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THE DRIFT ELIMINATION METHODS IN GAUGES BLOCK MECHANICAL COMPARISON PROCEDURES

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ABSTRACT
Gauge block calibration is one of the oldest high precision calibrations made in dimensional metrology. Gauge block comparison schemes are designed with a number of characteristics. The unknown length of a block is determined by measuring the difference between it and a reference block of the same nominal size and then calculating the unknown length. The sources of variation in measurements are numerous. Source of serious problems, which is not random, is the drift in the instrument readings. The instrumental drift can be obtained from any comparison scheme with more measurements than the number of unknown lengths plus one for the drift, since the drift rate can be includes a parameter in the model fit. This effect cannot be minimized by additional measurement because it is not generally pseudo-random, but a nearly monotonic shift in the readings. In this paper some techniques for drift eliminating of instrument are discussed.
Keywords: gauge blocks, mechanical comparator, instrument drift.

1. INTRODUCTION
Gauge blocks are most accurate standards in dimensional metrology and widely used for establishment of traceability chain from National Metrology Institutes (NMIs) to workshop floors. The traceability chain is achieved by calibration of the gauge blocks according to defined standards. International standard ISO 3650 [1] cover the range of accuracy requirements along the traceability chain and calibration method is selected according to accuracy requirements of the standard and the user. In mechanical comparison methods, the similar nominal size gauge blocks are compared to each other by suitable probing elements. Since the compared gauge blocks are in the same nominal sizes, the inductive probes which have a short measurement range with high accuracy is used in the mechanical comparison technique, figure 1.

Figure1. Gauge blocks comparator.

Factors influencing the measurement are: the length calibration of the standard, factors inherent in the comparator equipment used to measure the length difference such as scale linearity and reading capability, gauge geometry with respect to its effect on probing the length difference, the temperature and other environmental factor, etc [1,3,5].

2. GAUGE BLOCK CALIBRATION BY MECHANICAL COMPARISON

Metric gauges according to ISO 3650 are most commonly used length standards in the world. Gauge blocks are being calibrated by two methods: interferometric calibration and calibration by mechanical comparison to reference gauge block. For mainly economic reasons, most of customers of accredited laboratories prefer their standards being calibrated by mechanical comparison because of lower costs and shorter calibration time [4].

Many comparisons, especially those in dimensional metrology, cannot be done simultaneously. Using a gage block comparator, the standard, control (check standard) and test block are moved one at a time under the measurement stylus. For those comparisons each measurement is made at different time. The term calibration design can be applied to experiments where only differences between nominally equal objects or groups of objects can be measured. The simplest such experiment consists in measuring the differences between the two objects of the $n(n\text{-}1)$ distinct pairings that can be formed from n objects. If the order is unimportant, X compared to Y is the negative of Y compared to X, there are only $n(n\text{-}1)/2$ distinct pairings. Only one measurement per unknown is needed to determine the unknown, but more measurements are generally taken for statistical reasons. Ordinarily the order in which these measurements are made is of no consequence. The usefulness of drift eliminating designs depends on the stability of the thermal environment and the accuracy required in the calibration. The environment has to be stable enough that the drift is linear. Each measurement must be made in the same amount of time so that the measurements are made at fairly regular intervals. Finally, the measurements of each block are spread evenly as possible across the design.

The designs are constructed to:

- Be immune to linear drift
- Minimize the standard deviations for test blocks (as much as possible)
- Spread the measurements on each block throughout the design
- Be completed in 5-10 minutes to keep the drift at the 5 nm level

3. DRIFT ELIMINATING DESIGN

It is known that in any measurement both the gauge being measured and the measuring instrument may change size during the measurement. Usually this is due to thermal interactions with the room or operator. The instrumental drift can be obtained from any comparison scheme with more measurements than the number of unknown lengths plus one for drift, since the drift rate can be included as a parameter in the model fit. For example, it is possible to include six measurements each of four blocks for a total of 24 measurements. Since there are only three unknown block lenghts and the drift, least squares techniques can be used to obtain the best estimate of the lengths and drift.

The sources of variation in measurements are numerous. Measurements on gauge blocks are subject to drift from heat built-up in the comparator. This effect cannot be minimized by additional measurement because it is not generally pseudorandom, but a nearly monotonic shift in the readings. In dimensional work the most important cause of drift is thermal changes in the equipment during the test, [2].

The purpose of drift eliminating design is remove the effects of linear instrumental drift, but also alowing the measurement of the linear drift itself. This measured drift can be used as a process control parameter. For small drift rates an assumption of linear drift will certainly be adequate. But, for high drift rates or long measurements time the assumption of linear drift may not be true. The length of time for a measurement could be used as a control parameter.

One example of drift eliminating desings for two gauge blocks A and B will be presented. In this case, at least two measurements for each block are needed to verify repeatability. There are two possible measurements schemes: [A B A B] and [A B B A]. Supposing that the instrument is drifting by some D during each measuring interval, the measurement made are:

Table 1.

Measurement	Scheme ABAB	Scheme ABBA
m_1	A	A
m_2	$B+\Delta$	$B+\Delta$
m_3	$A+2\Delta$	$B+2\Delta$
m_4	$B+3\Delta$	$A+3\Delta$

Now, the measurement differences between two measurements are:

Table 2.

Difference	Scheme ABAB	Scheme ABBA
$y_1 = m_1 - m_2 =$	$A-(B+\Delta)$	$A-(B+\Delta)$
$y_2 = m_3 - m_4 =$	$(A+2\Delta)-(B+3\Delta)$	$(B+2\Delta)-(A+3\Delta)$

Solving for B in function of A gives:

Scheme ABAB Scheme ABBA

$$B = A - \frac{y_1 + y_2}{2} - \Delta \qquad B = A - \frac{y_1 - y_2}{2} \tag{1}$$

One can conclude that it is not possible to find B in terms of A without knowing D in the first case. The trift terms cancel out in the second case. In praxis, the drift terms will cancel only if the four measurements are done quickly in a uniform time sequences so that the drift is most likely to be linear. The most used scheme for gauge block comparisons uses two blocks, one as a master block – *L* and one as a control – *C*. Two blocks, one from each of two customers, are used as the unknowns *X* and *Y*. The 12 measured differences y_i are possible:

$$\begin{aligned}
y_1 &= L - C & y_7 &= L - X \\
y_2 &= Y - L & y_8 &= C - Y \\
y_3 &= X - Y & y_9 &= L - Y \\
y_4 &= C - L & y_{10} &= X - C \\
y_5 &= C - X & y_{11} &= X - L \\
y_6 &= Y - C & y_{12} &= Y - X
\end{aligned} \tag{2}$$

The solutions of equations (2) are [1]:

$$\begin{aligned}
C &= \frac{1}{8}(-2y_1 + y_2 + 2y_4 + y_5 - y_6 - y_7 + y_8 - y_9 - y_{10} + y_{11}) + L \\
X &= \frac{1}{8}(-y_1 + y_2 + y_3 + y_4 - y_5 - 2y_7 - y_9 + y_{10} + 2y_{11} - y_{12}) + L \\
Y &= \frac{1}{8}(-y_1 + 2y_2 - y_3 + y_4 + y_6 - y_7 - y_8 - 2y_9 + y_{11} + y_{12}) + L \\
\Delta &= -\frac{1}{12}\sum_{i=1}^{12} y_i
\end{aligned} \tag{3}$$

The standard deviation is calculated from the original comparison data. The value of each comparison y_i is calculated from the best fit parameters and subtracting form the actual data y_i^*:

$$\sigma_w^2 = \frac{1}{\nu}\sum_{i=0}^{n}\left(\Delta Y_i\right)^2 \quad (4)$$

Where ν - degree of freedom which can be calculated with substracting the number of observations (n=12) and unknowns (five unknowns: L, C, X, Y and Δ) plus 1. In this case, the degree of freedom is $\nu = n - m + 1 = 12 - 5 + 1 = 8$.

There are a number of ways to monitor the comparison process. The simplest is to compare the variance of each calibratioin to an accepted level based on the history. This accepted level (average variance from calibration history) is scharacteristic of the short term repeatability of the comparator process. The purpose of such variance is that it is a control point for the calibration process and it is used to calculate the process uncertainty, a part of total uncertainty reported to the customer. Usually, the variance for each calibration is recordes in diagram, figure 2.

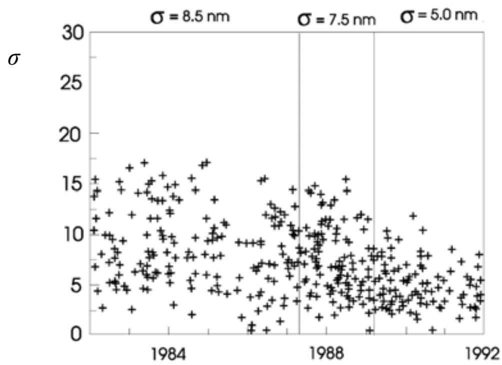

Figure 2. Example of variation of the short term standard deviation with time [1].

5. CONCLUSION

Because all of the measurements made in a calibration are relative comparisons, at least one value must be known to solve the system of equations. Calibration designs allow comparison of several gauge blocks of the same nominal size to one master gauge in a manner that promotes economy of operation and minimizes wear on the master gauge. The calibration design is repeated for each size until measurements on all the blocks in the test sets are completed. Measurements on gauge blocks are subject to drift from heat build-up in the comparator. This drift must be accounted for in the calibration experiment or the lengths assigned to the blocks will be contaminated by the drift term. The designs are constructed so that the solutions are immune to linear drift if the measurements are equally spaced over time. The size of the drift is the average of the n difference measurements. Keeping track of drift from design to design is useful because a marked change from its usual range of values may indicate a problem with the measurement system.

1. REFERENCES

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