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A Method to Calibrate Metal Length Measuring Rulers by Mechanical Comparison

N.P Liyanawaduge

Sabaragamuwa University of Sri Lanka, P.O Box 02, Belihuloya, Sri Lanka

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ABSTRACT

A Length measuring stick (length measuring ruler) is a very fundamental length measuring tool uses in many sectors such as construction industry, material processing industry, Apparel industry testing and calibration industry, and household. These measuring sticks are manufactured by different manufactures across the world and uses different references to mark the length on the sticks. Therefore, confirmation of maintaining the measurement traceability of length measuring sticks to the primary standard before their use is very essential. Even though sophisticated calibration systems are available globally for the calibration of length sticks, purchasing such a system became difficult due to high costs. As a solution, a low-cost mechanism for the calibration of industrial metal length measuring sticks is proposed here. The proposed method determines the length of the intervals of an unknown length stick (test ruler) in comparison with a pre-calibrated reference standard rule. The difference in length between test and reference ruler is measured by a mechanical movement of the reference standard ruler until coinciding the scale mark of the reference ruler with the corresponding scale mark of the test ruler. The linear movement of the reference ruler is measured by a dial gauge. The length of the test ruler is calculated by considering other factors such as the length of the standard stick and overall temperature correction as well. A calibration system was developed to determine length of the length intervals of test rulers in compliance to the proposed method. The combined uncertainty was calculated for the length determined by the proposed system using the proposed method and was ±0.33 mm at *k* =1 level corresponds to 68% confidence. The results from the proposed method were compared with the results from existing calibration methods and in compliance when the results are considered with above quoted uncertainty.

Key words: Metal length measuring sticks, Calibration, Mechanical Comparison, Reference Standard, Measurement traceability

INTRODUCTION

A length measuring stick is a very basic length measuring tool that is often used in manufacturing floors in many industries such as construction industry, material processing industry and apparel industry etc... As length measuring sticks are used for taking measurements in different stages of the production cycles and quality control activities, their measurement accuracy plays an important role to produce a good quality product in the end. If unreliable measurement tools are used for measurements, it will be reason for decrease the quality of the end product causing losses in the market. At the same time, it could cause financial losses with increasing wastage and finally decreases the profit margin of the industry. Though length measuring sticks manufactured by different manufactures and are easily purchased in the market for very lower prices, their measurement accuracy is questionable to use for the intended uses. International Standards [1,2] specifies the requirements in manufacturing meter sticks under deferent parameters such as scale mark width, evenness of graduation, square of edges and marked length from zero. Therefore, testing the compliance of these length measuring sticks to the international standards before the use is very essential and of prime importance to maintain measurement traceability [3,4] in order to maintain and certify the quality of the final products of industries.

The meter sticks calibration systems were built in the world by several principles. Each of these methods varies from others by the length measuring principle. Other basis prerequisites for the calibration are almost similar. From starting a very basic method, that is comparison of a meter stick with a standard stick on a flat bench. The deviations in length to scale marks from zero were measured by in either calibrated graph paper [5] or ocular microscope [6]. National Institute of Standards and Technology (NIST) of the United States has been using both techniques for calibration of meter sticks. Laser technology to detect the length of customer specified intervals of the precision metal rulers is another method is used by National level laboratories such as NIST USA. Since a frequency stabilized laser with application of temperature, pressure and humidity correction is used, this method is suitable for calibration of precision meter sticks. There is another method mentioned in the literature that is basically operates by optical and magnetic linear encoders. In this method, the graduation is compared with an incremental rule [7]. These systems operate with electronic optical scales with higher resolution such as 0.0001mm. This is a stable and robust measuring structure designed for user friendly operation and used in many industrial instrument calibration Laboratories. However, the purchasing and operating cost of these systems is very high. Also, the recalibration process is also expensive and needs long standard gauge blocks.

Recently, P. Greef *et.al* proposed a method to calculate the length difference between a test ruler and the reference standard line in a direct comparison technique [8]. This method uses an image of the camera/microscope and the image is calibrated by determining line centre distance of a previously calibrated standard ruler. Then the calibration factor is used to determine the deviation between the test ruler and the reference standard ruler. An automatic verification device on machine vision array in comparison calibration technique with reference tape was proposed by P. Wang *et.al* [9]. This machine vision technique for calculation steel tape indication error involves image recognition, data acquisition rather than manual reading through a microscope.

Due to the fact that high cost of precision calibration system for length measuring sticks, calibration laboratories and industrial quality control laboratories still follow a direct comparison technique with a calibrated master length stick (Reference stick). In this method the length difference between test and reference sticks is estimated by visual inspection. However, this is an estimation that depends upon technician who performs the calibration. Hence, this method is not a perfect method to determine length of a length interval of length stick and more probable for measurement errors.

In this study a novel method is proposed to determine the indicated length of length measuring sticks by measuring the difference in length between a reference standard ruler (reference ruler) and the test length measuring stick (test ruler) in the direct calibration technique. In this method, the difference in length between two sticks is determined by coincidence of corresponding scale marks of two rulers via mechanically moving one stick with respective to the other which is different approach to the aforementioned calibration techniques. Also, a method of construction of a relevant prototype is proposed here. Finaly, methods for calculation of the straight-line distance of a length interval of a test ruler at standard temperature and calculation of its measurement uncertainty are proposed here.

A model for the straight- line distance of a length interval

When a measuring tape is supported by N number of equidistant suspensions, the horizontal straight- line distance of a tape interval, L can be computed by considering the factors of applied tension, P, temperature, T of the tape and the number of suspensions, N by Eq.(1) [10].

$$L = L_C + L_n(P - P_S)/A.E + L_n(T - T_S).\alpha - \frac{L_n}{24}\left(\frac{w.L_n}{N.P}\right)^2 \quad (1)$$

Where:

L_C : The calibrated length of the tape interval on a flat surface at standard temperature, T_S and standard pressure, P_S

L_n: The designated Nominal length of the tape interval

P_S: The standard tension applied to the tape interval for L_C

T_S: The standard temperature of the tape interval (20 ^{O}C) for L_C

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A.E: The average cross section area times Young's modulus of Elasticity of the tape ribbon (*AE* value).

w: The average weight per unit length of the tape ribbon

α: The thermal expansion coefficient of the tape ribbon.

Since the length sticks are laid down completely on the calibrator, N can be assumed to be infinitely large when this equation is applied to a length measuring stick. Also, no pressure is applied to the length sticks, and P & P_S are equal to zero. Therefore, the Eq.(1) simplifies as below for a length stick is laid on the calibrator.

$$L = L_C + L_n(T - T_s).\alpha \tag{2}$$

When Eq. (2) is applied to a standard stick:

$$L_S = L_S^C + L_n(T^S - T_S).\alpha_S \tag{3}$$

Where:

T^S: The temperature of the standard stick

α_S: The thermal expansion coefficient of the standard stick

When Eq. (2) is applied to the test stick:

$$L = L_T^C + L_n(T^T - T_S).\alpha_T \tag{4}$$

Where:

T^T: The temperature of the test stick

α_T: The thermal expansion coefficient of the test stick

From Eq. (3) and Eq. (4):

$$L - L_S = (L_T^C - L_S^C) + L_n(T^T - T_S).\alpha_T - L_n(T^S - T_S).\alpha_S \tag{5}$$

Since the two sticks are conditioned to the laboratory environment for a considerable time period it is reasonable to assume that the average temperature of two sticks, T_{ave} such that:

$$T_{ave} \approx T^T \approx T^S \tag{6}$$

The measured length difference, d :

$$d = L - L_S \tag{7}$$

$$L_T^C = d + L_S^C + L_n(T_{ave} - T_S).(\alpha_S - \alpha_T) \tag{8}$$

$$L_T^C = d + L_S^C + \Delta K \tag{9}$$

Where:

L_T^C: The straight-line distance of a length interval of a test length stick at standard temperature (20°C).

L_S^C: The corresponding calibrated length of the length interval on the standard stick at standard temperature.

d: The measured length difference between two sticks for the length interval

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ΔK: The overall temperature correction, ΔK can be calculated from the formula

$$\Delta K = L_n[(T_{ave} - 20)(\alpha_S - \alpha_T)] \quad (10)$$

L_S^C is obtained from calibration certificate of the standard stick. The average value of measured deviations in length of the length interval, d is calculated for each length interval from the collected dial gauge readings.

Model for calculation of measurement Uncertainty

A mathematical model for the calculation of combined standard uncertainty [11], U_T^C of measured straight-line distance, L_T^C is given in Eq. (11):

$$(U_T^C)^2 = \left(\frac{\partial L_T^C}{\partial L_S^C}\right)^2 U^2(L_S^C) + \left(\frac{\partial L_T^C}{\partial d}\right)^2 U^2(d) + \left(\frac{\partial L_T^C}{\partial \Delta K}\right)^2 U^2(\Delta K) \quad (11)$$

Here, sensitivity coefficients

$$\left.\begin{aligned} \left(\frac{\partial L_T^C}{\partial L_S^C}\right) &= 1 \\ \left(\frac{\partial L_T^C}{\partial d}\right) &= 1 \end{aligned}\right\} \quad (12)$$

$$\left(\frac{\partial L_T^C}{\partial \Delta K}\right) = 1$$

$U(L_S^C)$: Uncertainty associated with the length of the reference stick, as given on the calibration certificate of the reference stick.

$U(d)$: Uncertainty associated with length difference, measured by the dial gauge. This consists with another several uncertainty components, caused by different sources of uncertainty as given below [12,13].

$$U^2(d) = U_{cal.g}^2 + U_{res.g}^2 + U_{repeat}^2 + U_{misalign}^2 + U_{coinc}^2 + U_{sharp}^2 \quad (13)$$

Where;

$U_{cal.g}$: Uncertainty in calibration of dial gauge

$U_{res.g}$: Uncertainty in resolution of dial gauge

U_{repaet}: Uncertainty in repeatability of the dial gauge reading

$U_{misalign}$: Uncertainty in misalignment of two sticks

U_{coinc}: Uncertainty in coincidence of scale marks

U_{sharp}: Uncertainty in non-sharpness of scale marks

$U(\Delta K)$: Uncertainty associated with temperature effect which can be written as

$$U^2(\Delta K) = U_{temp\ dif}^2 + U_{T.cal}^2 + U_{T.res}^2 \quad (14)$$

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Where;

$U_{temp.dif}$: Uncertainty in variation in temperature between two sticks

$U_{T.cal}$: Uncertainty in calibration of thermometer

$U_{T.res}$: Uncertainty in resolution of the thermometer

By substituting Eq. (12), Eq.(13) & Eq.(14) into the Eq.(11)

$$(U_T^C)^2 = U^2(L_S^C) + U_{cal.g}^2 + U_{res.g}^2 + U_{repeat}^2 + U_{misalign}^2 + U_{coinc}^2 + U_{sharp}^2 + U_{temp\ dif}^2 + U_{T.cal}^2 + U_{T.res}^2 \quad (15)$$

Then the expanded combined uncertainty with coverage factor k which related to the confidence level, is given by:

$$(U_T^C) = k \times \sqrt{\sum_{i=1}^{i=10} U_i^2} \quad (16)$$

MATERIALS AND EXPERIMENTAL METHOD

Since the metal rulers are manufacture as per the requirements specified by the international standards [1,2], the compliance of the manufactured rulers to those international standards has to be verified. Also, measurement traceability to the SI units shall be maintained before placed them into the measurements and a suitable calibration system is required for achieving this [3,4]. The proposed system for calibration of length measuring sticks basically operates on a direct comparison technique. The lengths indicated on an unknown test ruler were compared with corresponding lengths indicated by a reference standard ruler(pre-calibrated). The difference in length was measured by giving fine mechanical movement to the standard ruler with respective to the test ruler until coincide the relevant scale marks of two rulers. A length measuring Dial Gauge with flat contact surface was used to measure this movement of the standard stick which indicates the difference in length between two sticks. The front view of a measurement system configured to measure the length difference by this mechanical comparison method is shown in Fig .1.

An aluminum profile was used as the base and all the parts of the calibrator were fixed to the base. Among them, two linear guides with bearing carriages were also fixed to the base. One linear guide rail with two bearing carriages (slide units) was fixed to the top of the base for holding the platform of the standard stick. The second linear guide rail with one bearing carriage was fixed to the back side of the base to hold a microscope. A set of four height adjustment legs with rubber boots were mounted at four bottom corners of the base to adjust the horizontal level by means of a spirit level bubble.

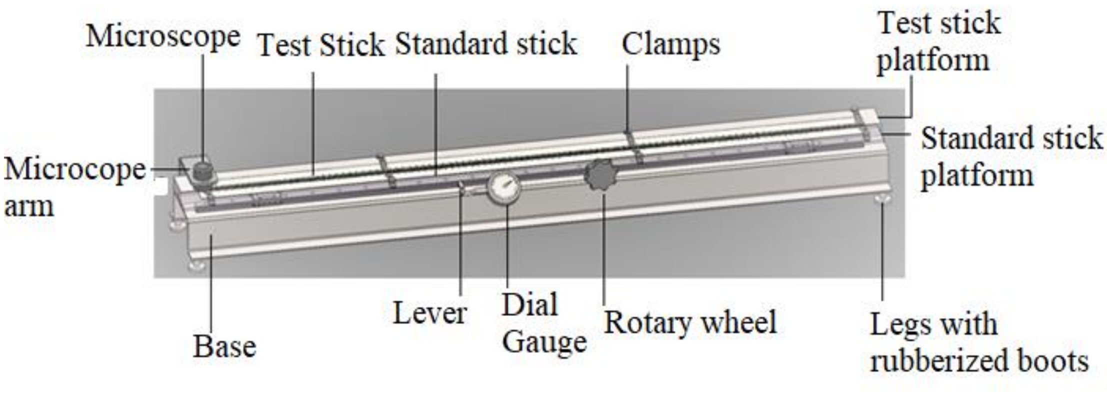

Fig.1. Diagrammatic representation of the front view of the calibrator

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The platform of the standard stick is an aluminum box bar with rectangular cross section, was fixed to the bearing carriages of top linear guide. The standard-length measuring stick was detachably attached to the platform by a set of equally spaced screw operated clamps along the platform. The standard-length measuring stick with its platform is movable back and forth by rotating a rotary wheel. A Dial Gauge with a back clamping jaw attached to the platform of standard stick was configured to measure the movement of the standard stick.

When the rotary wheel is rotated, the platform of the standard stick moves back or forth depending upon the direction of rotation, and the plunger of the Dial Gauge pressurizes or releases against a lever, that is rigidly attached to the base. Hence, the magnitude of movement of the standard stick is indicated by the dial gauge reading.

The test length measuring stick lays on a platform, which is an aluminum box bar for the test stick, which was rigidly attached to the base by means of mounting bolts and nuts. The test stick was detachably attached to the platform by a set of equally spaced screw actuated clamps.

The coincidence process of a scale mark of the standard stick with the corresponding scale mark of the test stick is performed while viewing the scale marks through a microscope. The arm which carries the microscope was fixed to the bearing carriage of linear guide, attached to the back side of the base as shown in the Fig.2. Hence, the microscope is free to move along the side linear guide and can be clamped to the base at any particular scale mark on the sticks. A clear image of the scale marks was obtained through rotating the fine focusing knob of the microscope under a suitable level of illumination provided by a LED light attached to the arm of the microscope.

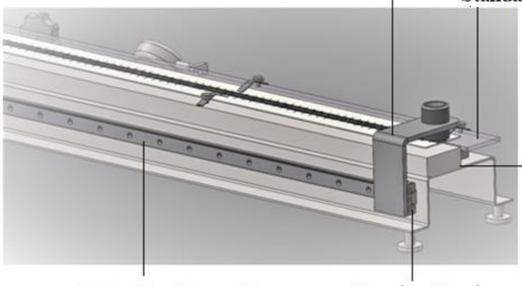

Fig.2. Diagrammatic representation of rear view of the calibrator.

In the method to determine difference in length between two sticks (d), first, the zero line of the test stick is coincided with the zero line of the standard stick and the reading of the dial gauge is tarred. Then the microscope is focused to a second scale mark of the test stick and scale mark of test stick is coincided with the corresponding scale mark of the standard stick by rotating adjustment wheel. Since the reading of the dial gauge was the overall difference at the second point, the gauge reading was set zero. Next, the microscope is focused to a third scale mark of the test stick and scale marks of the test stick is coincided with the corresponding scale mark of the standard stick. The overall difference in length at the third point was obtained by the addition of previous overall difference to the present dial gauge reading.

In this way of procedure, the upper edge scale of the test ruler was calibrated by coinciding the scale marks with the lower edge scale of the standard stick. To calibrate the lower edge scale of the test ruler, the test ruler and the standard ruler is interchanged on platforms so that the test ruler is on the movable platform while standard tape on the fixed platform. The length difference of scale marks of the test stick compared to the reference stick was calculated by multiplying the dial gauge reading by minus one (-1).

Performance of the proposed system was evaluated by a test steel ruler. First, the length difference of the test ruler (d) was found at each point in 100 mm increment from zero by the system proposed. The average length difference(d_{ave}) was calculated considering data from five repeated measurement cycles under repeatability conditions. This was corrected by adding the correction of the dial gauge, given on the calibration certificate of the gauge. Also, a temperature correction (ΔK) was found and added considering difference in average

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temperature of the rulers from the standard temperature (20 °C). The length of the length intervals of the test ruler (L_T^C) was calculated by the equation Eq.(9) above considering the L_S^C given on the calibration certificate of the standard stick. The departure from nominal value for each test length was calculated by subtracting the nominal length from the calculated average length of the length interval of the test ruler.

Subsequently, the test ruler was submitted to three calibration laboratories consecutively (Lab-1, Lab-2 and Lab-3) one after another for the calibration and the departure from nominal value of length was calculated for each calibration certificate issued by the different calibration laboratories.

RESULTS AND DISCUSSION

For the purpose of comparison, the calculated departure from nominal values are given in the Table. 1.

Table.1. Comparison of departure from nominal values. The departure from nominal values for Lab-1, Lab-2 and Lab-3 were calculated based on values given by calibration certificates

Nominal value/mm	Average measured length difference/mm	Calculate length/mm	Departure from Nominal value/mm			
			System	Lab-1	Lab-2	Lab-3
100	0.09	99.9	-0.08	-0.011	-0.01	-0.1
200	0.082	199.9	-0.13	-0.03	0.04	-0.1
300	0.124	299.9	-0.15	-0.025	0.03	-0.1
400	0.18	399.9	-0.10	-0.02	0.00	-0.1
500	0.208	499.9	-0.10	-0.017	0.03	-0.1
600	0.212	599.9	-0.07	-0.002	0.07	0
700	0.214	699.9	-0.11	0.001	0.07	-0.1
800	0.262	799.9	-0.11	0.005	0.00	-0.1
900	0.308	899.9	-0.12	-0.012	0.06	-0.1
1000	0.322	999.8	-0.15	-0.023	0.11	-0.1

The departure from nominal value for each length section from different calibration laboratories was plotted and results are given in the Fig. 3.

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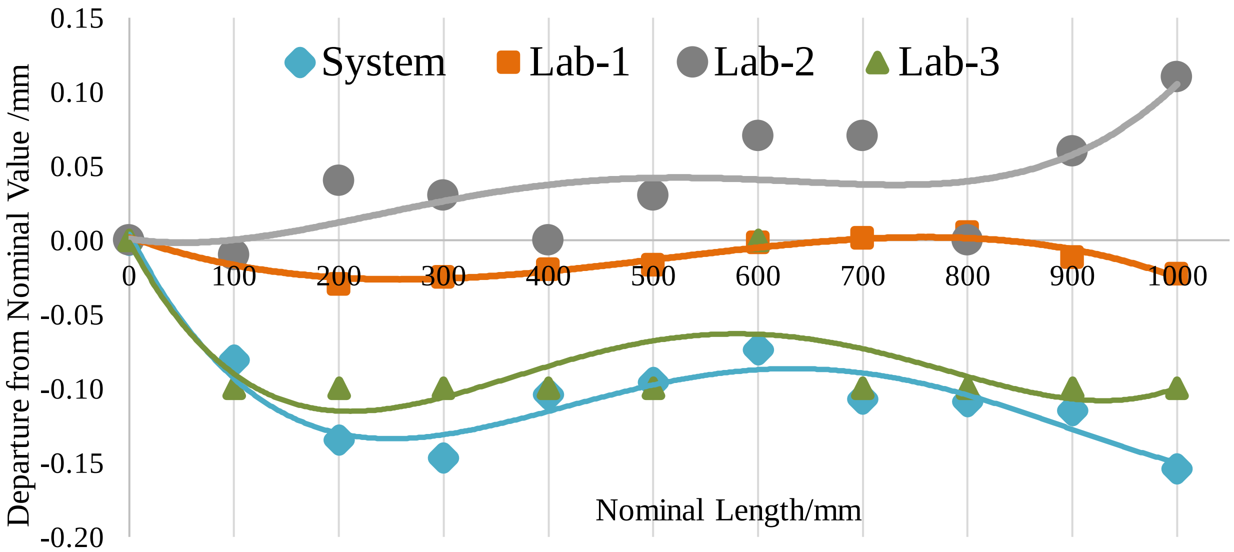

Fig.3. The departure from nominal values at each 100 mm length sections from zero. The light blue color points and the line indicate the values given by the proposed system. Other lines are generated based on the calibration results given by the other laboratories. The polynomial lines are just for the guide to the eye.

Based on the calculated departure from nominal values, it is clear that the Lab-1 and Lab-3 shows very closer values (negative values) to the values obtained by the proposed system Also, they follow approximately similar pattern of variations with length. In contrast, the lab-2 shows positive departure from nominal values and shows different pattern of variation.

Since the method proposed here involves with several unique measurement errors which may not available with other methods, it is worth to calculate combined measurement uncertainty of results given by the proposed method and compare the results of other laboratories with the calculated values of measurement uncertainty. It is important to assess uncertainty sources to understand the reliability and validity of the calculated values [14]. The above discussed model for calculation of measurement uncertainty is used to calculate associated combined measurement uncertainty of the data obtained by the proposed method.

Uncertainty associated with the length of the reference stick- $\mathbf{U(L_s)}$

The standard uncertainty associated with the length of the reference stick is calculated considering calibration uncertainty ($U_{cal} = 0.01$ mm) and the coverage factor (k = 2) as mentioned on the calibration certificate, traceable to SI units of the reference stick.

$$U(L_s) = \frac{U_{cal}}{k} = \frac{0.01\text{mm}}{2} = 0.0050\text{ mm} \tag{17}$$

Uncertainty in calibration of Dial Gauge $-\mathbf{U_{cal.g}}$

The standard uncertainty in calibration of the dial gauge is calculated by the calibration uncertainty ($U_{cal} = 0.01$ mm) and the coverage factor (k = 2) as mentioned on the calibration certificate traceable to SI units of the dial gauge.

$$U_{cal} = \frac{U_{cal}}{k} = \frac{0.01\text{mm}}{2} = 0.0050\text{ mm} \tag{18}$$

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Uncertainty due to the resolution of the dial gauge-$U_{res.g}$

The system measures the length deviation with a resolution 0.01 mm. Since the final length of the stick is given with a resolution 0.1 mm, the considered resolution for uncertainty calculation is 0.1 mm. The standard uncertainty due to resolution is calculated assuming the rectangular distribution.

$$U_{res.g} = \frac{0.1}{2\sqrt{3}} = 0.029 \text{ mm} \quad (19)$$

Uncertainty due to the repeatability of measured length deviation-U_{repeat}

Data are collected for length deviation for each point for five times and standard uncertainty due to the repeatability of measured length deviation is calculated assuming normal distribution.

$$U_{repeat} = \frac{\delta d_i}{\sqrt{n}} \quad (20)$$

Where

δd_i is the standard deviation of measured values of length deviation and the n is the number of repetitions.

Considering the worst case, $\delta d_i = 0.041$ mm

$$U_{repeat} = \frac{0.041 \text{ mm}}{\sqrt{5}} = 0.0183 \text{ mm} \quad (21)$$

Uncertainty due to the misalignment of two sticks ($U_{misalign}$)

The misalignment of edges of two sticks is assumed as 0.5 mm and the standard uncertainty due to the misalignment of two sticks is calculated by assuming rectangular distribution.

$$U_{misalign} = \frac{0.5 \text{ mm}}{2\sqrt{3}} = 0.1443 \text{ mm} \quad (22)$$

Uncertainty due to the coincidence of scale marks (U_{coinc})

Since the tolerance of thickness of a graduation line for a general purpose metal rule is 0.25 mm [2], the standard uncertainty due to the incorrect coincidence of scale marks is evaluated assuming rectangular distribution as follows.

$$U_{coinc} = \frac{0.25\ mm}{2\sqrt{3}} = 0.0722 \text{ mm} \quad (23)$$

Uncertainty due to the non-sharpness of scale marks (U_{sharp})

Assuming non sharpness of scale marks is 0.005 mm [13], the standard uncertainty caused by the non-sharpness of scale marks is estimated by the following way.

$$U_{sharp} = \frac{0.005\ mm}{2\sqrt{3}} = 0.0014 \text{ mm} \quad (24)$$

Uncertainty due to the temperature difference between two sticks ($U_{temp.dif}$)

Since both test stick and the reference stick are on the same base for considerable time before starting the calibration, it is reasonable to assume that there is no any temperature difference between two sticks. However, standard uncertainty due to the temperature difference between two sticks is calculated assuming a maximum temperature difference between two sticks is ± 0.4 ^{o}C and rectangular distribution.

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$$U_{Temp.dif} = \frac{L.\alpha.\Delta\theta}{\sqrt{3}} = \frac{L \times 1.2 \times 10^{-5} \times 0.4}{\sqrt{3}} = 0.0028.L \text{ mm} \quad (26)$$

Where:

L is the nominal length of the test stick measured in m, α is the average linear thermal expansion coefficients of test and reference stick (1.2×10^{-5} /ºC for steel) and $\Delta\theta$ is the temperature difference between two sticks.

Uncertainty due to the calibration uncertainty of the thermometer ($U_{T.cal}$)

The calibration uncertainty of the thermometer is calculated and the value was found to be 0.41 ºC (with coverage factor, *k*=2). The standard uncertainty due to the calibration uncertainty of the thermometer is calculated assuming the normal distribution.

$$U_{T.cal} = \frac{L \times \alpha \times 0.41}{2} = \frac{L \times 1.2 \times 10^{-5} \times 0.41}{2} = 0.0024.L \text{ mm} \quad (27)$$

Where, *L* is the nominal length of the test stick measured in m, α is the average linear thermal expansion coefficients of test and reference stick (1.2×10^{-5} /ºC)

Uncertainty due to the resolution of the thermometer, ($U_{T.res}$)

The resolution of the thermometer used is 0.1 ºC. Assuming the rectangular distribution, the standard uncertainty due to the resolution of the thermometer is calculated by the following way.

$$U_{T.res} = \frac{L \times \alpha \times 0.1}{2\sqrt{3}} = \frac{L \times 1.2 \times 10^{-5} \times 0.1}{2\sqrt{3}} = 0.0003.L \text{ mm} \quad (28)$$

Where, *L* is the nominal length of the test stick measured in m, α is the average linear thermal expansion coefficients of test and reference stick (1.2×10^{-5} /ºC).

The uncertainty budget for calibration of metal length measuring stick by the proposed technique is presented in the Table.2. The values were calculated assuming the test stick has been made by steel with $\alpha = 1.2 \times 10^{-5}$ /ºC

Table.2. Uncertainty budget for calibration of steel rulers up to 1000 mm by the proposed method

Source of Uncertainty	Uncertainty component	Distribution	Calculation	Value/mm
Calibration of Reference stick	$U(L_s)$	normal	$\frac{0.01\text{mm}}{2}$	0.0050
Calibration of dial gauge	$U_{cal.g}$	normal	$\frac{0.01\text{mm}}{2}$	0.0050
Resolution of dial gauge	$U_{res.g}$	rectangular	$\frac{0.1\text{ mm}}{2\sqrt{3}}$	0.029
Repeatability of the dial gauge reading	U_{repeat}	normal	$\frac{0.041\text{ mm}}{\sqrt{5}}$	0.0183
Misalignment of two sticks	$U_{misalign}$	rectangular	$\frac{0.5\text{ mm}}{2\sqrt{3}}$	0.1443
Coincidence of scale marks	U_{coinc}	rectangular	$\frac{0.25\text{ mm}}{2\sqrt{3}}$	0.0722

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Non sharpness of scale marks	U_{sharp}	rectangular	$\frac{0.005\text{ mm}}{2\sqrt{3}}$	0.0014
Temperature variation between two sticks	$U_{temp.dif}$	rectangular	$\frac{L \times 1.2 \times 10^{-5} \times 0.4}{\sqrt{3}}$	$0.0028.L$
Calibration of thermometer	$U_{T.cal}$	rectangular	$\frac{L \times 1.2 \times 10^{-5} \times 0.41}{2}$	$0.0024.L$
Resolution of Temperature	$U_{T.res}$	rectangular	$\frac{L \times 1.2 \times 10^{-5} \times 0.1}{2\sqrt{3}}$	$0.0003.L$

Combined standard uncertainly:

$$U_c(L) = \sqrt{0.0273 + 1.369 \times 10^{-5}.L^2}\ \text{mm} \tag{29}$$

Where, L in m

Expanded uncertainty at coverage factor k =2 and 95% confidence level,

$$U_L = 2 \times \sqrt{0.0273 + 1.369 \times 10^{-5}.L^2}\ \text{mm} \tag{30}$$

Where, L is the nominal length of the test stick measured in m.

According to the Eq.(29), the calculated values of the combined measurement uncertainty at different measured length sections are tabulated in Table.3.

Table.3. Calculated values of combined uncertainty.

Nominal Length/mm	Departure from Nominal Value/mm	Combined uncertainty/mm (k=1)
100	-0.08	0.33
200	-0.13	0.33
300	-0.15	0.33
400	-0.10	0.33
500	-0.10	0.33
600	-0.07	0.33
700	-0.11	0.33
800	-0.11	0.33
900	-0.12	0.33
1000	-0.15	0.33

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For acceptance of the data given by the proposed method it is worth to consider the results of the system with the calculated measurement uncertainty. The Fig. (4) shows the comparison of departure from nominal values of the measured length by the different laboratories together with the uncertainty calculated for the results of the system. Considering data shown by the Fig. 4 it is clear that the most of the values produced by other laboratories are well within the range of values given by the system when the values are considered with the measurement uncertainty. Therefore, the values derived from the system with its calculated uncertainty (k =1) in agreement with the values given by the other laboratories. However, last two points of Lab-2 are found out of the range.

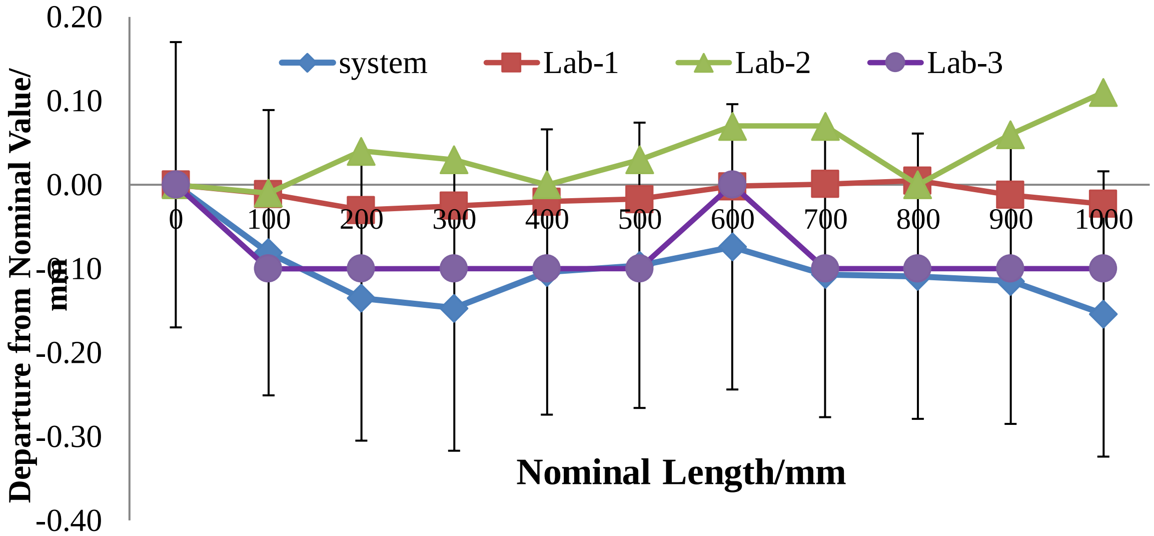

Fig.4. Comparison of calibration results generated by the system with calculated uncertainty with results of other laboratories. The doted vertical lines indicate the uncertainty limits at each test length. The confidence factor is, k =1corresponds to 68% confidence level. The solid lines are just for the guide to the eye.

CONCLUSION

A method of construction of a cost-effective calibration system for industrial metal length measuring rulers and a method for calibration of industrial grade metal length measuring rulers are proposed in the study. The calibration is performed against a pre-calibrated reference standard ruler and the difference in length between reference and test rulers is measured by mechanically moving the reference ruler with respective to the test ruler until coincidence the scale marks. The transitional movement of the reference standard tape is measured by a dial gauge. The length of the test ruler is calculated by considering the measured difference in length, length of the standard stick and the temperature correction. The measurement uncertainty of the calculated length of the test ruler is calculated by considering all the potential sources of uncertainty. Both the upper and lower edge scales of the test ruler could be calibrated in a similar way but interchanging the reference and test ruler on clamping platforms of the system. The results of the proposed system are compared with the results from three different accredited calibration laboratories that use calibrators with different mechanisms. The results generated by the system agree with results of all three laboratories when the results are considered with the measurement uncertainty. Hence, this system offers a cost-effective and reliable method for calibration of metal rulers thus provide good solution for industrial calibration laboratories in terms of initial cost and maintenance of measurement traceability to SI unit.

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