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The new Closed Loop pigsar high-pressure gas flow calibration facility and its projected CMC

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1. INTRODUCTION

In Dorsten on the northern edge of the German Ruhrgebiet a new high-pressure calibration facility is under construction: the Closed Loop Pigsar, short CLP. As the name already tells, it is a closed loop pipe system in which a blower circulates the gas. In this way a meter under test can be calibrated using reference turbine gasmeters under stationary flow conditions. The operating pressure is flexible between 8 bar and 65 bar.
The new CLP facility will be an extension of the existing 25 year old pigsar facility. To distinguish between the two facilities, the latter will be called the bypass pigsar facility, as it bypasses the regulator stations of the high-pressure gas network. The new CLP has become necessary due to changing customer demands. On the one hand customers require calibration facilities to be more flexible with respect to delivery times. On the other hand market demands require an expansion of operating ranges with respect to both lower and higher pressures and higher flowrates. Being dependent on the gas import from The Netherlands, the recent remark of the Dutch minister of economic affairs that the gas production from the Groningen gas field will be decreased and eventually stopped, made the investment decision easier.
Building a new facility is one thing, making it traceable to the German national high-pressure cubic metre another. Objective of the present study is to demonstrate that the target uncertainties of the CLP facility are achievable by expanding the present traceability chain. In addition a new gas flow reference and a new traceability chain are under development.

2. PIGSAR'S CALIBRATION FACILITIES

The bypass pigsar facility has an excellent track record of reliability and accuracy in the past decades. It is currently the most accurate high-pressure gas flow facility in the world. Thanks to direct access to the national standards of PTB and the special design of the test facility a very low measurement uncertainty of 0.13% to 0.16% (depending on flow) can be provided.
Figure 1 shows a schematic overview of the bypass pigsar 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 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. The specifications of the calibration facility are listed in the right-hand column of Table I. A more extensive description of the facility can be found in [1]. 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 measurement hall, which was added in 2003 [2].

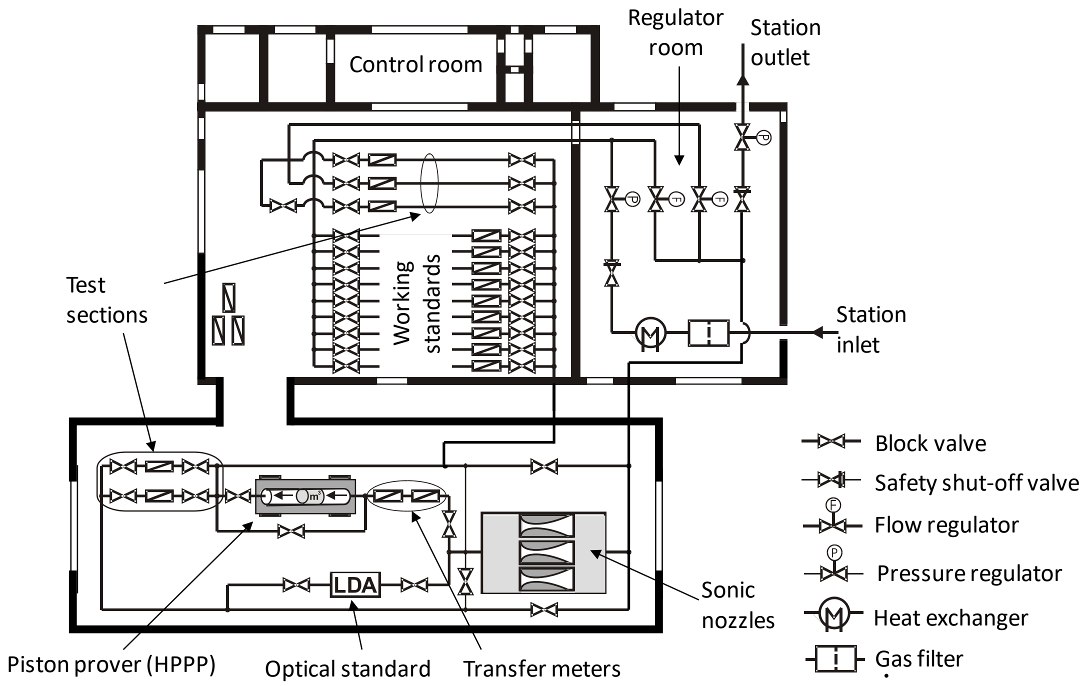

Figure 1: Schematic view of the current bypass pigsar facility.

Table I - Design specifications of the new Closed Loop pigsar versus the existing bypass facility (specifications subject to change)

	Closed Loop pigsar	**bypass pigsar**
Actual volume flowrate	40 – 22 000 m³/h	3 – 6 500 m³/h
Absolute pressure	8 – 65 bar	17 – 50 bar *
Meter diameter	DN 200 – 600 mm (8" – 24")	DN 50 – 400 mm (2" – 16")
Flanges and pressure classes	ANSI 150–1500, PN 16–64 **	ANSI 150–1500, PN 16–64 **
Length of test section	Approximately 37 meter	8 – 22 meter
Fluid	natural gas	natural gas
CMC uncertainty (k=2)	0.13% – 0.18%	0.13% – 0.16%
Reference turbine meters	3 x 6" G400 + 3 x 20" G6500	4 x 4" G250 + 4 x 8" G1000 + 1 x 3" G160

* 8 – 17 bar available on request ** Other flanges and pressure classes upon requestequest

Rather than integrating the new Closed Loop pigsar in the existing bypass facility, the CLP will be housed in a separate building next to the bypass facility. The rationale behind this decision was that the existing pigsar bypass facility was not designed to minimize the pressure loss over the facility, which is crucial for a closed loop system. Secondly, the construction of the new CLP does not interfere with the day-to-day operation of the bypass facility. And last, the operation of both systems can be performed independent of each other, which makes pigsar more flexible.
The Closed Loop pigsar (CLP) will be connected to the high-pressure gas transport system in or close to the so-called regulator room (see Figure 1) of pigsar to fill or empty the CLP. For the filling and emptying processes new compressors will be installed to pressurize the CLP up to 65 bar and to depressurize the CLP down to 8 bar, the lowest operation pressure, or to ambient pressure for repair works or installation of customer meters in the test sections.
The CLP is graphically displayed in Figure 2. On the left-hand side at the top the blowers and heat exchangers are shown. The heat exchangers are necessary to remove the heat coming from the blowers. Water will be used as cooling fluid. The gas flows through the reference meters first and then through the test section before returning to the blowers. At the top of Figure 2 a test line for primary and secondary references is shown, which has already been nicknamed PTB test line. Table I gives an overview of the target specifications of the new CLP, which are much wider than the specifications of the current facility.

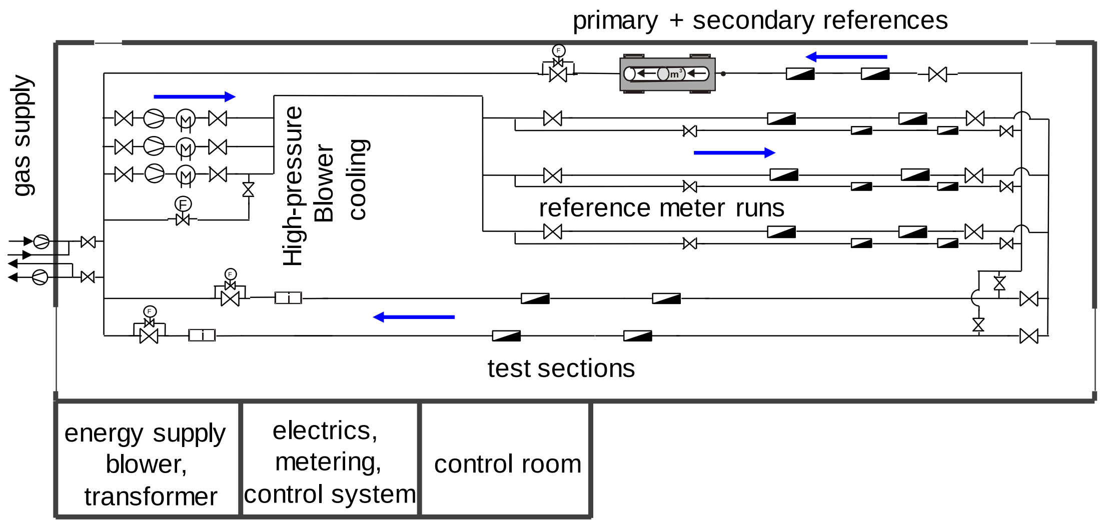

Figure 2: Schematic lay-out of the Closed Loop pigsar Calibration Facility. The different functionalities and utilities are marked in the drawing.

The blower must generate sufficient flow and pressure head to calibrate two 20" ultrasonic flowmeters in series, each equipped with a flow conditioner, at their maximum flowrate Q_{max}, which is around 22 000 m³/h for the meter types currently available, at a gas pressure of up to 65 bar. According to the characteristics of the high-pressure blowers and the pressure loss in the loop it will be possible to calibrate also 24'' meters or bigger at lower gas pressures and lower pressure losses. For that reason the reference meters are dimensioned to 30 000 m³/h or a bit higher.
The aim is to reach a minimum flowrate of 40 m³/h, which will allow the calibration of a G2500 meter in the range of 1:100 or a G1600 meter in the range of 1:50.

As reference meters turbine gasmeters are used, 3 times 20'' G6500 and 3 times 6'' (size not clear yet G1000 / G650 or G400). In a later stage ultrasonic meters will be installed upstream for diagnostic and check purposes.
Two test sections are foreseen, one for the calibration of meters under test (MuT) up to 16'' and one test section for the calibration of meter sizes of 20'' or greater, both with a designed length of 37 m.
A third meter run is foreseen for the installation of transfer meters or secondary reference meters or potentially new primary meters. This run will be used for the traceability, i.e. for the calibration and regular checks of the reference meters.

The main challenges during the design and construction phase will be to minimize measurement uncertainty, to optimize the gas and energy management, safety issues, minimize pressure losses and to optimize the construction with regard to future operation.

3. TRACEABILITY CHAIN

Pigsar's bypass facility plays a crucial role in national and international traceability as the facility houses PTB's national standards for high-pressure gas measurement. The facility participates in the EuReGa, which means that pigsar's calibration results are traceable to the European harmonized cubic metre.
The new CLP facility will be calibrated by expanding the present traceability chain. This process is graphically shown in Figure 3. The primary device is a 10" six meter long piston prover (blue rectangle). Its dimensions are calibrated every 5 years, which makes it traceable to the SI unit metre (red rectangle). Transfer standards (green boxes) are used to calibrate the working standards (yellow and orange boxes). The working standards are used in parallel to calibrate the bigger transfers and to calibrate the meters under test (gray boxes). The values in the gray boxes are the target Calibration and Measurement Capabilities (CMCs), i.e. the achievable expanded uncertainty of a good gasmeter. All working standards are calibrated at 17 bar and 51 bar absolute pressure. At intermediate pressures the curves are obtained by interpolation in the Reynolds domain.

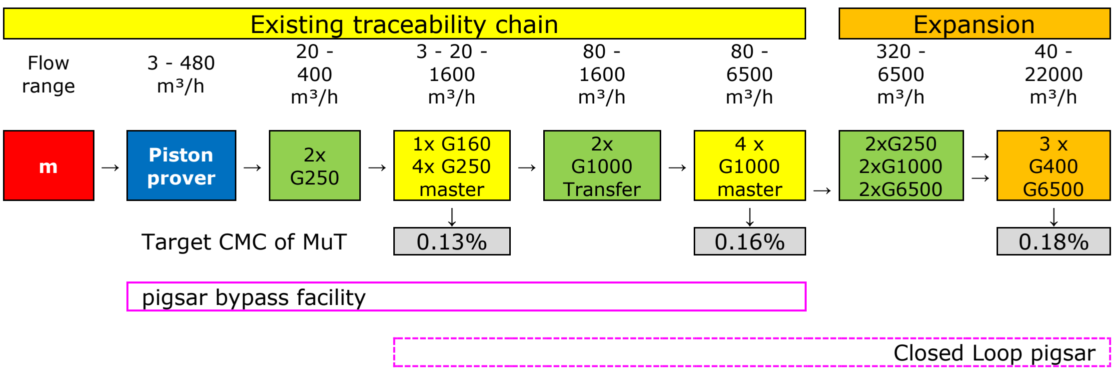

Figure 3: Schematic representation of the current German traceability chain for high-pressure gas flow measurement and its future expansion. The master meters (yellow and orange) are traceable via transfer standards (green) to the piston prover (blue) and the meter (red). The meter under test (gray) is calibrated by using a combination of master meters. The gray surfaces show the target CMCs. The pink edged rectangles show the part of the traceability chain used by the pigsar bypass facility and the new Closed Loop pigsar.

The new CLP not only requires traceability at higher flowrates but also at lower and higher pressures. At this moment it is possible to calibrate the first two G250 transfer standards down to 8 bar. These will be used to calibrate the CLP masters in their low flowrates. Higher flowrates at 8 bar are obtained by Reynolds interpolation using the 17 bar curves. In addition a new transfer package is in preparation that will allow bootstrapping at 8 bar. The calibration curve at 65 bar is achieved by interpolating the calibration curves obtained at 51 bar, in the Reynolds domain. This process limits the maximum flowrate of the individual master meters at 65 bar to 7400 m³/h.

Unit			m		Type A	Type B	Total	CMC
Long-term stability for turbine gasmet						0.075%		
			↓					
Primary reference			Old PP				0.050%	0.065%
Process						0.056%		
			↓				↓	
Secondary reference		4" G250 TM	4" G250 TM		0.01%	→	0.076%	
Process						0.056%		
	↓	↓	↓	↓			↓	
Reference	4" G250 TM	4" G250 TM	4" G250 TM	4" G250 TM	0.01%	→	0.095%	
Process						0.056%		
			↓	↓			↓	↓
Transfer Meter		2 x	8" G1000 TM	MuT	0.01%	→	0.110%	0.134%
Process						0.056%		
	↓	↓	↓	↓			↓	
Reference	8"G1000 TM	8"G1000 TM	8"G1000 TM	8"G1000 TM	0.01%	→	0.124%	
Process						0.056%		
			↓	↓			↓	↓
Transfer Meter		2 x	16" G6500 TM	MuT	0.01%	→	0.137%	0.156%
Process						0.056%		
		↓	↓	↓			↓	
References		20" G6500 TM	20" G6500 TM	20" G6500 TM	0.01%	→	0.148%	
Process						0.056%		
			↓	↓			↓	↓
Transfer Meter			Transfer	MuT	0.01%	→	0.159%	0.175%

Figure 4: Evaluation of the CMCs (k = 2) of pigsar's calibration facilities based on the current traceability chain and its expansion for the Closed Loop pigsar. All uncertainties are added by root-sum-square summation. The boxed value of 0.075% is the additional uncertainty for the longterm stability of the turbine gasmeters and is used to evaluate the CMC at the transfer meter level.

4. Projected CMCs

During the design stage of the new CLP, it is important to demonstrate that the target measurement uncertainties are feasible when using the traceability chain of Figure 3. The calibrations of this traceability chain are performed according the so-called master meter method, in which a meter under test (MuT) is compared with one or more references (masters). The physical model is based on the mass conseration principle with a small correction for line-pack effects. A full model description can be found in [3] and [10]. The conversion between volume flow and mass flow is obtained by using a real gas law for which pressure, temperature and the gas composition are inputs. The real gas factor is computed using the S-GERG algorithm [4] for the existing facility. For the new CLP, a more complex algorithm like AGA-8 [5] or GERG2008 [6] will be used.
For the calculation of the achievable uncertainties, the 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. So we will use a single uncertainty value for all process based uncertainty contributions together. In order to evaluate the contributions from the different categories in the deviation of the MuT e_{MuT}, the model was programmed into a Monte Carlo Simulator [10]. The result is that the expanded ($k = 2$) uncertainty contribution to e_{MuT} of all process variables equals $U_{process} = 0.056\%$. The uncertainty of the MuT due to repeatability of successive measurements is evaluated at 0.01%.
The evaluation of the uncertainties of the entire traceability chain is depicted in Figure 4. The process starts with the calibration of the piston prover using dimensional references which results in a starting uncertainty of 0.050%. Subsequently, the uncertainties of all traceability steps are added. 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 re-calibration of the traceability chain is done in a matter of weeks, the CMC is calculated for a period of 3 years. The results of the computations confirm the present CMCs of pigsar and show that the target CMCs of the new CLP are feasible.

5. Future outlook

In this section we will discuss some developments that will allow further improvement of the traceability of high-pressure gas flows by reducing measurement unertainties. These are:

- A new primary standard,
- A new transfer standard,
- The combination of different independent traceability chains.

5.1. A new primary standard

A new development is the design of a new primary standard for high-pressure gas flow measurement, called the PTB HP Comparator. The project has started last year with the construction of a scale model and will take three years to complete. In contrast to the current HP piston prover, the new prover will be an active driven system which is working based on the comparator principle [12]. The target specifications of the new HP Comparator are listed in Table II together with the specifications of the current HP piston prover. The new comparator will be bigger and will be able to operate at higher flowrates than the current piston prover.

Table II: Target specifications of the new HP Comparator versus the current HP Piston Prover

	New PTB HP Comparator	Current HP Piston Prover
Actual volume flowrate	40 - 1600 m³/h	3 – 480 m³/h
Absolute pressure	8 – 65 bar	17 – 50 bar *
Tube diameter	DN 600 mm	DN 250 mm
Piston stroke / effective stroke	6 m / 4 m	6 m / 3 m
Maximum piston velocity	1.8 m/s	3 m/s
Fluid	natural gas / air	natural gas
CMC uncertainty (k=2)	0.10% **	0.065%

* 8 – 17 bar available on request ** Initial value, to be improved

5.2. Development of a new transfer package

In order to make the transfer between the old facility and the new facility more easy a transfer package will be designed consisting of one 4” turbine gasmeter and two 8” turbine meters which can be operated either alone or parallel, see Figure 5(a). The package is to be inserted in the PTB test line of the CLP and will be used to calibrate the small master meters and the lower range of the bigger masters. Now only one bootstrap step will be necessary to calibrate the masters in the upper range up to 10000 m³/h, for which a new G6500 transfer package will be built up, see Figure 5(b).

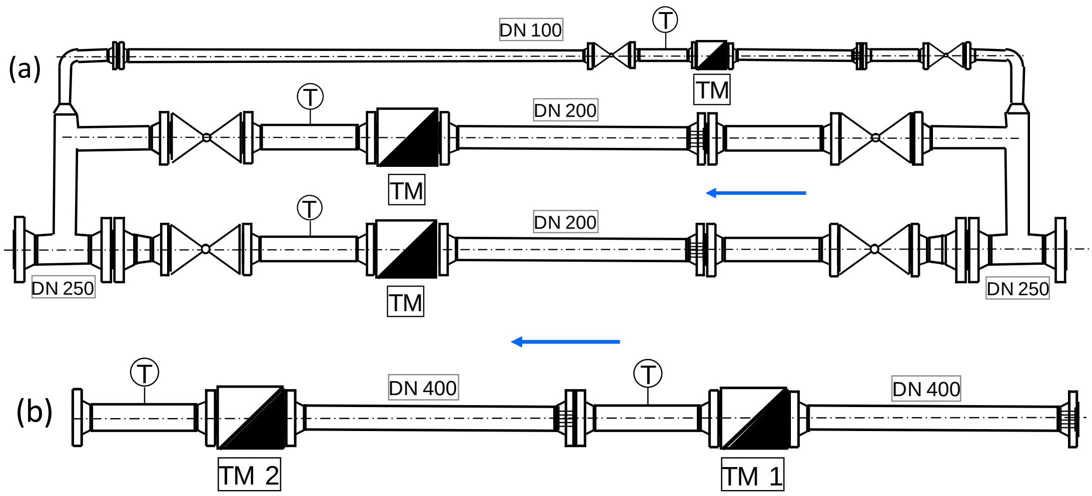

Figure 5: Schematic of the CLP transfer packages. The upper drawing (a) shows the package intended for low and medium operating range of master meters (40 m³/h to 3 800 m³/h). The bottom drawing (b) shows the package for the upper operating range of the master (1 000 m³/h to 12 000 m³/h).

5.3. The combination of different independent traceability chains

All the activities mentioned above will open the possibility to build pigsar’s traceability on three independent traceability chains with a lower uncertainty. The method will be identical to the method used for the harmonized m³ in the EuReGa framework [11]. The "knot point" to combine all the three sources of traceability will be the new transfer package. Figure 6 illustrates the basic traceability scheme down to the unit provided by the transfer package. According to the uncertainties for the calibration value of the transfer package by the three different chains, the combined (harmonised) uncertainty will be 0.0664 %. For the application of the transfer package we consider additionally a value for reproducibility of 0.05% for each of the parallel meter (see Figure 5a). As the reproducibility of two meters used in parallel can be considered as uncorrelated, we get a final uncertainty of 0.075% for the transfer of the unit, which is lower than the achievable uncertainties of the separate traceability chains.

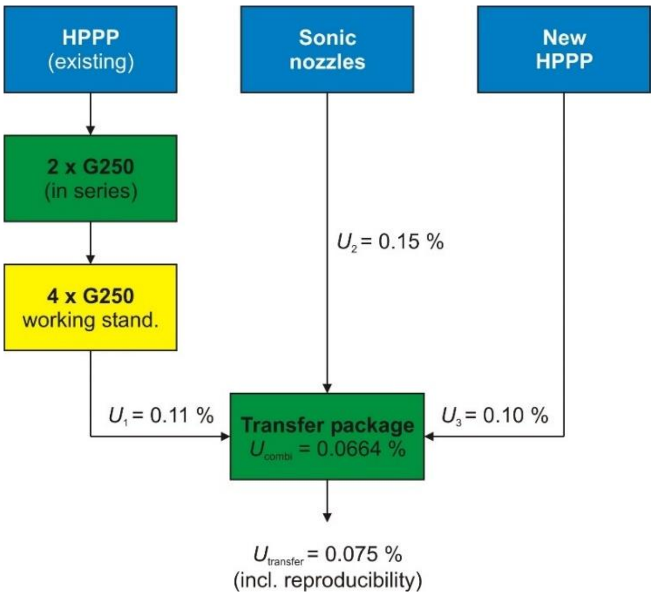

Figure 6: Effect on the final uncertainty for the unit of volume/flow rate provided by the transfer package based on calibrations with three independent sources of traceability. The combined uncertainty is determined according to [11]. Finally, for the uncertainty of the transfer package, a reproducibility of 0.05 % is considered for each of the two parallel G1000 transfer meters (see figure 5).

6. Summary

This year the construction has started of the new Closed Loop pigsar (CLP) facility. The new facility can be operated parallel to the pigsar bypass facility, which has a reliable track record of almost 25 years. The expanded measurement capabilities of the new CLP require the present traceability chain to be extended. The current study confirms the feasibility of the projected CMCs of the new Closed Loop pigsar. In addition, the work on a shorter traceability chain has started. A new primary standard is being developed which can be directly connected to the CLP. A new transfer standard will allow quicker calibrations of the CLP references. The use of multiple independent traceability chains will improve measurement uncertainties of high-pressure flow measurements, similar to the harmonized cubic metre.
The new CLP will enable PTB / pigsar to participate on the intercomparisons at 8 bar pressure and up to a flowrate of 6500 m³/h at all pressures. This will give a broader fundament to the harmonized cubic metre.

7. NOTATION

Abbreviations

CLP	Closed Loop Pigsar
MuT	Meter under Test

Latin symbols

e	deviation or error	[-]
k	coverage factor	[-]
Q	volume flowrate	[m³/h]
U	expanded uncertainty	
u	standard uncertainty	

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max	maximum condition
MuT	meter under test
$process$	process conditions

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