GULF ASSOCIATION FOR METROLOGY

Calibration of Gauge Blocks by Mechanical Comparison Method GULFMET.L-S1

Instructions and Technical Protocols

Contents

1. Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

At its meeting in September 1997, the Consultative Committee for the Definition of the Metre (CCDM, today called Consultative Committee for Length, CCL) has identified seven key comparisons in the field of dimensional metrology and decided upon the general content, the pilot laboratory and the starting date of each key comparison. In particular, it decided that a key comparison on gauge block measurements by interferometry shall be carried out, starting in spring 1998, with the Swiss Federal Office of Metrology (OFMET) as the pilot laboratory. Soon after this key comparison, similar comparison was organized by various regional metrology organizations (RMO) to provide linkage to the CCL comparison. For example, a key comparison on gauge block by interferometry was carried out in APMP, known as APMP.L-K1, with NMIJ Japan as pilot. It was carried out from 2001 to 2002 and has been approved for equivalence.

Recently, during the 35th meeting of the JCRB, it was pointed out that the GULFMET as a new RMO shall involve in comparison activities to improve its metrological equivalence with other RMOs. It was also suggested that the comparison shall be registered at KCDB website. During the first meeting of TC-L in Riyadh on the 25 Nov 2015, it was agreed that regional comparison in length measurement shall be carried out as part of the GULFMET TC-L action plan 2015-2017. It should be noted however, that the number of NMIs in GULFMET region having length measurement capability is rather limited. Based on recent survey it was decided that a regional comparison on calibration of gauge blocks by mechanical comparison method to be the most appropriate one. It is expected that participation of associate members should also be encouraged.

The procedures outlined in this document are principally intended to allow for a clear and unequivocal comparison of the measurement results and to complete the comparison in the time scale provided for. The procedures used for the comparison are based on the protocol for APMP DEC Comparison of gauge blocks by mechanical comparison which was organized by APMP between Sep 2006 and Jan 2009.

Laboratories, by their declared intention to participate in this regional comparison, accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly. A common way of evaluating and expressing the uncertainty of measurement is particularly important to demonstrate the degree of equivalence between the participating laboratories.

2. Organisation

The comparison will follow as closely as possible the rules set up by the BIPM. The comparison will be piloted by EMI-UAE and co-piloted by TUBITAK-UME.

2.1 Participants

Name	Laboratory Address	Contact details
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Majid AlSinawi	Directorate General for standardization and Measurements P.O. BOX 550 Postal Code 100 Sultanate of Oman.	Tel: 0096824817264 Fax: 00968 2415992 Email: mnalsinawai@gmail.com
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Faizah Almatkhor	Public Authority Of Industry, Kuwait.	f.Matkhor@pai.gov.kw

Tanfer Yandayan	Tubitak-UME Gebze Yesleskesi, Baris Mah. Dr. Zeki Acar Cad. No.1 41470 Gebze, Kocaeli Turkey.	Tel:+90 262 679 5000 Fax: +90 262 679 5001 Email: tanfer.yandayan@tubitak.gov.tr

2.2 Time schedules

The comparison will be carried out in a two loops format. One loop for short gage blocks and the second loop for long gauge blocks. Each laboratory has one month for calibration, including transportation. With its confirmation to participate, each laboratory has confirmed that it is capable of performing the measurements in the limited time allocated to him. It guarantees, that the standards arrive in the country of the next participant at the beginning of the next month. If for some reasons, the measurement facility is not ready or customs clearance takes too much time in a country, the laboratory has to contact the pilot laboratory immediately.

Short gauge blocks circulation schedule

Laboratory	Country	Date	Remark
EMI	United Arab Emirates	1 May 2017-30 May 2017	Subject custom issue
TUBITAK-UME	Turkey	1 Jun -30 Jun 2017	
NMIM	Malaysia	1 Jul -30 Jul 2017	
DPM	Albania	1 Aug-30 Aug 2017	
EMI	UAE	1 Sep -30 Sep 2017	
PAI	Kuwait	1 Oct- 30 Oct 2017	
SASO-NMCC	Kingdom of Saudi Arabia	1 Nov- 30 Nov 2017	
DGSM	Oman	1 Dec – 30 Dec 2017	
TUBITAK-UME	Turkey	1 Jan-30 Jan 2017	
EMI	United Arab Emirates	1 Feb -29 Feb 2017	

Long gauge blocks circulation schedule

Laboratory	Country	Date	Remark
EMI	United Arab Emirates	1 Jun 2017-30 Jun 2017	Subject to procurement of long gauge blocks
NMIM	Malaysia	1 Jul-30 Jul 2017	
EMI	UAE	1 Aug -30 Aug 2017	
TUBITAK-UME	Turkey	1 Sep-30 Sep 2017	
SASO-NMCC	Saudi Arabia	1 Oct -30 Oct 2017	
EMI	United Arab Emirates	1 Nov– 30 Nov 2017	

2.3 Transportation

Transportation is each laboratory's own responsibility and cost. The standards shall be packed in a box ready to be shipped. The box can be shipped with any appropriate carrier, using a fast mail service or hand-carried. Preference should be given as to the safety of the artefacts.

You are kindly asked to inform the pilot laboratory by Fax immediately after receiving the gauge blocks using the fax form in the annex.

Immediately after having completed the measurements, the box has to be sent to the next participant. It is advisable to prepare and organize this transportation beforehand. Please inform again the coordinator and the next laboratory by fax or e-mail about date of shipment, transportation company and possibly flight details.

2.4 Packing Unpacking, Handling, Packing

The package for loop **one** contains the following items:

-One box with 10 gauge blocks (5 steels and 5 tungsten carbides)
-1 copy of measurement instructions

The package for loop **two** contains the following items:

-One box with 3 gauge blocks
-1 copy of measurement instructions

After receiving the package, the standards have to be inspected carefully for any damage, scratches or rust. When handling the gauge blocks, please wear gloves to protect the gauge block

surfaces from being rusted. The gauge blocks must be handled with care! Any damage has to be communicated to the pilot laboratory. The measurement surfaces **should never be relapped** or **polished!** Damaged gauge blocks are not going to be replaced. Try to calibrate also gauge blocks judged to be damaged if there is no risk for damaging laboratory equipment.

After the measurements, the gauge blocks have to be cleaned and greased. Ensure that the content of the package is complete before shipment. Always use the original package.

2.5 Financial Aspects, Insurance

Each participating laboratory covers the costs for the measurements, transportation and eventual customs formalities as well as for any damages that may have occurred within its country. The overall costs for the organization and for the devices are covered by the organizing pilot laboratory through the financial support from GULFMET.

3. Description of the Standards

The package contains 5 pieces of short gauge blocks made of steel, 3 pieces of long gauge blocks made of steel and 5 pieces of short gauge blocks made of tungsten carbide. The gauge blocks are of rectangular cross section, according to the International Standard ISO 3650:1998. The thermal expansion coefficient and its standard uncertainty (k=1) supplied by the manufacturer shall be used.

i) Steel gauge blocks (**short gauge blocks**)

Table 1

Nominal value , /mm	S/N	Manufacturer	CTE
1	88061	TESA	11.9E-6/˚C
5	88061	TESA	11.9E-6/˚C
25	88061	TESA	11.9E-6/˚C
50	87268	TESA	11.9E-6/˚C
100	87268	TESA	11.9E-6/˚C

ii) Steel gauge blocks (**long gauge blocks**)

Table 2

Nominal value , /mm	S/N	Manufacturer	CTE
150	140510	TESA	11.2E-6/˚C
200	140512	TESA	11.2E-6/˚C
500	140516	TESA	11.2E-6/˚C

iii) Tungsten carbide gauge blocks (short gauge blocks)

Table 3

Nominal value , /mm	S/N	Manufacturer	CTE
1	09813W	TESA	4.23E-6/˚C
5	09225W	TESA	4.23E-6/˚C
25	07601W	TESA	4.23E-6/˚C
50	09598W	TESA	4.23E-6/˚C
100	10844W	TESA	4.23E-6/˚C

Some physical properties of materials taken from the manufacturer's information are listed in the following Table.3. The values given in this table for diamond are just typical ones. If the data could be obtained from the manufacturer of the diamond tip, then those values shall be used in the calculation.

Table 4

Material	Poisson's ratio	Young's modulus, /GPa
Steel	0.27 ±0.01	207 ± 2%
Tungsten carbide	0.24±0.02	604 ± 5%
Diamond	0.09±0.02	126 ± 2%

4. Measurement Instructions

Before calibration, the gauge blocks have to be inspected for damage of the measurement surfaces. Any scratches, rusty spots or other damages have to be documented by a drawing using the appropriate form in the annex (A3, A4 and A7).

Never magnetize the gauge blocks. If any gauge blocks are found to have a magnetic condition, the magnetism must be removed per individual laboratory practices before the central length measurements are performed.

4.1. Measurement of central length deviation

The measurand is the central length of the gauge blocks, as defined in the International Standard ISO 3650. The measurement results must be appropriately corrected to the reference temperature of 20°C using the thermal expansion coefficients given in this document. Additional correction for the contact deformation has to be applied according to the usual procedure of the laboratory if necessary. Gauge blocks are to be measured in the manner that is typically provided for client service.

4.2. Measurement of variation in length (for short gauge blocks only)

Measurement of variation of length is carried out by measuring the length deviation at 4 corners of the gauge blocks. Follow the notation below to obtain correct orientation of the gauge blocks.

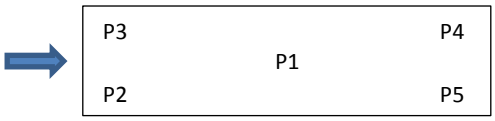

Figure 1: Measurement points on the gauge block for variation in length determination

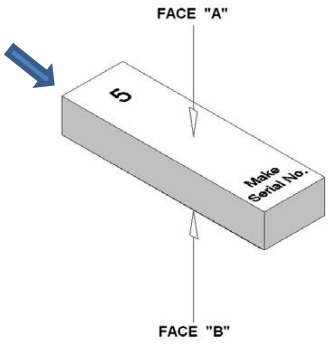

Figure 2: Orientation of the gauge block (<6 mm) for variation in length measurement.

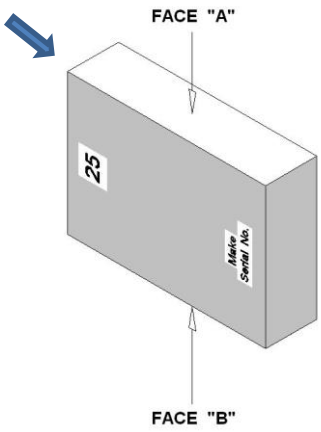

Figure 3: Orientation of the gauge block (> 20 mm) for variation in length measurement.

5. Measurement Uncertainty

The uncertainty of measurement shall be estimated according to the ISO Guide for the Expression of Uncertainty in Measurement (GUM). In order to achieve optimum comparability, the mathematical model containing the principal influence parameters for gauge block calibration by mechanical comparison is discussed below. There is a more detailed version of the example available in Annex H: Examples of the GUM.

The length of the gauge block can be calculated according to the following mathematical model:

$$l = l_r + d - L(\bar{\alpha} \cdot \Delta t - \Delta\alpha \cdot \delta t) + l_{cd} \qquad \text{.... 1}$$

where,

l : length of the test gauge block;
l_r : length of the reference gauge block;
d : the measured length difference between the reference gauge block and the test gauge block;
$\bar{\alpha} = \frac{\alpha_r + \alpha_x}{2}$: average of the linear thermal expansion coefficient of the reference gauge block and the test gauge block;
$\Delta\alpha = \alpha_x - \alpha_r$: difference in the linear thermal expansion coefficient between the test gauge block and the reference gauge block;
$\Delta t = t_x - t_r$: temperature difference between the test gauge block and the reference gauge block;
$\delta t = \frac{t_x + t_r}{2} - 20°C$: deviation of the average temperature of the test and reference gauge blocks from the reference temperature;
L : nominal length of the gauge block;
l_{cd} : correction for difference in contact deformation between the test and reference gauge blocks;

When the length l of the gauge block being expressed as a function of input quantities x_i is,

$$l = f(x_i), \qquad \text{.... 2}$$

the combined standard uncertainty $u_c(l)$ is the quadratic sum of the standard uncertainties of the input quantities $u(x_i)$ each weighted by a sensitivity coefficient c_i

$$u_c{}^2(l) = \sum_{i=1}^{n} c_i{}^2 u^2(x_i), \qquad \text{.... 3}$$

with, $c_i = \frac{\partial l}{\partial x_i}$.

In some cases, higher order terms of Eq.(3) might have to be taken into account as well. See also the Example in the GUM and the cited references.[1]

[1] *J.E. Decker and J.R. Pekelsky, Uncertainty of Gauge Block Calibration by Mechanical Comparison: A Worked Example, Proceedings of the 1997 Advanced School of Metrology: Evaluation of Uncertainty in Measurement, Angra dos Reis, RJ/Brazil, 2–7 March 1997 [NRC Document No. 39998]. For dissimilar standard and test gauge block materials, see Decker et al., Uncertainty of Gauge Block Calibration by Mechanical Comparison: A Worked Example for Gauge Blocks of Dissimilar Materials, SPIE Conference on Recent Developments in Optical Gauge Block Metrology, San Diego, CA, July 1998, SPIE Vol. 3477, pp. 225–246. Another example of evaluation of gauge block calibration can be found in the Supplement 1 of the Expression of the Uncertainty of Measurement in Calibration (EA-4/02).*

The participants are required to report their measurement uncertainty budget in the table shown in Annex A6, with format according to the example below. $\boldsymbol{\nu}_i$ is the number of degrees of freedom of $u(x_i)$, $\boldsymbol{\nu}_{\text{eff}}$ is the effective number of degrees of freedom of $u_c(l)$.

Example
(Please note that this is only an example and does not claim to be either correct or complete)

x_i	$u(x_i)$	$\boldsymbol{\nu}_i$	$c_i = \partial l / \partial x_i$	$\lvert c_i \rvert \cdot u(x_i)$
l_r	$\sqrt{(32\ nm)^2 + (0.5 \times 10^{-6} L)^2}$	100	1	$\sqrt{(32\ nm)^2 + (0.5 \times 10^{-6} L)^2}$
d	23	100	1	23 nm
$\bar{\alpha}$*	0.32X10^{-6}/K	100	$-\Delta t \cdot L = 0$	0
Δt	0.03 K	12.5	$-\bar{\alpha} \cdot L = -11.7 \times 10^{-6} \cdot L$	3.5 X10^{-7}L
$\Delta\alpha$†	0.65 X 10^{-6} /K	100	$-\delta t \cdot L = 0$	0
δt‡	0.07 K	200	$-\Delta\alpha \cdot L = -0.2 \times 10^{-6} \cdot L$	1.4 X 10^{-8}L
l_{cd}	5 nm	10	1	5 nm
$u(\bar{\alpha})u(\delta t)$	9.6 X 10^{-9}	-	L	9.6 X 10^{-9}L
$u(\Delta\alpha)u(\delta t)$	4.6 X 10^{-8}	-	L	4.6 X 10^{-8}L

The combined standard uncertainty is, $u_c(l) = \sqrt{(40\ nm)^2 + (0.61 \times 10^{-6} L)^2}$

For L=1 mm: u_c=40 nm with $\boldsymbol{\nu}_{\text{eff}}$=193
For L=100 mm: u_c=73 nm with $\boldsymbol{\nu}_{\text{eff}}$=114

6. Reporting

The quality of the measurement surfaces of the gauge blocks, the measurement results, instrument descriptions and a detailed evaluation of the uncertainty of measurement have to be reported using the forms enclosed in their related annexes . Handwritten notes are sufficient. . The measurement report forms in the annexes of this document are sent by e-mail (Word document) to all participating laboratories.

Measurement results shall be reported in Annex A-1 and Annex A-2. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the coordinator. In any case, the signed report must also be sent in paper form by mail. In case of any differences, the paper forms are considered to be the valid version.

The reports shall be sent within six weeks after completing the measurements to the pilot laboratory. No information about differences of the reported results with respect to others will be communicated before the completion of the comparison, unless large deviations of particular laboratories with respect to the preliminary reference results obtained by the pilot laboratory have been observed. In the latter case the laboratory in question will be contacted.

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* *$\Delta t=0$* has been assumed. Note that since the uncertainty contribution of ᾱ vanishes, the higher order terms should be included.
† *$\delta t=0$* has been assumed.
‡ *$\Delta\alpha = 0.2 \times 10^{-6}/K$* has been assumed.

Within 3 months after completion of the circulation, the pilot laboratory will prepare first draft (Draft A) report and send it to the participants for comment. Subsequently, the procedure outlined in the BIPM Guidelines will be followed.

7. Calculation of the reference value

Calculation of the reference values will be decided after completion of the circulation.

Measurement results:

Steel Gauge Blocks:

Nominal length l_n (mm)	Ident. No.	Central length deviation from the nominal length, l_c (/nm)	Deviation from central length /µm f_o	Deviation from central length /µm f_u	Uncertainty (k=1), $u_c(l_c)$ (/nm)	Effective deg. of freedom, $\boldsymbol{\nu}_{\text{eff}}$
1	88061					
5	88061					
25	88061					
50	87268					
100	87268					

Note:

Laboratory:.....

Date: ..... Signature:.....

Measurement results:

Tungsten Carbide Gauge Blocks:

Nominal length l_n (mm)	Ident. No.	Central length deviation from the nominal length, l_c (/nm)	Deviation from central length /µm f_o	Deviation from central length /µm f_u	Uncertainty (k=1), $u_c(l_c)$ (/nm)	Effective deg. of freedom, ν_{eff}
1	09813W					
5	09225W					
25	07601W					
50	09598W					
100	10844W					

Note:

Laboratory:.....

Date: ..... Signature:.....

Steel long gauge blocks

	Nominal length l_n (mm)	Ident. No.	Central length deviation from the nominal length, l_c (/nm)	Uncertainty (k=1), $u_c(l_c)$ (/nm)	Effective deg. of freedom, $\boldsymbol{\nu}_{\text{eff}}$
150	140510				
200	140512				
500	140516				

Note:

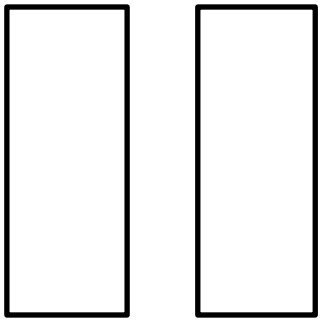
Laboratory:.....

Date: ..... Signature:.....

Inspection of the measurement faces, steel gauge blocks

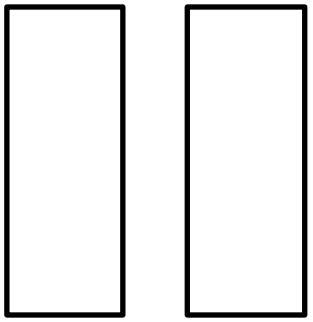
1.0 mm
s.n:……

Left Right



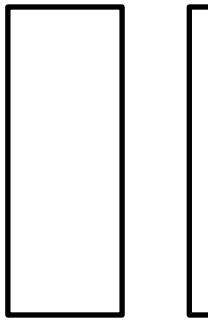
5.0 mm
s.n:……..

Left Right



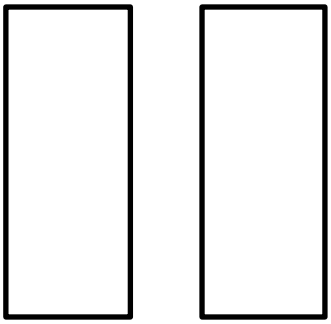
25.0 mm
s.n: ……..

Left Right



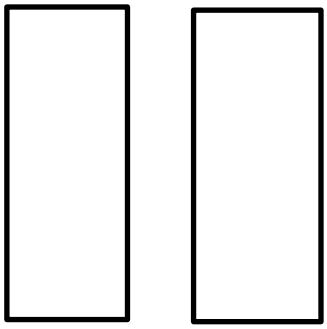
50.0 mm
s.n: ……

Left Right



100.0 mm
s.n: ……..

Left Right



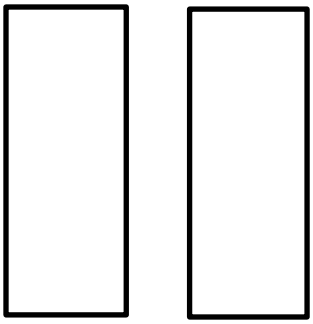
Laboratory: _____

Date: _____ Signature: _____

Inspection of the measurement faces, tungsten carbide gauge blocks

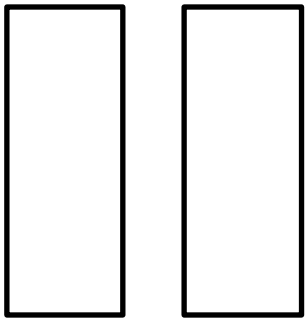
1.0 mm
s.n: …….

Left Right



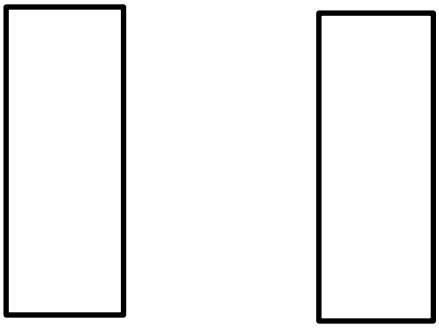
5.0 mm
s.n: ……

Left Right



25.0 mm
s.n: ……

Left Right

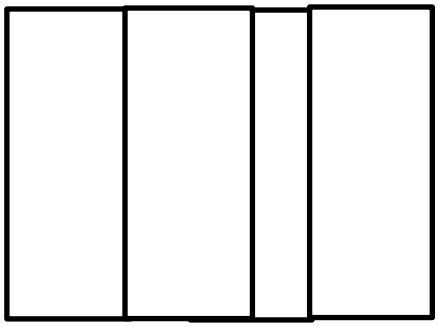


50.0 mm
s.n: ……

Left Right

100.0 mm
s.n: ……

Left Right



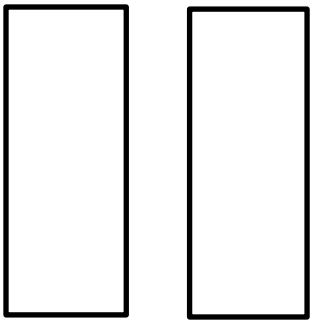
Laboratory: _____

Date: _____ Signature: _____

Inspection of the measurement faces, steel long gauge blocks

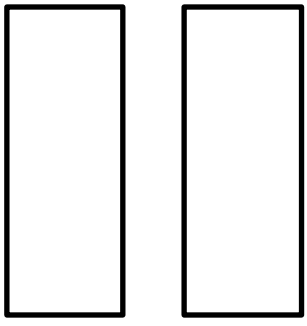
150 mm
s.n: ……..

Left Right



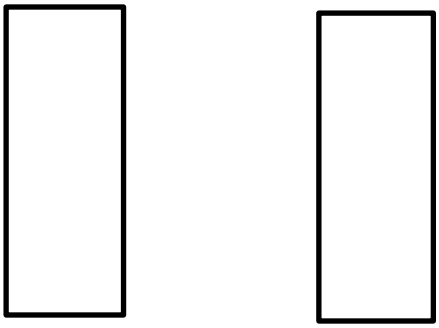
300 mm
s.n: ……

Left Right



500 mm
s.n: ……

Left Right



Laboratory: _____

Date: _____ Signature: _____

Description of the Mechanical Comparison Measurement Instrument

Make and Type of mechanical comparator:

_____

Tip material: _____

Upper tip diameter: _____, Lower tip diameter: _____

Upper tip measuring force: _____, Lower tip measuring force: _____

Source of traceability: _____

Calibration method used to determine the length value of the reference gauge blocks used in this mechanical comparison:

_____

_____

Range of gauge block temperature during measurements:

_____

_____

_____

Contact deformation correction:

Material of reference standard gauge block : _____

Contact deformation correction
applied (give range, if applicable) : _____

Laboratory: _____

Date: _____ Signature:_____

Prepare a detailed uncertainty budget for the calibration of the 1 mm and the 100 mm gauge block. The statement of uncertainty in the result form in Annexes A-8 should be consistent with the ISO-Guide for the expression of uncertainty in measurement.

Source of Uncertainty x_i	*Value of Standard uncertainty* $u(x_i)$	*Sensitivity coefficient* $c_i = \partial l / \partial x_i$	$u_i(l) = \lvert c_i \rvert \cdot u(x_i)$ (µm)	*Degree of freedom* ν_i

Effective degrees of freedom (V_{eff})=

Combined standard uncertainty: $u_c(l) =$

[$u_c^2(l) = \sum_i c_i^2 u^2(x_i)$ with $c_i = \frac{\partial l}{\partial x_i}$]

Expanded uncertainty with a coverage factor(k): U=

Laboratory:……

Date:……..Name……..Signature……..……..

Fax

To:

_____

_____

_____

_____

From: _____

_____

_____

_____
(participating laboratory)

We confirm having received the standards of the GULFMET regional comparison on gauge block measurement on _____ (date).

After visual inspection

- ☐ no damage has been noticed.
- ☐ the following damage(s) must be reported:

_____

_____

_____

_____

Date:

Signature: