Calibration of a Michelson Interferometer Laser Wavelength Meter

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Abstract: This paper deals about the traceability for the measurement of laser wavelength with a commercial meter, whose working principles is based on a Michelson interferometer setup.

Key words: wavelength traceability, wavemeter calibration.

1. INTRODUCTION

Knowledge of laser wavelength with the accuracy of picometer is important for several applications which require the use of tunable laser equipments [1]. Even for frequency beating experiments in optical combs, before finding the precise value of the measured laser frequency, it is required to determine the coarse wavelength (or frequency). Both tasks can be performed with wavelength meters based on Michelson interferometer (also known as wavemeters), which allow pursuing wavelength up to picometer accuracy.

According to BIPM recommendation [2] it is possible to acquire traceability for an unstabilized He-Ne laser by using a diffraction grating or a wavemeter. The recommended value is 632.99080 nm with uncertainty 2. 10^{-5} nm (k=2).

The subject of this paper is to show the procedure and results for the calibration of a commercial Burleigh WA-1500 wavemeter [3], which is done by measuring the wavelength of a primary standard HeNe laser. This measurements were performed at Division of Optical Metrology (Diopt) at Inmetro (National Institute of Metrology, Standardization and Industrial Quality).

2. EXPERIMENTAL

2.1. Wavemeter

The working standard for the measurement of laser wavelength at Laraf is a WA-1550 wavemeter purchased from Burleigh (now Exfo). This equipment is a modified Michelson interferometer.

Measurement of wavelength of the test laser is performed by comparison with a stabilized reference laser that is internal to the equipment. Both laser beams travel in opposite paths in the interferometer. A retro-reflector mirror is moved and the number fringes (m) generated by each beam is counted in separate detectors. It is possible to retrieve the wavelength (λ) with the equation (see reference [4]):

$$m\lambda = 4 n_{air}(\lambda) d \quad , \qquad (1)$$

which depends on the refractive index of air at the wavelength being measured ($n_{air}(\lambda)$) and the distance traveled by the mirror (d).

Since the wavelength of the internal reference laser is known to a relative accuracy of $0.1 \cdot 10^{-6}$ and both beams travel the same distance, equation (1) can be rewritten as:

$$m_{ref} \frac{\lambda_{ref}}{n_{ar}(\lambda_{ref})} = m_{teste} \frac{\lambda_{test}}{n_{ar}(\lambda_{test})} \quad . \qquad (2)$$

In order to find the test laser wavelength, the equipment uses the dispersion curve for air refractive index (given by Edlen equation), which is a function of temperature, pressure and humidity. The ratio of number of fringes (m_{ref} / m_{test}) is obtained by processing the signal acquired by the detectors.

2.2. Standard laser

One of the standard lasers used at Inmetro is a He-Ne stabilized to an atomic transition of iodine. This laser recently participated in the CCL-K11 key comparison of length [5], in 2009. In this comparison, the measured frequency for the line ‘f’ of standard laser from Inmetro was $\nu_{stand} = 473\,612\,353\,606.26(32)\ \mathrm{kHz}$. This frequency corresponds to a vacuum wavelength of:

$$\lambda_{0,stand} = 632.991212576(13)\ \mathrm{nm} \quad . \qquad (3)$$

2.3. Method of measurement

The procedure executed to calibrate the wavemeter involves two tests. In the first one, long term stability of the equipment is checked by leaving it measuring the wavelength of the standard laser overnight. The second test is to determine the uncertainty due to laser alignment in the interferometer. This is accomplished by small changes of the angle of entrance of the beam in the cavity.

3. RESULTS AND DISCUSSION

Table 1 shows the results for nearly 60 000 acquired values for the wavelength. These results are limited by the resolution of the equipment. Some values were outside of the range specified in Table 1 (to lower wavelengths). They were removed due to the indication that the standard laser went unlocked during these periods of time.

From Table 1 it is possible to verify that measurements performed by the wavemeter are very stable. The average measured wavelength is 632.9918 nm, with a standard deviation of $2.5 \cdot 10^{-9}$ nm. This deviation is much smaller than the equipment resolution ($5 \cdot 10^{-5}$ nm), which means there is no influence of this parameter to the uncertainty. In this stability test it was not taken into account the alignment or misalignment of the test laser.

Table 1: Stability test for the Burleigh Wavemeter.

λ (nm)	Counts
632.9913	0
632.9914	0
632.9915	5
632.9916	4
632.9917	18130
632.9918	24131
632.9919	6
632.9920	3
632.9921	2
632.9922	1
632.9923	0
632.9924	0

It was also performed an alignment test and the results are shown in Figure 1, where each point represents a measurement taken in a different alignment condition in the interferometer for line ‘f’ of the above mentioned standard laser.

The average wavelength value taken from those measurements is 632.9912 nm, which differs from the value determined during the stability test, because several alignment conditions were verified, so this result is more representative of the laser operational condition. The relative uncertainty of the measurement is $3 \cdot 10^{-7}$. This result shows that the best procedure for wavelength measurement of a laser using this wavemeter is making a series of measurement with small misalignments.

Table 2 shows the uncertainty budget for the calibration of the wavemeter. Uncertainties for accuracy and resolution were found at equipment operating manual [4].

The relative expanded uncertainty with a confidence level of 95.45 % (k = 2.3) is $7.6 \cdot 10^{-7}$. Thus, the result for the measured wavelength can be written as:

$$\lambda_{0,meas} = 632.9912(5)\,\text{nm}\,. \qquad (4)$$

This result shows that the wavelength measured by the mentioned wavemeter agrees well within the uncertainties with those of the standard laser (equation (3)).

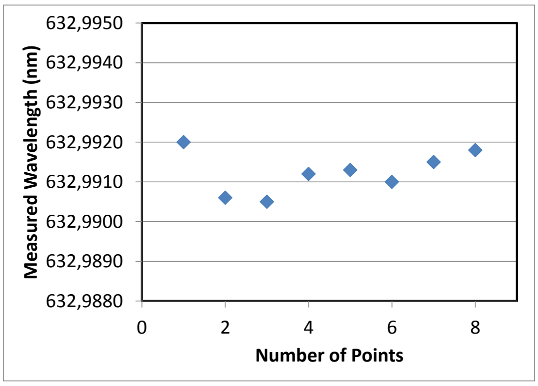

Figure 1: Measured value of the standard laser (line ‘f’) by the wavemeter under some different alignment conditions.

Table 2: Uncertainty budget for calibration of the wavemeter.

Source	**Type**	**u(λ)/λ**	**ν**
Reference Standard	b	3.4E-13	∞
Stability	b	7.7E-16	∞
Resolution	b	4.6E-8	∞
Accuracy	b	1.2E-7	∞
Repeatability	a	3.0E-7	7
Combined uncertainty		**3.3E-7**	**10**
Expanded uncertainty (k=2.3)		**7.6E-7**	

4. CONCLUSION

The tested wavemeter can perform measurements with excellent accuracy near 633 nm, whenever measurements are taken under several alignment conditions. These different alignment conditions make it easier to have an average that coincides two laser beams into the Michelson interferometer and have equal optical path inside the wavemeter. The relative expanded uncertainty for the measurement of wavelength is $7.6 \cdot 10^{-7}$. The measurements result obtained following the calibration procedure described in this work shows that the calibration of commercial wavemeter can be done using the wavemeter working standard of Laraf, that is traceable to S.I. length unit.

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[3] Commercial instruments are identified in this paper for the purpose of adequately describing experiment or test procedures. The identification does not imply recommendation or endorsement by Inmetro.

[4] Operating Manual Wavemeter WA-1500, Burleigh.

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