EURAMET comparison of gauge blocks by interferometry

EURAMET #1138
EURAMET.L-K1.2

Technical protocol

CONTENT

1. INTRODUCTION

During the EURAMET annual TCL meeting in Lisbon in October 2009 it was agreed to start a EURAMET key comparison of gauge blocks by interferometry between a small number of laboratories (institutes), in order to test the performance of new equipment or confirm existing measurement procedures. Croatian National Laboratory for Length and Egyptian National Institute of Standards will apply CMC values based on this comparison.
Initiative for this key comparison came from Croatian National Laboratory for Length (DZM/LFSB), which will act as pilot laboratory, with participation of 4 other institutes:

- MKEH (HU)
- DFM (DK)
- GUM (PL)
- NIS (EG)

2. ORGANIZATION

2.1. Participants

Country (code)	Laboratory	Name of contact	Address	
1 - Denmark (DK)	DFM	Joergen Garnaes	Danish Fundamental Metrology Matematiktorvet 307 DK-2800 Kongens Lyngby	Tel : 45 45 93 11 44 Fax : 45 45 93 11 37 e-mail : jg@dfm.dtu.dk
2 - Hungary (HU)	MKEH	Edit Bánréti	Hungarian Trade Licensing Office Németvölgyi ut 37-39 HU-1124 Budapest XII.	Tel : 36 1 3567 722 Fax : 36 1 214 31 57 e-mail : dimensional@omh.hu
3 - Egypt (EG)	NIS	Mohamed Amer	Tersa Street EG-12211 El Haram, Giza	Tel : + 202 0123 676 372 Fax : +202 33 889 744 e-mail : amer@nis.sci.eg
4 - Croatia (HR)	DZM/LFSB	Vedran Mudronja	National Laboratory for Length Ivana Lučića 5 10000 Zagreb	Tel : +385 1 616 8327 Fax : +385 1 616 8599 e-mail : vedran.mudronja@fsb.hr
5 – Poland (PL)	GUM	Zbigniew Ramotowski	Central Office of Measures Glówny Urzad Miar (GUM) P.O. Box 10 ul. Elektoralna 2 00-950 WARSZAWA	Tel : 48 22 620 54 38 Fax : 48 22 620 83 78 e-mail : gum@gum.gov.pl

2.2. Time schedule

Each laboratory has four weeks for measurement, including transportation. With its confirmation to participate, each laboratory has confirmed that it is capable to perform 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 week. 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 coordinator immediately and – according to the arrangement made - eventually to send the standards directly to the next participant before finishing the measurements or even without doing any measurements.

Country	Laboratory	Date
Croatia	DZM/LFSB	15.02. – 12.03.10.
Hungary	OMH	15.03. – 09.04.10.
Denmark	DFM	12.04. – 07.05.10.
Poland	GUM	10.05. – 04.06.10.
Egypt	NIS	07.06. – 02.07.10.
Croatia	DZM/LFSB	05.07. – 30.07.10.

2.3. Transportation

Transportation is on each laboratory's own responsibility and cost. The standards are packed in a plastic box. Inside this box, the gauge blocks are disposed in a wooden box with serial numbers written on it.

The box can be shipped with any appropriate carrier, preferably using a fast mail service.

> You are kindly asked to inform the pilot laboratory by fax immediately after receiving the gauge blocks using the form in the annex.
>
> Immediately after having completed the measurements, the pack 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, flight details..... .

2.4. Unpacking, Handling, Packing

The package contains the following items:

- One wooden box with 8 gauge blocks
- 1 copy of the Technical protocol

After receiving the package, the standards have to be inspected carefully for any damage, scratches or rust. **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 will not be replaced. Try to calibrate also gauge blocks judged to be damaged if there is no risk for damaging the platens used for wringing the gauge blocks.

After the measurements, the gauge blocks have to be cleaned and **greased**. Ensure that the content of the package is complete before shipment. Use always 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 organisation and for the devices are covered by the organising pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

3. DESCRIPTION OF THE STANDARDS

The package contains 8 steel gauge blocks. The gauge blocks are of rectangular cross section, according to the international standard ISO 3650:1998

Steel gauge blocks:

Serial number	Nominal length (mm)	Thermal expansion coeff. (10^{-6} K^{-1})	Manufacturer
87656	1	11,9	KOBA
87656	5		KOBA
87656	8		KOBA
87623	10		KOBA
87680	25		KOBA
87680	40		KOBA
87680	60		KOBA
87623	90		KOBA

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 (A2, A3).

Measurement item is the central length of the gauge blocks, as defined in the International Standard ISO 3650:1998. The gauge blocks have to be measured by interferometry, in their vertical position wrung to a flat plate. The central length of a gauge block is the perpendicular distance between the centre point of the free measuring surface and the plane surface of an auxiliary plate of the same material and surface texture upon which the other measuring surface has been wrung.

The measurement result to be reported is the deviation of central length from nominal length,

$$\Delta l = l_{\text{measured}} - L_{\text{nominal}}$$

The results of the measurements on both sides (Δl_1 and Δl_2) by wringing each measurement face in turn upon the reference flat and the average of the two wringings have to be reported on the table in the annex A1.

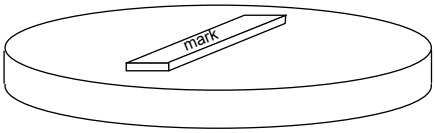


Figure 1a :
Position of the gauge block for Δl_1
The upper face is face 1

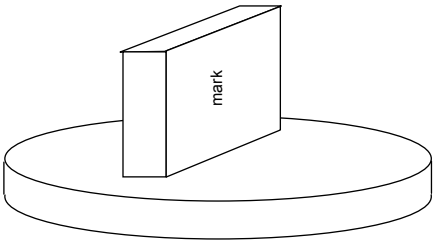


Figure 1b :
Position of the gauge block for Δl_1 ($L > 6$ mm)
The upper face is face 1

The measurement results have to be appropriately corrected to the reference temperature of 20 °C using the thermal expansion coefficients given in this document. Additional corrections have to be applied according to the usual procedure of the laboratory.

5. MEASUREMENT UNCERTAINTY

The uncertainty of measurement shall be estimated according to the *ISO Guide for the Expression of Uncertainty in Measurement (ISO/IEC Guide 98-3:2008)*. In order to achieve optimum comparability, a mathematical model[1] containing the principal influence parameters for gauge block calibration by interferometry is given in the following chapter. The participating laboratories are encouraged to follow this model as closely as possible, however adapted to their instruments and procedures.

[1] Decker J.E., Pekelsky J.R., Uncertainty evaluation for the measurement of gauge blocks by optical interferometry, *Metrologia*, 1997, **34** (6), 479-494.

The length of a gauge block measured by interferometry and fringe fraction determination is described by

$$l = \frac{1}{q}\sum_{i=1}^{q}(\kappa_i + F_i)\frac{\lambda_i}{2n} + \Delta t_g \cdot \alpha \cdot L + \delta l_\Omega + \Delta l_s + \delta l_A + \delta l_G + \delta l_w + \Delta l_\Phi \qquad (1)$$

where:

l length of the gauge block at the reference temperature of 20 °C;

L nominal length of the gauge block;

q number of wavelengths used for the determination of the length based on the method of exact fractions (i = 1, .., q);

k_i integer part of number of half wavelengths within gauge block length (fringe order);

F_i fractional part of fringe order;

λ_i vacuum wavelengths of the different light sources used;

n index of refraction of the air;

Δt_g = (20 - t_g) is the difference of the gauge block temperature t_g in °C during the measurement from the reference temperature of 20 °C;

α linear coefficient of thermal expansion of the gauge block;

δl_Ω obliquity correction for the shift in phase resulting from the angular alignment errors of the collimating assembly, with zero expectation value $\langle \delta l_\Omega \rangle = 0$;

Δl_S aperture correction accounting for the shift in phase resulting from the finite aperture diameter s of the light source : $\Delta l_s = \frac{s^2}{16 f^2} L$ (2)

f is the focal length of the collimating lens;

δl_A correction for wave front errors as a result of imperfect interferometer optics, with zero expectation value $\langle \delta l_A \rangle = 0$;

δl_G correction accounting for flatness deviation and variation in length of the gauge block, with zero expectation value $\langle \delta l_G \rangle = 0$;

δl_W length attributed to the wringing film, with zero expectation value $\langle \delta l_w \rangle = 0$, since the length of the gauge block is defined to include the wringing film;

Δl_Φ phase change accounting for the difference in the apparent optical length to the mechanical length.

The length l of the gauge block being expressed as a function of input quantities x_i

$$l = f(x_i), \tag{3}$$

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

$$u_c^2(l) = \sum_i c_i^2 u^2(x_i), \text{ with } c_i = \frac{\partial}{\partial x_i} \tag{4}$$

In some cases, higher order terms of Eq.(4) might have to be taken into account as well.

The participants are required to report their measurement uncertainty budget in the table of the annex A4, the format according to the example below. Some indicated standard uncertainties, in particular $u(n)$, $u(\delta l_\Omega)$ or $u(\Delta l_\Phi)$, might be based on a separate calculation, which can be added to the report. n_i is the number of degrees of freedom of $u(x_i)$, n_{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 neither complete nor correct).

x_i	$u(x_i)$	n_i	$c_i = \partial l/\partial x_i$	$u_i(l)$
l_1	$5\cdot10^{-9}$	100	L	$0{,}005\cdot10^{-6}\,L$
l_2	$2\cdot10^{-8}$	100	L	$0{,}02\cdot10^{-6}\,L$
F_i (i = 1,2)	0,02 fringe	10	$(l/2)/\sqrt{2}$	4,2 nm
n	$1{,}8\cdot10^{-7}$	100	L	$0{,}18\cdot10^{-6}\,L$
t_g	0,01 °C	100	$a\cdot L$	$0{,}11\cdot10^{-6}\,L$
α *	$0{,}5\cdot10^{-6}$ °C^{-1}	100	$\overline{\Delta t}_g \cdot L$	$0{,}05\cdot10^{-6}\,L$
δl_Ω	10^{-8}	100	L	$0{,}01\cdot10^{-6}\,L$
s (as part of Δl_S)	5 µm	100	$(s/8f^2)\cdot L$	$0{,}002\cdot10^{-6}\,L$
δl_A	3 nm	100	1	3 nm
δl_G	2,5 nm	100	1	2,5 nm
δl_W	6 nm	100	1	6 nm
Δl_Φ	5 nm	10	1	5 nm

The combined standard uncertainty is $u_c(l) = \sqrt{(9{,}7\text{nm})^2 + (0{,}22\cdot10^{-6}L)^2}$

For L = 0,5 mm: u_c = 9,7 nm with n_{eff} = 81
For L = 100 mm: u_c = 24 nm with n_{eff} = 251

* Note that the treatment of $u(\alpha)$ is not rigourously correct, since the expectation value of Δt_g is zero. This term should therefore be treated as a second order term in Eq.(4). In the simplified example above, an average deviation Δt_g from 20 °C of 0,1 °C has been assumed.

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 the annex. Handwritten notes are sufficient.

The measurement report forms in the annex of this document are sent by e-mail (Word document) to all participating laboratories. 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.

Within 3 months after completion of the circulation, the pilot laboratory will prepare a first draft report and send it to the participants for comment.

Measurement results:

Serial. no.	nom. length	central length (deviation from nominal length)			uncertainty (k=1)	eff. deg. of freedom
	L **(mm)**	***Δl1*** **(µm)**	***Δl2*** **(µm)**	***Δl*** **(µm)**	u_c **(nm)**	n_{eff}
87656	1					
87656	5					
87656	8					
87623	10					
87680	25					
87680	40					
87680	60					
87623	90					

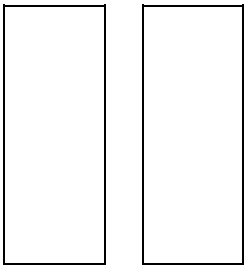
Laboratory : .....

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

Inspection of the measurement surfaces

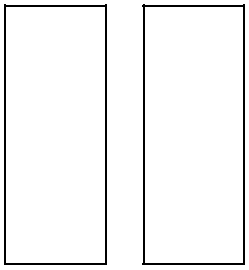
1 mm

face 1 face 2



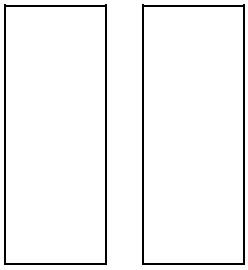
5 mm

face 1 face 2



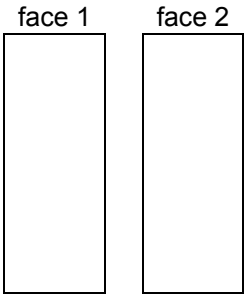
8 mm

face 1 face 2



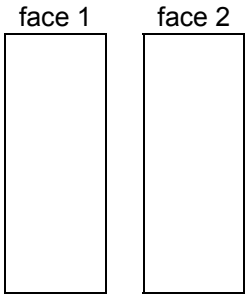
10

face 1 face 2



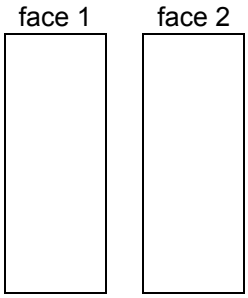
25 mm

face 1 face 2



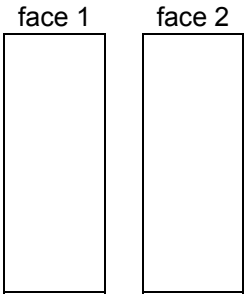
40 mm

face 1 face 2



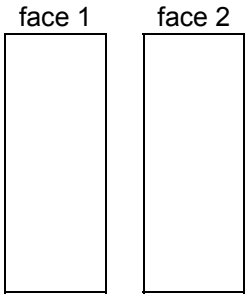
60 mm

face 1 face 2



90 mm

face 1 face 2



Laboratory : .....

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

Description of the measurement instrument

Make and Type of interferometer .....

.....

.....

.....

.....

.....

Light sources / Wave lengths used: .....

.....

.....

.....

.....

Method of fringe fraction determination: .....

.....

.....

.....

.....

Method used for determination of refractive index of the air: .....

.....

.....

.....

.....

Range of gauge block temperature during measurements: .....

.....

.....

.....

Phase correction:

Material of reference platen	Phase correction applied (give range, if applicable)

Laboratory : .....

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

Uncertainty of measurement

x_i	$u(x_i)$	n_i	$c_i = \partial l / \partial x_i$	$u_i(l)$

Combined standard uncertainty (k = 1): $u_c(l) =$

Laboratory : .....

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

Telefax Telefax Telefax Telefax Telefax

To :

LFSB **Tel : ++385 1 6168327**
Vedran Mudronja **Fax : ++385 1 6168599**
Ivana Lučića 1
10000 Zagreb **E mail :**
Croatia **vedran.mudronja@fsb.hr**

From : .....
(participating laboratory)

We confirm having received the standards of the *EUROMET comparison on gauge block measurement* on .....(date).

After visual inspection

☐ no damage has been noticed.

☐ the following damage(s) must be reported :

.....
.....
.....
.....

Date : Signature :

....