Determination of probe non-linearity and error due to measurement position for direct measurement type of gauge block comparator and its measurement uncertainty

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Abstract. The non-linearity of probes is one of the important components in gauge block calibration by the mechanical comparative method of two gauges blocks at the same nominal length. However, an advanced method for gauge block calibration is a mechanical direct measurement method of two gauge blocks showing the greatest difference in nominal length of 25 mm. This method uses a special probe based on the interferential scanning principle to produce the signals to measure the displacement. In this paper, non-linearity and error due to measurement position were investigated as they related to the accuracy of measurement results. The differences in central length of pairs of standard gauge blocks made of steel were measured by optical interferometry with the measurement uncertainty (k=2) 23 nm. Length in the range of 5 μm to 25 mm was used in the experiment. Non-linearity of the probe was evaluated by the simple linear regression model. Various factors such as origin setting point, temperature, and vibration have been analysed. In the preliminary experiment, the non-linearity, position error, repeatability and retrace error over the measuring range 25 mm are 13 nm, -18 nm, 15 nm, and 10 nm respectively. The standard uncertainty of direct measurement type caused by non-linearity is 4 nm.

1. Introduction

A gauge block comparator is a device used to calibrate the end standard of length or gauge blocks according to ISO3650:1998 [1]. Traditionally, a gauge block was measured using a comparative measurement method with the standard gauge block and the unknown gauge block having the same nominal length. However, this method had limitations on the non-linearity of the type of linear variable differential transformer (LVDT) probe. In other words, non-linearity is less than 25 nm in a different length up to 80 μm [2] caused the amount number of standard gauge blocks required for calibration. Differently, gauge blocks can be calibrated using a direct measurement method of two gauge blocks showing the greatest difference in nominal length 25 mm causing the number of the standard gauge blocks, calibration cost, and maintenance cost to significantly decrease. A special probe was used in this method based on the interferential scanning principle to produce the signal to measure the displacement [3].

In this paper, we investigated the non-linearity of a special probe and the error due to measurement position for a direct measurement type in the gauge block comparator and the investigated results were used to evaluate the measurement uncertainty and validate the measurement system to provide calibration services.

2. Measurement principle

2.1. Experiment and method

An experimental system was shown in figure 1. Direct measurement type of gauge block comparator (DGBC) manufactured by TESA, model UPD was used. This device can measure two different types of measurements: comparative type with 10 μm measurement range and direct type with 25 mm measurement range using a special probe manufactured by Heidenhain, model 2501 with display unit ND287 resolution 10 nm. The temperature correction system consisted of two platinum resistance thermometers (PRT) with a display unit manufactured by Fluke, model 1529 with a resolution of 0.001 °C.

Figure 1. Direct measurement type of gauge block comparator system.

Non-linearity of a probe and the error due to measurement position were determined by modifying the measurement method according to Euramet cg-2/v.2. The differences in central length of 13 pairs of gauge blocks made of steel, grade K were measured by optical interferometry with measurement uncertainty ($k = 2$) 23 nm. The 13 pairs of steel gauge blocks were presented in table 1. The non-linearity of the probe and its uncertainty were evaluated by the simple linear regression model [4].

Table 1. Measurement position of 13 pairs of gauge blocks made of steel.

Pair No.	Nominal length (mm)		Pair No.	Nominal length (mm)	
	A	B		A	B
1	25	50	8	25	26
2	25	45	9	25	25.5
3	25	35	10	25	25.1
4	25	30	11	25	25.01
5	25	29	12	25	25.005
6	25	28	13	25	25
7	25	27	-	-	-

2.2. *Measurement setup*

Zero position of a probe relative to a 25 mm measurement position on precision glass scale inside probe unit was determined using gauge block of 50 mm nominal length at A point. 25 measurement position on precision glass scale was defined at displacement 1.0645 mm ± 0.0002 mm of a display unit when origin point was the top of a probe unit.

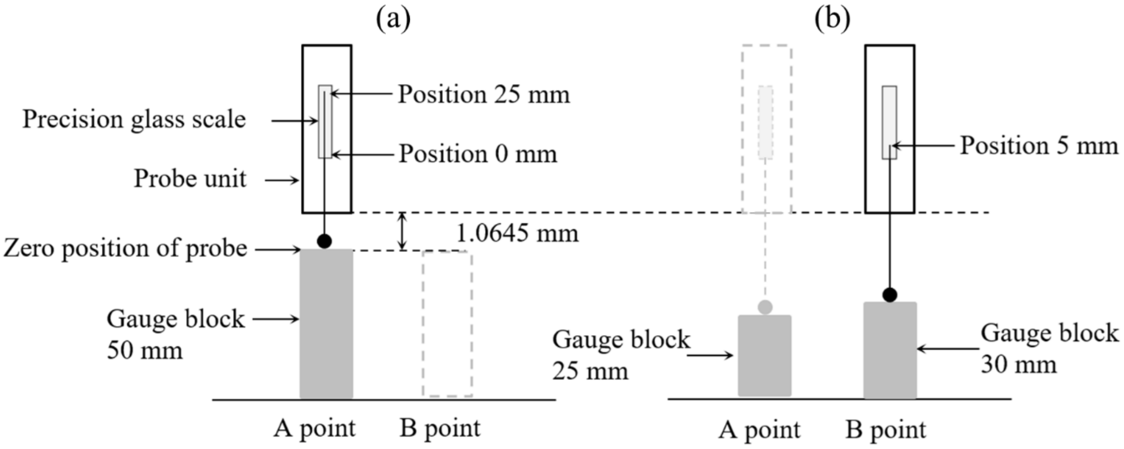

Figure 2. Zero position of a probe setup (a) and example of a direct measurement setup at 5 mm measurement position (b).

Next, a 0 measurement position was started using gauge block, nominal length 25 mm placed at point A and nominal length 25 mm placed at point B. Therefore, a 5 measurement position was shown as an example in figure 2. The measurement results of the measurement position on the precision glass scale were shown in table 2. Measurements at A and B points were performed using a special sliding system to control pitch and yaw motion and both gauge blocks were placed on a measuring table. The producibilities of the sliding system and variation of a measuring table were less than 10 nm and 20 nm respectively.

3. Results and discussions

The experiment was carried out under a laboratory environment of room temperature at 20.0 °C ± 0.3 °C, and relative humidity at 50 %RH + 10 %RH. The temperature difference between A and B points was less than ± 0.02 °C. All measurement results were compensated for the effect of temperature due to thermal expansion coefficient to reference temperature 20 °C refer to the ISO 1-1975. Since the special probe was considered as the high accuracy measuring system, the effect of vibration in this experiment was prevented using 20 mm rubber pads. The probe non-linearity of two comparative types over ± 10 µm and the direct measurement type over ± 25 mm determined by the linear interpolation of the measurement results was 2 nm and 13 nm sequentially as shown in figure 3.

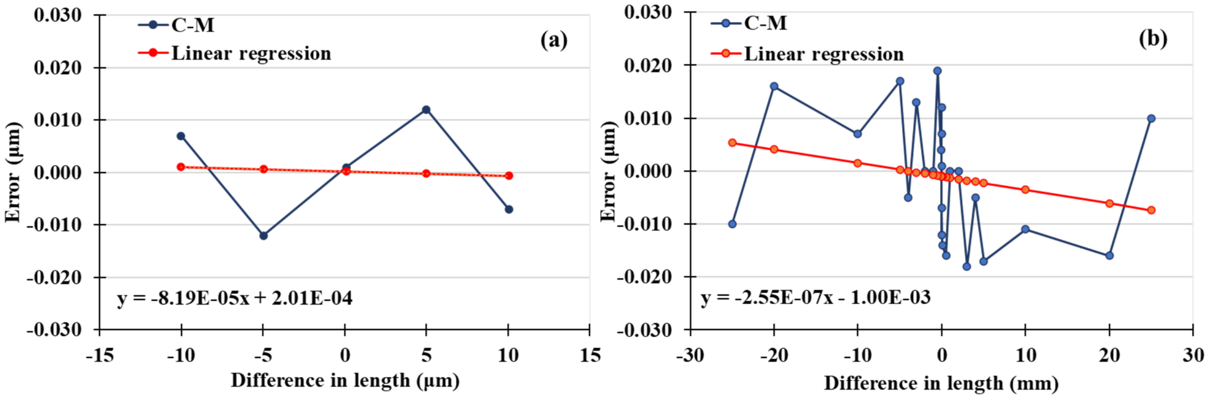

Figure 3. Non-linearity of the probe between comparative type (a) and direct measurement type (b).

The error due to a measurement position of the precision glass scale over 25 mm was shown in figure 4. A maximum error was -18 nm at a 3 mm measurement position. The results of the retrace errors as the difference between probe moving up and down were presented in table 2. A maximum retrace error was 10 nm at 0.1 mm. The experiment was repeated 10 times with repeatability less than 15 nm.

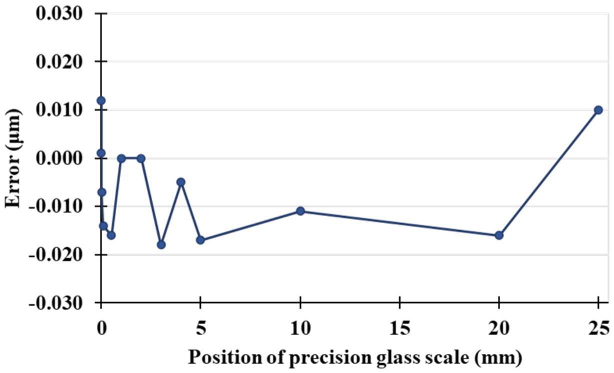

Figure 4. Relation between error and measurement position of precision glass scale inside probe unit.

Table 2. Errors of measurement position and retrace errors.

Position (mm)	Error (nm)		Retrace error (nm)	Position (mm)	Error (nm)		Retrace error (nm)
	Moved up	Moved down			Moved up	Moved down	
0	1	-	-	3	-18	-13	5
0.005	12	12	0	4	-5	-5	0
0.01	-7	-7	0	5	-17	-17	0
0.1	-14	-4	10	10	-11	-7	4
0.5	-16	-19	-3	20	16	16	0
1	0	0	0	25	10	10	0
2	0	0	0	-	-	-	-

Measurement uncertainty of non-linearity [2] and the error due to measurement position were evaluated by the EA publication EA-4/02 “Expression of Uncertainty of Measurement in Calibration”

[5]. The standard uncertainty of comparative type and direct measurement type caused by non-linearity was estimated as results of 1 nm and 4 nm severally. The standard uncertainty of measurement position error was also estimated given the result at 10 nm. Both standard uncertainties were considered as the rectangular distribution since they provided the effect of systematic uncertainty.

4. Conclusion

In this work, we investigated the parameters of a special probe of the direct measurement type gauge block comparator (DGBC). These parameters affected the measurement uncertainty on gauge block calibration using a gauge block comparator. Also, the measurement system was validated to provide calibration services. we found that the probe non-linearity of a comparative type and a direct measurement type were 2 nm and 13 nm, respectively. Moreover, we found a maximum error of a measurement position and a maximum retrace error were equal to -18 nm at 3 mm, and 10 nm at 0.1 mm, respectively. Finally, we evaluated the standard uncertainty of measurement position error with the result of 10 nm.

Therefore, it can be said that the accuracy of a DGBC probe was sufficient for providing calibration services on the gauge block by both of comparative type and direct measurement type.

References

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