Metrology Istitute of the Republic of Slovenia

(Laboratory for Production Mesurement)

EUROMET Key Comparison, EUROMET.L-K7

(EUROMET Project 882)

Calibration of line scales

Technical protocol (Issue 1)

Contents

1 Introduction

1.1 The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.2 At its meeting in October 2005, the TC for Length identified several EUROMET key comparisons in the field of dimensional metrology. In particular, it decided that a key comparison on line standards shall be carried out. This comparison follows the Nano3 comparison (WGDM-7 preliminary comparison on nanometrology).

1.3 Due to the large number of the participants, it has been decided to have 2 groups in the project. The participants for the 2 groups were chosen in accordance with their geographical position (in order to minimize travel times and expenses for the transportation of the standards). Linking laboratories between the groups were chosen among participants in Nano3 project.

1.4 The standards for the comparison were defined at the TCL meeting in October 2005. It was decided that only one line scale of 100 mm with line distance of 0,1 mm will be measured. The 2 groups will get equal standards offered (and produced) by NPL.

1.5 The pilot laboratory for both loops of the comparison is MIRS – LTM (Slovenia).

1.6 The procedures outlined in this document cover the technical procedure to be followed during measurement of the line scales. The procedures are principally intended to allow a clear description of the required measurements, handling and transportation of the circulating standards, and to complete the comparison in the defined time scale. This technical protocol was prepared following the layout principles of the documents for previous comparisons. The allowance to use parts of the prior work wherever possible is gratefully acknowledged.

1.7 A goal of the EUROMET key comparisons for topics in dimensional metrology is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA) [BIPM, 1999]. Therefore, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts.

2 Organisation

2.1 Participants

Laboratory	Address	Contact person/tel/fax/e-mail
BEV	Bundesamt für Eich – und Vermessungswesen Arltgasse 35 AT-1160 Wien Austria	Michael Matus +43 1 49 110 540 +43 1 49 20 875 michael.matus@bev.gv.at
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LNMC	Latvian National Metrology Centre 157, K. Valdemara Str. LV-1013 Riga Latvia	Edite Turka +371 7 362 086 +371 7 362 805 edite.turka@lnmc.lv
METAS	Bundesamt für Metrologie Lindenweg 50 CH-3084 Wabern Switzerland	Felix Meli +41 31 32 33 346 +41 31 32 33 210 felix.meli@metas.ch
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MIRS	University of Maribor Faculty of Mechancal Engineering Smetanova 17 SI-2000 Maribor Slovenia	Bojan Acko +386 2 220 7581 +386 2 220 7990 bojan.acko@uni-mb.si
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NMi-VSL BV	NMi Van Swinden Laboratorium B.V. Thijsseweg 11 P.O. Box 654 NL-2600 AR Delft The Netherlands	Gerard Kotte +31 15 269 16 01 +31 15 261 29 71 gkotte@nmi.nl
NML	National Metrology Laboratory Enterprice Ireland Campus Glasnevin IE-Dublin 9 Ireland	Howard McQuoid +353 1 808 2657 +353 1 808 2026 howard.mcquoid@enterprise-ireland.com
NPL	National Physical Laboratory Hampton Road Teddington, Middlesex TW 11 OLW United Kingdom	Michael McCarthy +44 20 8943 6655 +44 20 8614 0453 michael.mccarthy@npl.co.uk
OMH	National Office of Measures Németvölgyi út 37-39 H-1124 Budapest XII. Hungary	Edit Banreti +36 1 458 59 97 +36 1 458 59 27 e.banreti@omh.hu
PTB	Physikalisch-Technische Bundesanstalt Department 5.2, Length and Angle Metrology Bundesallee 100 DE-38116 Braunschweig Germany	Harald Bosse +49 531 5925200 +49 531 5925205 harald.bosse@ptb.de
SMD	FPS Economy DG Quality and Safety Metrology Division (SMD) Boulevard du Roi Albert II, 16 BE 1000 Brussels Belgium	Hugo Piree +32 2 277 7610 +32 2 277 5405 hugo.piree@mineco.fgov.be
SMU	Slovak Institute of Metrology Karloveská 63 SK-842 55 Bratislava Slovakia	Roman Fira +421 2 602 94 321 +421 2 654 29 592 fira@smu.gov.sk
ZMDM	Bureau of Measures and Precious Metals Mike Alasa 14 YU - 11 000 Beograd Serbia	Slobodan Zelenika +381 11 20 24 418 +381 11 21 81 668 zelenika@szmdm.sv.gov.yu
CENAM	CENAM-Centro Nacional de Metrologia Division de Metrologia Dimensional Km 4,5 Carretera a Los Cues Apartado Postal 1-100 Centro 76241 Queretaro Mexico	Carlos Colin Miguel Viliesid Alonso +52 442 211 05 74 +52 442 211 05 77 colin@cenam.mx mviliesi@cenam.mx

INMETRO	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial Laboratório de Metrologia Dimensional - Lamin - Prédio 3 Av. Nossa Senhora das Graças, 50 Xerém - 25250-020 Duque de Caxias Rio de Janeiro, Brazil	João Antônio Pires Alves +55 21 2679 9107 +55 21 2679 1505 jaalves@inmetro.gov.br
NIM	National Institute of Metrology Length Division Beisanhuandonglu 18 100013 Beijing China	Sitian Gao Tel: +86 10 84251574 Fax: +86 10 64218703 gaost@nim.ac.cn
NIST	National Institute of Standards and Technology Nano-Scale Metrology Group Precision Engineering Division Manufacturing Engineering Laboratory USA	William B. Penzes +301 975 3477 +301 869 0822 william.penzes@nist.gov
NPLI	National Physical Laboratory Physico-Mechanical Standards Length & Dimension Standards New Delhi -110012 India	R.P. Singhal +91-11-25732965 +91-11-25732965 singhal@mail.nplindia.ernet.in
NRC	Institute for National Measurement Standards (INMS) National Research Council Canada (NRC) 1200 Montreal Road Ottawa, ON, Canada K1A OR6	Jim Pekelsky +613 993 7578 +613 952 1394 jim.pekelsky@nrc.ca
NSCIM	National Scientific Center "Institute of metrology" Myronosytskaja st., 42, Kharkov, 61002, Ukraine	Valentin Solovyov +380 57 704-98-77 +380 57 700-34-47 solovyov@metrology.kharkov.ua
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VNIIM	VNIIM - All-Russian Institute for Metrology 19 Moscovsky prosp. RU - 198005 St. Petersburg Russia	Konstantin V.Chekirda +7 812 323 9664 +7 812 713 0114 K.V.Chekirda@vniim.ru

2.2 Groups

Group 1

BEV	Austria
DZHM-FSB	Croatia
GUM	Poland
INM	Romania
JV	Norway
LNMC	Latvia
METAS	Switzerland
MIKES	Finland
MIRS	Slovenia
NCM	Bulgaria
NML	Ireland
NPL	United kingdom
NSCIM	Ukraine
OMH	Hungary
PTB	Germany
SMU	Slovakia
ZMDM	Serbia and Montenegro

Group 2

CMI	Czech Republic
CEM	Spain
CENAM	Mexico
EIM	Greece
INMETRO	Brazil
INRIM	Italy
METAS	Switzerland
NIM	China
NIST	USA
NMi-VSL	Netherlands
NPL	United kingdom
NPLI	India
NRC	Canada
SMD	Belgium
SPRING	Singapore
VNIIM	Russia

2.3 Linking laboratories

Linking laboratories between the two groups will be METAS – CH and NPL – UK. The linking laboratories will measure both artefacts in the beginning and at the end of the loop.

2.4 Form of comparison

2.4.1 The comparison will be performed in a 'circular' form in both groups. The artefact will be circulated within a group of laboratories. Before sending it to the non-EU participants (in the end of each loop), they will be returned to the pilot laboratory in order to prepare the necessary ATA Carnet for the custom formalities.

2.4.2 All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 6 weeks of the completion of the measurements by a laboratory.

2.4.3 The participating laboratories were asked to specify a preferred timetable slot for their measurements of the artefact - the timetables given below have been drawn up taking these preferences into account.

2.4.4 Timetable for the group 1

Laboratory	Country	Date
MIRS	Slovenia	July 2006
METAS	Switzerland	August 2006
NPL	United kingdom	September 2006
OMH	Hungary	October 2006
BEV	Austria	November 2006
SMU	Slovakia	December 2006
PTB	Germany	January 2007
GUM	Poland	February 2007
MIKES	Finland	March 2007
JV	Norway	April 2007
LNMC	Latvia	May 2007
NML	Ireland	June 2007
The artefact shall be sent to MIRS – SI for shipment to non-EU group (ATA)!!		
NCM	Bulgaria	July 2007
INM	Romania	August 2007
ZMDM	Serbia and Montenegro	September 2007
DZHM-FSB	Croatia	October 2007
NSCIM	Ukraine	November 2007
METAS	Switzerland	December 2007
NPL	United kingdom	January 2008

2.4.5 Timetable for the group 2

Laboratory	Country	Date
METAS	Switzerland	August 2006
NPL	United kingdom	September 2006
CMI	Czech Republic	October 2006
EIM	Greece	November 2006
INRIM	Italy	December 2006
NMi-VSL	Netherlands	January 2007
CEM	Spain	February 2007
SMD	Belgium	March 2007
The artefact shall be sent to MIRS – SI for shipment to non-EU group (ATA)!!		
INMETRO	Brazil	April 2007
CENAM	Mexico	May 2007
NIST	USA	June 2007
NRC	Canada	July 2007
SPRING	Singapore	August 2007
NIM	China	September 2007
NPLI	India	October 2007
NPL	United kingdom	November 2007
METAS	Switzerland	December 2007
VNIIM	Russia	January 2008

2.4.6 Each laboratory has one month for calibration and transportation. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the time allocated to it. It guarantees that the artefact arrives in the country of the next participant at the beginning of the next month.

2.4.7 If for some reason, 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 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.

2.5 Handling of the artefact

2.5.1 The artefact shall be examined immediately after receipt. The condition of the artefact shall be noted (a microscope image or a drawing) and all discrepancies communicated to the pilot laboratory. The fax form in Appendix A.3 should be used for this purpose.

2.5.2 The artefact should only be handled by authorized persons and stored in a proper way in order to prevent damages.

2.5.3 The artefact shall be examined before dispatch and any change in condition during the measurement shall be communicated to the pilot laboratory.

2.5.4 Please inform the pilot laboratory and the next laboratory via fax or e-mail when the artefact is about to be sent to the next recipient.

2.5.5 The artefact shall be packed according to the instructions in the package. Ensure that the content of the package is complete before shipment. Always use the original packaging.

2.6 Transport of the artefact

2.6.1 It is of utmost importance that the artefact is transported in a manner in which it will not be lost, damaged or handled by un-authorised persons.

2.6.2 Packaging for the artefact is suitably robust to protect the artefacts from being deformed or damaged during transit. The artefact is in an original NPL wooden box, which is put into a robust suitcase (See Fig. 1). The suitcase is in a cardboard box.

Fig. 1: Scale containers

Note: If the cardboard box is significantly damaged, it should be replaced before sending the package to the next participant!

2.6.3 The package shall be marked as 'Fragile'.

2.6.4 The artefact will be accompanied by a suitable customs carnet (where appropriate) and documentation identifying the contents. **The ATA carnet shall always be shipped with the package, never inside the box, but apart. Please be certain, that when receiving the package, you also receive the carnet! Every time the carnet is used, it is stamped TWICE – on exit from one country and on entry into the next. In this regard, the EU member states are considered as being one country. Please examine the carnet and assure that the transportation company used has arranged for correct stamping of the carnet. Failure to ensure both stamps (exit, entry) subjects the carnet holder to a penalty.**

The ATA carnet is kept by the pilot during the circulation within EU countries. Pilot will provide the ATA CARNET for the shipment outside EU.

2.6.5 Transportation is each laboratory's responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges as well as for any damages that may have occurred within its country. The overall costs for the organisation, initial and interim measurements and the processing of results are covered by the organising pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

3 The artefact

3.1 Description of the artefact

At the Euromet TCL meeting in October 2005 in Bucharest it has been decided to measure a 100 mm quarz scale with 0.1 mm pitch. The artefact has been produced by NPL. Its basic purpose is to serve as a standard in precise industrial calibrations. The artefact is shown in Fig. 2.

Fig. 2: NPL line scale

The width of the scale lines is approx. 10 μm. The scale is provided by two parallel horizontal lines at the beginning and at the end of the scale. The distance between those 2 lines is approx. 50 μm. Some details of the scale can be seen in Fig. 3.

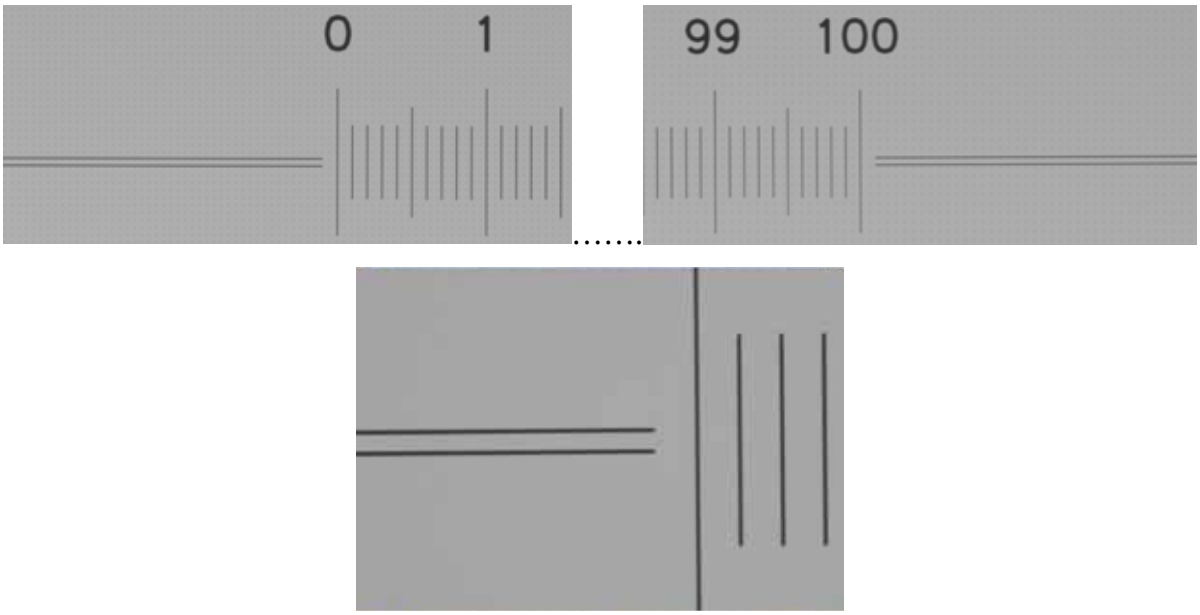

Fig. 3: Details of the scale

Equal artefacts will be used in both groups. The artefact for group 1 is marked with engraved letter “A” and the artefact for group 2 with “B”. The marks are in the right lower corners of the artefacts. The boxes are marked in the same manner with stickers.

Dimensions of the artefact are presented in Fig. 4.

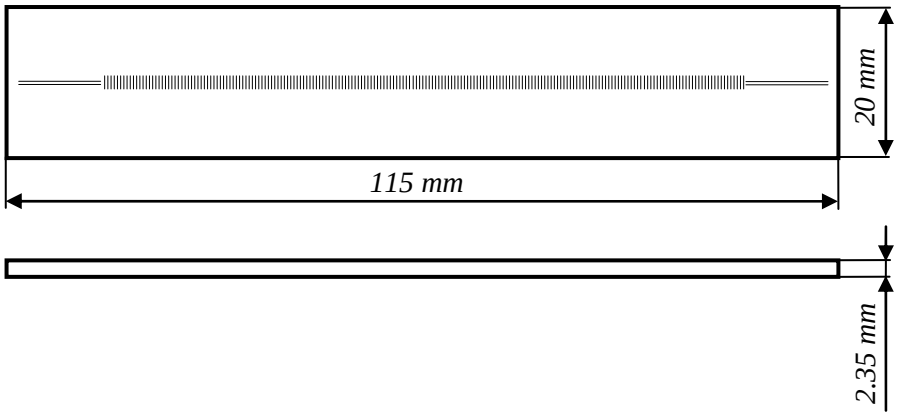

Fig. 4: Dimensions of the artefact

3.2 Fixing the artefact

The artefact will be shipped without any special mounting fixtures. It is recommended to support the measurement objects at the Airy points (distance of x = 0.2113·L from both ends), held only by their gravity forces. It is not allowed to use any type of glue or wax for mounting the scale. If additional clamping of the scale is required during measurement, e.g. because of a fast moving carriage, it is recommended to lightly pinch the scale on the sides at one of the Airy support points. If other support or clamping conditions were applied during measurement, it is the responsibility of the participant to refer his results to the Airy point support conditions.

3.3 Handling

General handling (see also 2.5!):

Open the transport container carefully and only in clean environment. Use clean room gloves to handle the scale and **never** touch the scale with bare fingers. It is not allowed to use any type of glue or wax for fixing the scale. When not in use, place the scale back into its container to avoid dust or dirt deposits.

Cleaning:

If it is necessary to clean the scale before the measurement, please use only alcohol or soap solution. It is also important to use very soft cleanroom materials. Clean compressed air shall be used for blowing dust away.

All cleaning activities should be performed with special care (very gently) in order to avoid mechanical damages!

Storage:

Use original transportation container to avoid dust deposits. Always try to keep the artefact under good measuring room conditions, i.e. within the room, where they get calibrated.

4 Measurement instructions

4.1 Traceability

4.1.1 Length measurements should be traceable to the latest realisation of the metre as set out in the current "*Mise en Pratique*".

4.1.2 Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

4.2 Measurand

Measurand is the distance between the center line position of the reference line (position "0") and the center line position of the measured line (Fig. 5). To increase comparability of the results, all measurements should be performed over the section between the two horizontal lines (at the beginning and at the end of the scale) with a width of approx. 50 µm. That is, it should be tried to apply an effective slit height or CCD image window **height of 50 µm** for the analysis of measurements. If the effective height cannot be set exactly to 50 µm, a value close to it should be chosen.

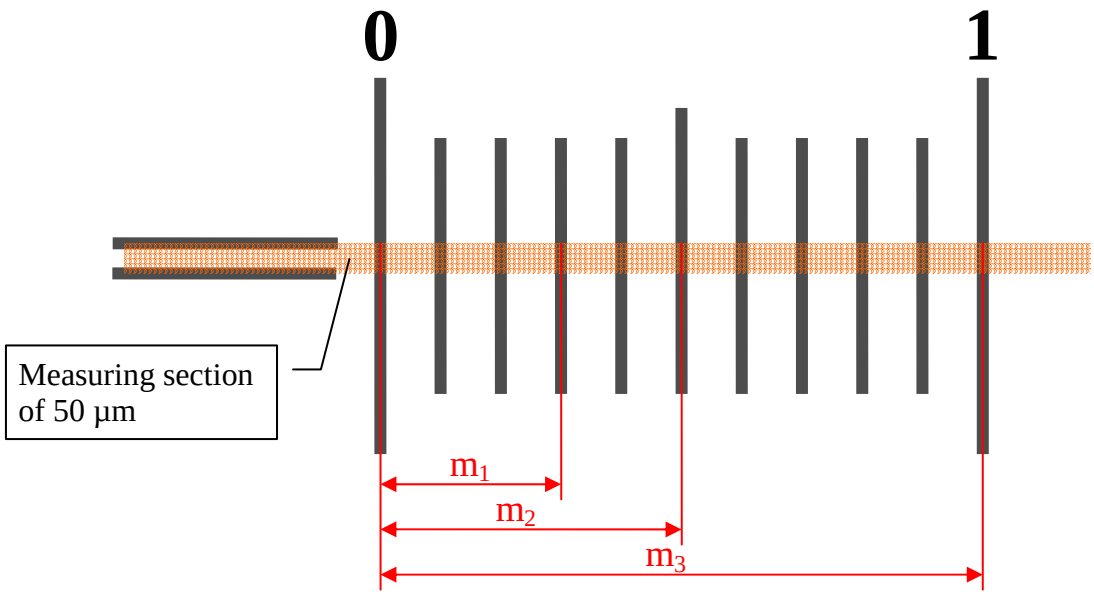

Fig. 5: Measurand (m_1, m_2, m_3) and measuring section

Table 1: The lines (distances) to be measured:

Nominal lengths in mm									
0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5	10	15	20	25	30	35	40	45	50
55	60	65	70	75	80	85	90	95	100

Measurement conditions:

The positions of the lines have to be determined as the **centre line positions**[1] of every line, while the scale is lying on the Airy points (see 3.2). The participants are asked to describe the way the position of the line was determined.

For alignment purposes of the graduation lines the upper horizontal lines at the beginning and at the end of the scale shall be used.

The measured values have to be referred to the following reference conditions:
- temperature of 20 °C (ITS-90),
- pressure of 1013,25 hPa (1013,25 mbar).

If necessary, corrections have to be applied based upon the following parameters:

Quartz:
- Thermal expansion coefficient: ..... $\alpha = 5 \cdot 10^{-7}\ K^{-1}$
- Length compressibility: ..... $\kappa = -\ 8.9 \cdot 10^{-7}\ bar^{-1}$

4.3 Measurement instructions

4.3.1 The calibration should be carried out as for a normal customer. The participants are free to choose their own method of measurement. However, under the assumption that the value of the measurand is a true property of the material measure of length, only one result for a measurand shall be given irrespective of the number of different measurement methods used. For each method applied, a complete description of the method has to be given. A detailed estimation of the measurement uncertainty according to the *ISO Guide to the Expression of Uncertainty in Measurement (GUM)* has to be supplied (see Appendix 3).

4.3.2 The measurements have to be reported for measuring conditions, given in 4.2.

4.3.3 Before calibration, the scale must be inspected for damages. Any scratches, dirty spots or other damages have to be documented (for handling and reporting discrepancies see 2.5!)

4.3.3 The measurement results (appropriately corrected to the reference conditions) have to be reported using the table in Appendix A.1.

4.3.4 No other measurements are to be attempted by the participants and the artefacts should not be used for any purpose other than described in this document. The artefacts may not be given to any party other than the participants in the comparison.

4.4 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. In order to achieve a better comparability, some possible influence parameters and notations are given in the following paragraph. The participants are encouraged to use all known and significant influence parameters for their applied methods. The following list can be used as an indication of possible influence parameters:

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[1] The key comparison guideline states, that the methods usually applied by the participants for calibrations should also be used within the comparison. Because different line center extraction algorithms will normally be used by the participants, it is essential that the different procedures are well described and that edge detection influences are accounted for in the uncertainty estimation. A possible edge detection algorithm e.g. is the arithmetic mean of left and right edge positions if those are explicitly measured (e.g. at 50% threshold) or the centroid of 2D image intensity data.

Possible contributions from **line position sensing** technique:

δ_{Eres} Resolution of edge detection

s_E Repeatability of edge detection

δ_{Edef} Edge geometry influence (roughness, parallelism)

δ_{lpos} Influence of adjustment of measurement line

δ_{lwin} Influence of adjustment of measurement window or slit length

δ_{Efoc} Influence of focal length variation

$\delta_{E\lambda}$ Influence of detection light wavelength

δ_{Epol} Influence of detection light polarization

δ_{Ecoh} Influence of detection light coherence

Mag Microscope magnification (or other position deviation sensing device)

δ_{Enon} Nonlinearities of position sensing technique

δ_{Ealig} Microscope axis alignment

δ_{Ealg} Influence of line edge detection algorithm, possible asymmetry of line profiles, line shape

δ_{Erev} Influence of measurement in reversed orientation

Possible contributions from interferometric **displacement measurement** technique:

λ_o vacuum wavelength of light source used for displacement measurement

n_{air} Index of refraction of air[2]

t_{air} Air temperature

p_{air} Air pressure

RH_{air} Air humidity

c_{CO2} Air CO_2 concentration

δl_{Res} Interferometer resolution

δl_{NL} Interferometer nonlinearity (polarisation mixing, etc.)

δl_{DP} Interferometer dead path influences (temperature variation, etc.)

δl_{MP} Variation of measurement path in one orientation (normal, meander, random, ..)

δl_{Drift} Drift influence (forward, backward measurement)

δl_{Rev} Influence of measurement in reversed orientation

δl_{Ai} Errors due to Abbe offsets and pitch and yaw of translation stages

δl_{Si} Errors of scale alignment

δl_{Ii} Cosine errors of interferometer alignment

Possible contributions from **scale properties**:

$\alpha_{Z,\,Cr}$ Linear coefficient of thermal expansion of scale material

Δt_s = (t_s - 20) is the difference of the scale temperature t_s in °C during the measurement from the reference temperature of 20 °C

[2] If the index of refraction is determined by the parameter method according to Edlen, the updated version of the formula should be applied as published in: G. Bönsch, E. Potulski, Metrologia, 1998, **35**, 133-139. The estimated combined standard uncertainty of the quoted formula itself is $1*10^{-8}$.

$\kappa_{Z,\,Cr}$ Linear coefficient of compressibility of scale material

δh Flatness deviation of scale graduation surface

δ_{supp} Influence of support conditions

The deviations *dl* from nominal length have to be measured and to be expressed as a function of input quantities x_i

$$\mathrm{dL} = \mathrm{f}(\mathrm{x_i}), \tag{1}$$

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

$$\mathrm{u_c}^2(\mathrm{dL}) = \sum_{\mathrm{i}} \mathrm{c_i}^2 \mathrm{u}^2(\mathrm{x_i}), \mathrm{with} \mathrm{c_i} = \frac{\partial \mathrm{dL}}{\partial \mathrm{x_i}}. \tag{2}$$

In some cases also higher order terms of equation (2) might have to be taken into account. If correlation between input quantities is present the correlation coefficients should be considered.

The participants are required to report their measurement uncertainty budget in the table of the Appendix A.2 with the format according to the scheme below. "Distrib." is the type of distribution of the input quantity (N=normal, R=rectangular, T=triangular, etc.), ν_i is the number of degrees of freedom of $u(x_i)$. Some indicated standard uncertainties, might be based on a separate calculation, which can be added to the report.

Example scheme:

Input quantity x_i	Distrib.	$u(x_i)$	ν_i	$c_i = \partial dL / \partial x_i$	$u_i\,(dL)$ / nm
Edge detection reproduc. s_E	N	3 nm	10	1	3
Cosine error scale alignment	R	140 µrad	>100	-	$10^{-8}\,L$
...	...	...	...	...	...

4.5 Transmission of results

4.4.1 As soon as possible after measurements have been made, the results should be communicated to the pilot laboratory and at the latest within six weeks.

4.4.2 The measurement report forms in Appendix A.1 of this document will be 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 co-ordinator. **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 definitive version.

4.4.3 Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. The procedure outlined in the BIPM '*Guidelines for CIPM key comparisons'* and EUROMET Guide 3 will be followed.

A.1 Measurement results

I. Short description of the instrument / measurement method

(Use more sheets if necessary, enclose photo(s) and/or sketch(es) of the instrument)

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.....

.....

.....

.....

II. Measurement results

Nominal length L (mm)	Measured deviation dL (nm)
0	0, per definition
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	
5	
10	
15	
20	
25	

Nominal length L (mm)	Measured deviation dL (nm)
30	
35	
40	
45	
50	
55	
60	
65	
70	
75	
80	
85	
90	
95	
100	

Laboratory:.....

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

A.2 Uncertainty of measurement

Input quantity x_i	Distrib.	$u(x_i)$ unit	ν_i	$c_i = \partial dL / \partial x_i$	$u_i\,(dL)$ / nm

Combined standard uncertainty: $u_c(L)$ =

Effective degree of freedom: $\nu_{eff}(dl)$ =

Expanded uncertainty: $U_{95}(dl)$ =

Laboratory: .....

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

A.3 Receipt confirmation

FAX

To:

Bojan Acko

tel.: +386 2 220 7581

fax:+386 2 220 7990

bojan.acko@uni-mb.si

University of Maribor – Faculty of Mechanical Engineering

Laboratory for Production Measurement

Smetanova 17

SI – 2000 Maribor

Slovenia

From: (participating laboratory)

We confirm the receipt of the artefact for the *EUROMET key comparison on line scale* on .....(date).

After visual inspection

o no damage has been noticed;

o the following damage must be reported:

.....

.....

.....

.....