

The Technical Protocol for EURAMET Project No. 1469

Inter-laboratory Calibration Comparison of the Turbine Gas Meter G6500

1. Introduction

The aim of the comparison is to compare the performance of calibrations of the gas meter in different gas flow laboratories in Europe. An axial turbine gas meter G6500 will be used to compare low pressure test facilities over the flow range (1000 ÷ 10000) m³/h. If laboratories are not able to cover all the flow rates they may calibrate the meter over a part of the flow range.

2. Participants and time schedule

Each country will take 3 weeks to perform the calibration of the meter and to transfer the meter to a next laboratory. The participants and the time schedule are mentioned in *table 1*. In the *table 1* there the “*address of the place of calibration*” is the address where the meter should be sent.

Table 1 - Participants and the time schedule

Country	Laboratory	Address of the place of calibration	e-mail telephone	Date of calibration	Responsible person
Czech Republic (PILOT LAB)	Czech Metrology Institute (CMI)	Czech Metrology Institute Gas Flow Department Prumyslova 455 530 03 Pardubice Czech Republic	tvalenta@cmi.cz +420 466 670 728	20.8.-10.9. 2019	Tomas Valenta
Denmark	FORCE Technology	FORCE Technology, Vejen, Navervej 1 6600 Vejen Denmark	jrb@force.dk +45 43 25 06 20	10.9.-1.10. 2019	Jesper Busk
France	Laboratoire Associé de Débitmétrie Gazeuse (LNE-LADG)	LNE-LADG 43 route de l'Aérodrome 86000 POTIERS FRANCE	c.windenberger@cesame-exadebit.fr +33 5 49 37 91 26	1.10.-22.10. 2019	Christophe Windenberger
Czech Republic (PILOT LAB)	Czech Metrology Institute (CMI)	Czech Metrology Institute Gas Flow Department Prumyslova 455 530 03 Pardubice Czech Republic	tvalenta@cmi.cz +420 466 670 728	22.10.-12.11. 2019	Tomas Valenta

3. Device

The axial turbine gas meter will be the instrument which will be tested. The description and the picture of the meter are mentioned down in *table 2* and in the *figure 1*.

Table 2 - Technical specification of the meter

Manufacturer: ELSTER AG Mainz Germany	
EEC type approval: E D77/721105	P_{\max} : 10 bar
Size: G6500	Inside diameter: DN 400
Serial number: 83001411	Pulse number: 371,20 imp/m ³
Q_{\min} : 1000 m ³ /h	Q_{\max} : 10000 m ³ /h
Weight: approximately 400 kg	
Maximum pressure loss in Q_{\max} with air ($\rho=1.2 \text{ kg/m}^3$) : 1200 Pa	

Figure 1 – Axial turbine gas meter ELSTER



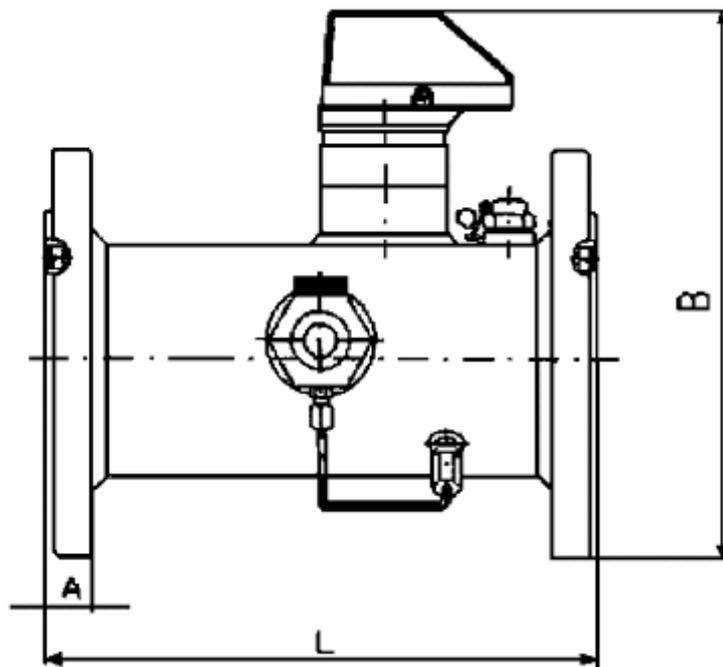


The dimensions of the meter are mentioned in *table 2* and in the *figure 2*.

Table 2 - Dimensions of the meter

L	A	B
1200 mm	45 mm	650 mm

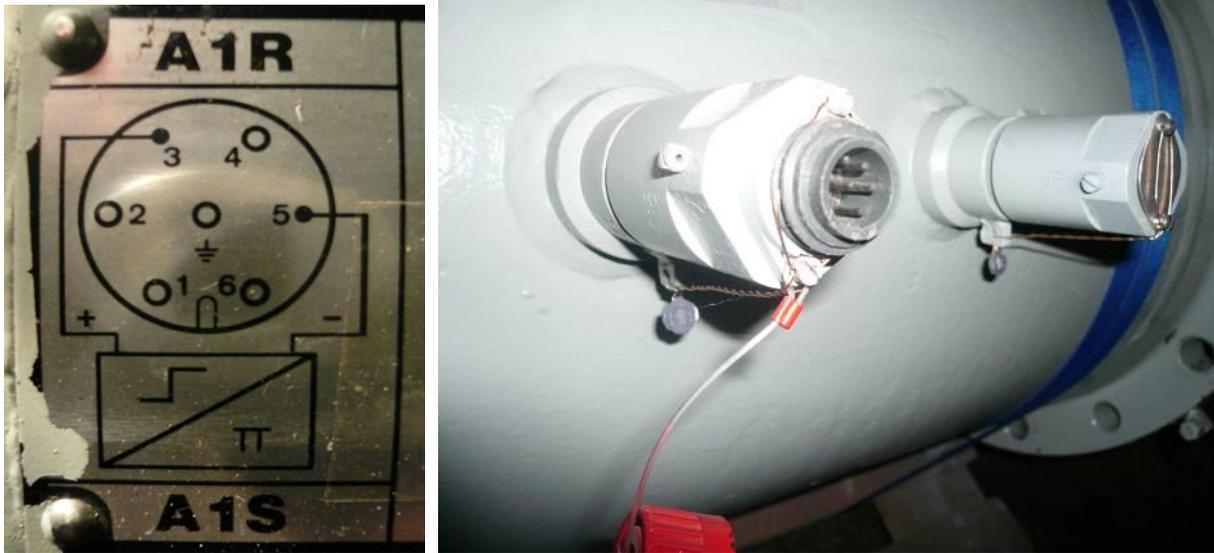
Figure 2 - Dimensions of the meter



The high frequency pulse emitter A1S will be used. This emitter A1S is made according to DIN EN 50227 (NAMUR). The pulse emitter is mentioned in the *figure 3*.

Operating data of the A1S pulse emitter:
Supply voltage $U_n = 8 \text{ V DC}$

Figure 3 – Pulse emitter A1S



The meter will be packed in wooden box that is mentioned in the *figure 4*. The diameter of the box is (1530 x 970 x 840) mm. The weight of the complete box with the meter is approximately 500 kg. In the wooden box there the gas meter will be fastened with two textile slings with ratchets (*figure 5*).

Figure 4 – The wooden box for the turbine gas meter G6500



Figure 5 – Textile slings with ratchets



In the box there will be the meter, chocks, textile slings with ratchets, a pulse emitter connector and the copy of this protocol.

4. Advice on handling and on travelling

It is necessary to handle with care with the meter during travelling and also during packing and unpacking. The meter is not resistant against any beats and downfalls. During packing and unpacking each laboratory will have to use its own ropes with hooks and its own

crane (figure 1). The gas meter has to be fastened again with the textile slings with ratchets during subsequent packing.

During test the air may flow through the turbine meter only in the direction marked by the arrow on the meter. It is advisable to protect the turbine meters against pressure shocks, big gas flow changes and against overload.

5. Actions to be taken on receipt and after sending of the meter

Each participant laboratory has to give information to the coordinator after sending of the meter to the next laboratory. Each participant laboratory has to give information to the coordinator after receipt of the meter. The best way is to send e-mail to the coordinator's address tvalenta@cmi.cz.

6. Test procedure

The participating laboratories can use their usual calibration procedure. Only instructions mentioned down have to be fulfilled.

- The turbine gas meter has to be tested in horizontal position by air near barometric pressure.
- For the test it is necessary to use the upstream straightening pipe that is long at least 5xDN.
- For the test it is necessary to use the downstream straightening pipe that is long at least 3xDN.
- The reference pressure from the turbine gas meter has to be measured from the output "p_r".
- The reference temperature from the turbine gas meter should be measured in the distance (2÷3)x DN downstream of the turbine gas meter.
- For the test it is necessary to use the pulse emitter A1S.
- The test should be performed in the laboratory where the temperature is from 19.5°C to 23.5°C. The upstream pressure of the meter should be near atmospheric pressure.
- The oil pump of the turbine gas meter has not to be used.
- Before the beginning of the test the gas meter has to work 20 minutes in nominal flow rate $Q=4000 \text{ m}^3/\text{h}$.
- The turbine gas meter has to be tested in 8 flow rates: 10000 m^3/h , 8000 m^3/h , 6500 m^3/h , 5000 m^3/h , 4000 m^3/h , 3000 m^3/h , 2000 m^3/h , 1000 m^3/h .
- The test in one flow rate should be repeated at least 3 times and then the means of values in the *table 3* have to be calculated. The flow rate has to be in the interval $\pm 3\%$ of the required value.
- The one single test in one flow rate has to take more than 1 minute. Beforehand the flow rate has to be accurately stabilised.
- Each participant has to record the results in the form of *table 3* mentioned down.

Table 3

Flow rate in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter
(m ³ /h)	(Pa)	(°C)	(Pa)	(%)
10000				
8000				
6500				
5000				
4000				
3000				
2000				
1000				

Error of the meter is value which shows the relationship in percentage terms of the difference between the volume indicated by the meter and the volume which has actually flowed through the meter, to the later value.

$$E = \frac{V_i - V_c}{V_c} \cdot 100 \quad (\%) \quad [1]$$

where E is the error of the meter

V_i is the indicated volume by the meter (m³)

V_c is the real volume which has actually flowed through the meter (m³)

7. Instruction for reporting results

During 3 weeks after the test of the meter in the laboratory all the data mentioned down have to be sent to coordinator by e-mail.

- the table of means of the measured values and the uncertainty of the error of the meter

Flow rate in the meter	Absolute pressure in the meter	Temperature in the meter	Pressure loss of the meter	Error of the meter	Uncertainty of the error U(k=2)
(m ³ /h)	(Pa)	(°C)	(Pa)	(%)	(%)
10000					
8000					
6500					
5000					
4000					
3000					
2000					
1000					

- the description of the test facility which was used for the test of the turbine gas meter and the address where the facility is situated
- the traceability of the standard meters and other measuring instruments which were used during the test including the recalibration interval of the meters
- the description of the test procedure

The determination of the error of the meter is usually based on the comparison of the volume (or mass) of the air indicated by standard meter and of the volume which was indicated by the meter under test after calculations of corrections concerning different temperatures and pressures in the standard meter and in the meter under test.

The volume of the air depends on the pressure and temperature. Hence it is clear that the main sources of uncertainty of measurement are the uncertainties of the standard meter (for example standard gas meter, sonic nozzles), of the temperature meters and of pressure meters. The humidity, the time measurement and the barometric pressure can also be involved in the uncertainty budget. The uncertainty of the error of the meter $U(k=2)$ has to be calculated according to the *Guide to Expression of Uncertainty in Measurement* (published by ISO, Geneva, 1995).

8. Evaluation

8.1. Description of the method

The reference value will be determined in each flow rate separately. The method of determination of the reference value in each flow rate will correspond to the procedure A presented by M.G.Cox¹⁾. Only results from independent laboratories will be taken into account for the determination of the key comparison reference value (KCRV) and of the uncertainty of the key comparison reference value. Then the results from dependent laboratories will be compared with the key comparison reference value and with the uncertainty of the key comparison reference value.

8.1.1. The determination of the Key Comparison Reference Value (KCRV) and its uncertainty

The reference value y will be calculated as weighted mean error (WME):

$$y = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x2}^2} + \dots + \frac{x_n}{u_{xn}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \dots + \frac{1}{u_{xn}^2}}, \quad [2]$$

where x_1, x_2, \dots, x_n are errors of the meter in one flow rate in different independent laboratories $1, 2, \dots, n$
 $u_{x1}, u_{x2}, \dots, u_{xn}$ are standard uncertainties (not expanded) of the error in different independent laboratories $1, 2, \dots, n$ including the uncertainty caused by stability of the meter

The standard uncertainties (not expanded) of the error in different laboratories $u_{x1}, u_{x2}, \dots, u_{xn}$ (equation [2]) will include the stability of the meter. These uncertainties will be calculated by

$$u_{xi} = \sqrt{\left(\frac{U_{xi-lab}}{2}\right)^2 + \left(\frac{U_{tm}}{2}\right)^2} \quad [3]$$

¹⁾ Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, **39**, 589-595

where U_{xi_lab} is the expanded uncertainty (k=2) determined by laboratory i and presented in results of laboratory i
 U_{tm} is estimated expanded uncertainty caused by the stability (reproducibility) of the turbine gas meter (The meter will be tested three times in the pilot laboratory and from these results U_{tm} will be determined.)

The standard uncertainty of the reference value u_y is given by

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \dots + \frac{1}{u_{xn}^2} \quad [4]$$

The expanded uncertainty of the reference value $U(y)$ is

$$U(y) = 2 \cdot u_y \quad [5]$$

The chi-squared test for consistency check will be performed using values of errors of the meter in each flow rate. At first the chi-squared value χ_{obs}^2 will be calculated by

$$\chi_{obs}^2 = \frac{(x_1 - y)^2}{u_{x1}^2} + \frac{(x_2 - y)^2}{u_{x2}^2} + \dots + \frac{(x_n - y)^2}{u_{xn}^2} \quad [6]$$

The degrees of freedom ν will be assigned

$$\nu = n - 1 \quad [7]$$

where n is number of evaluated laboratories.

The consistency check will be failing if

$$Pr\{\chi_{\nu}^2 > \chi_{obs}^2\} < 0,05 \quad [8]$$

(The function $CHIINV(0,05; \nu)$ in MS Excel will be used. The consistency check will be failing if $CHIINV(0,05; \nu) < \chi_{obs}^2$)

If the consistency check does not fail then y will be accepted as the key comparison reference value x_{ref} and $U(y)$ will be accepted as the expanded uncertainty of the key comparison reference value $U(x_{ref})$.

If the consistency check fails then the laboratory with the highest value of $\frac{(x_i - y)^2}{u_{xi}^2}$ will be excluded for the next round of evaluation and the new reference value y (WME), the new standard uncertainty of the reference value u_y and the chi-squared value χ_{obs}^2 will be calculated again without the values of excluded laboratory. The consistency check will be calculated again, too. This procedure will be repeated till the consistency check will pass.

8.1.2. The determination of the differences “Lab to KCRV” and “Lab to Lab” as well as their uncertainties and Degrees of Equivalence

When the KCRV will be determined, the differences between the participating laboratories and the KCRV will be calculated according to

$$di = x_i - x_{ref} \quad [9]$$

$$dij = x_i - x_j \quad [10]$$

Based on these differences, the **Degree of Equivalence (DoE)** will be calculated according to:

$$Ei = \left| \frac{di}{U(di)} \right| \quad [11]$$

and
$$Eij = \left| \frac{dij}{U(dij)} \right|, \quad \text{respectively.} \quad [12]$$

The *DoE* is a measure for the equivalence of the results of any laboratory with the KCRV or with any other laboratory, respectively:

- The results of a laboratory will be **equivalent (passed) if Ei or $Eij \leq 1$.**
- The laboratory will be determined as **not equivalent (failed) if Ei or $Eij > 1.2$.**
- For values of *DoE* in the range $1 < Ei$ or $Eij \leq 1.2$ the **“warning level”** is defined. In this case some actions to check are recommended to the laboratory.

The reason for such “warning level” is that it is necessary to consider the confidence in the determination of the uncertainties (for the results of labs as well the KCRV). Conventionally we work at a 95% confidence level. Therefore in some comparisons a range up to $E < 1.5$ is used for these “warnings”²⁾. This is a reasonable value where stochastic influences dominate the uncertainty budgets. In the case of comparisons for gas flow, the smaller value 1.2 was chosen, which reflects the dominance of non-stochastic parts of uncertainty compared to the stochastic parts. (The reproducibility is usually much better than the total uncertainty of a laboratory).³⁾

The calculation of the *DoE* needs the information about the uncertainty of the differences di and dij (equations [11] and [12]). To make statements about this, it is necessary to consider first the general problem of the difference of two values x_1 and x_2 . If we look to the pure propagation of (standard) uncertainty we find:

$$u_{x_1-x_2}^2 = \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} & \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \text{cov} \\ \text{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} \\ \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2 \cdot \text{cov} \quad [13]$$

Simply spoken, the (standard) uncertainty of the difference is the quadratic sum of the uncertainties of the inputs (u_1 and u_2) subtracting twice the covariance (cov) between the two input values.

²⁾ C.Ullner et al., *Special features in proficiency tests of mechanical testing laboratories*, and P. Robouch et al., *The „Naji Plot“, a simple graphical tool for the evaluation of inter-laboratory comparisons*,

Both in: D. Richter, W. Wöger, W. Hässelbarth (ed.) *Data analysis of key comparisons*, 178. PTB-Seminar/International Workshop, ISBN 3-89701-933-3.

³⁾ D.Dopheide, B.Mickan, R.Kramer, H.-J.Hotze, J.-P.Vallet, M.R.Harris, Jiunn-Haur Shaw, Kyung-Am Park, *CIPM Key Comparisons for Compressed Air and Nitrogen, CCM.FF-5.b – Final Report*, 07/09/2006 http://kcdb.bipm.org/appendixB/appbresults/ccm.ff-k5.b/ccm.ff-k5.b_final_report.pdf

Therefore it is possible find the different cases in this comparison:

A) Differences to the KCRV

A1) *Independent laboratories with contribution to the KCRV*

The covariance between the result of a laboratory (with contribution to the KCRV) and the KCRV is the variance of the KCRV itself.¹⁾

$$\Rightarrow u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2} \quad [14]$$

A2) *Independent laboratories without contribution to the KCRV*

There is no covariance between the result of a laboratory without contribution and the KCRV.

$$\Rightarrow u(di) = \sqrt{u_{xi}^2 + u_{xref}^2} \quad [15]$$

A3) *Laboratories with traceability to a laboratory contributing to the KCRV*

In this case we have covariance between the laboratory and the KCRV because the laboratory is linked to the KCRV via the source of traceability. Although we have no detailed information about it, we can determine a conservative estimation of an upper limit of this covariance. The upper limit is determined for the theoretical case if we have no additional stochastic influence in the traceability of the lab from its source (which is the lab contributing to the KCRV). Then the results of the lab considered here would be strongly correlated with the results of the laboratory contributing to the KCRV (correlation coefficient = 1) and there would be the same covariance to the KCRV as in case A1. In any case of additional uncertainty caused stochastically the correlation and consequently the covariance is smaller.

$$\Rightarrow u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2} \quad [16]$$

B) Differences Lab to Lab

B1) *Independent laboratories*

There is no covariance between the results of two independent laboratory i and j

$$\Rightarrow u(dij) = \sqrt{u_{xi}^2 + u_{xj}^2} \quad [17]$$

B2) *Dependent laboratories with common source of traceability*

In the case of two labs i and j with a common source of traceability we will find again a covariance between these labs which is caused by the common source. In our case the common source is another laboratory from which the traceabilities of both labs are derived. Again we can determine a conservative upper limit of the covariance for the same reason as in A3 as $\text{cov} = u_{\text{SourceLab}}^2$.

$$\Rightarrow u(dij) = \sqrt{u_{xi}^2 + u_{xj}^2 - 2u_{\text{SourceLab}}^2} \quad [18]$$

The equations from [14] to [18] use the standard uncertainties ($k = 1$). The expanded uncertainties $U(di)$ and $U(dij)$ (see equations [11],[12]) are determined by

$$U(di) = 2 \cdot u(di) \quad [19]$$

¹⁾ Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, **39**, 589-595

$$U(d_{ij}) = 2 \cdot u(d_{ij}) \quad [20]$$

9. Financial aspects

The participation of any laboratory in this comparison is free of charge. Of course, each laboratory is responsible for the delivery of the meter to the next laboratory. It means the expense of the delivery of the meter to the next laboratory will be paid by the previous participating laboratory.

The meter is the property of the pilot laboratory.