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TRACEABILITY OF 633 nm LASER CALIBRATION AT NIMT

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Abstract – The National Institute of Metrology (Thailand), NIMT, maintains the standard of length in accordance with the definition of the meter through a 633 nm iodine stabilized He-Ne laser. Its accuracy is transferred to stabilized and non-stabilized lasers regarding to beat-frequency method and direct measurement using a wavelength meter, respectively. The traceability in wavelength measurement at the NIMT is discussed here. The iodine stabilized He-Ne laser is self-calibrated using the master and slave beat frequency system. NIMT participated in APMP.L-K11 intercomparison and the results are presented. The standard uncertainty is 2.5x10^{-11}.

Keywords: iodine stabilized He-Ne laser, beat frequency method, traceability

1. INTRODUCTION

According to the definition of the meter, the Comité International des Poids et Measures (CIPM) drew up recommendations for the practical realization of the definition since 1983. It was understood that the practical realization would, from time to time, be updated to take into account of new measurements and improvements in techniques of laser stabilization. Therefore, the Comité Consultatif pour la Définition du Métre (CCDM) had adviced the revisions of the *mise en pratique* in Recommendation 3 (CI-1992) [1], Recommendation 1 (CI-1997) [2], Recommendation 1 (CI-2002) [3] in 1992, 1997 and 2002, respectively. CIPM adopted the advices consequently. The current definition of one meter is the length that light travelled in vacuum within the time interval of 1/299 792 458 second.

NIMT established the primary standard using iodine stabilized He-Ne lasers at 633 nm in 2003 because it has been widely used for the practical realization of the definition of the meter. The traceability chain of length metrology at NIMT will be discussed. The experimental systems and the results for beat frequency technique and direct measurement will also be explained in the following sections.

2. TRACEABILITY OF THE 633 nm LASER CALIBRATION AT NIMT

The NIMT traceability chain in length measurements is shown in Fig. 1. From the primary standard, 633 nm iodine stabilized He-Ne laser, can be split into two parts. One goes to stabilized He-Ne lasers and another goes to wavelength meters. Stabilized He-Ne lasers are calibrated against the primary standard using beat frequency techniques. Gauge block interferometers, line scale interferometers, laser interferometers and interference microscopes are traceable to this branch since the use of light sources is stabilized He-Ne lasers. The accuracy of stabilized He-Ne lasers is better than 10^{-7}.

Traceability of non-stabilized He-Ne lasers comes from the wavelength meter calibrated by the primary standard. Non-stabilized He-Ne lasers are calibrated using direct measurements. The transfer standards can be used in flatness measurement using flatness interferometers, for instance. The accuracy of non-stabilized He-Ne lasers is worse than 10^{-7}.

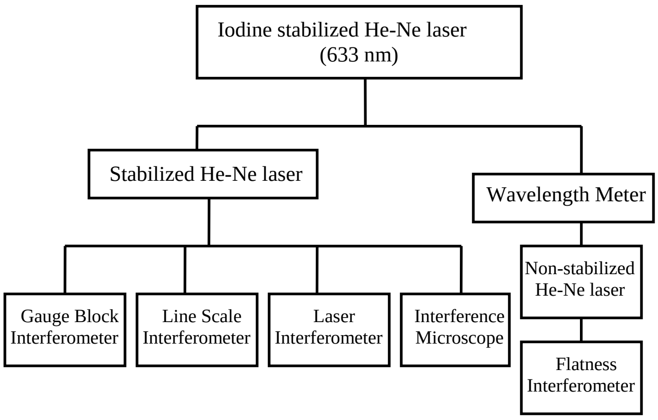

Figure 1 Traceability chart of the 633 nm laser calibration at NIMT.

3. EXPERRIMENT SET-UP

3.1 The beat frequency calibration system.

The beat frequency method is used for stabilized laser wavelength calibration at 633 nm. This method is to measure frequency difference between a pair of stabilized lasers. The reference frequency comes from a stabilized He-Ne laser (a slave laser) having frequency offset with the iodine stabilized He-Ne laser controlled by a PLL (phase locked loop) controller [4]. The under test laser is a stabilized laser. The advantages in using the slave laser are to increase the overall laser power of the reference beam because the iodine stabilized laser has low power (50 μW)

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and to remove any modulation frequency. Use of this master and slave beat frequency technique can be applied to interferometry applications [5]. The experimental set-up is shown in Fig 2.

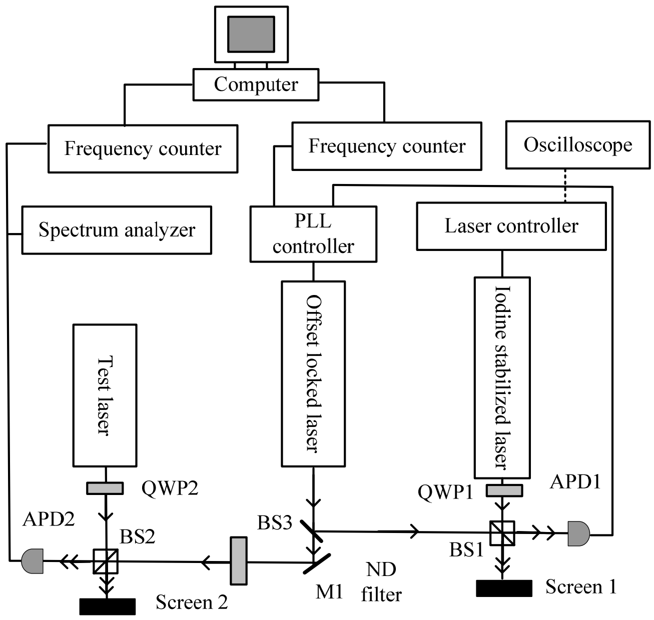

Fig. 2 Beat frequency measurement set-up.

The system consists of an iodine stabilized laser, an offset locked laser with PLL controller, an under test stabilized laser, beam splitters, quarter waveplates, photodiodes, a spectrum analyzer and two frequency counters.

A beam from the offset locked laser (NF company: NEO-OL101K) is split into two beams by the beam splitter, BS3. One is sent to the beam splitter, BS1, and optically combined with the beam from the iodine stabilized laser, called NIMT-1(NF company: NEO-92SI-NF-P). The mixed beam incidents on the avalanche photodiode, APD1 (Hamamatsu : C5658). The beat signal obtained from APD1 is sent to the PLL controller and a frequency counter (Hewlett Packard: HP 53131A) in order to detect frequency difference compared to the reference frequency. Normally, the stabilized frequency shift of the offset locked laser is 200-500 MHz. In this system, the offset at 400 MHz is used.

Another beam from the BS3 is delivered and is optically interfered with the under test stabilized laser at the beam splitter, BS2. The beat signal of this mixed beam is detected at the avalanche photodiode, APD2 (Hamamatsu: C5658) which sends signal to the frequency counter (Hewlett Packard: HP 53131A) to determine frequency difference. Two frequency differences are calculated in order to determine wavelength of the under test laser in LabView environment. The program is also used to set the gate time interval of beat frequency display. The spectrum analyzer (Hewlett Packard: HP 8590L) allows the program to monitor the spectral accuracy and signal-to-noise ratio of the beat signal.

3.2 The direct measurement system.

Non-stabilized lasers are calibrated using a wavelength meter. The measurement principle is based on the direct measurement. Fig. 3 shows the diagrammatical set-up system for non-stabilized lasers calibration based on the direct measurement. The system comprises a wavelength meter, an under test non-stabilized laser, an optical isolator and an objective lens with an optical fiber. Laser beam of the under test non-stabilized laser is transmitted to the optical isolator to prevent any reflected beams disturbing the laser wavelength and is sent to the wavelength meter (HighFinesse: WS 7) through the optical fiber. The wavelength of the under test laser is calculated within LabView environment.

For the calibration of the wavelength meter, the same set-up is used but instead of non-stabilized laser, the iodine stabilized laser is placed.

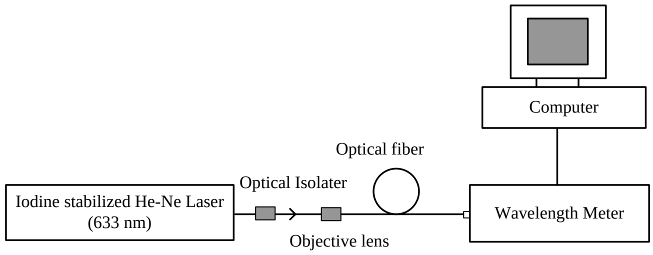

Fig. 3. Direct measurement setup.

4. RESULTS

All operating conditions of the NIMT-1 were adjusted to the nominal value: laser power of 50 μW (one-way intra-cavity power of 10 mW), peak-to-peak frequency modulation width of 6 MHz (monitored by spectrum analyzer) and cold-finger temperature at 15 ^{o}C.

The traceability to SI unit of lasers used at NIMT at wavelength of 633 nm through NIMT-1 were measured by 2 methods, beat frequency method and direct measurement method.

4.1 Beat frequency method

We measured wavelength components of stabilized laser by using **d**, **e**, **f** and **g** hyperfine of the iodine spectra. At NIMT, we have three iodine stabilized He-Ne laser systems which are NIMT-1: 02022, NIMT-2: 02023 and NIMT-3: 802545 serving as the primary standards.

Table 1. Beat frequency results year 2003-2008.

	Beat frequency, kHz					
	2003	2004	2005	2006	2007	2008
NIMT-1 and NIMT-2	3.4	7.4	10.8	28.6	30.4	32.1
NIMT-1 and NIMT-3	1.5	2.5	2.2	2.6	1.7	3.4
NIMT-2 and NIMT-3	2.4	5.5	7.3	24.8	27.5	28.6

All of them are used together in beat frequency method for self calibration of three iodine stabilized lasers. Beat frequency result obtained from three pairs of laser since 2003 are summarized in Table 1.

While operating beat frequency measurement, we keep the standard deviation of the frequency shift below 2 kHz. Fig. 4 illustrates beat temporal change in frequency shift for 12 hours. Data points were recorded every 10 seconds.

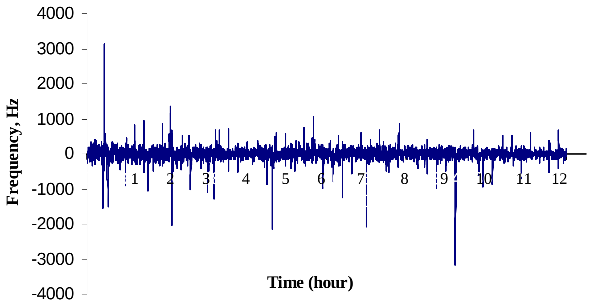

Fig. 4. Temporal change of the shift frequency when beat the NIMT-1 with the offset locked laser.

We maintain NIMT-1 as a primary standard at the NIMT according to the Practical Realization of the Definition of the Meter and achieve standard uncertainty of 2.5 x 10^{-11} or 11.7 kHz. It should be noted that some beat frequency between NIMT-1:NIMT-2 and NIMT-2:NIMT-3 exceed 11.7 kHz while beat frequency between NIMT-1:NIMT-3 is within 11.7 kHz. This is due to decrease in power of the NIMT-2 below the recommendation power value of the CIPM since 2006. Thus, we are confident that the frequency (vacuum wavelength) of the laser NIMT-1 is in good performance.

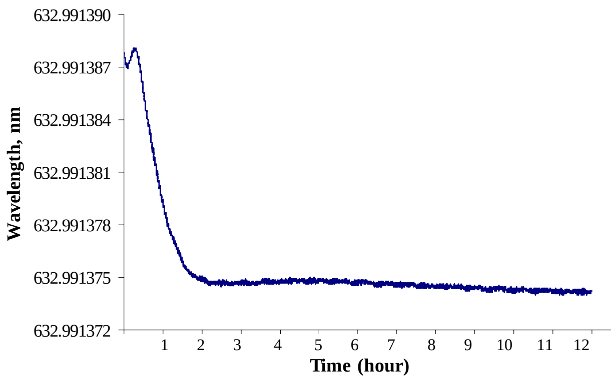

Fig. 5. Long term stability of laser HP 5518.

Accuracy of the NIMT-1 wavelength is then transferred to the stabilized He-Ne laser used in many length measuring instruments. Gauge block interferometer, line scale interferometer, laser interferometer and interference microscope all have stability He-Ne laser as light sources. Wavelength stability of the laser is also monitored every 10 seconds for 12 hours by looking at the **f**-component. Long term stability of laser HP 5518 is shown in Fig. 5.

4.2 Direct measurement method

Non-stabilized lasers are calibrated using a wavelength meter that was calibrated against the iodine stabilized He-Ne laser, NIMT-1. Wavelength of the under test laser is calculated within LabView environment. Long term stability of the wavelength meter was investigated by looking at the **f**-component of the iodine hyperfine and is observed to be in good performance. Using direct measurement method, we achieve the expanded measurement uncertainty for wavelength meter calibration of 2.5 x 10^{-7}.

Fig. 6 shows stability of the non-stabilized laser monitored by the wavelength meter longer than 12 hours. Stability of the laser is 3.5 x 10^{-6}.

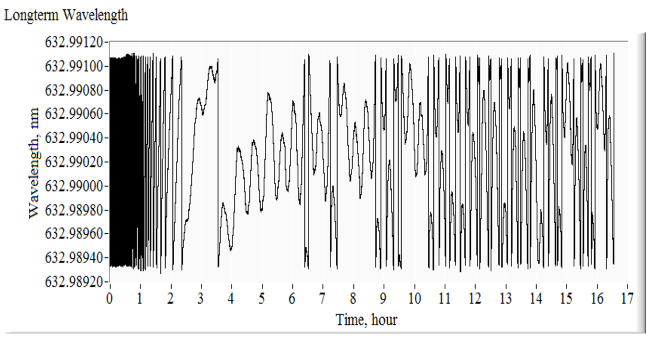

Fig. 6. Long term stability of non-stabilized laser monitored by the wavelength meter.

4.3 Key comparison

The iodine stabilized He-Ne, NIMT-1, had joined in the regional APMP.L-K11 comparison in November 2004 [6]. Laser from eight national metrological institutes were brought to the NIM in Bejing for the comparison. The frequency difference between the **f**-component of the R(127) 11-5 transition was measured according to the protocol for BIMP.L-K11 [7]. Fig. 7 illustrates the comparison result from the BIMP.L-K11 and the APMP.L-K11 comparison.

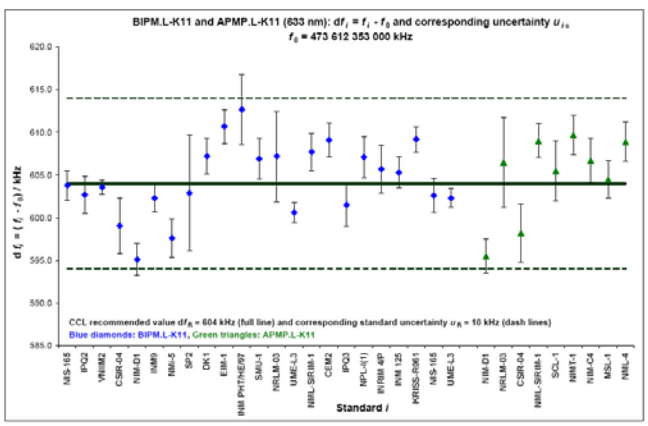

Fig. 7. Key comparison result from the BIPM.L-K11 and APMP.L-K11.

The results confirm performance of the NIMT-1 that can achieve standard uncertainty within 2.5 x 10^{-11} or 11.7 kHz according to the CCDM recommendation.

5. CONCLUSION

The 633 nm iodine stabilized He-Ne laser has been served as the primary standard of length in accordance with the definition of meter in SI unit at NIMT since 2003. The standard uncertainty of this primary standard is 2.5 x 10^{-11} or 11.7 kHz. Its performance has been investigated regularly. The APMP.L-K11 comparison in 2004 that we joined shows that NIMT's primary standard of length is compatible with primary standards of all participated NMIs. Its accuracy has been used to transfer to many length measurement devices that comprised of the lasers through either beat frequency method or direct measurement method.

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