An accurate double-faced optical-interferometric strategy for estimation of gauge block Fo/Fu dimensional variations

R S França[1]

[1] Laint/Diopt/Dimci, Inmetro, Xerém/Duque de Caxias, 25250, Brazil

rsfranca@inmetro.gov.br

Abstract. A new and fast calculation method for length variations or Fo/Fu, as estimations for gauge blocks, uses a double-face-wringing interferometric approach, through length scanning of their five center and corner points, as defined through their optical inspection in both opposite gauge measurement surfaces. This method achieves realistic dimensional/bidirectional length definitions for such dimensional standard parameters as obtained by optical measurements.

1. Introduction

According to a definition from a fundamental gauge block pair standard [1] used for characterization of electromechanical length comparators, a thin block must be chosen, from a specific pair gauges set mentioned in that standard, in order to calibrate all gauge block mechanical length variation measurements performed by these devices. The so-called Fo/Fu parameters are defined there as the maximum and minimum length variations of gauge corner points with respect to its central point and, as such, must be defined only from their five-axis passing through its central and four corner points.

Actual mechanical comparators measure lengths through pair of probe sensor displacements, by bringing them toward close contact in both opposite gauge faces, along a measurement axis. Dimensional gauge lengths are defined from its main axis connecting both their centralized face points, and as such is “bidirectional” by definition. Common optical-interferometric measurements, as those from GBI/Mitutoyo operating in Interferometric Laboratory in Inmetro [2], otherwise, are one-directional by construction. Their measurements result from optical path differences between one-sided beam reflection from an upper gauge block surface and parallel beams reflected from high-flatness wringing support plates (for researches at other type of “plateless” interferometric measurements, see [3]). This lower reflection surface corresponds to an abstract reference plane, coplanar to the lower gauge block face, and their measuring reference points are laterally displaced from the gauge central axis.

2. Five-point heights and Fo/Fu modelling

The main drawback of this one-sided optical approach lies in the bold assumption that both lower gauge and wringing plate surfaces are “ideally planes” or without any height variations that can affect any inspected local variations seen at upper gauge faces. Figure 1 shows an example of global upper height mapping for a gauge, and without any height variation contributions due to supported face or wringing plate flatness excluded.

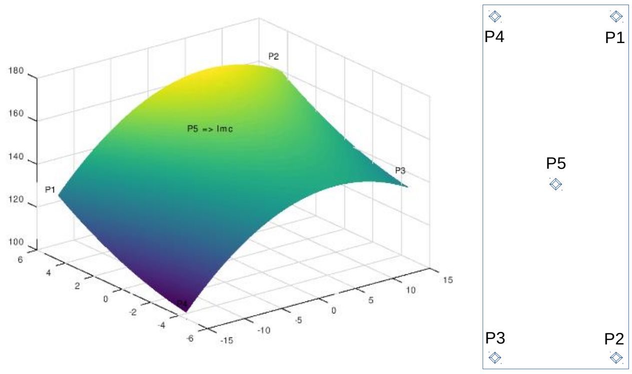


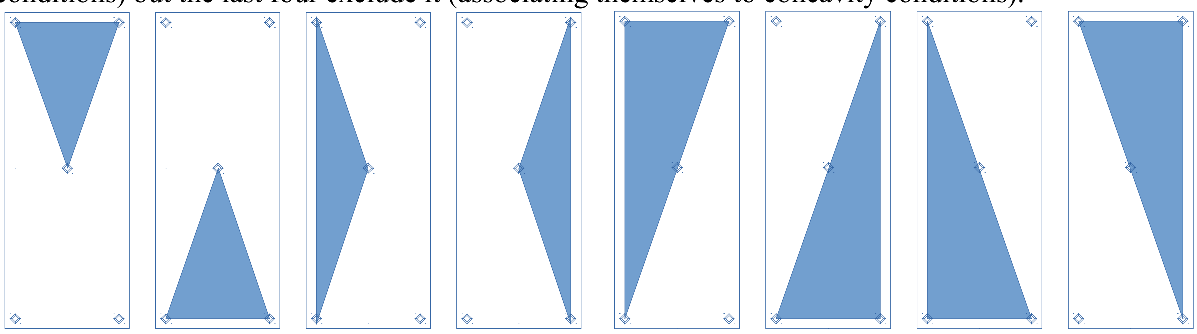
Figure 1. Hypothetical definition of five-height points taken from one-sided optical-interferometric measurement of a gauge block upper surface. Any variations due only to the lower face wringing and faces coupling are not taken in account.

2.1. Mechanical-Optical geometric modelling

A proposed solution for achieving a better agreement of both gauge length measurands (i.e., those produced by optical-interferometric and electromechanical methods), is to inspect all height variations through both gauge surfaces. For accurate Fo/Fu estimations we need to execute double interferometric measurements, by wringing both opposite faces over the same wringing plate, Afterwards, their surface curvatures and parallelism deviations from both interferometric measurements can be numerically extracted directly from its 2x5-point lengths.

In our strategy, non-plane surfaces attached to the wringing plate were described as based on 3-4 points support triangles, as we get them directly from all five-center-and-corner-points height information got from both previous interferometric measurements. If the center point is included in such triangle, that condition defines a lower convex face. Otherwise, the gauge lower face must be considered as a concave one, only if its center point is excluded from the gauge support triangle, as shown in figure 2. A special case can be included when the support stands over all four corner points.

Figure 2 – Eight hypothetical support triangles from gauge block support surface, chosen in function of strict non-planarity at its five points. The first four triangles include the center point (fulfilling convexity conditions) but the last four exclude it (associating themselves to concavity conditions).



Therefore, we can classify global gauge block double-face profiles within six generalized type forms: Bi-Plane (B-P), Plane-Convex (P-V), Plane-Concave (P-C), Bi-Convex (B-V), Bi-Concave (B-C) and Convex-Concave (V-C), with respect to both surface curvatures, as seen in figure 3. Each form must offer distinct contributions to evaluate its final five-point mechanical lengths.

If we classify one of surfaces as "Plane" (i.e., for B-P, P-V or P-C), within some predefined tolerance, and a gauge was wrung over this face on a flat plate, any accurate phase-shifter interferometric system can indicate the five-point mechanical heights, as taken directly from its opposite upper face. For all other types, some discount for center and corner lengths must be included, due to any support and curvature effects from both gauge surfaces. A fast algorithm was developed, in order to use this basic information to discount and correct their measured heights, giving accurate Fo/Fu parameters as their final results.

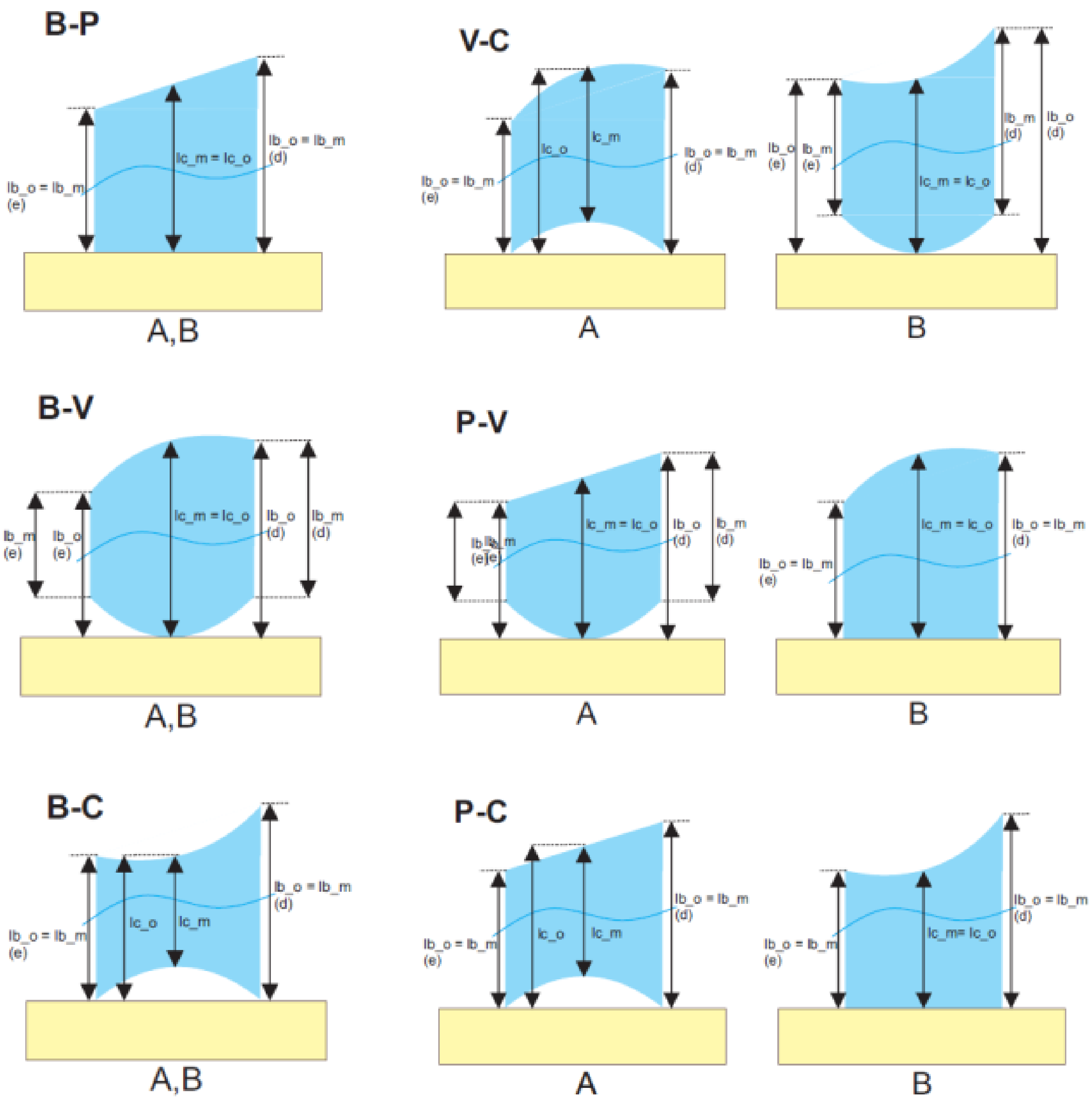


Figure 3. Six suggested "generalized form" gauge profiles.

3. Measured and algorithmic results

We fed a double set of five height points, taken from two automated interferometric measurements of opposite wrings, within an algorithm that embed the above mentioned form and support type modelling, in order to obtain more accurate Fo/Fu parameters than those obtained by previous one-sided interferometric measurements. Table 1 depicts the measured and obtained height corrections at five-point lengths as produced by GBI/Mitutoyo interferometric measurements, as also the Fo/Fu adequate measurands for two steel gauge blocks (those with nominal lengths 1.01 mm and 1.005 mm).

Table 1. Five-point heights and their Fo/Fu measured and calculated values (in nm) obtained by an estimation algorithm that is based on form models and previous two-opposite-wring-surfaces ("e" and "d") interferometric measurements, from two steel gauge blocks wrung over a fused silica platen.

	l_1	l_2	l_3	l_4	l_c	*Fo*	*Fu*
1,01 (e)	9	2	50	44	28	23	26
1,01 (d)	55	53	5	-15	43	11	58
Calculated	-26.25	-43.75	74.25	56.75	**35.5**	**38.75**	**79.25**
1,005 (e)	71	100	66	93	68	32	2
1,005 (d)	114	82	111	82	55	59	0
Calculated	101.04	107	74	102	**32**	**75**	**0**

Note: The bidirectional Fu = 0 got from second gauge, that can be seemingly classified as a 'biconcave", shown that its realistic "lc" (center gauge length) must be presented as strictly smaller than their both individual as also unidirectional measurements.

4. Conclusion

Well-defined model and algorithm were proposed to calculate realistic variation height lengths (Fo/Fu) of gauge blocks through double interferometric five-point automated measurements. A further optical-mechanical intercomparison must still be performed, with these measurands as its main issue, in order to check any results obtained from this approach for dimensional metrology laboratories.

As the measurement uncertainties for these strategy were so strongly dependent from the classified gauge form type, as also it must be taken in account its double one-sided classic interferometric measurements, their deductions were not shown in that preliminary study.

Nevertheless, such suggested approach can provide us with much more reliable results, by design, than those obtained by regular strictly mechanical or one-sided optical measurements. As a collateral result we still potentially can provide much better accuracies center gauge length measurements, than those obtained from both mechanical and one-sided interferometric methods.

References

[1] Calibration of Gauge Block Comparators, Calibration Guide EURAMET cg-2 Version 2.0 (03/2011), European Association of National Metrology Institutes.

[2] GBI Interference Fringe Analysis System, User's Manual (Hardware Guide) No. 99M BD040 A - SERIES N°. 565, 2005, Mitutoyo.

[3] Abdelaty A, Walkov A, Franke F and Schödel R 2012, *Metrologia* **49** (3) 307-314.