TECHNICAL PROTOCOL FOR EURAMET PROJECT – 1162

Intercomparison of Water Meter Reference Standard

Technical Protocol

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1. Introduction

The aim of the comparison is to compare the performance of calibrations of the water flow facilities in different water flow laboratories in the NMIs participating in this exercise. A DN 32 Bopp&Reuther type turbine meter will be used as a transfer standard to compare water test facilities in the flow range from 3 m^3/h to 30 m^3/h. If laboratories are not able to cover the full range they may calibrate the meter over a part of the flow range.

2. Participants and time schedule

Each participant is given 1 week to perform the calibration of the meter and 1 week to transfer the meter to the next participating laboratory. The participants and the time schedule of the comparison are given in Table 1. Participants should have the transfer standard delivered to the address of the participant scheduled to perform the calibrations after themselves according to the schedule.

Table 1. Participants and the time schedule of the comparison

Institute /Country	Delivery Address	Contact	Date of calibration
TUBITAK UME /TURKEY	TUBITAK UME Fluid Mechanics Laboratory, Anibal-Caddesi, TUBITAK-GEBZE Yerleskesi, P.O. Box 54, 41470 Gebze-Kocaeli, TURKEY	**Dr. Vahit Ciftci** vahit.ciftci@ume.tubitak.gov.tr tel; ++90 262 679 50 00/5100 fax: ++90 262 679 5001	**Calibration:** 01 - 05 November 2010 **Delivery:** 22 November 2010
BoM/ MACEDONIA	Bureau of metrology - Skopje Bul. "Jane Sandanski" 109-a Skopje, MACEDONIA	**Anastazija Sarevska** anastazija.sarevska@bom.gov.mk phone:++389 2 24 03 676 fax: ++389 2 24 44 677	**Calibration:** 29 Nov. - 03 December 2010 **Delivery:** 06 December 2010
EIM /GREECE	AIM - Hellenic Institute of Metrology Mechanical Measuring Department Industrial Area of Thessaloniki Block 45, GR 57 022, Sindos Thessaloniki, GREECE	**Dr. Zoe Metaxiotou** zoe@eim.org.gr 30 2310 56 99 62 30 2310 56 99 99	**Calibration:** 13 - 17 December 2010 **Delivery:** 20 December 2010
DMDM/ SERBIA	Directorate of Measures and Precious Metals (DMDM) Mike Alasa 14, RS-11 000, Beograd, SERBIA	**Dr. Branislav Tanasic** tanasic@dmdm.rs Phone: +381 11 2024 465 Fax: +381 11 2181 668	**Calibration:** 27-31 December 2010 **Delivery:** 03 January 2011
TUBITAK UME /TURKEY	TUBITAK UME Fluid Mechanics Laboratory, Anibal-Caddesi, TUBITAK-GEBZE Yerleskesi, P.O. Box 54, 41470 Gebze-Kocaeli, TURKEY	**Dr. Vahit Ciftci** vahit.ciftci@ume.tubitak.gov.tr tel; ++90 262 679 50 00/5100 fax: ++90 262 679 5001	**Calibration:** 10 - 14 December 2011 **First Draft Report:** 24 January 2011

3. Transfer Device

The turbine type water meter will be the instrument to be tested. A description and a picture of the transfer meter are given in Table 2 and in Figure 1. Also dimensions of the meter are presented in Table 3 and in Figure 2. A flow straightener (within a pipe) in addition to the water meter will be mounted on the upstream side of the flowmeter, as seen in Figure 3. All participants should take care to set up their systems to provide 470 mm of space for the mounting of the pipe and the water meter (Figure 4).

On Figure 5, pulse transmitter can be seen. A screen box (display) will be connected with that transmitter. You can see below parameters on the display:

- Transfer meter water flow rate,
- Transfer meter total water volume that was passed through out (It is suggested to take total water volume for your calculation)
- And also it can be seen the pulse collecting time on the screen as well (if participant has diverting system and if it wants to actuate the timing by diverting system (5V DC pulse signal) it could be used).

The meter will be packed in a wooden box as depicted in Figure 6. The dimensions of the box are 400 mm x 400 mm x 400 mm. The weight of the complete box with the meter is approximately 30 kg. In the wooden box, the turbine meter will be fastened with two textile slings with ratchets.

Table 2. Technical specification of the meter

Manufacturer: Bopp&Reuther	
Serial number: 19148	P_{max} : 40 bar
Inside diameter: DN 32	Pulse number: 56,623 imp/liter
Transmitter serial number: 3646 and 3647	$T_{fluid,max}$ = 60 °C
Q_{min} : 3 m^3/h	Q_{max} : 30 m^3/h
Weight: approximately 30 kg	
Minimum operation pressure: 2 bar	

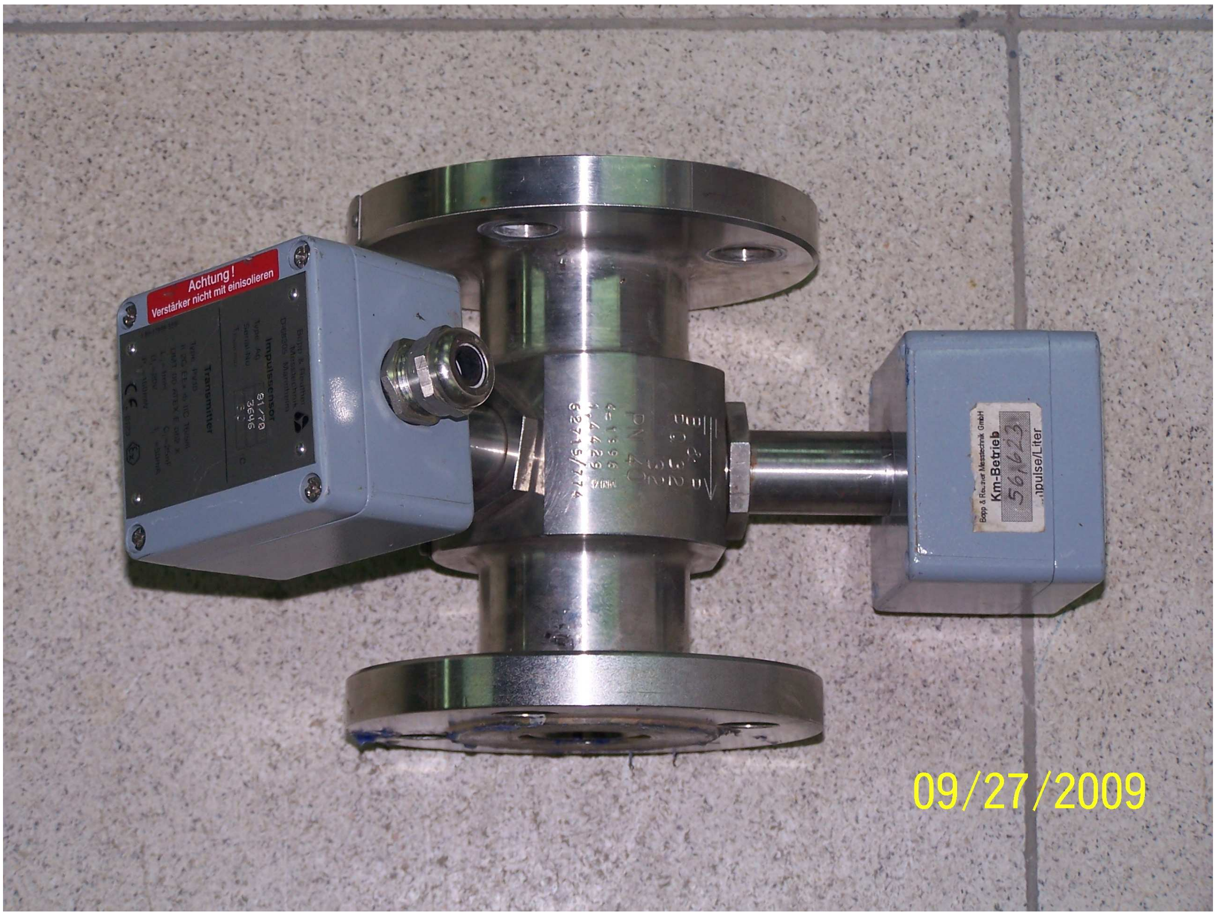


Figure 1. Turbine type water meter

Table 3. Dimensions of the meter

L	A	B
155 mm	160 mm	310 mm

Flanges are DN32, PN40, as shown below

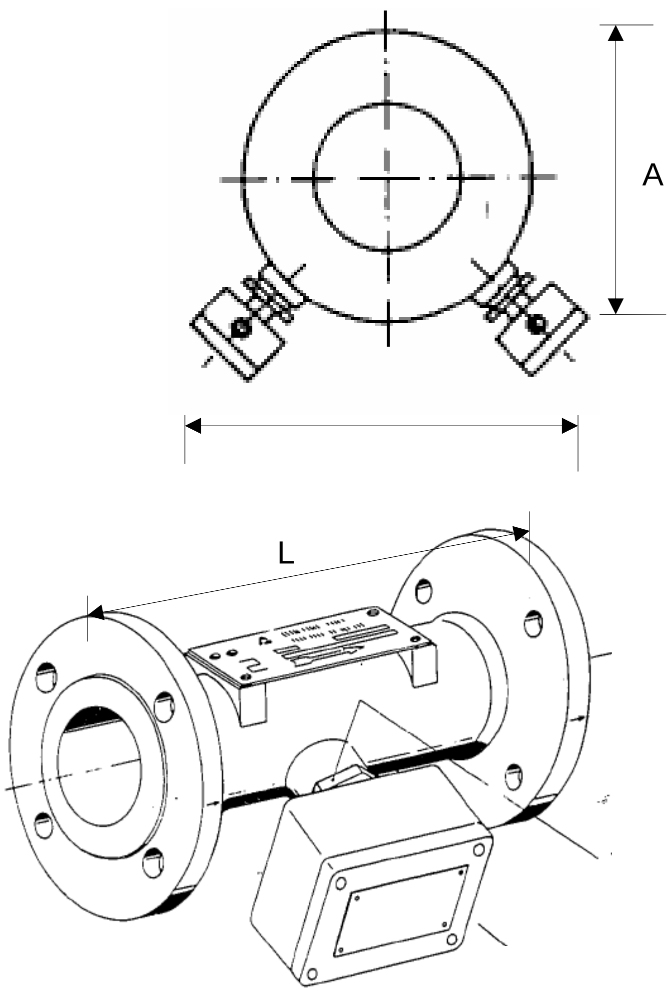
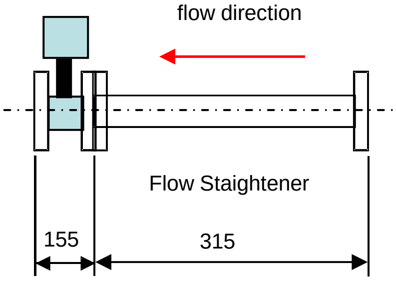


Figure 2. Dimensions of the turbine type water meter

Figure 3. Flow staightener



Flanges are DN32, PN40

Figure 4. Fittings dimensions for the turbine type water meter

Figure 5. Pulse Transmitter

The meter will be packed in a wooden box as depicted in Figure 6. The dimensions of the box are 400 mm x 400 mm x 400 mm. The weight of the complete box with the meter is approximately 30 kg. In the wooden box, the turbine meter will be fastened with two textile slings with ratchets.

Figure 6. The wooden box for the turbine type water meter DN32

The box will contain the meter with two pulse transmitters, a display unit, chocks, damage indicators, textile slings with ratchets and a copy of the Technical Protocol of the comparison.

4. Advice on handling and on travelling

It is necessary that the meter be handled with care during shipment and during packing and unpacking. The meter is not resistant to impacts or falls. During packing and unpacking each laboratory will have to use its own ropes with hooks and its own crane. The meter has to be fastened again with the textile slings with ratchets during subsequent packing.

During testing, the water 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, high water flow changes and against overload.

For the transport of the meter from one country to another it is strongly recommended to use the services of well-known companies (for example DHL http://www.dhl.com), which are able to ensure the handling of all customs transactions without problems.

Any customs documents accompanying the transfer standard will be provided by the shipping company. This approach allows reliable information on the location of the transfer standard to be easily obtained.

The proposed intercomparison plan and timing is shown in Table 1.

Each laboratory should be notified of the actual arrival date of the package from the previous participating laboratory. If no notification is received when expected, please check with the previous laboratory.

Inform the Pilot laboratory immediately if a problem or delay occurs.

Check the package casing for damage and on opening the package check the contents against the contents list.

Check the transfer standard for damage.

Report any damage or missing parts to the Pilot laboratory and the previous participant.

If a problem arises during testing, please inform the Pilot laboratory, and inform the next laboratory of the delay in completion.

On completion: Inform the next laboratory of the expected dispatch date

Pack and check the package against the list presented in Appendix 1.

Check that all paperwork is available to the carrier.

Dispatch and then inform the Pilot laboratory and the next laboratory on the day of the dispatch.

Report: To be completed within 3 weeks after the completion of tests and sent to the Pilot Laboratory in electronic version and as a signed hardcopy.

Timing: Allow 1 week for testing and 1 week for transport of the transfer standard to the next laboratory.

<u>In the case of failure of the transfer standard</u>

If a participant suspects a failure of the transfer standard it shall be reported immediately to the Pilot laboratory. The Pilot laboratory shall decide if repair is required and make arrangements for any repairs. The total costs for repairing and shipping will be shared equally among all participants.

The transfer standard is fitted with impact evident devices. These are located on the base and are visible through holes in the base. If either of these devices shows red the pilot laboratory should be contacted immediately for further instructions.

<u>In the case of a laboratory joining after start of the project</u>

A laboratory may be added to the project after the start date and undertake the calibration of the transfer standard after the original members have completed their calibrations. The laboratory would be liable for any additional transportation costs.

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 notify Pilot laboratory bu sending e-mail message to the coordinator’s address: vahit.ciftci@ume.tubitak.gov.tr.

6. Test procedure

The participating laboratories shall use a calibration procedure ordinarily used during calibration service for customers. Only the instructions given below must be fulfilled.

- The transfer meter should be installed according to Figure 4 and tested in horizontal position.
- The transfer meter has to be tested at 5 flow rates: 3 m^3/h, 5 m^3/h, 10 m^3/h, 20 m^3/h and 30 m^3/h. The test in one flow rate should be repeated at least 4 times and the flow rate has to be within the interval ± 3% of the required value.
- During the test, laboratory air temperature must be close to 20℃. Water temperature should be about 20℃.
- The test meter should be kept in laboratory conditions for at least 24 hours before testing begins.
- Before the beginning of the test, the test meter has to work 20 minutes at Q=10 m^3/h flow rate.
- The duration of a single test at one flow rate must be more than 1 minute. Prior to the test, the flow rate has to be accurately stabilised.
- Start the test and report results in the format presented in Table 4.
- <u>For the Stability of the transfer standard it was found out that the minimum flow rate should be more than 3,5 m^3/h and the maximum flow rate should be less than 29,5 m^3/h.</u>

Table 4. Data Table

Nominal Flow rate	Water Temperature	Water Density	Inlet pressure at the transfer meter	Outlet pressure at the transfer meter	Total Volume of Reference standard or Flow rate	Total Volume of Transfer meter or Flow rate	Mean Error of the meter	Mean Deviation	Total Uncertainty (k=2)
(m^3/h)	(℃)	kg/m^3	(Pa)	(Pa)	(m^3) / (m^3/h)	(m^3) / (m^3/h)	(%)	(%)	(%)
3									
5									
10									
20									
30									

Nominal Flow rate	Water Temperature	Water Density	Inlet pressure at the transfer meter	Outlet pressure at the transfer meter	Total Volume of Reference standard or Flow rate	Total Volume of Transfer meter or Flow rate	Mean Error of the meter	Mean Deviation	Total Uncertainty (k=2)
(m^3/h)	(°C)	kg/m^3	(Pa)	(Pa)	(m^3) / (m^3/h)	(m^3) / (m^3/h)	(%)	(%)	(%)

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

$$E = \frac{Q_t - Q_r}{Q_r}.100 \qquad (\%) \qquad [1a]$$

$$E = \frac{V_t - V_r}{V_r}.100 \qquad (\%) \qquad [1b]$$

where, E is the error of the meter,
Q_t is the volume flow rate measured by the transfer meter (m^3/h)
Q_r is the volume flow rate measured by the reference meter (m^3/h)

V_t is the total volume rate measured by the transfer meter (m^3)
V_r is the total volume rate measured by the reference meter (m^3)

7. Instruction for reporting results

Within 3 weeks after the completion of tests of the meter in the laboratory, all data listed below shall be sent to the Pilot laboratory by e-mail in addition to the completed **Table 4.**

- the table of means of the measured values and the uncertainty of the error of the meter,
- the description of the reference test facility, which was used for the test of the transfer meter and the address where the facility is situated,
- the traceability of the standard (reference) meters and other measuring instruments which were used during the test, including the recalibration interval of the meters,
- a description of the test procedure and uncertainty budget,
- certificate for the transfer meter.

The determination of the error of the meter is usually based on the comparison of the volume (or mass) flowrate of the water indicated by standard (reference) meter and of the flowrate, which was indicated by the meter under test (transfer meter) after calculations of density taking into account different temperatures in the standard meter and in the meter under test.

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.Cox[1)]. 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 KCRV. 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):

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

where $x_1, x_2, \dots.. x_n$ are errors of the meter in one flow rate in different independent laboratories,

$u_{x1}, u_{x2}, \dots.. u_{xn}$ are standard uncertainties (not expanded) of the error in different independent laboratories 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 the following equation.

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

[1)] Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, **39**, 589-595 where U_{xi_lab} is the expanded uncertainty (k=2) calculated by laboratory *i* and presented in results of laboratory *i*

U_{tm} is estimated expanded uncertainty caused by the stability (reproducibility) of the turbine meter (The meter will be tested two 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

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \ldots\ldots.. \frac{1}{u_{xn}^2} \qquad [4]$$

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

$$U(y) = 2.u_y \qquad [5]$$

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^2_{obs} will be calculated by

$$\chi^2_{obs} = \frac{(x_1 - y)^2}{u_{x1}^2} + \frac{(x_2 - y)^2}{u_{x2}^2} + \ldots\ldots\ldots\ldots \frac{(x_n - y)^2}{u_{xn}^2} \qquad [6]$$

The degrees of freedom ν will be assigned

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

where n is number of evaluated laboratories.

The consistency check will be failing if

$$Pr\{\chi^2_\nu > \chi^2_{obs}\} < 0{,}05 \qquad [8]$$

(The function *CHIINV(0,05;ν)* in MS Excel will be used. The consistency check will be failing if *CHIINV(0,05; ν)*< χ^2_{obs})

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^2_{obs} will be calculated again without the values of the excluded laboratory. The consistency check will be calculated again as well. This procedure will be repeated till the consistency check will pass.

8.1.2. The determination of the differences "Laboratory to KCRV" and "Laboratory to Laboratory" as well as their uncertainties and Degrees of Equivalence

When the KCRV will be determined, the degrees of equivalence of the participating laboratories with respect to KCRV will be calculated according to

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

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

Based on these differences, the **D**egree **o**f **E**quivalence (*DoE*) will be calculated according to:

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

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

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

- The results of a laboratory will be ***equivalent (passed) if Ei or Eij ≤ 1.***
- The laboratory will be determined as ***not equivalent if Ei or Eij >1.2***.
- For values of *DoE* in the range ***1 < Ei or Eij ≤ 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 laboratories as well the KCRV). Conventionally calculations will be made for 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* requires the information about the uncertainty of the differences d_i and d_{ij} (equations [11] and [12]). To make statements about this, it is

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[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

necessary to consider first the general problem of the difference of two values x_1 and x_2. Looking to the the pure propagation of (standard) uncertainty one can find:

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

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.

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

A) <u>Differences to the KCRV</u>

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)]

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

A2) *Independent laboratories without contribution to the KCRV*

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

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

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 laboratory from its source (which is the laboratory contributing to the KCRV). Then the results of the laboratory considered here would be strongly correlated with the results of the laboratory contributing to the KCRV (correlation coefficient is 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.

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

B) <u>Differences Lab to Lab</u>

B1) *Independent laboratories*

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

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

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

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 traceability of both laboratories are derived. Again we can determine a conservative upper limit of the covariance for the same reason as in A3 as cov = $u^2_{SourceLab}$.

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

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

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

$$U(dij) = 2.u(dij) \quad [20]$$

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 that the cost of the delivery of the meter to the next laboratory will be paid by the previous participating laboratory.

The cost of ATA CARNET will be paid by the Pilot laboratory. The meter is the property of the Pilot laboratory.

Appendix 1. Contents of Package

Use this list to verify a presence of all required items when unpacking or packing this case.

Notes:

- Report any packing list shortages to UME without delay.
- Check damage indicator, and if red advise UME without delay.
- Read the manual before operation.

Hardware:

Description	Part Number	Serial Number
Sensor	-	19148
Pulse transmitter	81/70	3647
Pulse transmitter	81/70	3646
Display unit	-	-

Cables:

Description	P/N	Qty
Power cable	-	1

Manuals / Information:

Turbine meter type RQ Operating Manual

The transfer package dimensions are 400 mm x 400 mm x 400 mm,
The weight of the transfer package is about 30 kg