Asia/Pacific Metrology Programme gauge block comparison – 1993/94

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Abstract. A comparison of gauge blocks has been carried out in the Asia/Pacific Region as part of an international comparison decided on by the Comité Consultatif pour la Définition du Mètre. Ten national standards laboratories measured a set of five grade 00 gauge blocks (and two replacements) using interferometry. This paper reports on the comparison and shows that for gauge block lengths up to 40 mm (original set) all laboratories agreed to within ± 0,03 μm and for the 100 mm gauge block they agreed to within ± 0,08 μm.

1. Introduction

At the 8th Meeting of the Comité Consultatif pour la Définition du Mètre (CCDM) in September 1992, it was resolved to implement a limited, small-scale, international comparison of gauge blocks, using a recent European comparison as a model [1]. The comparisons were to be conducted regionally and be linked together by a CCDM comparison involving one laboratory from each region. The regions were those covered by EUROMET (Western Europe), COOMET (Eastern Europe), NORAMET (North and Central America) and APMP [2] (Asia/Pacific Metrology Programme). The National Measurement Laboratory of Australia (NML, CSIRO Division of Applied Physics) represented the APMP in the CCDM comparison and organized the regional comparison in the APMP. This paper reports the results of the APMP regional comparison.

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2. Participants and measurements

Ten laboratories (Table 1) took part in the APMP comparison between May 1993 and August 1994. All are members of the APMP except for the South African Council for Scientific and Industrial Research (CSIR), which was invited to take part as this laboratory is not a member of a regional metrology group.

3. Measuring instructions

The aim was to measure five grade 00 rectangular steel gauge blocks with lengths 1 mm, 3 mm, 8 mm, 40 mm and 100 mm, using interferometry according to International Standard ISO 3650. Two gauge block sets were donated by the Japan Precision Measuring Instrument Association. The second set acted as a back-up for the first set and two blocks were used from this set as substitutes and back-up for damaged blocks. As the pilot laboratory, the NML measured the blocks three times, near the start, in the middle and at the end of the comparison. The National Research Laboratory of Metrology (NRLM, Japan) organized the supply of the blocks and carried out their own measurements before shipping them to Australia. The schedule, which was a compromise between ease of transport and individual laboratory programmes, was followed fairly closely despite several disruptions caused by transport problems and the need to replace one block.

Table 1. Participants, the planned schedule and actual start times for each laboratory.

Laboratory	Country	Contact	Planned start	Actual start
1 NRLM	Japan	H. Matsumoto	3 May (1993)	7 May (1993)
2 NML	Australia	N. Brown	7 June	10 June
3 CSIR	South Africa	B. Burke	12 July	16 July
4 KRISS	Korea	T. B. Eom	16 August	16 August
5 NIM	China	Y. Xu	20 September	12 October
6 NPLI	India	R. P. Singhal	25 October	11 November
7 NML	Australia	N. Brown	29 November	15 December
8 MSL	New Zealand	E. Howick	3 January	10 January
9 KIM-LIPI	Indonesia	J. Pusaka	7 February	25 February
10 SISIR	Singapore	S. L. Ling-Tan	14 March	15 April
11 CMS/ITRI	Taiwan	Y. Lan	18 April	31 May
12 NML	Australia	N. Brown	23 May (1994)	6 July (1994)

Participating laboratories were asked to use interferometric techniques to measure the following:

(a) The deviation of the central length of each block from its nominal size, determined from the mean of two measured lengths (obtained by wringing to each end of the block), and referred to 20 °C. For temperature corrections the measured coefficient of thermal expansion was to be used or the value $\alpha = 11{,}6 \times 10^{-6}\ \mathrm{K}^{-1}$ if this was not measured by the participant. These results were to include the correction for the phase change on reflection between the block and the reference flat.

(b) The deviation from flatness.

(c) The variation in length.

(d) The coefficient of thermal expansion (if possible).

Measurement uncertainties were to be stated with a confidence level of 99 %.

Additional information was also requested on the following points:

(a) The make or type of interferometer used.

(b) The mean temperature and the temperature range for each measurement set.

(c) Light sources used (e.g. Cd114 lamp, He-Ne 633 laser).

(d) The derivation of the refractive index of air.

(e) The material of the reference flat.

(f) The derivation of the phase correction.

4. Comparison schedule

The original timetable allowed five weeks for each participant to measure the gauge blocks and ship them to the next laboratory, giving a period of about one year for the entire comparison. Table 1 shows that the schedule was followed quite closely to begin with and then suffered some transport/customs delays but was only fifteen days behind when the NML received the blocks for their second measurement. The second cycle was completed a further thirty-three days behind schedule, partly due to the need to replace the 8 mm block half-way through the measurement cycle. This was an excellent achievement, particularly for those laboratories that measured the coefficient of expansion.

All the blocks except the 40 mm one were in reasonable condition after the first cycle with surface scratches but no edge burrs or significant damage. The 40 mm block had an edge burr and a deep scratch across one face. This was most probably caused by a customs official dropping the block while trying to read the serial number. Although this could not be established, finger prints on the blocks gave clear evidence that they had been handled. A customs-proof box which protected the blocks but allowed officials to read the serial numbers was then constructed in order to avoid further damage. The 40 mm block from the back-up set was added to the comparison set and the scratched 40 mm block was measured in only one direction by participants in the second round. The Singapore Institute of Standards and Industrial Research (SISIR) reported significant scratching on the 8 mm block and consequent problems with wringing. This block was replaced and a substitute block was measured by the SISIR and the Center for Measurement Standards (CMS/ITRI, Taiwan). The CMS/ITRI also had problems with wringing one side of the 3 mm block and only measured one side. The NML measured the length of the replacement blocks three times (twice at the end) to be consistent with the other blocks.

The Indonesian Institute of Sciences (KIM-LIPI, Indonesia) was included in the comparison although the laboratory does not have a conventional gauge block interferometer. It has a laser interferometer which measures the height of a probe which can be lowered onto the block and then onto the platen once the block has been removed. While this method can give precise results the laboratory lacked adequate temperature control for accurate results on longer blocks and therefore did not report on the 40 mm and 100 mm blocks.

The National Physical Laboratory (NPLI, India) had difficulties with its first set of measurements of the 40 mm and 100 mm blocks due to problems with the interferometer lamp and thermometry. These blocks were therefore remeasured at the end of the comparison.

5. Results

Each participant was provided with a performance report, compared with the average result up to that time, soon after the results were submitted. Initially the results were kept confidential, but this policy was changed with the agreement of all participants.

5.1 Coefficient of linear expansion

The coefficient of linear expansion (α) was measured by laboratories 1, 6 and 8 with the NML measuring it at 2 and 12 in the measurement sequence. Good agreement occurred between the measurements from laboratories 1, 2, 8 and 12. Laboratory 6 found a value of $11{,}8 \times 10^{-6}$ K^{-1} but later withdrew this due to suspected thermometry errors. The reported values for the 100 mm block were $\alpha = 10{,}9 \times 10^{-6}$ K^{-1}, $10{,}8 \times 10^{-6}$ K^{-1}, $10{,}8 \times 10^{-6}$ K^{-1} and $10{,}8 \times 10^{-6}$ K^{-1}. Because of the large difference between the measured and default values for α, each laboratory was asked to recalculate the deviation from nominal length using $\alpha = 10{,}8 \times 10^{-6}$ K^{-1} for the 40 mm and 100 mm blocks.

5.2 Deviation from nominal length

Figure 1 shows a summary of the deviation from the mean length (for $\alpha = 10{,}8 \times 10^{-6}$ K^{-1}) with the mean value subtracted. Measurements are shown in the order listed in Table 1, with the NML measurement shown with clear bars. Measurements which lie on the zero line are represented by small rectangles centred on the mean, to distinguish them from the case where no value was reported. The mean deviation from the nominal value is printed, together with the greatest and least value (from the mean), at the foot of each column for each gauge block. Actual values and their uncertainties are given in the Appendix.

Results for five gauge blocks (1 mm, 3 mm, 8 mm, 40 mm and the replacement 8 mm) lie within $\pm 0{,}03$ μm with nearly all the measurement uncertainty bars including the mean value. Some significant differences exist for the 100 mm block although in this case only two laboratories do not span the mean value with their uncertainty bars. Laboratory 11 reported a problem with the stability of measurements on the replacement 40 mm block (SN 9389) and recorded a significant departure from the mean value of $-0{,}07$ μm.

5.3 Deviation from flatness

Figure 2 summarizes the flatness measurements which agree quite well given the 10 nm resolution increments. This was not reported in measurements from laboratories 1, 5, 7 and 9.

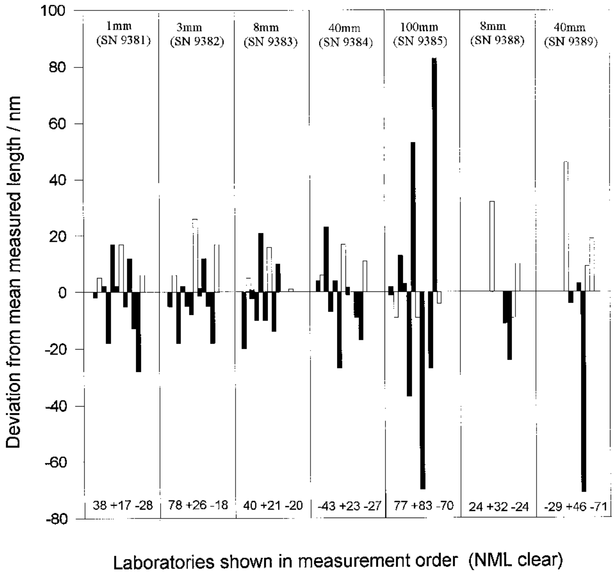

Figure 1. Summary of all measurements of the deviation from the mean measured length, shown in the order of measurement with the NML clear. At the foot of each column the mean value is given. This is followed by the difference between the mean and the longest and shortest measurements (in nm). Readings which match the mean value are shown as a rectangle centred on the mean to distinguish them from the case of no reading where nothing is shown.

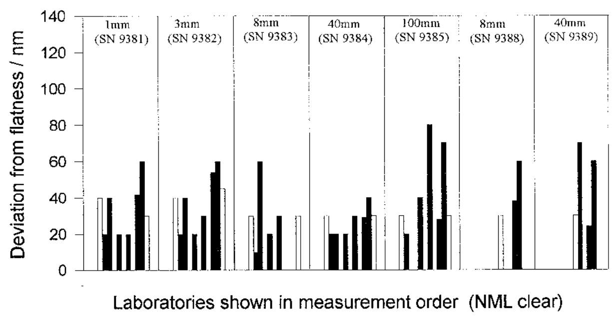

Figure 2. Deviation from flatness for all gauge blocks.

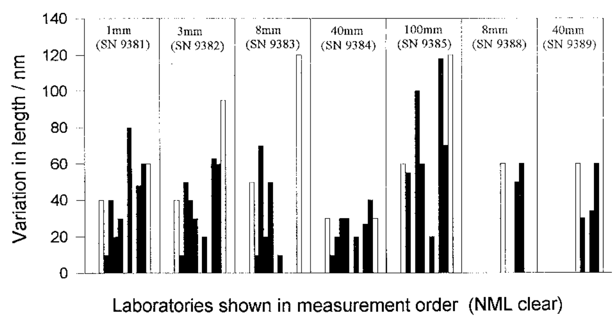

Figure 3. Variation in length for all gauge blocks.

5.4 Variation in length

Figure 3 summarizes the variation in length. There appears to be an increase in this quantity throughout the comparison, particularly for the 3 mm, 8 mm (SN 9383)

Table 2. Summary of equipment used for measurements.

Laboratory	Interferometer	Platen	Phase correction	Lamp
1 NRLM	Kosters NRLM-Tsugami	Quartz/glass	Cover block	Lamp
2 NML	NPL-Hilger 190.2 (modified)	Steel	Indirect	Red/Green He-Ne
3 CSIR	Zeiss	Quartz	Standard value	Lamp
4 KRISS	Tsugami (modified)	Steel	Standard value	Lamp
5 NIM	Kosters	Glass	Standard value	Lamp
6 NPLI	NPL-Hilger TN180	Tungsten carbide	Standard value	Lamp
8 MSL	NPL-Hilger 192.1 (modified)	Steel	2 × 3 stack	Red He-Ne/Lamp
9 KIM-LIPI	Laser displacement interferometer	Steel	n.a.	n.a.
10 SISIR	NPL-Tesa (automatic)	Steel	2 × 4 stack	Red/Green He-Ne
11 CMS/ITRI	Michelson	Steel	Standard value	Red He-Ne/Lamp

and 100 mm blocks. This probably reflects damage to the block surfaces affecting the quality of the wring. This was not reported in measurements from laboratories 1, 7 and 9.

6. Additional information from participants

Table 2 provides a summary of the additional information requested, except for the questions about temperature of measurement and refractive index determination. Most measurements were carried out within 0,2 °C of 20 °C and all were within 0,8 °C. The refractive index was calculated by all participants, rather than measured with a refractometer. As laboratory 9 used a displacement interferometer, the platen material and phase effect were not applicable. A variety of platen materials were used and this, together with the determination of the phase correction, is the most interesting information to emerge from these questions.

International Standard ISO 3650 requires the block to be measured by wringing to a platen which is made of the same material and surface texture as the block. In practice the material and surface texture can be different and the measurement has to be corrected. The correction is referred to as the phase correction as it involves a phase shift on reflection due to the complex refractive index of the materials and an apparent phase shift caused by the surface roughness [3, 4]. Six laboratories simply applied a correction that had been determined beforehand, in some cases by the manufacturer of their interferometer. The four laboratories that measured the phase correction all used different techniques. Laboratory 1 used a sub-block which was first wrung to the platen and then wrung to the top of each block being measured. Laboratory 2 used a platen of the same material as the blocks and measured the surface roughness of the platen and blocks to determine a compensating factor for the different surface textures. Laboratory 8 wrung two stacks of three blocks and laboratory 10 two stacks of four blocks. They both then compared stack heights with individual heights to determine the difference between the phase correction between blocks, and between block and platen. While the correction for material differences can easily be predicted, the correction for surface texture can vary over a range of ±30 nm although it is normally quite small and about 10 nm. It would appear to be inappropriate simply to apply a standard correction; however, a great deal of effort is required to wring block stacks or cover blocks and the results can be unreliable as they depend on the quality of several wrings. Also, there is evidence that the wringing of blocks is variable with a standard deviation of ±7 nm [5]. Although the NML measured the surface roughness and took this into account in applying a correction, there is clear evidence of a systematic difference in the three measurements made by the NML and these correlate with the two people who wrung the blocks (the wring of one worker resulted in a length increase of about 10 nm – clearly seen in the first four blocks) indicating an effect caused by the wringing technique.

7. Conclusion

For most of the participants this is the first international comparison involving gauge block interferometry and the results show that the participating laboratories are performing well. A comparison like this puts a lot of pressure on all the participants to make the best measurements and to carry them out in the shortest possible time. Some problems were revealed and steps have been taken to rectify them by the laboratories concerned. At the end of the comparison the blocks were all fairly scratched: several laboratories found they could not wring either side of the 8 mm block (SN 9383) and one laboratory could not wring one side of the 3 mm block. Another laboratory (9) withdrew the results for the long blocks.

Measurements of the deviation from nominal length were within ±0,03 μm for lengths up to and including the 40 mm block (with one unusual reading on the replacement 40 mm block). This is half the ISO 3650 tolerance on nominal length for blocks up to 10 mm and about one third of the tolerance for a 40 mm block (±0,10 μm). Measurements on the 100 mm block were all within ±0,08 μm which is about half the ISO 3650 tolerance for this block length (±0,14 μm).

The deviation from flatness results agree reasonably well, with most readings falling into a ±0,02 μm band. Measurements of the variation in length are much more scattered and may indicate wringing problems caused by damage to the block surface.

With laser sources replacing lamps and improved methods for determining the fringe positions on gauge block and platen, the wring and its effect on the measured length of the block has become an important factor determining measurement performance. This comparison has shown that laboratories are using a variety of different platens and different techniques for correcting for their optical properties. Damage to the block surface can easily occur while wringing the block and this has been a major problem. This is particularly unfortunate for the laboratories measuring late in the programme and may have affected their measurements.

The NML took part in the CCDM comparison during September 1993, approximately half-way through this comparison. This will provide the link to the international part of the programme.

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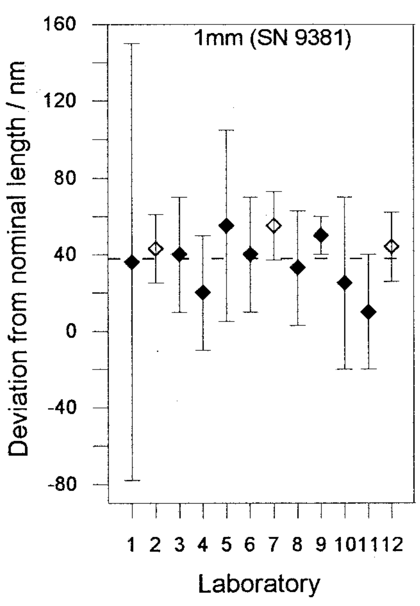
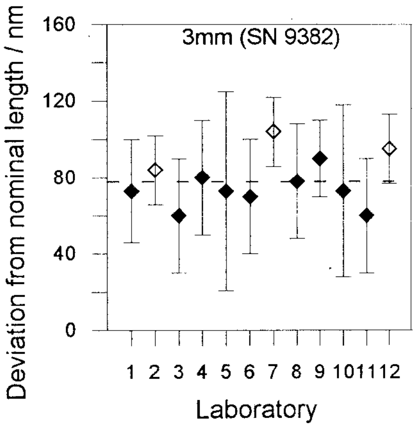
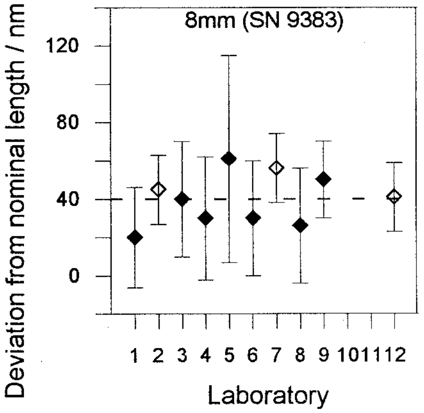
Appendix

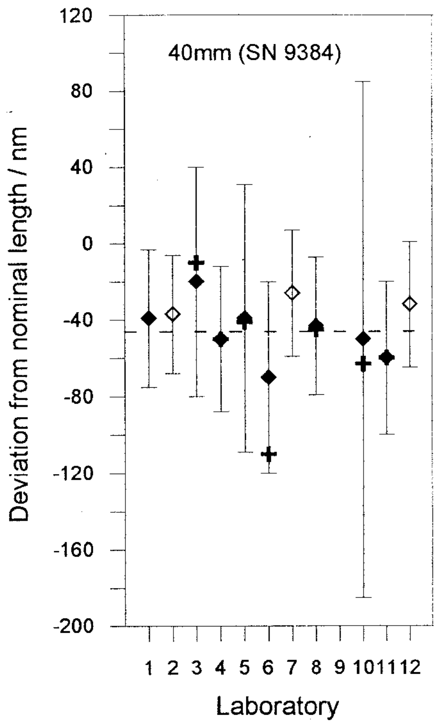
Summary of the results of deviation from nominal length

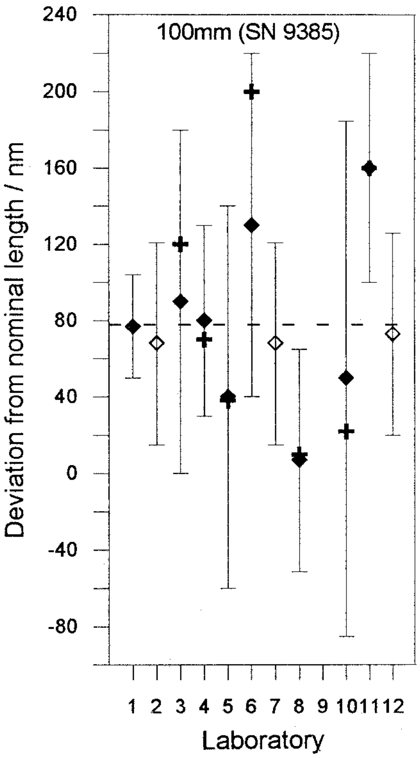
The following plots give the deviation from nominal length for the seven gauge blocks used in the comparison. The laboratories are identified by the numbers shown in Table 1 with the NML indicated with an open diamond and all other laboratories shown with a closed diamond and in some cases a diamond and cross. The closed diamond is for length determined for a coefficient of linear expansion $\alpha = 10{,}8 \times 10^{-6}$ while the cross is for $\alpha = 11{,}6 \times 10^{-6}$ (the default value to be used if α was not measured).

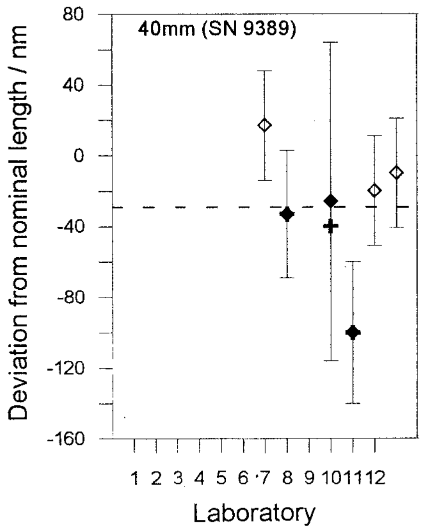


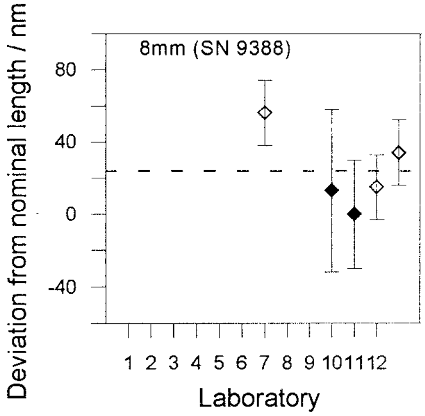



8mm (SN 9383)
Deviation from nominal length / nm
Laboratory


40mm (SN 9384)
Deviation from nominal length / nm
Laboratory


100mm (SN 9385)
Deviation from nominal length / nm
Laboratory


40mm (SN 9389)
Deviation from nominal length / nm
Laboratory


8mm (SN 9388)
Deviation from nominal length / nm
Laboratory