18th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2014, Budapest, Hungary, 10-12 September 2014

THE METHOD OF CALIBRATION OF He-Ne LASER USING THE NPL IODINE STABILIZED He-Ne LASER WITH WAVELENGTH AT 633 nm

Alen Bošnjaković
Institute of Metrology of Bosnia and Herzegovina
Sarajevo
Bosnia and Herzegovina

Hazim Bašić
University of Sarajevo, Mechanical Engineering Faculty Sarajevo
Sarajevo
Bosnia and Herzegovina

ABSTRACT

NPL iodine stabilized He-Ne laser at wavelength 633 nm is intended for work with the 2nd class lasers in visible spectrum, respectively, it is a laser with the output energy that is lower than 1mW and operates at wavelength from 400 nm to 700 nm. This referent standard is designed to be stabilized to the b21 component of the 6-3 P (33) iodine transition. This transition is listed in the CIPM recommendation for practical realization of the meter. NPL iodine stabilized He-Ne laser was used for calibration of He-Ne laser. The technique for dissemination unit of the length on the highest metrology level which is used for calibration of stabilized He-Ne lasers is called beat frequency. In the experimental part of work the practical mode of conducting calibration of frequency stabilized He-Ne Laser, respectively, determination of its referent frequency with the estimation uncertainty of measurement was done. Additionally, parameters that have influence on measuring results were estimated.

Keywords: *length standard, measure uncertainties, beat frequency, iodine stabilized He-Ne laser*

1. INTRODUCTION

The calibration procedure is very complex process which involves a series of elements such as information about drift of a standard and measuring instruments, procedure of calibration, introduction corrections which are relating to estimation of certain influence quantities-effects, uncertainty of measurement result from which it is obtained, etc. Having in mind that the measuring results and data provided by metrology laboratories are determinated to a large extent by the quality of the expression of the measuring uncertainty that follows the results themselves. The result of each measurement contains a certain level of measurement uncertainty, whose causes can be numerous, and generally all cannot be taken into account. At the top of the metrology length pyramid, there are lasers as primary standards for the length which are used for dissemination unit of the length to lower rank standards. As a primary standard for realization unit of the length Iodine stabilized He-Ne laser wavelength 633nm is used, in accordance with the recommendation of the International Committee for Weights and Measures (CIPM) which refers to the practical realization of the metre. The NPL Iodine stabilized He-Ne laser is the primary standard, [1]. The laser is a primary-standard reference laser designed to stabilize to component b21 of the 6-3 P (33) transition in iodine. This iodine transition is listed in the recommendations of the CIPM 2001/2003 for the realization of the metre, [2]. All measurements, whose results were showed in this paper, were performed at Laboratory of Length, Bosnia and Herzegovina’s Institute of Metrology.

2. OPTICAL SETUP OF THE CALIBRATION

The most convenient means of studying and testing the satiability of these lasers is heterodyne method (i.e. beat frequency). This technique is founded at the optical interference method. The method of detection is identical to Michelson interferometer when it is used for photoelectrical detection, [3].

The purpose of the optical system is to superpose output beams of the lasers. The technique which is used for dissemination the unit of the length on the highest metrological level for calibration stabilized He-Ne lasers is called beat frequency. Most usually these two lasers comprise test laser and referent lasers of better stability, figure 1. The heterodyne signal is generated when the output beams from reference laser and test laser being tested are combined on the active area of the avalanche photo-detector (APD). Overlapping and combining the output of beams is achieved by adjustment of the beam steering mirror and the beam splitter mirror. The mixed beams are directed to the APD by the focusing lens. It is necessary to perform the following steps before the calibration process: procedure of adjustment, determination sign of beat frequency and checking signal of beat frequency for reliable counting. The arrangement of the two lasers side by side, as in figure 1, is not necessary but it is usually convenient for the practical measurements.

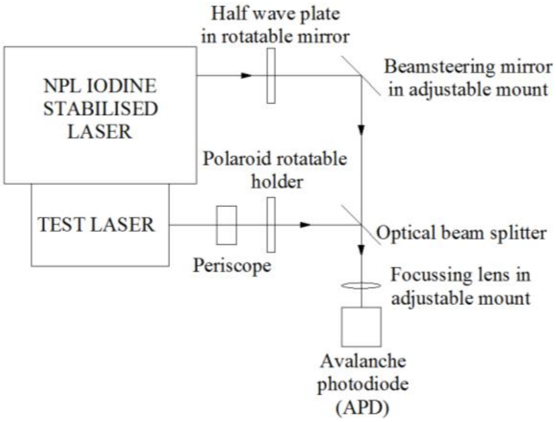


Figure 1. *Schematic of the NPL beat frequency monitoring system*

The single data measurements X_i (b, m_1) are average of the number of repeated measurements. The second mode m_2, where existing, is measured only once, it is not the case with our test laser since it is single-frequency laser. These measurements represent one set of data X_i (b, m_2), which are obtained from frequencies of the test and the reference laser.

$$X(\mathrm{bi}, \mathrm{m}_1) = |f_\mathrm{N}(\mathrm{bi}) \pm f_\mathrm{P}(\mathrm{m}_1)| \tag{1}$$

Where is:

- X(b, m) the deference frequencies between the primary standard and the secondary standard,
- f_N (b) the frequency of primary standard
- f_P (m) the frequency of mode m of the secondary standard/ test laser,
- i the number of repeated measurements,
- b the hyperfine component (HFS) of the primary standard/ reference leaser.

The average value of the frequency of mod m_2 is calculated according to mode m_1 and heterodyne frequencyf_H:

$$f_\mathrm{p}(\mathrm{m}_2) = f_\mathrm{p}(\mathrm{m}_1) \pm f_\mathrm{H} \tag{2}$$

The wavelength in vacuum is calculated from two frequencies found according to the following term:

$$\lambda(\mathrm{m}_\mathrm{i}) = \frac{\mathrm{c}_0}{f_\mathrm{P}(\mathrm{m}_\mathrm{i})} \tag{3}$$

Where is: c_0 – the speed of light.

3. ESTIMATION MEASUREMENT UNCERTAINTY

The measurement uncertainty represents parameter associated with the measurement result which describes the dispersion of values which can be reasonably attributed to the measured value [4, 5, 6]. The maximum and minimum value X is determined for the component b21, and it assumed rectangular dispersion. The standard uncertainty is given by the following term:

$$u\left(f_\mathrm{p}(\mathrm{m}_1)\right) = \frac{1}{\sqrt{3}} \cdot \max[\max_\mathrm{i} X_\mathrm{i}(\mathrm{k}_{\mathrm{b}21}, \mathrm{m}_1) - \min_\mathrm{i} X_\mathrm{i}(\mathrm{k}_{\mathrm{b}21}, \mathrm{m}_1)] \tag{4}$$

The measurement uncertainty of the laser is determined analogue to the previous term:

$$u(f_{\mathrm{H}}) = \sqrt{\frac{1}{3}\cdot[\max_{\mathrm{i}} f_{\mathrm{Hi}} - \min_{\mathrm{i}} f_{\mathrm{Hi}}]^2 + u(f_{\mathrm{n}})^2} \tag{5}$$

Where is:

- $u(f_{\mathrm{H}})$ the measurement uncertainty of the test laser,
- $u(f_{\mathrm{n}})$ the measurement uncertainty of the reference laser,

$$u(f_{\mathrm{n}}) = u(\delta_{\mathrm{N}}) + u(\delta_{\mathrm{SN}}) + u(\delta_{\mathrm{C}}) \tag{6}$$

- $u(\delta_{\mathrm{N}})$ the measurement uncertainty of the reference frequency,
- $u(\delta_{\mathrm{SN}})$ the measurement uncertainty of the signal noise ratio,
- $u(\delta_{\mathrm{C}})$ the measurement uncertainty of the frequency counter.

The standard measurement uncertainty of mode m_2 is calculated by the following term:

$$u(f_{\mathrm{p}}(\mathrm{m}_2)) = \sqrt{u(f_{\mathrm{p}}(\mathrm{m}_1))^2 + u(f_{\mathrm{H}})^2} \tag{7}$$

The value of wavelength measurement uncertainty in vacuum (λ) is calculated by frequency and its measurement uncertainty by means of speed of light in vacuum (c_0).

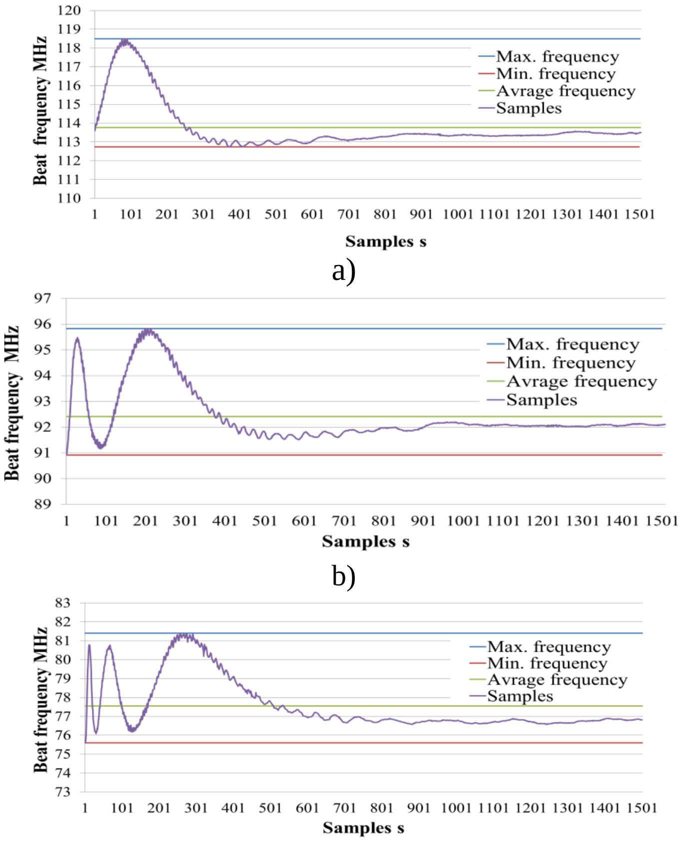
$$u(\lambda) = \frac{c_0}{f^2}\cdot u(f) = \lambda\cdot\frac{u(f)}{f} = \lambda\cdot u^*(f) \tag{8}$$

$$u^*(\lambda) = \frac{u(\lambda)}{\lambda} = u^*(f) \tag{9}$$

In order to calculate relative expanded measurement uncertainty U^*, a certain combined measurement uncertainty u^* is multiplied by coverage factor 2.

4. RESULTS

The calibration results of reference frequencies were showed in the figure 2. During the calibration process 1500 samples and beat frequencies respectively, were recorded. The samples were recorded with time-gate of 10 second.



a)

b)

(c)

***Figure 2**. The results of measurements with reference frequency (a) b21, (b) b20, (c) b19*

The calibration process was performed with the heterodyne method. NPL Iodine stabilized He-Ne laser, which has sufficient stability for its fluctuations to be ignored in comparison with those of the test laser, was used as a referent standard. All three diagrams are almost identical, as a result of that, it can be concluded that the test laser has a good repeatability. When the calibration process with reference component b21 was finished, it was continued with two remaining reference frequencies b20 and b19. The results showed a drift during the first calibration hour. It is most probably a reflection that came from the outer surfaces of one of the mirrors. The frequency was stabilized after one hour and it could be expected that a day to day reproducibility is to be within a 1 MHz range. The results of calibrations and parameters that have influence on results are given in the table 1.

Table 1. *The results of measurement*

The result of calibrations			Measurement uncertainty			
Ref. freq. (MHz)	Beat freq. (MHz)	Res. freq. (MHz)	Parameter	Type	*u* (MHz)	*U* (MHz)
b21 473612942,21	114,67	473612828,10	$u\left(f_p(m_1)\right)$	A	2,85	-
			$u(\delta_N)$	B	0,138	-
b20 473612920,20	92,41	473612827,79	$u(\delta_{SN})$	B	neglected	-
			$u(\delta_c)$	B	0,164	-
b19 473612905,42	75,54	473612829,88	$u(f_H)$	The combined measurement uncertainty	0,95	1,90

On the basis of measurement results, the complete measurement results with measurement uncertainty and frequency of the test laser respectively, can be expressed:

$$f_p(m_1) = 473612828{,}10 \pm 1{,}90 \text{ MHz}$$
$$\lambda = 632.99 \pm 2{,}53 \cdot 10^{-6} \text{ nm}$$

5. CONCLUSION

One of the most important tasks of all metrology laboratories is giving measurement results which have to be clear and accurate. The measurement result is complete if it contains a value associated with measuring quantity and measuring uncertainty associated with that quantity. The calibration process was performed three times with component b21 and repeated once again with two remaining frequencies b20 and b 19. Afterwards, the average value of the first three calibrations was founded. Estimations of parameters which have influence on measuring result were performed: estimation measurement uncertainty of reference frequency, estimation measurement uncertainty signal-noise ratio and estimation of measurement uncertainty of the frequency counter. The estimation of parameters is necessary in order for the measurement result to be complete. From the reported measurement result it can be concluded that measurement result is relatively low and that the biggest contribution to the measurement uncertainty comes from the beat frequency. As a result, it can be concluded that based on the obtained values, calibration process was performed successfully.

6. REFERENCE

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