# GEOMETRIC QUALIFICATION OF STANDARD RINGS AND PLUGS

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*Abstract: This work aims to demonstrate the metrological capability of the Dimensional Metrology Laboratory of the National Institute of Metrology, Standardization and Industrial Quality (INMETRO) in the calibration of internal and external diameter standards. Reference systems are used to measure roundness, diameters, straightness of generators, squareness between a reference surface and generators and parallelism between generators. The roundness deviation is measured with a special form measuring machine, achieving a very small measurement uncertainty. The other features are measured with a system composed by a co-ordinate measuring machine (CMM) and a linear laser interferometer adapted to it.*

*Some technical considerations and cares that have to be taken when carrying out measurements aiming more accurate results are presented, as well as measurement results of a standard ring and a comparison between our laboratory and the "Physikalisch- Technische Bundesanstalt " (PTB - Germany).*

*Keywords: Metrological capability, Reference systems, Geometric qualification.*

## 1 INTRODUCTION

Standard rings and plugs are length material measures used to establish reference diameters. In this work, those ones used as reference standards in the calibration of other standards by comparison or even in the calibration of measuring machines are considered.

Considering that the main responsibility of the Dimensional Metrology Laboratory is to provide traceability to the accredited laboratories of the Brazilian Calibration Network (RBC) and to others from the industry, it is effective calibrating them as accurate as possible, that is, with the smallest possible measurement uncertainty. For diameter measurements, evaluation of generators straightness, squareness between a reference surface and generators as well as parallelism between two opposite generators [1], it is used a system composed by a co-ordinate measuring machine UMM-500, from Carl Zeiss and an interferometric laser 5528A, from Hewlett Packard, whose retro-reflector is adapted on the machine table. The laser is carefully aligned to the X axis of the machine in order to reduce Abbe's error [2]. For the determination of the roundness deviation it is used a form measuring machine, model TALYROND 73-HPR, from Taylor Hobson.

## 2 SYSTEM USED TO MEASURE DIAMETERS, PARALLELISM, STRAIGHTNESS AND SQUARENESS

As mentioned in the previous section, a linear laser measuring system was adapted to a CMM aiming the substitution of the machine's scale. This setting up improves the accuracy of the results because the laser is the reference. In order to measure the main influence quantities, namely, air humidity, pressure and temperature, as well as the material temperature, it was used a digital barometer, a humidity indicator and a set of temperature sensors (PT-100), all of them previously calibrated. The laser system and the other devices were interfaced to a personal computer so as to speed up the data acquisition process. A software was developed to get the positions coming from the laser device and influence quantities data, to perform the corrections and finally to calculate the measurement results. The measurements were carried out with the air and material temperature range of (20±0,2) °C. The relative humidity was kept around 50%. The figure 1 shows the system used.

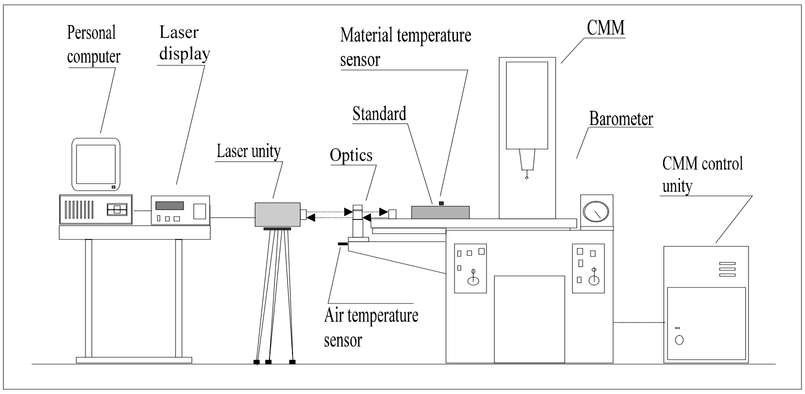


**Figure 1 .** System used to measure diameters, parallelism, straightness and squareness.

## 3 CALIBRATION OF THE CMM PROBE

The probe diameter must be determined with high accuracy because it affects directly the diameter measurement results of the standard under calibration.

In order to obtain the probe diameter, it was used, as reference, a gage block calibrated by interferometry. A 5mm gage-block was positioned on the machine table so that the measuring face of the gage block could be as perpendicular as possible to the laser beam direction. The co-ordinates in X direction of four points over the surface of the gage block, separated by fixed distances were obtained and the alignment was considered reasonable when the influences of cosine errors in the determination of the probe diameter got negligible. Using this strategy, the expanded measurement uncertainty [3] obtained in the determination of the probe diameter was about 0,073 μm for a coverage factor (k) of 2 and a confidence level of about 95%.

## 4 DIAMETER MEASUREMENTS

A 90 mm standard ring was measured in two perpendicular directions in a plane at its mean height. Taking advantage of the CMM's programming capability, the centre of the ring was determined so that the probe could be positioned at that point. Travelling the machine through the X axis, the ring could be touched in two opposite points over a pre-defined number of measurement cycles to determine its diameter, to this called 0° position. Then, the ring was rotated of about 90° and measured again. In order to obtain the correct diameters at 0° and 90° positions some corrections were applied concerning to the material thermal expansion coefficient, as well as to the influence of the pressure, temperature and humidity of the air in the laser beam path. It was used the Edlén [4] equation in order to determine the correct laser wavelength. Effects of the elastic compression of the standard surface due to the measurement force were considered.

The system reproducibility was evaluated by measuring the ring in different days, with very good compatibility among results.

## 5 STRAIGHTNESS, SQUARENESS AND PARALLELISM MEASUREMENTS

Keeping the ring at the same position when determining the diameter (position 0°), it was evaluated the straightness, squareness and parallelism between two diametrically opposite generators (A and B in figure 2) of the inner cylindrical surface. The co-ordinates of seventeen points, equally spaced along the standard ring height, in both opposite generators, were taken. The standard ring was, then, rotated 180° and the same procedure was carried out, aiming to separate the machine errors from those of the standard, by means of the reversal method.

For a complete geometric evaluation of a standard plug or ring, the procedure should be performed also for 90° position (generator C and D in figure 2). This procedure was not done here, because the intention was just to validate the methodology proposed.

## 6 ROUNDNESS MEASUREMENTS

After performing the measurements discussed above, the roundness was evaluated by the roundness measurement system TALYROND 73-HPR, as mentioned before.

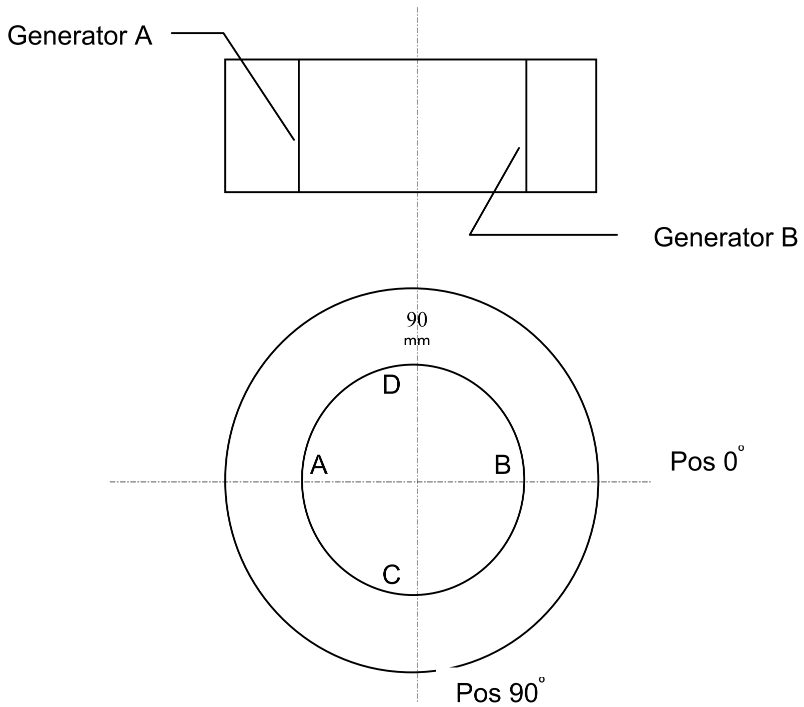


Figure 2 – Measured positions on the standard ring.

## 7 DIAMETERS MEASUREMENT RESULTS

The results obtained for the standard ring calibration for both, 0° and 90° positions, are presented on table 1. The number of measurements adopted to the evaluation of the repeatability was 5, for each position. The expanded measurement uncertainty here declared was obtained for a coverage factor (k) equal to 2 and a confidence level of approximately 95 %.

Table 1 – Diameter results for a 90mm standard ring

| Position | Diameter | Uncertainty |
|---|---|---|
| 0° | 89,99516 mm | 0,15 μm |
| 90° | 89,99493 mm | |

## 8 STRAIGHTNESS, SQUARENESS AND PARALLELISM MEASUREMENT RESULTS

The table 2 presents the measurement results for straightness and squareness deviations of generators A and B, as well as the parallelism deviation between them. The figure 3 shows the graphic representation of the deviations from a perpendicular direction, taking the standard lower surface as reference. The deviations presented are for a evaluated length of 30,4 mm.

Table 2 - Straightness, squareness and parallelism results

| Generator | A | B |
|---|---|---|
| Straightness deviation | 0,13 μm | 0,16 μm |
| Squareness deviations | 0,25 μm | 1,13 μm |
| Parallelism between A and B | 1,38 μm | |

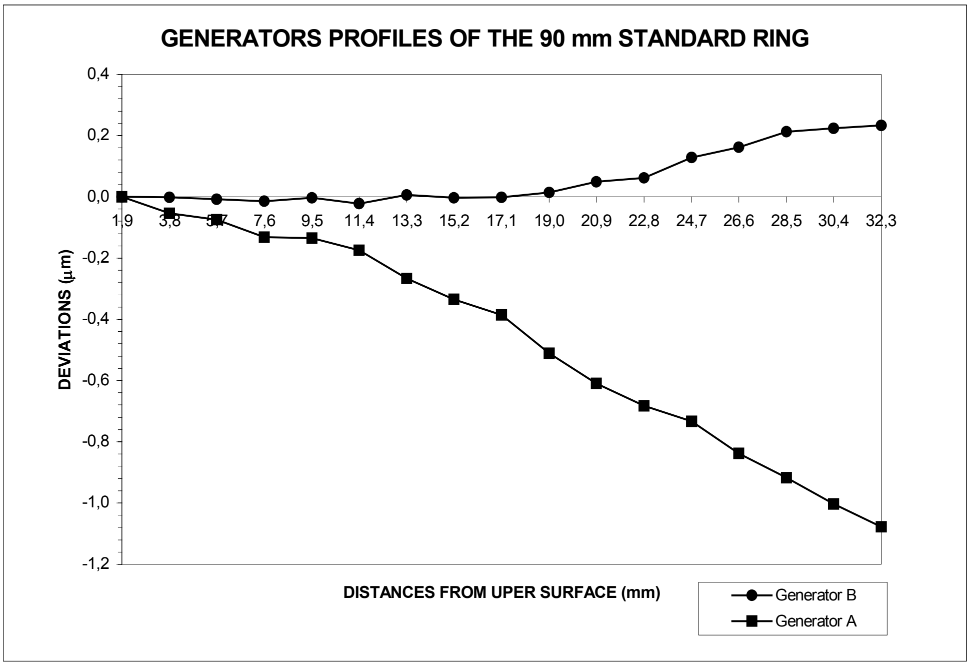


Figure 3 – Deviations obtained for generators A and B

## 9 ROUNDNESS MEASUREMENT RESULT

The figure 4 shows the roundness profile of the standard ring at its mean height. It was used a filter 2CR adopting 1-150 upr. The number of points used to analyse the profile was 2000. The roundness deviation found in a least square analysis was 0,35 µm.

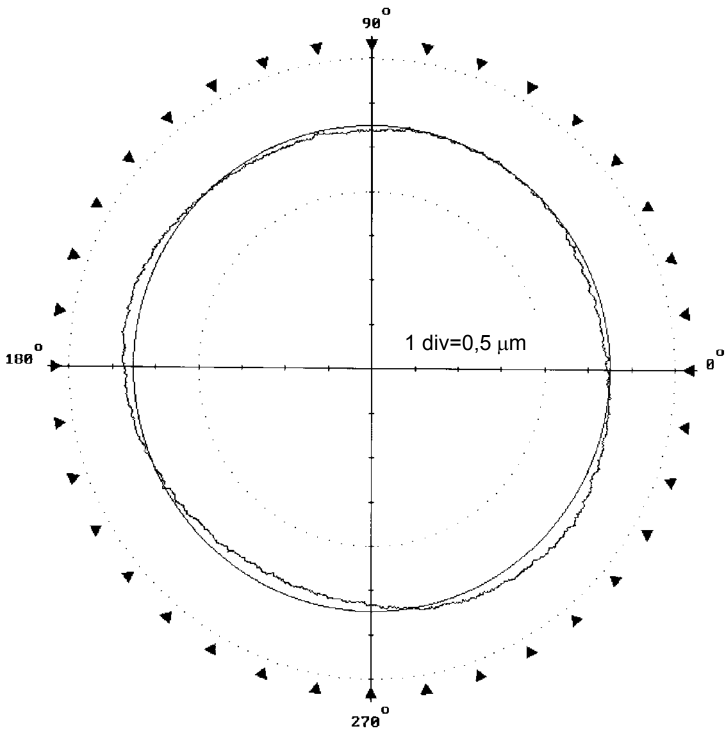


Figure 4- Roundness profile for the 90 mm standard ring (mean height).

## 10 INMETRO/PTB COMPARISON

A 40 mm standard ring was calibrated using the presented system in order to evaluate and validate it as a reference for length calibration (diameter, in this case). The standard ring had been previously calibrated by PTB.

Considering INMETRO and PTB results (the last one considered as reference), it can be seen in table 3 that they are compatible.

Table 3-Diameter results PTB/INMETRO

| Calibration results for a 40 mm standard ring | | |
|---|---|---|
| | Diameter | Uncertainty |
| INMETRO | 40,00951 mm | 0,1 μm |
| PTB | 40,00947 mm | 0,1 μm |

## 11 CONCLUSIONS

1) The system used for diameter measurements has shown good performance. The measurement uncertainties obtained are compatible with the accuracy required in the calibration of standards for internal and external diameters, as the ones here considered.

2) Keeping the measurement temperature in the range of (20 ± 0,2) ºC, performing the calibration of the CMM probe diameter with the smallest possible measurement uncertainty and achieving the best possible setting up and alignment of the interferometric laser (related to the X axis of the CMM table) are the main factors to obtain reduced measurement uncertainties with this system.

3) Confident results are obtained using this system in the determination of form (straightness) and position (squareness and parallelism) of rings and plugs, if the methodology for separation of the CMM geometric deviations in the Z direction (vertical) is adopted.

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