INMETRO'S PERFORMANCE IN CALIBRATION OF BALL BARS

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*Abstract:*The Dimensional Metrology Laboratory of the National Institute of Metrology, Standardization and Industrial Quality (LAMIN /INMETRO) has implemented a measuring system for calibration of length standards by adapting a linear interferometric laser to a coordinate measuring machine (CMM). This measuring system has shown to be efficient, through the association of the interferometric laser high accuracy to the high displacement versatility of the CMM, obtained by a numeric control program. With this system, the measuring uncertainties can be considerably reduced, when compared to those obtained exclusively with the CMM. This measuring system was evaluated through a laboratorial comparison with the national German institute "Physikalisch-Technische Bundesanstalt" - PTB, involving the calibration of two steel and one Aluminium ball bars, used as reference in the coordinate measuring technique. The comparison results have proved to be compatible, assuming the technical competence of the Dimensional Metrology Laboratory to provide traceability to accredited laboratories by the Brazilian calibration service (RBC) and by the German calibration service (DKD) in Brazil, as well as to other laboratories installed in the countries which take part of the MERCOSUL.
Keywords: laboratory comparison, ball bar, calibration

1 INTRODUCTION

Due to the CMM's complexity, the influence of errors in the measuring results presents high difficulty of analysis, making very particular the calibration procedure of these equipment. Therefore, CMM's differ, from the metrological point of view, from other equipments or common measuring instruments. PTB has developed techniques for calibration, acceptance testing and periodical inspection of CMM's, based on the use of ball or hole plates, instead of conventional methods. In order to obtain the traceability of these bidimensional standards to the length unit, there are two possibilities. They can be directly calibrated by using a length measuring reference - for example, an interferometric laser - or by comparison to a materialized length standard - for example, a ball bar previously calibrated by an interferometric laser.

Aiming at meeting users demand for ball bars calibration, LAMIN has implemented a system for calibration of this type of length standard, whose methodology is presented below.

2 METHODOLOGY

A linear laser measuring system HP-5528A was adapted to a CMM ZEISS model UMM-500. The laser, which substitutes the machine scale and measures in X direction, was interfaced to a PC. Calibrated sensors were used to measure room temperature and pressure, as well as the material temperature (main influence quantities in the measuring process). The machine was programmed by numerical control, in order to perform the adequate positioning of the measuring probe, on the right and left side of each sphere, on their center lines, parallel to the center line of the bar to be measured. During the measuring force application (probe touching the surface of one of the bar spheres), this position value was recorded in real time and corrected automatically, considering the influence quantities at the moment of the measurement. After that, the positions of the spheres centers and the distance between them were calculated. A computer program developed at the laboratory was used for acquisition, correction and processing of the data. The criteria for wavelength correction was based on the known Edlén equation [1][2]. During the whole measuring process the ABBE principle was observed. The system described is shown in figure 1.

A gage block of nominal size close to the ball bar length was used for the determination of the systematic error inherent to the measuring process. The measurements were carried out for a material temperature about (20±0,1) °C. The relative humidity was maintained around 50% and the influence of its variation was considered negligible in the determination of the standards length.

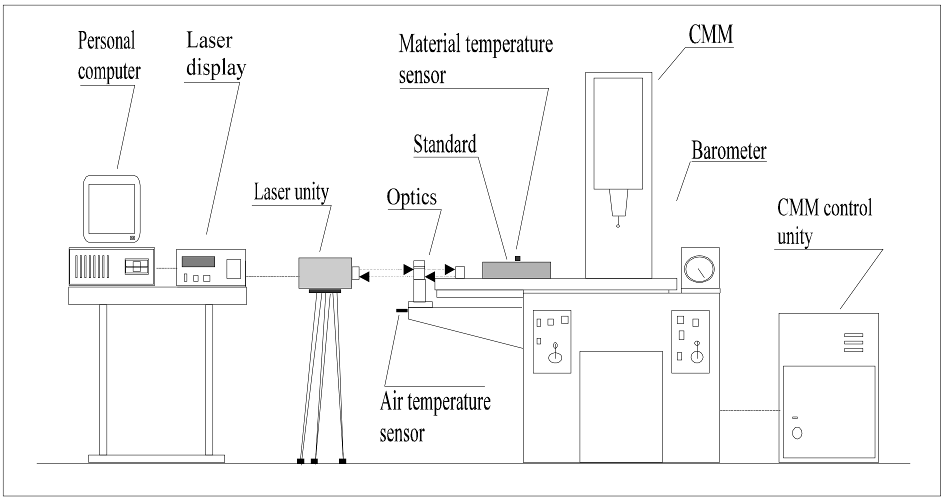

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Figure 1. System used in the calibrations.

3 SYSTEMATIC ERROR DETERMINATION

The reference gage block, made of steel, with nominal length of 300 mm, aligned related to the laser, was measured as shown in figure 2. An optical parallel was adhered to one of the gage block measuring surfaces, to simplify the systematic error determination. On this way, the probe could touch the gage block in point 1 and the adhered surface of the optical parallel in points 2 and 3, equidistant to the gage block center line. This procedure maintained the measuring force direction and minimized the effects caused by a possible perpendicularity error between the measuring axis and the optical parallel surface.

The measuring sequence adopted (1-2-3-1), is that shown in figure 2. The length value for one single mesurement is given by

$$L_i = \frac{La_i + Lb_i}{2} \tag{1}$$

where La_i e Lb_i are the measured lengths 1-2 and 3-1, respectively. Considering the influence quantities effects, L_i values were corrected in the form

$$Lc_i = L_i + \Delta L_i \tag{2}$$

where ΔL_i is the length correction due to that influences. After 10 measurements of the reference gage block, the systematic error was determined, as follows:

$$Es = \overline{L} - Lcert \tag{3}$$

where $\bar{L}$ is the average of the 10 values obtained by the expression (2) and $Lcert$, the calibration certificate value of the gage block. The systematic error determined for a length of 300 mm was +0,2 µm and was used for the ball bars measuring length correction, proportionally to their length.

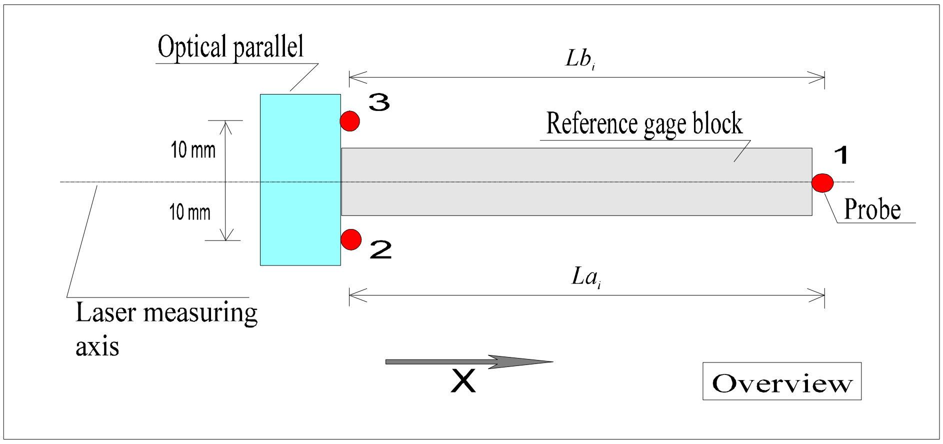

Figure 2 - Probe positioning in the gage block measurement.

4 BALL BARS MEASUREMENTS

The gage block was replaced by the ball bar at the same position on the machine table, also aligned related to the laser. The spheres were touched by the probe in the sequence showed in figure 3. The center of each sphere was determined by touching it at right and at left, in a direction parallel to direction of the laser beam. The distance between the two spheres was calculated by the expression:

$$l_i = Xd_i - Xe_i \tag{4}$$

The values obtained by expression (4) were corrected, considering the effects of the influence quantities in the measurement process, yielding the following:

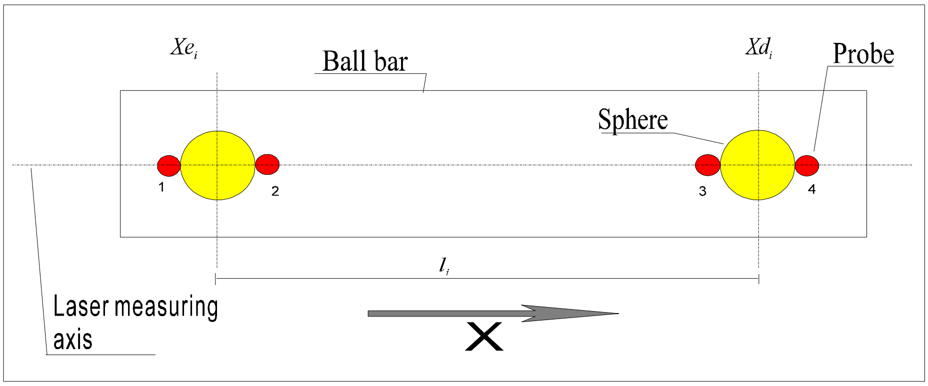

Figure 3 - Probe positioning, relative to spheres.

$$lc_i = l_i + \Delta l_i \tag{5}$$

where Δl_i is the correction in length due to these influences. After ten measurements, the final length between spheres was determined by the expression:

$$l = \bar{l}c - Es \qquad (6)$$

where $\bar{l}$ is the average of these values.

5 RESULTS

The measurement results were obtained following the procedures established in [2] e [3], for the measuring uncertainties determination and are presented in tables 1, 2 and 3. The results in table 2 refer to the ball bar of 332 mm. The uncertainty for the 311 mm ball bar has the same value.

Table 1. Measuring uncertainty.of the process systematic error.

Symbol	Uncertainty sources	Value	Distribution	Divisor	c_i	$u_{i(}$(μm)	ν_i
Lc	Gage block calibration	0,04μm	Normal	2,0	1,0	0,02	∞
L	Repeatability	0,03 μm	Normal	1,0	1,0	0,03	9
T	Gage temperature	0,05 °C	Normal	2,0	3,21	0,08	∞
∝	Thermal exp.coef.	0,0005 K^{-1}	Rectangular	√3	30	0,015	∞
Θ	Air temperature	0,1 °C	Rectangular	√3	0,277	0,016	∞
P	Pressure	1,0 mmHg	Rectangular	√3	0,107	0,062	∞
u_c	Combined uncertainty		Normal			0,110	>1000
U	Expanded uncertainty		Normal (k=2)			0,220	>1000

Table 2. Measuring uncertainty of the steel ball bar of 332 mm.

Symbol	Uncertainty sources	valor	Distribuição	Divisor	c_i	u_i(μm)	ν_i
Lc	Systematic error uncertainty	0,22μm	Normal	2,0	1,0	0,11	∞
L	Repeatability	0,046 μm	Normal	1,0	1,0	0,046	9
T	Ball bar temperature	0,05 °C	Normal	2,0	3,82	0,095	∞
∝	Thermal exp.coef.	0,0005 K^{-1}	Rectangular	√3	33,2	0,010	∞
Θ	Air temperature	0,1 °C	Rectangular	√3	0,294	0,017	∞
P	Pressure	1,0 mmHg	Rectangular	√3	0,140	0,081	∞
u_c	Combined uncertainty		Normal			0,175	>1000
U	Expanded uncertainty		Normal (k=2)			0,350	>1000

Table 3. Measuring uncertainty of the Aluminium ball bar.

Symbol	Uncertainty sources	value	Distribution	Divisor	c_i	u_i(μm)	ν_i
Es	Systematic error uncertainty	0,22μm	Normal	2,0	1,0	0,11	∞
L	Repeatability	0,046 μm	Normal	1,0	1,0	0,046	9
T	Ball bar temperature	0,05 °C	Normal	2,0	8,10	0,203	∞
∝	Thermal exp.coef.	0,0005 K^{-1}	Rectangular	√3	36,0	0,010	∞
Θ	Air temperature	0,1 °C	Rectangular	√3	0,329	0,019	∞
P	Pressure	1,0 mmHg	Rectangular	√3	0,151	0,087	∞
u_c	Combined uncertainty		Normal			0,252	>1000
U	Expanded uncertainty		Normal (k=2)			0,504	>1000

The final calibration results obtained by LAMIN and PTB are presented in the table 4 and their graphic analysis is shown in figure 4. The values are compatible, showing the technical competence of LAMIN in the calibration of ball bars.

Table 4. Comparative results of the ball bars - LAMIN and PTB

	INMETRO/LAMIN	**PTB (LAB 532)**

KOBA STEEL BALL BAR	**311,0049 ± 0,0004 mm**	**311,0049 ± 0,0005 mm**
RETTER STEEL BALL BAR	**331,9920 ± 0,0004 mm**	**331,9922 ± 0,0005 mm**
ALUMINIUM BALL BAR	**360,0427 ± 0,0005 mm**	**360,0425 ± 0,0005 mm**

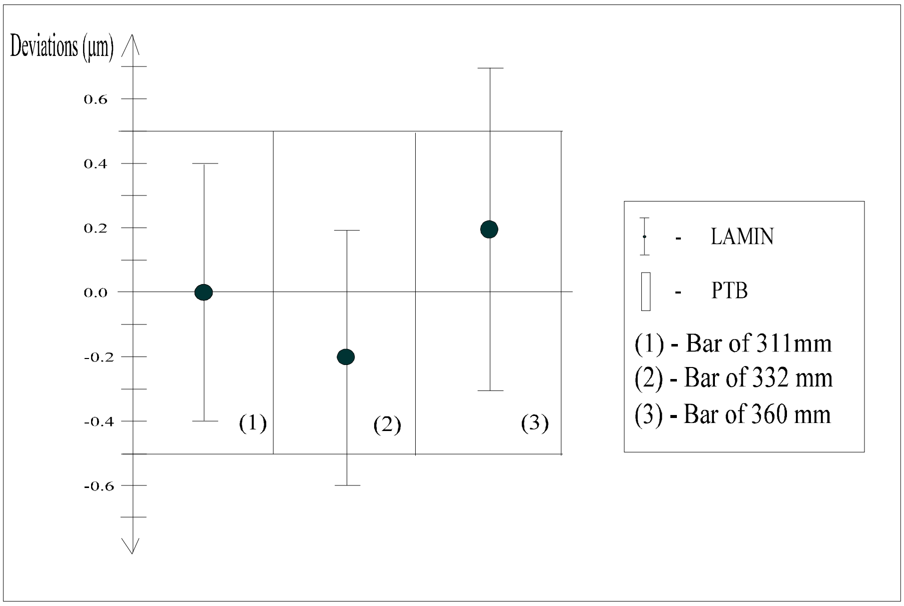

Figure 4. Graphic analysis of the comparison results.

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