

Theme № 440/RU/08

Supplementary comparison

**International comparisons of Stabilized He-Ne/I<sub>2</sub> lasers at wavelength 633 nm**

**TECHNICAL PROTOCOL**

Pilot-laboratory: Research division for geometric measurements.

Name and abbreviation of .... All-Russian Research Institute for Metrology  
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**1. Project description**

1.1 The standards of length –meter in the field of calibration of the He-Ne lasers are intended for reproduction, conservation and transference the dimension the unit of length to any standards and precision devices (He-Ne lasers) applied in different spheres of technology with aim of providing the uniform of measurements.

1.2 The comparisons of frequency-stabilized He-Ne/I<sub>2</sub> lasers, which are the standards of frequency and length, are carried out by the method of BIPM (Bureau International des Poids et Mesures) using heterodyning method and include studying of stability and reproducibility of the frequencies of the stabilized lasers.

Since the He-Ne/I<sub>2</sub> lasers could reproduce different frequencies depending on the tuning on different hyperfine peaks of iodine-127, the integrated estimation of the laser frequency reproducibility was used. Tuning the lasers frequencies at opposite components of hyperfine structure (HFS) we can estimate the laser frequency reproducibility (mainly the components of one group – “defg” are used for this estimations, because they position approximately corresponds to the center of the laser gain curve.

The results are represented as a matrix 4x4 and the less square method is used for estimation of the results of the measurements. This way allows to get the frequency difference of the lasers under test and, also, to determine the frequency splitting of HFS-components in each He-Ne/I<sub>2</sub> laser. Every element of matrix is average over three consequent results of beat frequency measurements with averaging time 10 s, the main matrix diagonal corresponding the lasers tuning at the same peaks does not measured.

So, we get matrix of 12 elements, each pair of 6 items corresponds to the laser beat frequency in course of symmetrical tuning of lasers to concrete peaks.

Semi-differences of corresponding readings of the lasers beat frequencies are the measure of divergence of the lasers frequencies when the lasers are stabilized symmetrically( For example: 1st laser is tuned to the ”d”-peak, 2nd –to the “f” and vice versa). Averaging value of the six semi-differences is a measure of integral lasers frequency difference in presented set of measurements. The standard deviation of the 6 semi-differences may be used as estimation of influence of curvature of the Doppler gain contour of Ne.

The average value of all sets of the measurements in the series to be an estimation of the frequency difference between two lasers under test, while the standard deviation on all sets to be an estimation of the frequency reproducibility of the stabilized lasers.

According to BIPM, method of determination the frequency stability estimates by “Allan variance”. Allan variance is the mean value of the frequency variations at definite averaging time.

Usually averaging time taken 1s, 10s, 100s and so on, standard number of measurements is 100, in opposite case the number of the measurements has to be pointed out. Allan variance is marked as  $\langle\sigma(2,\tau)\rangle$  and is presented in graphic form, which show dependence of Allan variance via averaging time.

The measurements of the frequency stability of He-Ne/I<sub>2</sub> lasers may be carried out by any pair of different components of HFS. A 101 successive results (readings) of the beat frequency are registered at a frequency counter and we get 100 pairs data for determination Allan variance at the given averaging time.

## 2. Goal of the project

2.1 The main purpose of the project is to confirm the measuring possibilities declared for CMC and to establish extent of equivalence of the standards between National metrological laboratories.

## 3. Participants

**Tabl.1**

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## 4. Organization of intercomparisons

### 4.1. Scheme of comparisons

Intercomparison of frequency stabilized He-Ne/I2 lasers are carried out in VNIIM.

## 4.2. Time-table

**Table 2**

BelGIM-VNIIM	May 2009
KazINMETR-VNIIM	July 2009
NNC Institute for Metrology	September 2011
Preparing of report	2012

## 4.3. Testing of the Stabilized He-Ne/I<sub>2</sub> lasers

Main characteristics of He-Ne/I<sub>2</sub> laser VNIIM2 showed in Tabl.3. Laser VNIIML has certificate BIPM № 08/2005.

**Table 3**

<b>Characteristic</b>	<b>Characteristic value of Laser VNIIM2</b>
Last comparisons	1999
Frequency (“I” peak)	473 612 353 606.603
“Cold finger” temperature of I <sub>2</sub> -cell, °C	15.00
Wall temperature of I <sub>2</sub> -cell, °C	25
I <sub>2</sub> -cell active length, mm	100
Cavity length, mm	330
Mirror radius (R <sub>1</sub> ) –gain-tube side, mm	1000
Mirror radius (R <sub>2</sub> ) –cell side, mm	1500
Mirrors’ transmittance (R <sub>1</sub> , R <sub>2</sub> ), %	1.1
Modulation frequency, kHz	10.00
Modulation amplitude, MHz	6.0
Iodine pressure in the cell, Pa	17.32
Laser output power, μW	102.5

## 5. Measurements method

### 5.1. Measurements conditions:

- ambient temperature, °C 20±0.5;
- atmospheric pressure, mmHg 760±30;
- relative air humidity, % 60±20.

5.2. Before beginning of the measurements lasers under the test have to be heated in the course of 1..3 hours until the linear thermal drift of laser cavities comes to the end. A checking of the thermal extension rate of drift is observed at the screen of the control oscilloscope.

When the thermal balance is achieved, than monotonous drift of the concrete peak at the X-axis of the oscilloscope screen becomes accidental.

### 5.3. Measurements of the frequency reproducibility of the He-Ne/I<sub>2</sub> lasers

5.3.1. Measurements of the frequency reproducibility of the He-Ne/I<sub>2</sub> lasers is carried out during 3-5 days, each measuring day has to include 2-3 series.

5.3.2. Each series includes 5-7 measurements of matrix, time interval between measurements is 0.5 ÷ 1 hour.

5.3.3. Measuring of the reproducibility of the He-Ne/I<sub>2</sub> lasers should carried out with the next conditions, which was established by International specifications:

- “Cold finger” temperature of the I<sub>2</sub>-cell (15±0.2) °C,
- Wall temperature of the I<sub>2</sub>-cell (25±5) °C,
- Deviation of optical frequency (6±0.3) MHz,
- Power density inside the laser cavity (10±5) mW.

Conditions, pointed above, guaranties the frequency reproducibility of the He-Ne/I<sub>2</sub> lasers as high as ±10 kHz (or ±2x10<sup>-11</sup> in relative unites).

Measurements are carried out according point 1.2.

### 5.4. Measuring of frequency stability of the lasers

5.4.1. A 101 reading of beat frequency are saved and we get 100 pairs of the dates for calculation the Allan variance with averaging time 10 s.

5.4.2. Some readings of beat frequency are saved with averaging time 100 s and so on. Generally speaking the data which have got with the averaging time τ may be used for calculation intermediate results with averaging time 2τ, 3τ and so on. Obviously, the number of samples is to be reduced in proportion on this process.

5.4.3. Analytically the Allan variance may be presented in following form:

$$\langle \sigma(2, \tau) \rangle = \sqrt{\frac{1}{2n} \cdot \sum_{i=1}^n (v_{i+1} - v_i)^2}$$

- where:  $\langle \sigma(2, \tau) \rangle$  - Allan variance,  
 τ- averaging time,  
 n- number of pairs of measurements,  
 v<sub>i+1</sub>, v<sub>i</sub> - successive values on the beat frequency.

The results of measured stability should be presented in graphic or table form as function of averaging time.

## **6. Form of presentation the results of measurements**

The results of measurements have to be presented in form of report and consist of:

- short description and structure of the standard;
- measuring conditions;
- protocols of measuring of frequency reproducibility;
- protocols of measuring of frequency stability

The Document was created by the Chief of Length & Lasers Division VNIIM  
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