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Uncertainty Evaluation in calibration of Engineer’s Steel Rulers and Measuring Tapes; GUM and Monte Carlo Methods

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Abstract

Engineer’s steel rulers and measuring tapes are considered versatile dimensional measuring tools for many industrial applications. Calibrations of these tools are carried out by comparing their scales with reference length standards. The reference standards can be geodetic baselines provided by a laser interferometer system or linear encoder that integrated in well-designed guideway. This work aims to study not only the calibration process for steel rulers and measuring tapes but also the affecting parameters on this process and the assessment of associated uncertainty by different evaluation methods. In this paper, a 1000 mm engineer’s steel ruler and 5000 mm measuring tape are calibrated. A calibration system of precise guideway provided by linear encoder of 1 µm resolution are used. Associated uncertainties have been estimated based on GUM and Monte Carlo Simulation (MCS) methods. The parameters that may affect the calibration processes are carefully studied through the uncertainty evaluation. Expanded uncertainties of about 20 µm and 80 µm for calibration of 1000 mm engineer’s steel ruler and 5000 mm measuring tape respectively are achieved. This study presents two issues. (1) it is first documented work in the study of uncertainty assessment and related parameters in this calibration type. (2) application of Monte Carlo Simulation (MCS) method in uncertainty evaluation in calibration of these tools.

Keywords: Steel Rulers, Measuring Tapes, Calibration, Monte Carlo, GUM

1 Introduction

Length measuring tools i.e. engineer’s steel rulers and measuring tapes are versatile and fast measuring tools that are used for dimensional measurements [1]. These tools are used in many applications fields i.e. industry, construction, surveying services and adjusting distances for fringe projection systems [2]. Although these tools have limited resolution of about 1 mm or 0.5 mm in best cases. It is still suitable for the nature of applications that the rulers and tapes are used for. The calibration of such tools becomes a necessary demand. The calibrations are common performed at steps of 100 mm and 1000 mm for rulers and tapes respectively. It is preferred to carry out the calibration in the same setup. This requires to use reference length instruments of long ranges [3, 4]. Many reference instruments are used in this calibration type i.e. geodetic baselines with laser interferometers and tape calibrators. Geodetic baselines have capability to measure lengths upto 40 m with accuracy upto 0.05 µm. Tape calibrators are calibration system that have linear encoders integrated with well-designed guideways. These calibrators can measure lengths upto 5 m with accuracy upto few micrometers. Although, geodetic baselines have higher accuracy in comparison to tape calibrators; the calibrators have low costs in their design and establishment [5]. The affecting parameters and associated uncertainty in such calibration processes should be studied and evaluated [6]. There are different uncertainty sources that affect the total combined uncertainty. Line width of scale divisions, non-sharpness degree of scale divisions, resolving power and accuracy of reference instruments are examples for the most effective contributors in evaluation of associated uncertainty [7–9]. Line width of scale divisions differs from steel rulers to measuring tapes. Steel rulers have higher sharpness in shape of scale divisions than measuring tapes. Guide to the Expression of Uncertainty in Measurement (GUM) and Monte Carlo simulation (MCS) are common methods for uncertainty evaluation in calibrations and measurements [10, 11]. GUM is published by Joint Committee for Guides in Metrology (JCGM). It provides the estimation guidelines of measurement uncertainty using law of propagation. The output quantity is characterized using normal distribution or t-distribution. The law of propagation provides a means for propagating uncertainties through a mathematical model. MCS is a numerical method that is used in calculating the uncertainty in many fields i.e. engineering, physical, biological and industrial systems based on simulation of random numbers. Evaluation of uncertainty by MCS is based on generating of random numbers for all the input parameters that affect the calibration process. Depending on individual PDFs of inputs, the probability density function (PDF) of the output is obtained. In this paper, 1000 mm engineer's steel rulers and 5000 mm measuring tape are calibrated with step of 100 mm. The associated uncertainty in each calibration type is evaluated applying two evaluation methods; GUM and MCS. The effects uncertainty sources are studied and expanded uncertainties at full range are evaluated.

2. Methods and Procedure

2.1. Calibration system

In this study, a Measuring Scale and Tape calibration system (MSTC2000, Octagon) is used, figure 1. It is a one dimension (1D) measuring Instrument of 2000 mm measuring range and 1 µm resolution. This calibration system is traceable to SI units through its calibration by reference He-Nu heterodyne laser interferometer system. The system has a movable head that moves along 2000 mm linear encoder, Figure 2. This movable head has large display screen and digital camera. The screen has a crosshair that is used to be aligned with scale lines of ruler or tape at start measurements and interval steps

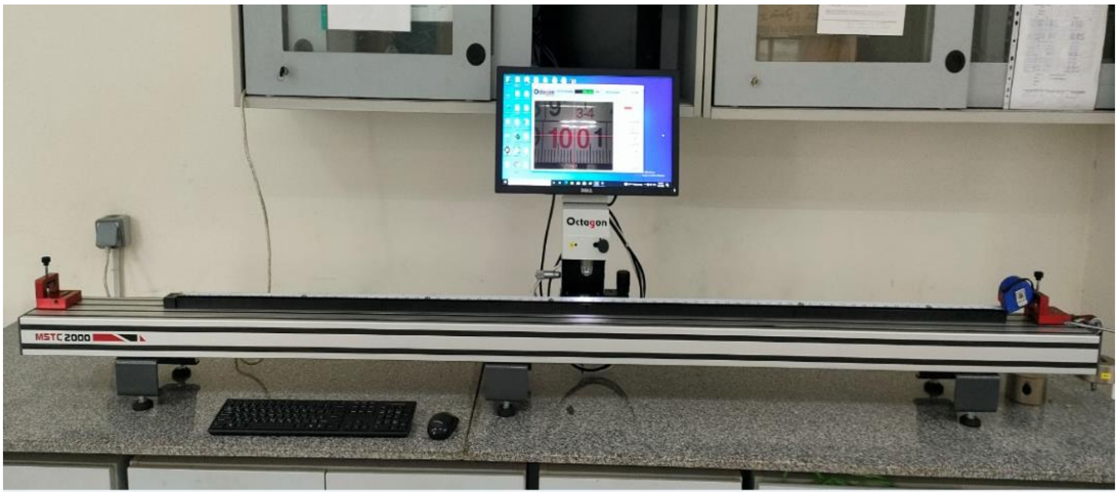

Figure 1: Measuring Scale & Tape Calibration System

The linear encoder that integrated in calibration system is considered in this system as the reference for length measurements in all measurements types that can be performed by it. The calibration using this system can be done with or without pressure loads. For both rulers' and tape calibration, no loads are applied. The calibration system is provided two pressure loads of 20 and 40 kg. These loads are applied only for depth tapes and tapes of plastic materials

Figure 2: Movable head with digital screen

2.2. Length Measuring Tools

Two length measuring tools of 1000 mm engineer's steel ruler and 5000 mm measuring tape are calibrated. Both tools have scale division of 1 mm. The calibration is carried out at interval of 100 mm.

2.3. Measurement Procedure

In calibration of steel ruler and measuring tape, length errors are measured based on the standards; BS 4372:2012 [12] and ISO 8322-2:1989 [13] respectively. There are four steps for calibration process, (1) the ruler or tape should be aligned and fixed on the guideway of the calibration system. (2) the starting point should be selected where you should check if the ruler-start side is clear or damaged. (3) press zero at this start side. (4) move the system head to the next length interval and check the resulted measured distance against the nominal length to determine the length deviation.

The method of measuring length deviation depends on measuring travel distance from specified point to a similar one at next specified scale division line, Figures 3–4.

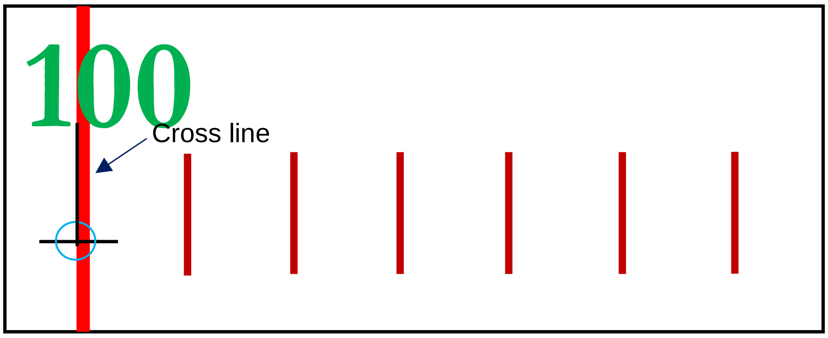

Figure 3: Cross line is adjusted at the beginning of scale division line.

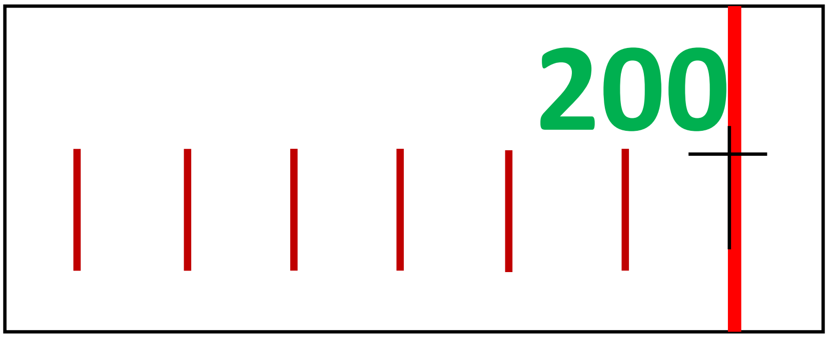

Figure 4: Cross line is adjusted at similar point in the next interval the beginning of scale division line.

3. Experimental Results

The engineer's steel ruler is calibrated along its full length. The measurements at each step are repeated 10 times. The calibration is done for scale range and scale division, Table 1–2. In similar way, the measuring tape is calibrated. The measuring tapes are calibrated commonly each 1 m but for this study it is calibrated each 100 mm, Table 3–4. The calibration results for both engineer's steel ruler and measuring tape are shown in Figures 5–6.

Table 1: Calibration of 1000 mm Engineer's steel ruler

Nominal length, mm	Average measured errors, mm
100	0.249
200	0.170
300	0.150
400	0.131
500	0.101
600	0.059
700	0.043
800	-0.022
900	-0.063
1000	-0.067

Table 2: Calibration of Scale division of 1000 mm Engineer's steel ruler

Nominal Thickness, mm	Average measured width, mm
0.25	0.245

Table 3: Calibration of 5000 mm measuring tape

Nominal length, m	Average measured errors, mm	Nominal length, m	Average measured errors, mm
100	0.125	2600	0.758
200	0.250	2700	0.753
300	0.284	2800	0.756
400	0.315	2900	0.750
500	0.342	3000	0.754
600	0.385	3100	0.766
700	0.450	3200	0.783
800	0.556	3300	0.795
900	0.680	3400	0.800
1000	0.755	3500	0.803
1100	0.760	3600	0.820

1200	0.755	3700	0.830
1300	0.780	3800	0.860
1400	0.775	3900	0.885
1500	0.750	4000	0.895
1600	0.745	4100	0.897
1700	0.763	4200	0.899
1800	0.755	4300	0.895
1900	0.756	4400	0.894
2000	0.757	4500	0.900
2100	0.750	4600	0.901
2200	0.745	4700	0.903
2300	0.755	4800	0.902
2400	0.760	4900	0.900
2500	0.745	5000	0.904

Table 4: Calibration of Scale division of 5000 mm measuring tape

Nominal Thickness, mm	Average measured width, mm
0.25	0.223

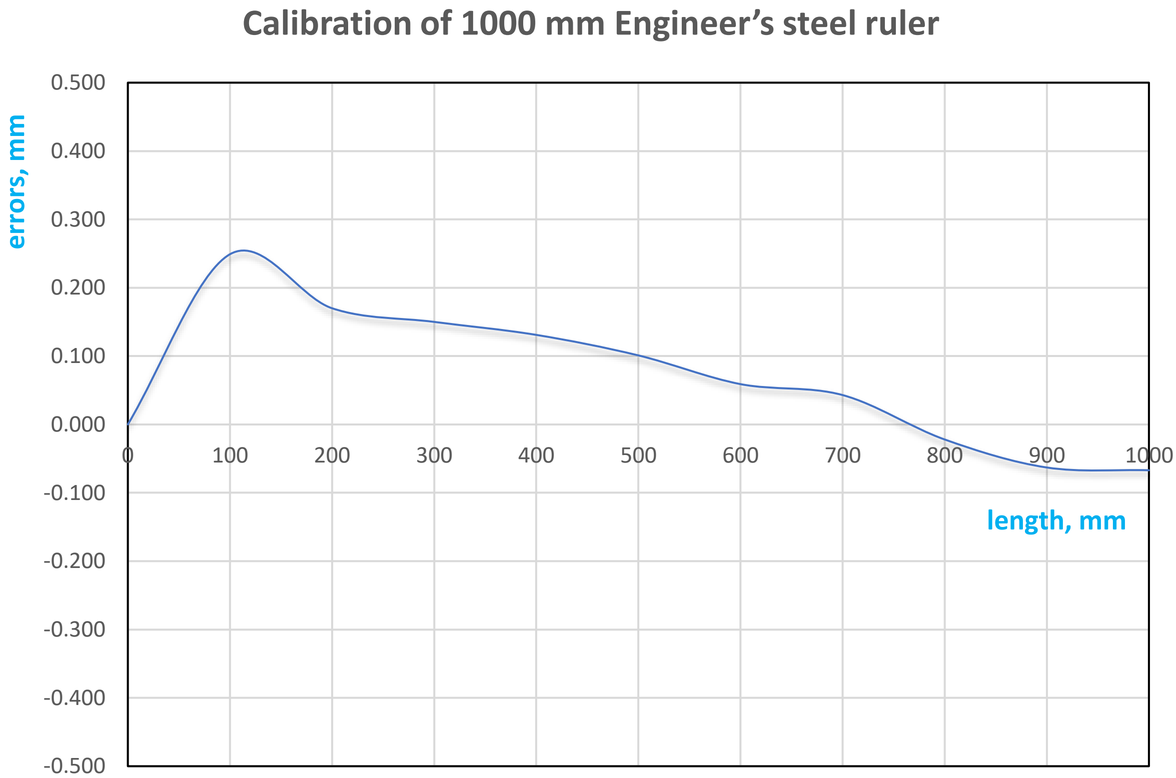

Figure 5: Errors in calibration of 1000 mm Engineer's steel ruler

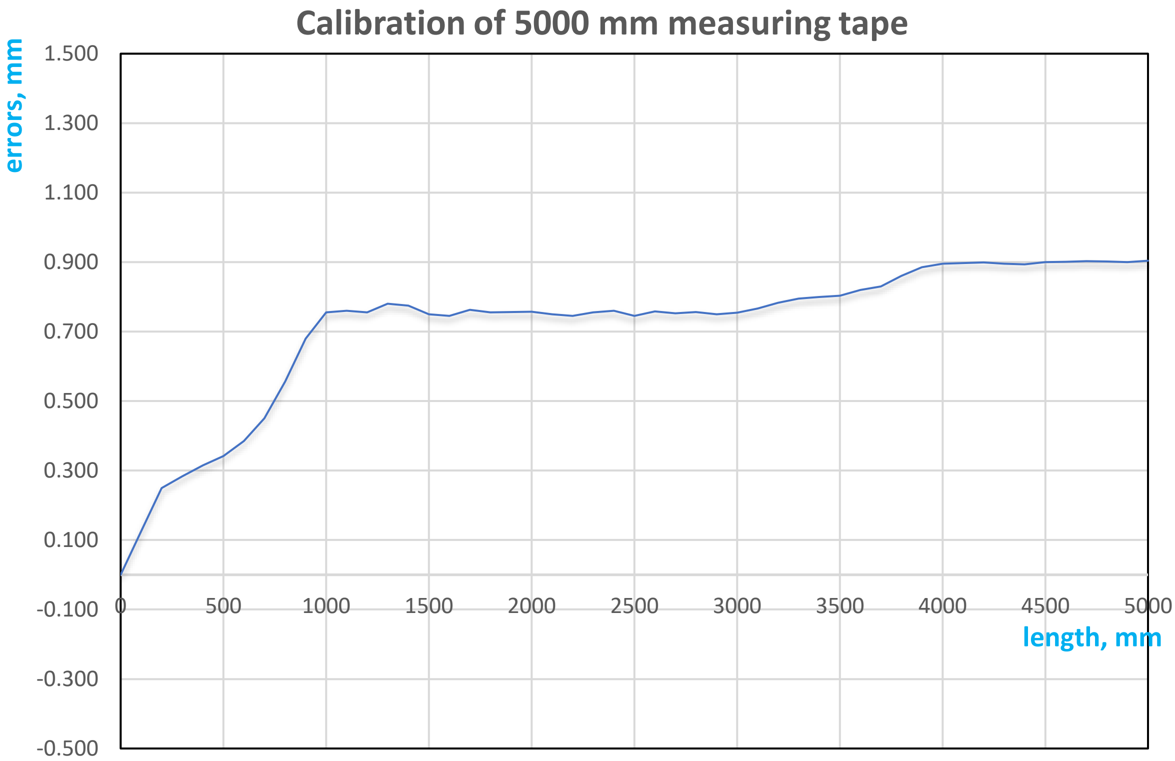

Figure 6: Errors in calibration of 5000 mm measuring tape

4. Uncertainty Evaluation based on GUM

The associated uncertainties are evaluated based on GUM [11]. In order to evaluate the associated uncertainty, the most affecting factors on the calibration process should be clearly determined. For this type of calibration, uncertainties due to instrument calibration, resolution, accuracy, graduations of ruler scale, sharpness of scale lines and temperature effect are most common factors. The calibration process of Engineer's steel ruler/tapes is expressed by mathematical model;

True length (L) = Measured length (x)+correction(Δ)+other factors ($\varepsilon_1; \varepsilon_2; \ldots\ldots\ldots \varepsilon_n$)

$$\mathbf{L = x + \Delta + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4 + \varepsilon_5 + \varepsilon_6 + \varepsilon_7} \qquad (1)$$

Where;

L	Length of Ruler / Tape
x	Measured length of Ruler / Tape
Δ	Correction due to calibration of reference instrument
ε_1	Correction due to reference instrument resolution
ε_2	Correction due to maximum errors in reference instrument
ε_3	Correction due to line width of scale division of Ruler / Tape
ε_4	Correction due to non-sharpness of scale lines of Ruler / Tape.
ε_5	Correction due to miss alignment of scale of Ruler / Tape with reference instrument scale.
ε_6	Correction due to temperature difference between Ruler / Tape and instrument.
ε_7	Correction due to temperature difference between Ruler / Tape and environmental standard temperature.

Assuming a linear model and sensitivity coefficients equal 1. by differentiation of equation (1); the contributory variances are

$$u^2(L) = u^2(x)+u^2(\Delta)+u^2(\varepsilon_1)+ u^2(\varepsilon_2)+u^2(\varepsilon_3)+u^2(\varepsilon_4)+u^2(\varepsilon_5)+u^2(\varepsilon_6)+u^2(\varepsilon_7) \qquad (2)$$

Where;

$u(L)$	uncertainty in Length (L)
$u(x)$	uncertainty due to repeatability (x)
$u(\Delta)$	uncertainty in calibration of reference instrument calibration
$u(\varepsilon_1)$	uncertainty in reference instrument resolution
$u(\varepsilon_2)$	uncertainty due to maximum errors in reference instrument
$u(\varepsilon_3)$	uncertainty due to line width of scale division of Ruler / Tape
$u(\varepsilon_4)$	uncertainty due to non-sharpness of scale lines of Ruler / Tape.
$u(\varepsilon_5)$	uncertainty due to miss alignment of scale of Ruler / Tape with reference instrument scale.
$u(\varepsilon_6)$	uncertainty due to temperature difference between Ruler / Tape and instrument.
$u(\varepsilon_7)$	uncertainty due to temperature difference between Ruler / Tape and environmental standard temperature.

the associated calibration uncertainty will be;

$$u(L) = [u^2(x)+u^2(\Delta)+u^2(\varepsilon_1)+u^2(\varepsilon_2)+u^2(\varepsilon_3)+u^2(\varepsilon_4)+u^2(\varepsilon_5)+u^2(\varepsilon_6)+u^2(\varepsilon_7)]^{0.5} \quad (3)$$

the expanded uncertainty of calibration can be determined by;

$$U(L) = K.u(L) \quad (4)$$

Where, K is a coverage factor which related the confidence level. It depends on the effective degree of freedom of all contributors and number of repetition of measurement results.

These factors or contributors in equation (3) that affect the calibration of either Engineer's steel ruler or Measuring tape will be described in details.

4.1. uncertainty due to repeatability u(x)

The calibration for engineer's steel ruler and measuring tape is repeated 10 times at each point. The standard uncertainty due to repeatability of calibration results $u(x_i)$ is determined by;

$$u(x_i) = \frac{\delta(xi)}{\sqrt{n}} \quad (5)$$

where; δ(xi) is standard deviation of calibration results at point xi. n is number of repetitions. The values of u(xi) for steel ruler and measuring tape is represented in tables 5 and 6.

Table 5: u(xi) for 1000 mm Engineer's steel ruler

at worst case	$\delta(xi)$, mm	u(xi), mm
	0.0042	0.0013

Table 6: u(xi) for 5m measuring tape

at worst case	$\delta(xi)$, mm	u(xi), mm
	0.004	0.0013

4.2. uncertainty due to calibration of reference instrument u(Δ)

The expanded uncertainty in calibration of this reference instrument is determined by;

$U_{(instrument)} = (0.70+0.96L)$ µm, L is nominal length in meter
at a coverage factor K = 2 and confidence level of 95% assuming normal distribution.

The standard uncertainty **u(Δ)** due to calibration uncertainty of reference instrument will be determined by;

$$u(\Delta) = \frac{U(reference)}{K} \quad (6)$$

then;

$$u(\Delta) = \frac{(0.70+0.96L)}{2} \text{ µm}$$

$$u(\Delta) = (0.35 + 0.48L) \text{ µm, L is length in meter.}$$

4.3. uncertainty due to resolution of reference instrument u(ε₁)

The calibration System that used for calibration has a resolution of 1 µm. The standard uncertainty u(ε₁) due to calibration uncertainty of reference instrument will be determined by;

$$u(\varepsilon_1) = \frac{half\ of\ resolution}{\sqrt{3}} \quad (7)$$

$$u(\varepsilon_1) = 0.0003\ mm$$

where √3 is the devisor factor assuming a rectangular uncertainty distribution.

4.4. uncertainty due to maximum errors in measuring instrument u(ε₂)

The maximum error in calibration of measuring instrument "Measuring Scale & Tape Calibration System (MTSC2000)" is found to be 3.43 µm. The standard uncertainty u(ε₂) due to this maximum error will be determined by;

$$u(\varepsilon_2) = \frac{0.00343}{\sqrt{3}} \quad (8)$$

$$u(\varepsilon_2) = 0.002\ mm$$

where √3 is the devisor factor for rectangular uncertainty distribution.

4.5. uncertainty due to line width of scale lines of Ruler / Tape u(ε₃)

The line width of scale divisions of both engineer's steel ruler and measuring tape are measured with 10 times repetition, tables 2 and 4. The standard uncertainty **u(ε₃)** due to line width of scale division is determined by equation 1;

$$u(\varepsilon_3) = \frac{\delta(xi)}{\sqrt{n}} \quad (9)$$

The values of u(**ε**₃) for steel ruler and measuring tape are represented in table 7.

Table 7: u(ε3) for Engineer's steel ruler and Measuring tape

Uncertainty factor	Engineer's steel ruler	Measuring tape
u(ε₃), mm	0.0005	0.0022

4.6. uncertainty due to non-sharpness of scale lines of Ruler / Tape u(ε₄)

The uncertainty due to non-sharpness of scale divisions of Ruler and Tape is determined experimentally and found to be about 5 µm. The standard uncertainty **u(ε₄)** value with rectangular distribution is represented in table 8.

Table 8: u(ε4) for Engineer's steel ruler and Measuring tape

Uncertainty factor	standard uncertainty **u(ε₄)**, mm
non-sharpness of scale divisions of Ruler / Tape	0.00289

4.7. uncertainty due to miss alignment of Ruler/Tape scale with instrument scale u(ε₅)

The standard uncertainty **u(ε₅)** due to miss alignment of Ruler/Tape scale with instrument scale is determined experimentally and found to be about 5 µm. The standard uncertainty **u(ε₅)** value with rectangular distribution is represented in table 9.

Table 9: u(ε5) for Engineer's steel ruler and Measuring tape

Uncertainty factor	standard uncertainty **u(ε₄)**, mm
miss alignment of Ruler/Tape scale with instrument scale	0.00289

4.8. uncertainty due to temperature difference between Ruler / Tape and instrument u(ε6)

The ruler/tape has a measured temperature difference of 0.5 °C from the actual temperature of the Calibration System. The material of both calibration system standard uncertainty $u(\varepsilon_6)$ due to this temperature difference will be determined by;

$$u(\varepsilon_6) = \frac{L \times \alpha \times \Delta}{\sqrt{3}} \tag{10}$$

where; L is measured length, α is thermal expansion coefficient of ruler/tape and calibration system materials (12×10^{-06}/°C), Λ is temperature difference between ruler/tape and the calibration system (0.5 °C) and √3 is the devisor factor for rectangular uncertainty distribution.

then; $$u(\varepsilon_6) = \frac{L \times 12 \times 10-6 \times 0.5}{\sqrt{3}}$$

$$u(\varepsilon_6) = 0.0035L \text{ mm} \quad \textit{where L is nominal length in m.}$$

4.9. uncertainty due to temperature difference between Ruler / Tape and standard temperature u(ε7)

The standard calibration temperature for ruler/tape is 20°C ± 1°C. The standard uncertainty **u(ε6)** due to this temperature fluctuation (± 1°C) will be determined by;

$$u(\varepsilon_7) = \frac{L \times \alpha \times \Delta}{\sqrt{3}}$$

where; L is measured length, α is thermal expansion coefficient of ruler/tape and calibration system materials (12×10^{-06}/°C), Λ is temperature deviation from standard temperature (±1°C) and √3 is the devisor factor for rectangular uncertainty distribution.

then; $$u(\varepsilon_7) = \frac{L \times 12 \times 10-6 \times 1}{\sqrt{3}}$$

$$u(\varepsilon_7) = 0.0069L \text{ mm} \quad \textit{where L is nominal length in m.}$$

The combined uncertainty budget for calibration of Engineer's Steel Rulers and Measuring Tape will be as represented in tables 10 and 11.

Table 10: Evaluation of associated uncertainty u(L) in calibration of 1000 mm steel ruler

Uncertainty sources	denoted by	standard uncertainty	distribution	degree of freedom	Contribution, %
uncertainty due to repeatability (x)	u(x)	0.0013 mm (worst)	Normal	9	2.0
uncertainty in calibration of measuring instrument	u(Δ)	(0.35+0.48L) ×10^{-3} mm	Normal	∞	0.8
uncertainty in instrument resolution	$u(\varepsilon_1)$	0.000289 mm	Rectangular	∞	0.1
maximum error in calibration of measuring instrument	$u(\varepsilon_2)$	0.00198 mm	Rectangular	∞	4.7

uncertainty due to line width of scale lines of Ruler.	u(ε_3)	0.000577 mm	Rectangular	∞	0.4
uncertainty due to non-sharpness of scale divisions of Ruler.	u(ε_4)	0.00289 mm	Rectangular	∞	10.0
uncertainty due to miss alignment of scale of Ruler with instrument scale.	u(ε_5)	0.00289 mm	Rectangular	∞	10.0
uncertainty due to temperature difference between Ruler and instrument.	u(ε_6)	0.0035L mm	Rectangular	∞	14.4
uncertainty due to temperature difference from standard temperature.	u(ε_7)	0.0069L mm	Rectangular	∞	57.6
Combined Uncertainty u(L)		$[(0.0048)^2+(0.0078L)^2]$ mm	Normal distribution, effective degree of freedom = ∞		100.0
Expanded uncertainty U(L)		$\sqrt{(0.0096)^2+(0.0156L)^2}$ mm, L in m	at Coverage factor K = 2 & confidence level 95%		

Table 11: Evaluation of associated uncertainty u(L) in calibration of 5 m Measuring Tape

Uncertainty sources	denoted by	standard uncertainty	distribution	degree of freedom	Contribution, %
uncertainty due to repeatability (x)	u(x)	0.0013 mm (worst)	Normal	9	1.0
uncertainty in calibration of measuring instrument	u(Δ)	$(0.35+0.48L)\times10^{-3}$ mm	Normal	∞	0.5
uncertainty in instrument resolution	u(ε_1)	0.000289 mm	Rectangular	∞	0.1
maximum error in calibration of measuring instrument	u(ε_2)	0.00198 mm	Rectangular	∞	0.3

uncertainty due to line width of scale division of Tape.	$u(\varepsilon_3)$	0.000577 mm	Rectangular	∞	0.1
uncertainty due to non-sharpness of scale divisions of Tape.	$u(\varepsilon_4)$	0.00289 mm	Rectangular	∞	0.5
uncertainty due to miss alignment of scale of Tape with instrument scale.	$u(\varepsilon_5)$	0.00289 mm	Rectangular	∞	0.5
uncertainty due to temperature difference between Tape and instrument.	$u(\varepsilon_6)$	0.0035L mm	Rectangular	∞	19.5
uncertainty due to temperature fluctuations in standard temperature.	$u(\varepsilon_7)$	0.0069L mm	Rectangular	∞	78.4
Combined Uncertainty u(L)		$[(0.0048)^2+(0.0078L)^2]$ mm	Normal distribution, effective degree of freedom = ∞		100.0
Expanded uncertainty U(L)		$\sqrt{(0.0096)^2+(0.0156L)^2}$ mm, L in m	at Coverage factor K = 2 & confidence level 95%		

5. Uncertainty Evaluation by Monte Carlo Simulation

The associated uncertainties in calibration of Engineer's steel ruler and measuring tape are evaluated once more by Monte Carlo [10–11], Figures 7–8. The evaluation process in calibration of 1000 mm Engineer's steel ruler is run with the software specifications:

```
GUM Workbench Edu
Simulator: OMCE V:1.2.3\n
Mean Value: 999.9676 mm\n
Standard Uncertainty: 0.0092 mm\n
Coverage Interval (p=0.9545): [999.9498, 999.9853] mm (Probabilistically Symmetric) \n
Expanded Uncertainty Interval (p=0.9545): (+0.018, -0.018) mm (Probabilistically Symmetric) \n
Number of Monte Carlo Trials: 4000000\n
Block size: 10000 runs\n
```

The evaluation process in calibration of 5000 mm Measuring tape is run with the software specifications:

```
GUM Workbench Edu
Simulator: OMCE V:1.2.3\n
Mean Value: 5001.015 mm\n
Standard Uncertainty: 0.039 mm\n
Coverage Interval (p=0.9545): [5000.942, 5001.087] mm (Probabilistically Symmetric) \n
Expanded Uncertainty Interval (p=0.9545): (+0.073, -0.073) mm (Probabilistically Symmetric) \n
Number of Monte Carlo Trials: 4000000\n
Block size: 10000 runs\n
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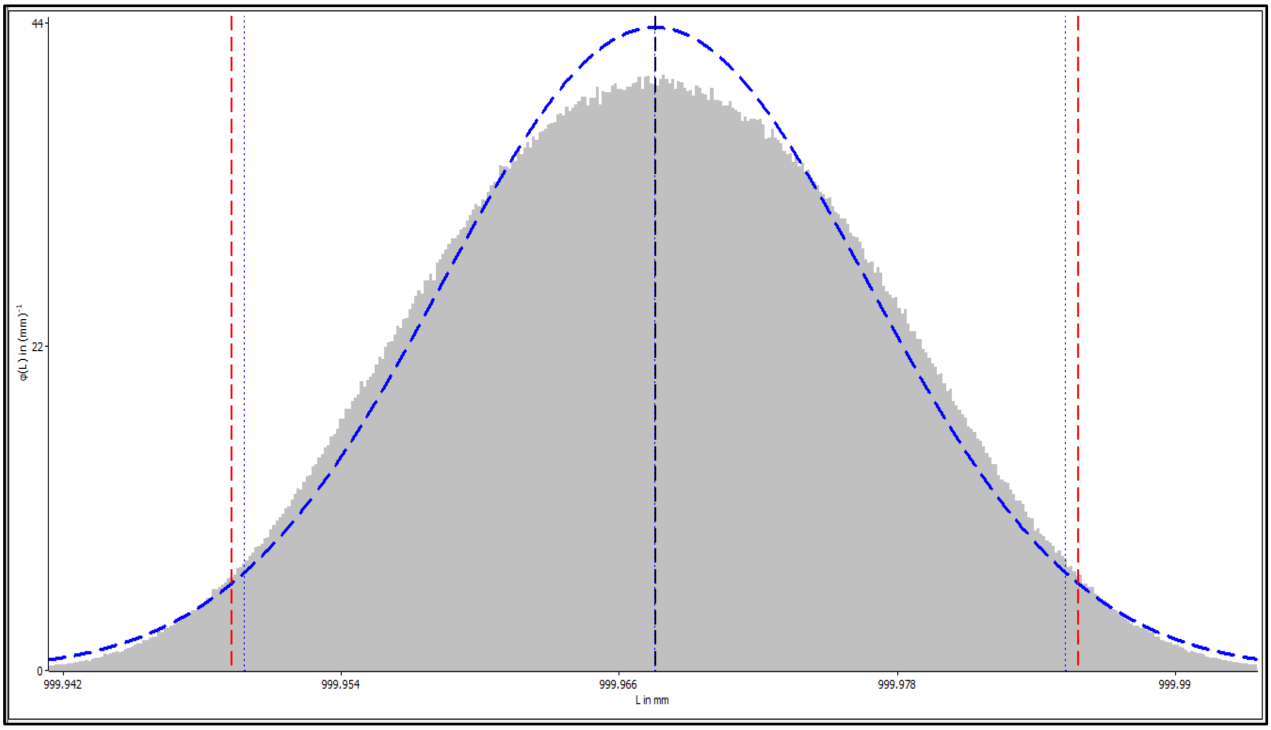
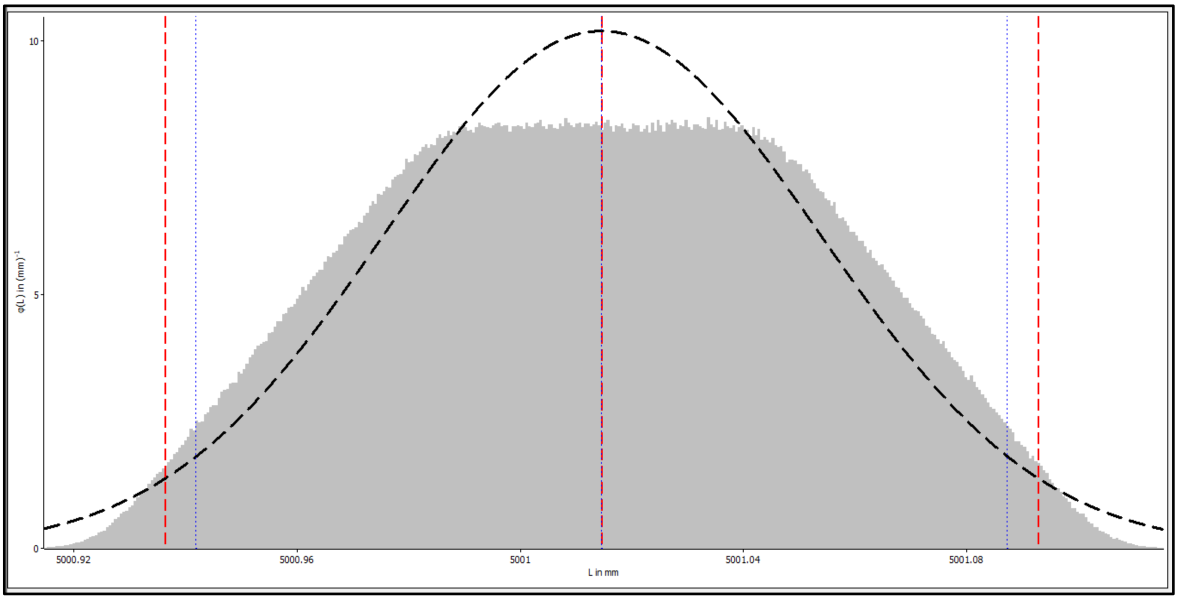


Simulator: OMCE V:1.2.3\n
Mean Value: 999.9676 mm\n
Standard Uncertainty: 0.0092 mm\n
Coverage Interval (p=0.9545): [999.9498, 999.9853] mm (Probabilistically Symmetric) \n
Expanded Uncertainty Interval (p=0.9545): (+0.018, -0.018) mm (Probabilistically Symmetric) \n
Number of Monte Carlo Trials: 4000000\n
Block size: 10000 runs\n

Figure 7: Result of the Monte Carlo Simulation for uncertainty evaluation in calibration of 1000 mm Engineer's steel ruler



Simulator: OMCE V:1.2.3\n
Mean Value: 5001.015 mm\n
Standard Uncertainty: 0.039 mm\n
Coverage Interval (p=0.9545): [5000.942, 5001.087] mm (Probabilistically Symmetric) \n
Expanded Uncertainty Interval (p=0.9545): (+0.073, -0.073) mm (Probabilistically Symmetric) \n
Number of Monte Carlo Trials: 4000000\n
Block size: 10000 runs\n

Figure 8: Result of the Monte Carlo Simulation for uncertainty evaluation in calibration of 5 m Measuring Tape

6. Discussion

There are many factors that act as sources for uncertainty in calibration process of Engineer's steel rulers and Measuring Tapes. The most common factors are (1) repeatability in measurement results, (2) calibration uncertainty of the reference instrument that used in calibration process, (3) the resolution of reference instrument, (4) maximum error in measuring instrument, (5) non-sharpness of scale divisions, (5) line width of scale division, (6) non-sharpness of scale divisions, (7) miss-alignment of Ruler/Tape scale with instrument scale, (8) temperature effect due to difference in temperature between Ruler/Tape and instrument and (9) temperature fluctuations in standard temperature for calibration. The relative effects of each factor are represented in Pie and Bar charts in Figures 9–10.

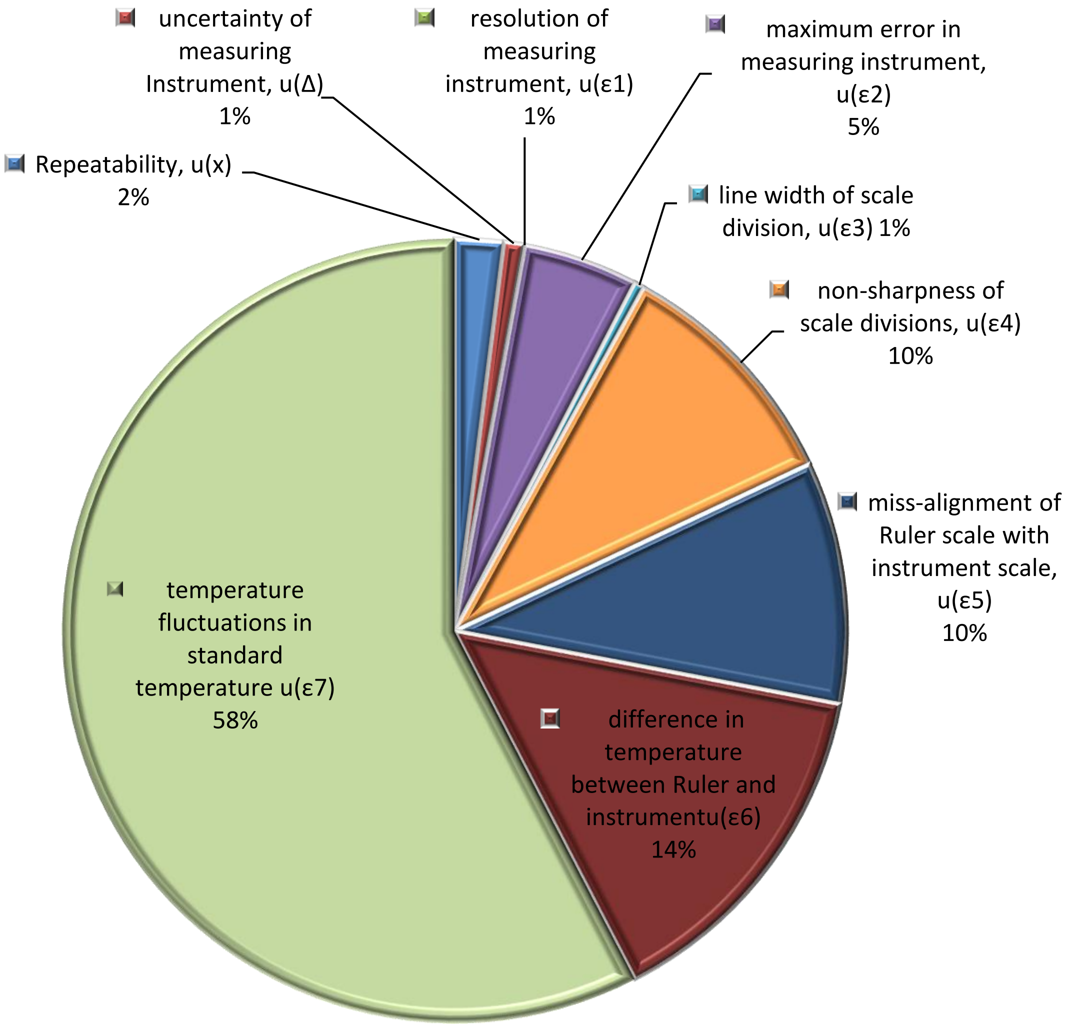


Figure 9: Relative effects of uncertainty sources in total combined uncertainty at full scale for calibration of 1000 mm Engineer's steel ruler.

For calibration of Engineer's steel rulers, the highest uncertainty sources that have percentage effects in total combined uncertainty are non-sharpness of scale division about 10%, miss-alignment of ruler scale with instrument scale about 10%, difference in temperature between ruler and measuring instrument about 14% and temperature differences from standard temperature about 58%. The total effect of these four factors is about 92%. The precise control of temperature conditions and differences may reduce the effect due to these two factors. The factor of miss-alignment can be improved through precise adjustment. The factor of non-sharpness depends on the nature of under-calibration steel ruler. In general, the total expanded uncertainty at full scale of 1000 mm Engineer's steel ruler is about 0.018 mm (18 µm).

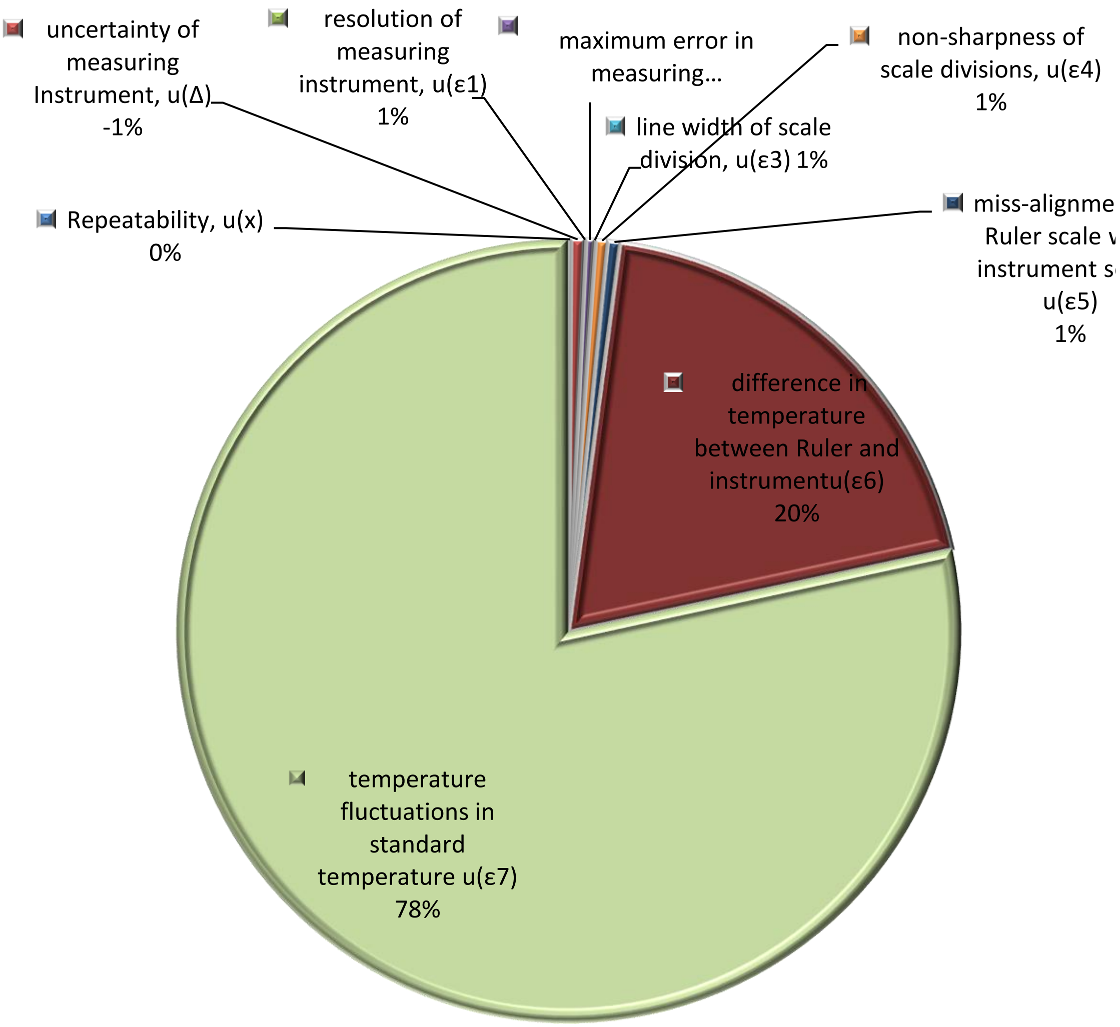


Figure 10: Relative effects of uncertainty sources in total combined uncertainty at full scale for calibration of 5m Measuring tape.

For calibration of measuring tapes, the highest uncertainty sources that have percentage effects in total combined uncertainty are temperature fluctuations in standard temperature about 78% and difference in temperature between tape and measuring instrument about 20%. The total effect of these four factors is about 98%. The precise control of temperature conditions and differences may reduce the effect due to these two factors. In general, the total expanded uncertainty at full scale of 5000 mm measuring tape is about 0.080 mm (80 µm).

In a comparative way to the uncertainty evaluation based on GUM approach. The Monte Carlo simulation method is used to evaluate the associated uncertainty in calibration of steel ruler and measuring tape. The mean and standard deviation of calibration results for simulations of 4000000\n (Number of Monte Carlo Trials) provide an estimate of the true value and its coverage interval. The Monte Carlo simulations resulted in expanded uncertainty of 0.018 mm and 0.078 mm in calibration of ruler and measuring tape respectively.

7. Conclusions

A 1000 mm steel ruler and 5000 mm measuring tape are calibrated using reference calibration system at intervals of 100 mm. The associated uncertainty in each calibration type is evaluated in details. For ruler calibration, the highest uncertainty sources that have percentage effects in total combined uncertainty are non-sharpness of scale division, miss-alignment of ruler scale with instrument scale, difference in temperature between ruler and measuring instrument and temperature fluctuation in standard temperature. For calibration of measuring tape, the highest uncertainty sources that have percentage effects in total combined uncertainty are temperature fluctuations in standard temperature, difference in temperature between tape and measuring instrument. The expanded uncertainty at full scale of 1000 mm Engineer’s steel ruler is about 0.018 mm (~20 µm). The expanded uncertainty at full scale of the measuring tape is about 0.080 mm (80 µm). The uncertainties in calibrations are revaluated by Monte Carlo simulation method and found to be 0.018 and 0.078 mm in calibration of ruler and tape respectively.

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