CMC of 0.10% [6].

| Traceability combination | U(2x G1000) ≤ 1600 m³/h | CMC WS2 ≤ 6500 m³/h | CMC WS3 ≤ 21000 m³/h |
|---|---|---|---|
| 1 – – – | 0.110% | 0.156% | 0.175% |
| 1 2 – – | 0.095% | 0.146% | 0.166% |
| 1 2 3 – | 0.089% | 0.142% | 0.163% |
| 1 – – 4 | 0.082% | 0.137% | 0.159% |
| 1 2 – 4 | 0.075% | 0.133% | 0.156% |
| 1 2 3 4 | 0.072% | 0.132% | 0.154% |

Theoretically, several traceability chains with equal measurement uncertainties will result in the lowest combined measurement uncertainty. For this reason, we introduced a fourth traceability chain with a CMC of 0.10% in Table 2. Combination of the first and the fourth traceability chain (Table 2, row 4 below header) results in a lower uncertainty than the three parallel traceability chains 1, 2 and 3.
In row 5 of Table 2 the CFVNs are added. Combination of chains 1, 2 and 4 results in uncertainties that are approximately 0.02% better than the single traceability chain. Four parallel chains result in uncertainties that are approximately 0.002% better than the previous combination. The improvement is only one tenth of the previous improvement, which makes the additional efforts costly.

In this study several traceability chains have been combined at a flowrate level of 1600 m³/h maximum. If the two G6500 TRMs could be calibrated at a level of 6500 m³/h with an additional traceability chain with an uncertainty equal to the present traceability chain, and using the same method that leads to Figure 3, a CMC of 0.151% can be achieved for the working standards up to 21000 m³/h. This value is better than any of the CMCs listed in the righthand column of Table 2. So it makes sense to combine traceability chains at the flowrate level where meters are calibrated for application in the field. However, the difference with the combination of chains 1, 2 and 4 is 0.005%, a value that does not justify the additional work to build a second independent traceability chain up to flowrates of 6500 m³/h. In addition, these flowrates are also covered by international cooperation on the harmonized cubic metre [1].

In the EuReGa framework of international cooperation an intercomparison between primary standards has been performed [8],[9] with flowrates up to 400 m³/h. Combination of two primary standards results in an uncertainty reduction of less than 0.005% for the two G250 in the first traceability chain. Due to additional uncertainty sources, this benefit will disappear further down the traceability chain.

## 6. Conclusion

From this study the following conclusions can be derived.

- Combining PTB's present three parallel independent traceability chains results in better CMCs for transfer reference meters (TRMs) and working standards. Compared to the present single traceability chain. The improvement is 0.021% for the two G1000 travelling reference meters and 0.014% and 0.012% for the working standards.
- The LDA optical standard is the traceability chain with the highest CMC. If this standard is omitted, the two remaining chains obtain CMCs of the working standards that are 0.009% and 0.010% better than the CMC values obtained with a single traceability chain. Using two traceability chains is a consideration as CMCs are generally published in two digits.
- Combining a new primary standard with an uncertainty of 0.10% with the present traceability chain will lead to an uncertainty reduction of almost 0.03% for the TRMs and almost 0.02% for the working standards.

## Abbreviations and symbols

| | |
|---|---|
| CFVN | Critical Flow Venturi Nozzle |
| CLP | Closed Loop pigsar, pigsar's new calibration facility, which is currently under construction |
| CMC | Calibration and Measurement Capability, i.e. the best expanded uncertainty ($k$=2) that can be routinely achieved for a well repeatable meter under test |
| HPPP | High-Pressure Piston Prover |
| LDA | Laser Doppler Anemometry |
| MuT | Meter under Test |
| TRM | Transfer Reference Meter |

Latin symbols

| | | |
|---|---|---|
| $k$ | coverage factor | [-] |
| $U$ | expanded uncertainty | [-] |

Index

| | |
|---|---|
| $TRM$ | Transfer Reference Meter |
| $1, 2, 3$ | first, second and third traceability chain |

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