MEDLABORATORIJSKA PRIMERJAVA KOT VIR INFORMACIJ O TEŽAVAH

INTERLABORATORY COMPARISON AS A SOURCE OF INFORMATION ABOUT THE PROBLEM

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IZVLEČEK

Metode vrednotenja rezultatov medlaboratorijske primerjave so predpisane s standardi ISO. Ravnilo je verjetno eden izmed najbolj uporabljanih dolžinskih merilnih instrumentov na svetu. Za laboratorije, ki želijo biti akreditirani za umerjanje ravnila, pridobitev specializirane merilne mize ni ekonomsko smiselna. Zaupanje v izmerjeni rezultat je odvisno od merilne negotovosti, kjer pa se opazijo pomanjkljivosti, je treba raziskati vrednosti, ki prispevajo k merilni negotovosti. V tem prispevku je opisana medlaboratorijska primerjava za majhno število laboratorijev na primeru merilne klopi za umerjanje ravnila, opisan je postopek za identifikacijo morebitnih težav in diagnostika vzrokov; upoštevanje rešitev; začetek ukrepanja za izboljšanje in spremljanje rezultatov uporabnih rešitev. Avtorji so dokumentirali težavo in našteli elemente, ki so prispevali h končni oceni medlaboratorijskih primerjav »nezadovoljivo«. Opisali so ukrepe, ki so jih predvideli za izboljšanje rezultata »nezadovoljivo«, analizirali, ali so predlagane rešitve prispševale k oceni »zadovoljivo«, in sprejeli ustrezne ukrepe. V prispevku so predstavljeni rezultati mednarodne medlaboratorijske primerjave, ki pričajo o usposobljenosti osebja, ustreznosti merilne kalibracijske opreme in metode kalibracije.

ABSTRACT

Methods of evaluation of interlaboratory comparison results are prescribed by ISO standards. Ruler is probably one of the most widely used length measuring instrument in the world. For laboratories that plan to be accredited for the calibration of Ruler, the acquisition of a specialized Measuring bench is not economically feasible. Confidence in the measured result depends on the measurement uncertainty, and where deficiencies are observed, the values that contribute to the measurement uncertainty should be investigated. This paper describes an interlaboratory comparison for a small number of laboratories on the example of a Measuring bench for calibrating Ruler and indicates the procedure for problem identification; diagnosis of causes; consideration of solutions; initiation of action for improvement and monitoring of the results of applied solutions. The authors documented the problem and listed the elements that contributed to "Unsatisfactory" result in interlaboratory comparisons. They described the actions they took to overcome the "Unsatisfactory" result, analyzed whether the proposed solutions led to "Satisfactory" result and took actions accordingly. The paper presents the results of the international interlaboratory comparison, which are a confirmation of the competence of the personnel, measuring calibration equipment and calibration method.

KLJUČNE BESEDE

akreditacija, kalibracija, medlaboratorijska primerjava (ILC), sodelujoči laboratorij, ravnilo, merilno linearno merilo, merilna negotovost

KEY WORDS

accreditation, calibration, interlaboratory comparison (ILC), participant laboratory, ruler, measuring linear scale, measurements uncertainty

1 INTRODUCTION

A successful system of metrology implies the application of international and national standards. "When there is a national metrology system and measurement standards are used throughout a country, then it is necessary to establish trust in the measurements and in the competence of the laboratory. Therefore, accreditation is needed to provide confidence in a laboratory's competence to make measurements and generate trust in the use of the measurement results. Accreditation is a thirdparty attestation that a laboratory has demonstrated competence to carry out specific measurements" (Tholen, 2011). The activities related to conformity assessment are carried out by bodies that meet requirements described in the ISO/IEC 17000 family of standards. Quality control means participation in proficiency testing programs or in interlaboratory comparisons. "Proficiency testing (PT) is the evaluation of participant performance against preestablished criteria by means of interlaboratory comparisons" and "Interlaboratory comparison (ILC) is the organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories or inspection bodies in accordance with predetermined conditions" (ISO/IEC 17043, 2010), (ISO 13528, 2022).

Competent calibration in the laboratory is supported by the accreditation of the laboratory and the application of standard calibration procedures. PT and ILC are indispensable tools for the development and maintenance of the infrastructure of modern society. It is a significant tool in detecting problems related to Resource requirements: Personnel, Facilities and environmental conditions, Equipment and Metrological traceability, which Standard ISO/IEC 17025 states in Chapter 7.7.2.: "The laboratory shall monitor its performance by comparison with results of other laboratories... a) participation in proficiency testing, b) participation in interlaboratory comparisons other than proficiency testing" (ISO/IEC 17025, 2017). The results obtained in the ILC for evaluating the performance of the participant's laboratories are processed according to the evaluation strategy ISO/IEC 17043: "B.4. Calculation of performance statistics"(ISO/IEC 17043, 2010) and the results are designated as "Satisfactory" or "Unsatisfactory".

In this paper, the authors, on the example of the accreditation of the Coordinate Metrology Laboratory in Belgrade (LKM-Belgrade) for calibration of line scale in the Republic of Serbia have: Discussed the way to demonstrate its competences, the possibility of performing measurement and standardization; Showed how to perform a search in the database of key comparisons of the KCDB for the area from the Scope of Accreditation; Described the measuring equipment at their disposal; Took part in an international ILC and presented the procedure for its realization; Identified the problem for the obtained measurement results and undertake an action for its improvement; Eliminated problems and confirmed the competence of the LKM-Belgrade.

Interlaboratory research plays an essential role in ensuring the quality of laboratory testing. The growing interest in this topic reflects the scientific literature (Voiculescu, Olteanu, & Nistor, 2013), (Allard and Amarouche, 2017), (Berk Sönmez, Oytun Kılınç, Ahmet Yüksel and Sinem Ön Aktan, 2019), (Briggs,2012). In accordance with the ISO/IEC 17025 standard, each laboratory participating in the ILC performs measurements with the same means of measurement and on the same measurement position, in order to determine the characteristics of the means of measurement according to previously agreed conditions.

National Metrology Institutes (NMIs) have set strict requirements for the accreditation of testing and calibration laboratories. By participating in proficiency testing programs, the laboratory should demonstrate and ensure the quality of calibration results. "In the case of a lack of proficiency tests because of, for example, the technical characteristics of the measurement or the low number of existing laboratories in the sector, other methods of assuring quality are accepted. However, ILCs are preferred by accreditation bodies.

This is the reason why interlaboratory comparisons are organized..." (Szewczak, Bondarzewski, 2016).

"Interlaboratory comparisons are a form of experimental verification of laboratory activities to determine technical competence in a particular activity. Successful results of conducting ILCs for the laboratory are a confirmation of competence in carrying out certain types of measurements by a specific specialist on specific equipment." (Velychko, Gordiyenko, 2022).

2 DEMONSTRATION OF COMPETENCES

"Measurement is in most cases not an end in itself, but rather provides the means to make objective decisions, such as "do the new set of measurements differ from previous measurements?" or "do measurements show that a product satisfies requirements?" (Pendrill, 2014). Calibration laboratories aim to provide reliable information on the verification of the metrological characteristics of the measuring instrument and tools being calibrated. The standards used by mechanical engineers, geodesists, civil engineers, architects and other professionals, must be calibrated to ensure traceability and avoid various discrepancies and problems.

Accreditation is defined as a set of activities that the Accreditation Body of Serbia (ATS) undertakes to ensure, with an appropriate degree of confidence, the competence of the laboratory to provide services within the defined Scope of Accreditation. When applying for accreditation, in order to prove the competence of the Calibration Laboratory, the subdisciplines and dynamics of participation in programs for PT or ILC are prescribed. It is necessary to provide a "Satisfactory" result of the laboratory participating in ILC with the NMIs or other Designated Institutes (DIs), which has a published Calibration Measurement Capabilities (CMCs) for the given field of calibration in the International Committee for Weights and Measures (CIPM) Mutual Recognition Agreement (MRA) database - KCDB (URL 1).

An ILC in the field of Dimensional metrology is planned for the successive calibration technique. Successive calibration implies that Participant laboratories (Participant), one after the other, perform calibration of the same measurement sample in the established order. Traditionally, the results obtained in an interlaboratory comparison are transformed into Number, which is calculated as follows:

$$E_n = \frac{(x - X)}{\sqrt{U_x^2 - U_X^2}} \tag{1}$$

where: U_x^2 is estimate of the standard uncertainty from the result from the Participant, U_X^2 is standard uncertainty from the reference assigned value, with the interpretation of the results:

$$|E_n| \leq 1 \tag{2}$$

$$|E_n| \geq 1 \tag{3}$$

where: Equation (2) generates a "Satisfactory" result, while Equation (3) generates an "Unsatisfactory" result (ISO/IEC 17043. 2010), (Gučević, Vasović Šimšić, Delčev, Kuburić, 2022). "The E_n the ratio should usually be within the range ± 1. If the analysis reveals that it lies outside this range, results are labelled as unsuccessful. So, it is expected to investigate the results and require that any necessary corrective and preventive actions are undertaken. The assessment team will assess the activities of the laboratory in resolving any issues." (Durgut, 2021).

When a laboratory (e.g. LKM-Belgrade) plans to submit a Request for accreditation in the field of Dimensional metrology, it itself approaches the search for a Reference Laboratory that has published CMCs for the given field. Performing a search in the KCDB (URL 1), for NMIs and DIs that have published CMCs means: *Select Metrology Area* > *General physics* > *Length* > *Dimensional metrology*.

Under the conditions of modern business, laboratories are faced with various factors and limitations related to resources. The costs of successive calibration include the transport of the same measuring sample, so savings in transport costs are achieved by selecting countries and regions for search in the KCDB. With a simple query to the KCDB, a search was performed and it was established that the competence from the proposed Scope of Accreditation can be proved by ILC with:

– Faculty of Mechanical Engineering and naval architecture, Laboratory for precise measurement of length (FSB-LPMD) from Croatia (URL 2);
– MIRS/University of Maribor, Faculty for Mechanical Engineering/Laboratory for Production Management (MIRS/UM-FS/LTM) from Slovenia (URL 3).

3 EQUIPMENT FOR THE REALIZATION OF MEASUREMENTS

Equipment procured for calibrations must be able to achieve the measurement uncertainty required to obtain a valid result from the proposed Scope of Accreditation. The correct performance of the laboratory calibration activities of the Length measure also entailed the acquisition of an adequate Linear Scale Digital Readout (DRO) System. In the process of purchasing Length calibration equipment, the laboratory LKM-Belgrade purchased Mitutoyo's Linear Scale System AT103 Model, No. A1737292; Standardsize Type; Accuracy: Highaccuracy type $(3 + 3 \cdot L_0/1000)$ µm; Effective range: 1100 mm (Catalog No. E13000(5)). To identify the measured length of Linear Scale DRO Systems, a Mitutoyo KA Counter, type KA-212, was purchased Resolution: With AT100 series: 0.05 - 0.0001 mm. Digital relative humidity & temperature sensor RHT03 was purchased to measure the measuring means temperature and air pressure with the accuracy: humidity ± 2% RH (Max ± 5% RH) and temperature ± 5° C. The entire system is installed on the Measuring bench presented in Figure 1.

Mitutoyo's Linear Scale System Model AT103 No. A1737292 is calibrated in NMI of the Republic of Serbia: Directorate of Measures and Precious Metals (DMDM). Note: The calibration of Mitutoyo's Linear Scale System was performed without a Measuring bench, in the premises of DMDM. "The Directorate of Measures and Precious Metals, as a competent state organ ensuring traceability of measurement results in Serbia, calibrates measurement standards and measuring instruments in order to disseminate the value of a unit of the physical quantity the level of measurement uncertainty of which shall be as low as possible." (URL 4).

Figure 1: Measuring bench (LKM-Belgrade)

3.1 The procedure for the implementation of interlaboratory comparison

Due to limited possibilities and relatively scarce regional capacities in terms of realized CMCs, Interlaboratory comparison as an essential requirement of laboratory practice was agreed with the laboratory: FSB-LPMD. LKM-Belgrade and FSB-LPMD signed the Technical Protocol for ILC. The aim of this bilateral comparison was to confirm the Laboratory's metrological capabilities in the process of calibrating measuring rods. The Ruler of the laboratory FSB-LPMD manufactured by Meba was chosen as the means of measurement (Figure 2). Meba Ruler has the measuring area from 0 mm to 300 mm and reading resolution of 1 mm.

Figure 2: Meba Ruler

The Technical protocol for ILC foresees 10 measuring places (line scale), every 30 mm. Measured values (li) represent the distances between the middle of the reference line (position "0" on the Ruler) and the middle of the line of the measured position, that is, the middle of the line of the nominal value, as shown in Figure 3.

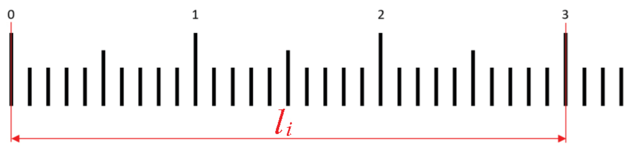

Figure 3: Measuring positions (l_i)

The results of the organizers of the Interlaboratory comparison: FSB-LPMD, were declared as reference values for this comparison. The obtained results in the ILC were transformed into Number E_n (Equation (1)) and then conclusions were drawn. Laboratory LKM-Belgrade measured in 3 days (three series of measurements). The measurement was carried out as "Forward", where after the last nominal value (300 mm) was read, the initial nominal value was read again (0 mm). Each measuring line scale (L [mm]: 0; 30; 60; 90... 300; 0) was read 5 times at three different starting measurement points (m) of Mitutoyo's Linear Scale: 0 mm, 300 mm and 700 mm. After the measurements in the LKM-Belgrade were finished, the processing of the measurement results began and included the following calculation of:

Mean values from a larger number of readings as follows:

$$l_{(j)} = \frac{\sum_{1}^{n} l_i}{n}, \quad i = 1, \ \ldots n. \tag{4}$$

Mean values of readings on one dividing line of the examined Ruler for all initial measurement points (L) m of Linear Scale as follows:

$$l_{av(j)} = \frac{\sum_{1}^{m} l_{(j)}^{(LS)}}{m}, \quad LS = 1, \ \ldots m. \tag{5}$$

Definitive reading of the bar/line was calculated by adding corrections of each measurement for Ruler temperature deviation from 20° C (v_{temp}) and adding corrections for the linear scale from the Calibration Certificate (v_{LS}) as follows:

$$l_{def(j)} = \frac{\sum_{1}^{s}\left(l_{av(j)} + v_{temp} + v_{LS}\right)^{(series)}}{s}, \; series = 1, \; ....s \tag{6}$$

where: l_i single line scale measurement (j) of the Ruler, j number of measured line scale of the Ruler, n number of readings per one lines scale of the Ruler, $l_{(j)}$ the mean value of the line scale reading (j) of the examined Ruler, for a total of k line scales that are examined, $l_{(j)}^{(LS)}$ line scale reading (j) of the examined Ruler, for the initial measurement point (LS) of the Mitutoyo's Linear Scale System Model AT103, $l_{av(j)}$ intermediate reading of the line scale (j) of the examined Ruler for a total of m starting places of the Mitutoyo's Linear Scale System Model AT103 No. A1737292, (v_{temp}) correction for temperature deviations, (v_{LS}) correction for linear scale of the Mitutoyo's Linear Scale System Model AT103 No. A1737292 from the Calibration Certificate, $l_{def(j)}$ definitive reading of the line scale (j) of the examined Ruler for the total number of Series s = 1, 2, 3.

Note: In all three series of measurements, the difference between the values at 300 mm and the other two positions (0 mm and 700 mm) was many times greater than the measurement error, so the values for the initial measuring position of Mitutoyo's Linear Scale System Model AT103 No. A1737292 of 300 mm were excluded from further processing of the measurement results. After rejecting the mentioned measurements, mean values from the remaining results were calculated (Equation (6)) and they were adopted as definitive measurements.

"When the results reported in the comparisons, it is necessary to state the estimated measurement uncertainty." (Medić, Kondić, Runje, 2012). Since each line scale $l_{(j)}$ was read 5 times (n = 5), from the deviation of individual measurements from the arithmetic mean $\overline{l}_{(j)}$ the mean errors of individual measurements were calculated as follows:

$$\sigma_i = \sqrt{\frac{\sum\left(\overline{l}_{(j)} - l_{(j)}\right)^2}{n-1}}, \quad i = 1, \; ...n. \tag{7}$$

According to the described procedure, readings were made on: k = 12 measuring places of the examined Meba Ruler (L [mm]) (j = 1, …k); and on m = 2 on two initial measuring points of Mitutoyo's Linear Scale System (0 mm and 700 mm); and a total of 24 readings of $l_{av(j)}$ were obtained in one Series of measurements. Accordingly, for three Series (s = 3, Series = 1, 2, 3) this amounts to a total of 72 measurements $l_{def(j)}$ on examined Meba Ruler.

The total mean error of a single measurement σ_{av} was calculated as:

$$\sigma_{av} = \sqrt{\frac{\sum \sigma_i^2}{(k \cdot m \cdot s)}} = 3{,}61 \; \mu\text{m}. \tag{8}$$

Total mean error of a single measurement (Equation (8)) and a measurement uncertainty u_{LS} from the Calibration Certificate, Mitutoyo's Linear Scale System, calculated as:

$$u_{LS} = (3 + 2{,}1 \cdot L_{[\text{m}]})\mu\text{m} \tag{9}$$

were used to calculate the total measurement uncertainty of a single measurement L, as the following:

$$u^2 = \sigma_{av}^2 + u_{LS}^2. \tag{10}$$

The measurement uncertainty calculation was performed using the procedure and equations prescribed in the standard ISO 17123-4:2012, Part 4: Electrooptical distance meters (EDM measurements to reflectors) (ISO 17123-4, 2012). Extended measurement uncertainty (*U*) is calculated as:

$$U = 2 \cdot u \; [\mu m]. \tag{11}$$

3.2 The procedure for the implementation of interlaboratory comparison

Report on calibrating Meba Ruler, done by LKM-Belgrade, was forwarded to the organizer of an interlaboratory comparison: FSB-LPMD. The FSB-LPMD reference laboratory processed the measurement results further and produced the Final Report of ILC shown in Table 1. The results of ILC show that in 5 out of 10 cases the Number E_n was greater than 1 (Table 1.), which leads to an "Unsatisfactory" result (Equation (3)) that is not favorable for LKM-Belgrade.

Table 1: Final Report of an interlaboratory comparison between LKM-Belgrade and FSB-LPMD

L [mm]	The absolute difference [μm]	$U_{LKM-Belgrade}$ [μm]	$U_{FSB-LPMD}$ [μm]	E_n
30	0.6	9.50	8.0	0.19
60	0.7	9.62	8.0	0.06
90	9.2	9.74	8.0	0.73
120	12.2	9.86	10.0	0.87
150	11.6	9.98	10.0	0.82
180	16.9	10.10	10.0	**1.19**
210	16.3	10.24	10.0	**1.14**
240	-19.8	10.38	12.0	**1.24**
270	-22.2	10.50	12.0	**1.39**
300	-23.5	10.64	12.0	**1.47**

4 IDENTIFICATION OF PROBLEMS

Upon receiving the "Final report interlaboratory comparison" made by FSB-LPMD, LKM-Belgrade established that it had a problem and set out to identify the root causes of its occurrence. LKM-Belgrade divided the problem into components related to personnel, resources, and equipment and set about gathering facts. First step made by LKM-Belgrade was to contact DMDM, with a request to clarify how the measurement and calibration of Mitutoyo's Linear Scale System Model AT103 No. A1737292 equipment was performed. In the conversation with the metrologist who performed the calibration, it was determined that the measurements were done in the opposite direction (from 1100 mm - 0 mm), which means that the corrections from the Calibration Certificate refer to other values of the linear scale position than those entered (by Equation (9)) in measurement results. Also, it was recorded that these differences depend on the direction of measurement ("Forward" or "Backward") and that they are in the range from 2 μm to 14 μm. Listed facts were an important step in solving the problem and several decisions and actions for improvements were carried out, such as:

1. Additional measurements on the existing Measuring bench were done. The Ruler used by the laboratory LKM-Belgrade (which has a Calibration Certificate issued by an accredited laboratory) was chosen as the object of measurement.
2. Recalibrate the Mitutoyo's Linear Scale System Model AT103 No. A1737292, but the whole procedure of calibration should be done onsite in the LKM-Belgrade laboratory, along with the sighting system on the Measuring bench.
3. Upon the completion of the measurement and with the knowledge gained, perform the new Interlaboratory comparison and confirm the competence of the calibration laboratory LKM -Belgrade.

4.1 Additional measurement on the existing Measuring bench

Additional measurements on the existing Measuring bench were done with Fennel Kassel Ruler of 1 m length, with a division of 1 cm. The Fennel Kassel Ruler had a Certificate of Calibration issued by an accredited laboratory: MIRS/UM-FS/LTM (URL 3). The confirmation included measurements on the Measuring bench before the implementation of additional stability procedures of the entire system. The function of the difference of the nominal values of the measurements achieved in the MIRS/UM-FS/LTM is shown on Figure 4. From these measurements, we can obtain the mean values and standard deviations for the measuring point/place (*x*) of the ruler and finally, through linear regression, the parameters *a* and *b*, where a is the slope of the straight line, and *b* is the intersection with the vertical axis *y* on which "differences" are represented as follows:

$$y = a \cdot x + b. \quad (12)$$

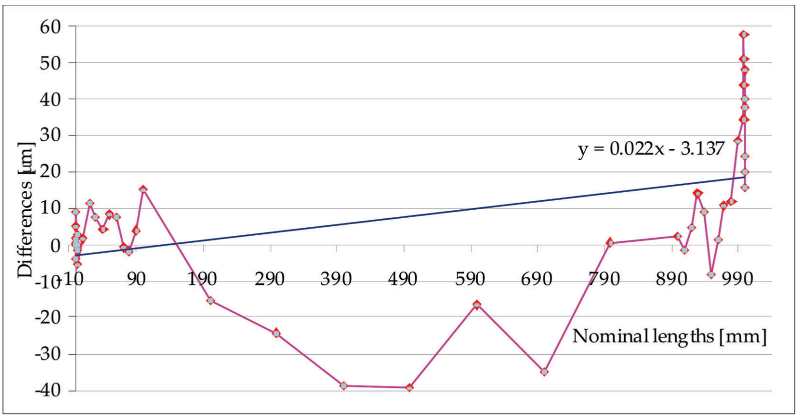

Figure 4: The function of the difference of the nominal values of the measurements achieved in the MIRS/UM-FS/LTM.

4.2 Recalibration of Mitutoyo's Linear Scale System Model AT103 No. A1737292

After the installation of additional connections, calibration of the Mitutoyo's Linear Scale System Model AT103 No. A1737292 began. DMDM was once again engaged for calibration. This time the entire Measuring bench system was calibrated in the premises of LKM - Belgrade. It was agreed with the metrologist from DMDM, that the measuring data should be registered in an interval of 2 cm to 5 cm, and not at 1 dm as provided according to the DMDM procedure for the calibration of length measurement.

Metrologist from DMDM performed the measurement on Mitutoyo's Linear Scale System Model AT103 No. A1737292: "Forward"-"Backward", at an agreed interval of 2 cm to 5 cm in three Series. Deviations from nominal reading values for all three Series of measurements are shown in Figure 5.

Figure 5: Calibration Measuring bench with Mitutoyo's Linear Scale System AT103 Model no. A1737292 (scale 0 mm to 1100 mm). a) Series 1 ("Forward"-"Backward" measurements); b) Series 2 ("Forward"-"Backward" measurements); c) Series 3 ("Forward"-"Backward" measurements).

After recalibrating the Measuring bench with Mitutoyo's Linear Scale System AT103, the Fennel Kassel Ruler was recalibrated, with an improved displacement mechanism and new correction values from the DMDM Certificate of Calibration. The differences between these two measurements were significant, especially in the middle of the Mitutoyo's Linear Scale System (Figure 6) where they range from 30 µm to -90 µm, which is the proof of cause for significant differences in the intercomparison. At the beginning (from 0 mm to 300 mm) and at the end of the Mitutoyo's Linear Scale System (from 700 mm to 1000 mm), the measurement differences in the two epochs of the Fennel Kassel Ruler calibration were of the order of several micrometers Figure 6. It is clear from Figure 6 that at a distance larger than 300 mm there is a sharp jump in the absolute differences between the values obtained in the two epochs of the measurements (before and after the installation of additional connections in the entire Measuring bench) on the Fennel Kassel Ruler. Those differences change "direction" and reach a value of up to -90 µm. The first decision and its implementation confirmed that deviations can be expected (as in Table 1.) and pointed to the fact that this is one of the causes producing the problem.

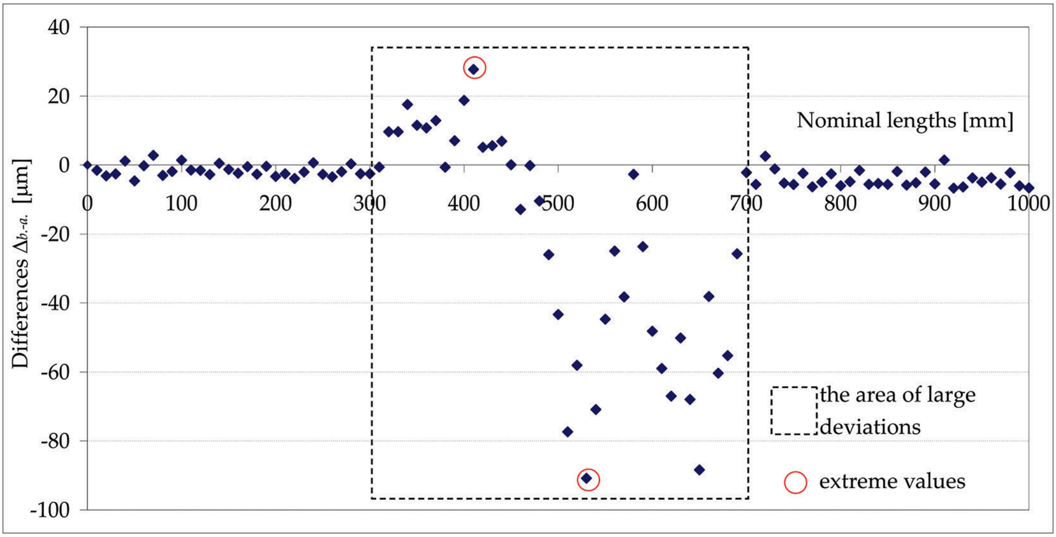

Figure 6: Differences in measurements on a Fennel Kassel Ruler in two Epoch of measurements: (Before-b. and After-a. installation of additional connections in the entire Measuring bench).

In order to check the performance of the applied solution, it was decided to use the data from the new Calibration Certificate (issued by the DMDM) of the Measuring bench and to recalculate the measurements data of the LKM-Belgrade laboratory obtained by intercomparison with FSB-LPMD (Table 1.). The calculations were performed by using the expression:

$$l_{new} = l_{old} + (r_{FKnII} - r_{FKnI}) + (v_{L,SII} - v_{L,SI}) \tag{13}$$

where: a new ruler length value (as means of measurement) used for intercomparison, old value of ruler length (as means of measurement) for intercomparison, the measurement value on the Ruler Fennel Kassel, linear scale correction value from the Calibration Certificate, II, I, - indices that indicate the epoch of the first and second calibration of the Measuring bench with Mitutoyo's Linear Scale System AT103.

The differences between the new length values and the new values for the Number En are shown in Table 2. From the table it can be concluded that all the Number En values are "Satisfactory" (Equation (2)).

Table 2: New values for Interlaboratory comparison between LKM-Belgrade and FSB-LPMD

L [mm]	The absolute difference [μm]	$U_{LKM\text{-}Belgrade}$ [μm]	$U_{FSB\text{-}LPMD}$ [μm]	E_n
30	4.7	9.50	8.0	0.38
60	1.0	9.62	8.0	0.08
90	8.6	9.74	8.0	0.68
120	8.3	9.86	10.0	0.59
150	11.5	9.98	10.0	0.81
180	7.0	10.10	10.0	**0.49**
210	2.1	10.24	10.0	**0.15**
240	5.5	10.38	12.0	**0.35**
270	10.7	10.50	12.0	**0.67**
300	2.3	10.64	12.0	**0.14**

4.3 Confirmation of competence within the Interlaboratory comparison

With the knowledge obtained (as presented in Chapter 4.1 and Chapter 4.2), the LKM-Belgrade launched a new action of Interlaboratory comparison and decided to choose the laboratory: MIRS/University of Maribor, Faculty for Mechanical Engineering/Laboratory for Production Management (MIRS/UM-FS/LTM) from Slovenia. A Technical protocol was signed by both laboratories (parties in ILC), with the aim to confirm the best calibration and measurement capabilities (CMC) of the laboratory LKM-Belgrade, within this ILC. The Technical protocol defined the Measurement instruction as follows: Object/means of measurement is the Ruler with the millimeter scale length of 400 mm. Reference point for the measurements is point 0 mm (Figure 7 (a)); The following distances L shall be measured: 40 mm, 80 mm, 120 mm, 160 mm, 200 mm, 240 mm, 280 mm, 320 mm, 360 mm, 400 mm. Measuring positions (li) between the centers of the lines shall be measured in the position indicated in Figure 7 (b).

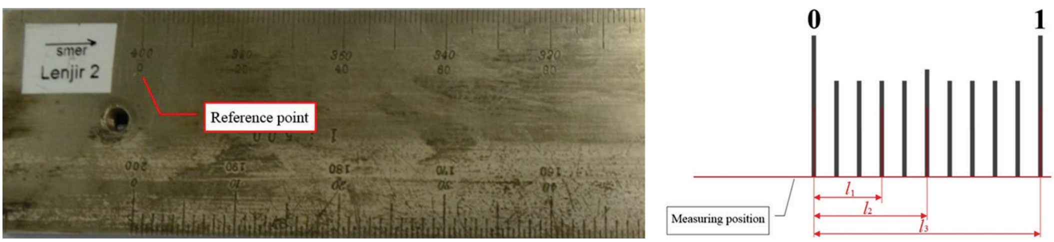

Figure 7: (a) Means of measurement for ILC (Ruler with the millimeter scale length of 400 mm); (b) Measuring positions.

Measurements were performed in four Series according to the principle: "Forward"-"Backward" at the beginning of the Mitutoyo's Linear Scale System Model AT103 No. A1737292. The measurement processing was performed by calculating the mean values from a large number of readings using the Equation (4); the mean values of "Forward" and "Backward" measurements by using the Equation (5); correcting for the deviation of the measurement temperature from 20°C and entering corrections for the linear scale from the Calibration Certificate in accordance with Equation (6). Each line length (L) was measured five times and from these measurements the mean errors of individual measurement for each series of measurement was determined separately (Equation (7)). According to the described procedure, 11 lines ($k = 11$) of a Ruler with a length of 400 mm (L [mm]) were read, and for two initial measuring points of Mitutoyo's Linear Scale ($m = 2$). In this way, a total of 22 measurements were obtained $l_{av(j)}$ in one Series of measurements; which for four Series $s = 4$ (*Series* = 1,2,3,4) amounts to a total of 88 measurements $l_{def(j)}$. Total mean error of a single measurement σ_{av} was calculated as follows:

$$\sigma_{av} = \sqrt{\frac{\sum \sigma_i^2}{k \cdot m \cdot s}} = 7{,}11\ \mu\text{m}. \qquad (14)$$

Calculated total mean error of a single measurement (Equation (14)) and a measurement uncertainty u_{LS} from the Calibration Certificate Linear Scale no. A1737292 calculated as:

$$u_{LS} = (3 + 10{,}48 \cdot L_{[m]})\ [\mu\text{m}] \qquad (15)$$

were used to calculate the total measurement uncertainty of each reading L, by the following

$$u^2 = \sigma^2_{av} + u^2_{LS} \qquad (16)$$

$$u = (7{,}72 + 10{,}48 \cdot L_{[m]})\ [\mu\text{m}] \qquad (17)$$

Extended measurement uncertainty U was calculated as:

$$U = 2 \cdot u\ [\mu\text{m}] \qquad (18)$$

The values for measured distance l_{def} and extended measurement uncertainty (U) were sent to the laboratory MIRS/UM-FS/LTM. Final report of ILC between LKM-Beograd and MIRS/UM-FS/LTM is given in Table 3. All results of the participating laboratory LKM-Beograd fulfil the acceptance criterion $E_n < 1$ and confirm its metrological capabilities.

Table 3: Final report of interlaboratory comparison between LKM-Belgrade and MIRS/UM-FS/LTM

L [mm]	The absolute difference [μm]	$U_{\text{LKM-Belgrade}}$ [μm]	$U_{\text{MIRS/UM-FS/LTM}}$ [μm]	E_n
40	7	16.3	3.7	0.42
80	1	17.1	4.5	0.06
120	5	18.0	5.4	0.27
160	13	18.8	6.2	0.66
200	6	19.6	7.1	0.29
240	11	20.5	8.0	0.50
280	1	21.3	8.8	0.04
320	2	22.1	9.7	0.08
360	3	23.0	10.5	0.12
400	4	23.8	11.4	0.15

It could be concluded that for the Ruler with a length of 400 mm (used in this ILC), a lower measurement accuracy (Table 3.) was achieved than on the previous Meba Ruler (Table 1.). The reason lies in the fact that some of the lines/bars on this Ruler with a length of 400 mm (used in this ILC) were of a poor quality, which was stated in the Appendix of the Technical Report on ILC between LKM-Beograd and MIRS/UM-FS/LTM.

5 CONCLUSIONS

Participation in PT/ILC programs improves the quality of laboratory work. By analyzing the results, laboratories maintain the constant quality of measurements in the calibration process. "From a practical point of view (in risk analysis), the reproducibility of the results, i.e., the degree of agreement between the results obtained by different analysts in different laboratories using a given measurement procedure, is essential" (Stancu, Michalak, 2022). The guidelines specified in the ISO 13528 (ISO 13528, 2022).) document contain recommendations on the interpretation of proficiency testing data and should be applied in analyzing the results obtained in the ILC.

Values for *Number* E_n, calculated according to Equation (1) for ILC between FSB-LPMD and LKM-Belgrade laboratories show "Satisfactory" result at five measuring places, while the problem was noted by "Unsatisfactory" result where $|E_n| \geq 1$ (Table 1). By increasing the length, *Number* E_n increases from 0.06 to 1.47, which indicates the existence of a systematic measurement error at the LKM-Belgrade, i.e. Measuring bench and Mitutoyo's Linear Scale System Model AT103 No. A1737292. In order to confirm doubts about the existing Measuring bench, a *Fennel Kassel* Ruler was used as a means of measurement. Measurements were performed at the determined measuring places (ruler line/bar) and a linear regression function was formed for the differences in the nominal values of the measurements results achieved by calibration in the MIRS/UM-FS/LTM (Gučević, Vasović Šimšić, Delčev, Kuburić, 2022) and on the Measuring bench of LKM- Belgrade, Figure 4. The sudden jump in the absolute differences of nominal values at the measuring point L = 150 mm confirmed the initial suspicions that the existing "geometry" was the cause of the "Unsatisfactory" result in Table 1. Installation of additional connections and calibration of the complete Measuring bench in the premises of LKM-Belgrade, led to the knowledge that the corrections of Mitutoyo's Linear Scale System AT103 no. A1737292 in the interval within 1 dm of Fennel Kassel Ruler length are nonlinear (Figure 5). The deviations greater than 10 μm were recorded within the first decimeter of ruler's length in the third Series of "Forward" measurement, which is a significant value (Figure 5).

Another "dimension" of this knowledge is the existence of a significant difference in the range of 30 μm up to -90 μm (Figure 6) with repeated measurements of the Fennel Kassel ruler with an improved Measuring bench mechanism (LKM-Belgrade) and with new correction values from the Certificate of Calibration issued by the DMDM. The difference in two epochs $\Delta_{b.-a.}$ (before - *b*. and after - *a*. installation of additional links in the entire Measuring bench) led to "Unsatisfactory" ILC results at the measuring point from 180 mm to 300 mm of the Meba Ruler (Figure 2). Entering corrections and recalculating the measurement results (Equation (13)) lead to the "Satisfactory" result for all values of the *Number* E_n, i.e. they were in the range between 0.08 and 0.81 (Table 3).

Since the obtained results have been marked as "Satisfactory", from the perspective of "Demonstration of competence", the LKM-Belgrade laboratory performs the ILC again, with another laboratory. The second ILC was performed with the MIRS/UM-FS/LTM, which was selected from the KCDB and as a means of measurement was used the Ruler with the millimeter scale length of 400 mm (Figure 7). The obtained results for the *Number* E_n were from 0.06 to 0.66 (Table 3.), i.e. "Satisfactory", that is an additional argument that the consideration of solutions and the decisionmaking process were implemented in the right way, i.e. this was confirmed by implementation of decisions with monitoring of results.

The methods of evaluating ILC results are based on different data processing algorithms, and therefore it is necessary to choose the most optimal processing method that will allow obtaining reliable results. The assessment of data consistency using *Number* E_n, or other indicatiors prescribed by the ISO standards, are important, not only to confirm the technical competence of laboratories participating in the ILC, but also to the achieved measurement uncertainty and to confirm the accuracy of calibration for the laboratories participating in the ILC. This is the right way to confirm to the customers the quality of the measuring equipment and accessories that are used in calibration. Coordinate metrology techniques are widely used in industry to carry out dimensional measurements. Measuring benches involving measurements in the submillimeter range use different aiming and collimating microscopes. The authors of this paper recognize the need for and importance of calibration of the entire measuring system, including the part related to the microscope for sighting and coincidence of the measuring lines. The procedure for the calibration of optical instruments is applied in accredited industrial dimensional laboratories for calibration.

National accreditation bodies accredit significantly more testing laboratories than calibration laboratories. NMI of the Republic of Serbia - DMDM, as a referent laboratory in the published Service Catalog offers Calibration service for Area: Length; Subject of calibration: Ruler with lines; Measuring range: up to 3000 m, for which there is no declared CMC in the International Bureau of Weights and Measures (BIPM) database (URL 5.) DMDM does not provide an ILC service for rulers with lines and this was the reason for the authors of the paper to search the KCDB and contact laboratories abroad.

For "small" laboratories that plan to be accredited for calibration of precision line scale instruments with small measurement uncertainty, the purchase of a specialized Measuring bench is not economically viable. Laboratories are looking for an alternative solution to adapt the measuring equipment to the requirements in the Scope of Accreditation (Vodopivec,Kogoj,2002). "Positioning systems differ largely, starting from simple magnifying glass over optical microscope to enhanced video systems with line recognition." (Godina, A. & Acko, B., 2012). The resulting deviations in Table 1. led to the knowledge that Mitutoyo's Linear Scale System AT103 should be calibrated directly on the Measuring bench together with positioning systems.

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