DEVELOPMENT OF A SOFTWARE FOR THE LINE SCALES CALIBRATION SYSTEM IN INMETRO

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Abstract. *The main changes in the dimensional metrology happened together with the scientific and industrial developments and demands, with the aim of having better measuring methods that could achieve results in a higher precision level. Using microscopes for measuring and analysing parts and materials can be highlighted as one of those. Line scales are used as reference standard for this kind of measurement, in the way to guarantee its confiability. So, it is extremely necessary to have traceability to national metrology standards. The Dimensional Metrology Laboratory of Inmetro has a system for calibration of line scales from 1mm up to 300mm, wich demands some improvement in its Best Measurement Capability. This paper presents a methodology for the development and implementation of a software with that purpose. The software uses an image captured from a CCD camera mounted on the microscope, wich allows a better visualization and centralization of the line scale marks in the monitor, using tools as: different reticulations to alignment and calibration of the scale; and zoom tools. Results show that with the new system, the uncertainty of measurement reduces from 400nm to 60nm, in 1mm scales, an improvement of about 85%.*

Keywords*: line scale, dimensional metrology, CCD camera, uncertainty of measurement.*

1. INTRODUCTION

The calibration of line scales consist of determining the distance between the centers of the marks along the scale, using a reference value. Improvement on the methods and systems used for that calibration is always happening, with new technologies applied and increasing demand for more precise results.

In the Dimensional Metrology Laboratory (Lamin) of the National Metrology Institute of Brazil (Inmetro) two points can be highlighted as the motivation to the new line scale calibration system development and implementation: a) demand of the Accredited Calibration Laboratories in Brazil (RBC) and traceability to other Quantities Reference Laboratories in Inmetro, which need that measuring service (reference material, hardness) with larger ranges and better uncertainty values; b) and the participation of Lamin in the Euromet Key Comparison for line scales (LK7.EUROMET).

The old system was composed by a interferometer laser (reference value), a table with horizontal displacement where the line scale is fixed, with a maximum range of 25 mm, and a microscope for the visualization of the marks “Fig. 1”.

In this system the scale is aligned to the laser beam and to the microscope crosshair grid to minimize errors like the ABBE and the cosine error. With the scale aligned, the table is moved until the first mark can be visualized and its center is determined (estimated). On this first point the value of reference laser is set to zero, then the table is moved till the next mark is also centered and the laser value is registered. This happens to all marks to be measured in the scale, always using the same proceeding for centralizing the microscope crosshair and referring to the same zero point line (Beers and Penzes – 1999).

Analyzing the mathematical model for the measuring uncertainty, we can highlight that the laser alignment and the marks centralization are the main sources to systematical contributions. On this way, the crew decided to act on the main three points to improve the system:

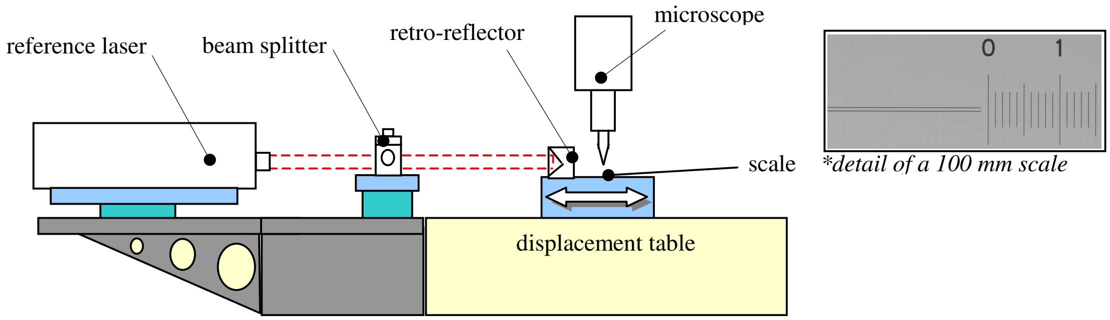

Figure 1: Diagram of the system assembly; *detail of a 100 mm scale in the microscope

- Use a rotate table to fix and align the scale;
- Covering the system for a better laser stabilization;
- Use a CCD camera in the microscope

The table with a micrometer displacement system, with a maximum range of 25 mm, was substituted by a table with a 300 mm range and moved by a continuous current motor. With this change, and also with the implementation of an acrylic cover, the error due to the stabilization of the laser is minimized. Besides that, the range of the laboratory is now increased.

Another and more important implementation was the development of a software that helps the operator to centralize the marks through the image of a CCD camera displayed in the monitor. The next topics describe its main functions and the methodologies used to validation (Lassila and Riski – 1994a, 2003b; Lipinski and Larsonnier, 2003).

2. SOFTWARE FUNCTIONS

The software, here named as "ReticuloV01", was developed in Visual Basic® in a very simple algorithm and interface, what makes it faster and easy to operate.

Different functions reproduce the microscope crosshair over the image captured in real time from the camera and displayed by its own software. At this point it is important to highlight that the software used for image capture from the camera (DT3155_1) is specific for that, it means, during measurements both software will *run* simultaneously.

The interface of the software is simple, with only one window with all functions showed on a menu:

- *Alignment* – the software displays a cursor, with a cross shape, which is used to align the marks edges "Fig. 2". It is first done to the zero mark line, then the scale is moved till the last mark line (nominal value of the scale) where the alignment maintenance is verified.
- *Calibration* – the cursor has now the shape of three vertical lines, one principal and two auxiliary "Fig. 3". The distance between the lines can be modified according to the width of the marks. This cursor is used during the calibration.
- *Color* – change the color of the cursor to make contrast, depending on the line scale colors.
- *Zoom* – opens a window reproducing the area of the screen around the middle of the cursor. On this window the operator can change the intensity of the zoom, according to lines width. This is the main function of the software, where the scale can be visualized even 5 times larger on the zoom window, what really makes easier and more trustful to measure.

Figure 2 – Software DT3155_1 and "RetículoV01" running simultaneously; cursor in *alignment function.*

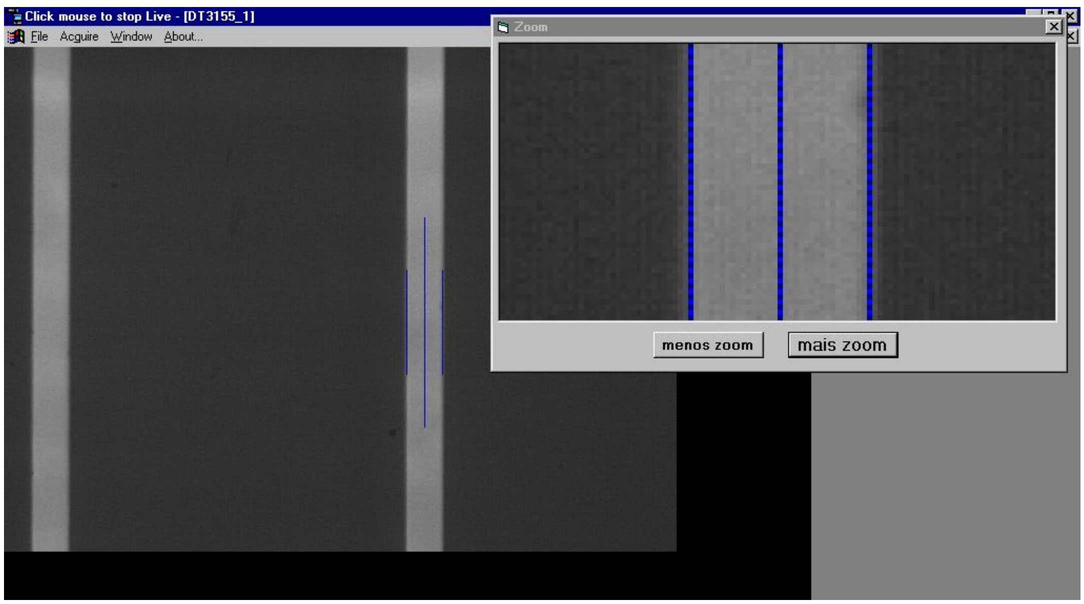

Figure 3 – Calibration screen.

3. RESULTS (METROLOGICAL VALIDATION)

The best way to analyze and validate the results from the new method should be comparing them, using the Normalized Error concept, to results acquired in the "old" system. So, results from the calibration of a 1 mm scale (manuf. Zeiss), with resolution of 0,01 mm, in both methods were used. Like in a conventional calibration, ten points were measured (10% of the scale) in 5 cycles. "Tab. 1" shows the results.

For all points, repeatability had better results, what has direct influence in the final uncertainty of measurement value. The model used for the uncertainty evaluation is showed in the "Eq. 1".

$$Comp = \left[lb \cdot \frac{\eta_0}{\eta} - \ln \cdot (\alpha \cdot \Delta t) \right] + \delta lm + \delta lpo + \delta li + \delta lre \qquad (1)$$

lb = *Gross length of the laser*
η_0 = *Index of refraction of air (reference conditions)*
η = *Index of refraction of air (measurement conditions)*
ln = *Nominal length of the scale*

α = *Thermal expansion coefficient*
Δt = *Material temperature difference*
δlm = *Errors of scale alignment*
δlpo = *Determination of the scale marks centers*
δli = *Laser instability*
δlre = *Laser resolution*

Table 1: Average values and repeatability in both methods

Nominal Value (mm)	*old method*		*Retículo V01*	
	Aver. Value (mm) – M_1	Repeatability (mm)	Aver. Value (mm) – M_2	Repeatability (mm)
0,0	0,00000	0,00000	0,00000	0,00002
0,1	0,09990	0,00008	0,10007	0,00002
0,2	0,19980	0,00008	0,20004	0,00002
0,3	0,29930	0,00013	0,29961	0,00006
0,4	0,39980	0,00010	0,40006	0,00003
0,5	0,49950	0,00006	0,49984	0,00006
0,6	0,59980	0,00007	0,59996	0,00005
0,7	0,69980	0,00006	0,70007	0,00003
0,8	0,79970	0,00008	0,79989	0,00002
0,9	0,89940	0,00007	0,89979	0,00006
1,0	0,99880	0,00007	0,99914	0,00006

The contributions due to alignment, marks centralization and the laser instability were estimated using sensitivity coefficients, derived from the model according to the "Guide to the Expression of Uncertainty in Measurement" (ISO GUM Third Brazilian Edition), and with the analysis of the system behavior along the time.

As already presented, the main parameter to be improved corresponds to the marks centralization. So, for quantifying this contribution, a simple method was applied: (a) set the cursor to a reference point in the scale (for example the centre of a mark), (b) the value of the laser is set to zero (c) then it is moved away from this reference point and (d) brought back to centralize again; (e) the "return value" is registered. This proceeding is repeated in 10 cycles. With the analysis of these 10 values, and also of other 10 measured by different operators, the average difference was calculated in 0,4 µm for the old system and 0,07 µm for the proposed method. From these results, the final estimative for the Expanded Uncertainty of Measurement improved from 0,5 µm (U_1) to 0,1 µm (U_2) with a coverage factor k = 2 for a probability of 95% (ISO GUM - 2003).

In metrological analysis one of the methods used for validation and verification of results and proceedings is through the evaluation of the normalized error. It is important that all quantities are in the same units of measure, it means, measured values (M) and uncertainty values (U) are in mm. If all results are between -1 and +1 the method is considered acceptable and proficient.

Calculating the Normalized Error (EN), according to "Eq. 2" which considers both expanded uncertainty and average value, we have the following results "Tab. 2". All values are considered satisfactory, as they are under the limit of ±1 for that approval.

$$EN = \frac{M_1 - M_2}{\sqrt{U_1^{\,2} + U_2^{\,2}}} \qquad (2)$$

Table 2: Normalized Error values.

Nominal length (mm)	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
EN	0,00	-0,33	-0,47	-0,61	-0,51	-0,67	-0,31	-0,53	-0,37	-0,76	-0,67

4. CONCLUSION AND RECOMENDATION

Analyzing the results presented, the implementation of the new system was considered very satisfactory, once the uncertainty budget is decreased in about 5 times and the method is well validated, based on the evaluation of the Normalized Error values.

Another good parameter to study and validate the new system will be the participation of Lamin in the Euromet Key Comparison for line scales (LK7. EUROMET), which will happen in 2007.

5. REFERENCES

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