Measurement of the beam diameter at the polarimeter for quartz control plate calibration

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Abstract. The Knife Edge method was used to measure the diameter of a HeNe laser beam in the sample position of the high resolution polarimeter at Diopt. The acquired data profile was fitted to an equation and from the fitting parameters the diameter was calculated. The resulting laser beam diameter value obtained is a part of the polarimeter full characterization.

Keywords. Polarimeter, Knife Edge method, laser beam, quartz control plates

1. Introduction
Quartz control plates (QCP) are transfer standards for the calibration of polarimeters and schararimeters. The Optical Metrology Division of Inmetro, at the Laboratory of Optical Applications, calibrates these standards at the built polarimeter [1] by means of the measurement of the angle of rotation of the plane of polarization according to the ICUMSA standard [2]. The assessment of the laser beam width at the exact position where the QCP is mounted at the polarimeter for the optical rotation measurement is necessary in order to fully characterize the instrument.

There are several methods for measuring a laser beam diameter [3] and the Knife Edge method is the more straightforward to apply. It consists in measuring the laser output while a thin blade is sliding through the beam. An intensity profile as a function of distance is recorded and further analyzed by a curve fitting procedure to provide the beam diameter. This method has been attempted and reported here.

2. Materials and Methods
The polarimeter described in [1] uses a 633 nm stabilized HeNe laser. The output beam goes through an optical isolator and a calcite polarizer before crossing the QCP; there are no lenses in this setup. The QCP is mounted at the center of a copper tube 10 cm in length which goes inside a water bath thermalized chamber. A previous evaluation of the laser beam width have been made at both the copper tube entrance and exit positions by means of a millimeter grid and resulted in an average value around 2 mm.

Figure 1a shows the copper tube and a blade fixed at the position where the QTZ is mounted, covering one third of the 10 mm diameter of the circular opening where the laser beam traverses. Figure 1b shows the inside of the tube and the blade fixed at the opening. After fixing the blade, the other half of the tube is assembled, thus the blade is at half of the length of the 100 mm length tube; the vertical position is marked for alignment, and the tube is inserted inside the thermalizing chamber,
as shown in figure 2a. Figure 2b shows a lateral view of the set up, with the Si photodetector at the exit side. A motorized linear stage moves the platform supporting the thermalizing chambers perpendicular to the laser beam.

![Figure 1](image1.png)

**Figure 1.** (a) Blade mounted at the sample position inside the tube; (b) view of the blade inside the tube.

![Figure 2](image2.png)

**Figure 2.** (a) Thermalizing chamber with the sample tube inserted; (b) setup lateral view.

The measurement consisted in moving the platform in a way that the blade slowly approaches the laser beam and slides transversally until completely covering the laser beam, while the laser output is read by the photodetector connected to a digital multimeter and the output in volts.

A LabVIEW program was developed in order to command the linear stage and acquire the data from the photodetector. Figure 3 shows a print screen of the developed program. The program moves the platform from its initial position to the position where the beam crosses the tube without blocking and the linear stage moves with a higher velocity. As the blade approaches the beam, the velocity is reduced and the scan measurement starts. The program records simultaneously the linear stage
position and photodetector output; the linear stage returns to the scan start position and repeats the measurement. The graph in Figure 3 shows the acquired profile. It starts at a maximum when the beam is not blocked and decreases as the blade slides through it until completely covering the beam and the flat minimum is measured. These scans were repeated ten times.

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The HeNe laser has a Gaussian beam that can be described as a beam which has a circular cross section with a normal irradiance distribution. The acquired data from the Knife Edge method applied to the measurement of the beam diameter can be described as an error function equation that can be fitted to the experimental data and the beam radius extracted from the fitted parameters. Although there are more exact mathematical approaches to the fitting equation [4, 5], this simple method resulted reliable and gave diameter values far more precise than the millimeter grid evaluation.

The equation used to fit the acquired photodetector output intensity $I$ was:

$$I = a + b \left( 1 - \text{erf} \left( \frac{\sqrt{2}(x-c)}{w} \right) \right)$$

Where:
- $a$ is the background measured intensity;
- $b$ is the half of the maximum intensity;
- $c$ is the position corresponding to the half of the maximum intensity;
- $w$ is the beam radius

3. Results and discussion

Equation (1) was used in a curve fitting routine in Origin 8.0 by Non Linear Curve Fitting-User Defined. In order to describe the measured data, the first minus sign was changed to plus sign due to the negative values of $x$ position measured. For each of the ten scans 618 to 588 points were measured at a path length of 6.5 mm resulting in an average step of 0.010 mm.

Figure 4 exemplifies the measured and fitted curve for one scan. The fitted curve reasonably reproduces the data. For this particular example the fitted parameters and standard errors are $a = (0.18017 \pm 0.00008) \text{ V}$; $b = (0.08000 \pm 0.00007) \text{ V}$; $c = (-50.0239 \pm 0.0013) \text{ mm}$; $w = (0.790 \pm 0.003) \text{ mm}$; and Adj. R-square = 0.99963. Calculating the beam diameter as
$2 \times w = 1.58 \text{ mm}$. Table 1 presents the Adj. R-Square for the fittings and the values close to 1 attest to the good quality.

The curve fitting results for all the 10 repetitions are shown in Table 1. One can observe the very good reproducibility of the results for the ten sequential scans, and also that the fitted values present relatively small errors consistent with the fitting quality.

![Figure 4. Curve fitting of equation (1) to the acquired data.](image)

**Table 1.** Values and standard error of equation (1) fitted parameters.

| Parameter | a (V) | a (V) | b (V) | b (V) | c (mm) | c (mm) | w (mm) | w (mm) | Statistics | Adj. R-Square |
|-----------|-------|-------|-------|-------|---------|---------|---------|---------|------------|---------------|
| scan      | Value | Value | Value | Value | Value  | Value  | Value  | Value  | Value  | Value        |
| INT-1     | 0.1802 | 1 E-4 | 0.0800 | 7 E-5 | -50.0239 | 0.0013 | 0.7904 | 0.0035 | 0.99963 |
| INT-2     | 0.1795 | 1 E-4 | 0.0803 | 7 E-5 | -50.0244 | 0.0014 | 0.7883 | 0.0036 | 0.99961 |
| INT-3     | 0.1807 | 1 E-4 | 0.0797 | 7 E-5 | -50.0222 | 0.0013 | 0.7894 | 0.0036 | 0.99963 |
| INT-4     | 0.1806 | 1 E-4 | 0.0798 | 7 E-5 | -50.0235 | 0.0014 | 0.7916 | 0.0036 | 0.99964 |
| INT-5     | 0.1807 | 1 E-4 | 0.0798 | 7 E-5 | -50.0216 | 0.0013 | 0.7899 | 0.0035 | 0.99964 |
| INT-6     | 0.1804 | 1 E-4 | 0.0799 | 7 E-5 | -50.0236 | 0.0013 | 0.7898 | 0.0036 | 0.99962 |
| INT-7     | 0.1804 | 1 E-4 | 0.0799 | 7 E-5 | -50.0247 | 0.0013 | 0.7889 | 0.0036 | 0.99962 |
| INT-8     | 0.1805 | 1 E-4 | 0.0798 | 7 E-5 | -50.0251 | 0.0014 | 0.7864 | 0.0036 | 0.9996 |
| INT-9     | 0.1799 | 1 E-4 | 0.0801 | 7 E-5 | -50.0274 | 0.0013 | 0.7889 | 0.0035 | 0.99963 |
| INT-10    | 0.1791 | 1 E-4 | 0.0805 | 7 E-5 | -50.0300 | 0.0013 | 0.7904 | 0.0036 | 0.99962 |

**Table 2.** Average value of the laser beam radius.

| Mean | Standard Deviation |
|------|--------------------|
| Value (mm) | 0.7894 | 0.0014 |
| Diameter (mm) | 1.579 | 0.003 |
Figure 5 shows the individual values of the measured radius (triangles); the error in the fitted parameter $w$ value was set as the error bar; the black line is the radius average value and the dotted lines are the standard deviation of the radius mean value.

Table 2 presents the average value of the measured laser beam radius and the calculated beam diameter that is twice the radius mean value.

4. Conclusions
The calculated diameter value from the fitted laser beam radius measurements resulted much more precise than the millimeter grid evaluation that yielded a 2 mm rough estimative for this value. Actually, the sample is a quartz disc measuring up to 16 mm in diameter and an estimative of the laser beam crossing its center is necessary. In fact the Knife Edge method was used mainly due to the difficult task of evaluating the beam diameter at the middle position inside a 10 cm tube. A simple evaluation of the beam profile from the plotted graphs already gave reliable values for the laser beam radius. An improvement was achieved by fitting the measured curves to equation (1). Although this result is very good compared with the initial condition, a better and more precise fitting could have been done once derivatives of the error function were used for the fittings instead of the error function itself as shown in reference [5]. The present method already fulfilled the needs of measurement precision in order to characterize the laser beam at the sample position, as a part of the polarimeter full characterization.

Acknowledgements
A P D Alvarenga thanks CNPq.

References
[1] Alvarenga A D, Pereira N C E, Gomes B S and Grieneisen H P H 2011 Evaluation of measurement uncertainties for polarimetric calibration of quartz control plates Proc. 6th Brazilian Congress on Metrology Natal Brazil
[2] ICUMSA Method SPS-1 2009 Polarimetry and the International Sugar Scale-Official

[3] Wrigth D, Greve P, Fleischer J 1992 Laser beam width, divergence and beam propagation factor - an international standardization approach Optical and Quantum Electronics 24 S993

[4] Magnes J, Odera D, Hartke J, Fountain M, Florence L and Davis V 2006 Quantitative and Qualitative Study of Gaussian Beam Visualization Techniques arXiv:physics/0605102v1 [physics.optics] 12 May 2006

[5] Araújo M A C, Silva R, Lima E, Pereira D P and Oliveira P C 2009 Measurement of Gaussian laser beam radius using the knife-edge technique: improvement on data analysis Appl Op 48 394