THE PERFORMANCE OF STABILIZED LASER (633 NM) FOR INTERFEROMETRY

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Abstract: The stabilized laser at 633 nm has been developed and can be used as a standard wavelength in all interferometry system at the National Institute of Metrology (Thailand). The laser is stabilized by controlling the cavity length using a thermo foil heater and a PID control. Two orthogonal polarized modes are obtained after applying the magnetic field to create an axial Zeeman effect. The performance of stabilized laser were investigated by monitoring the temperature of laser tube and laser power of two orthogonal polarized mode. The temperature stability of the laser tube and the laser power are 0.1 ^{O}C and 26.1 μW respectively. In additional, the increase in length of laser tube at the stabilized state was determined by the temperature and the mode sweeping were 2.71x10^{-5}m and 2.75x10^{-5} m respectively. Long term stability of the vertical polarization beam of the stabilized laser measured by beat frequency with iodine stabilized He-Ne laser was observed to be in order of 10^{-8}.

Key words: stabilized laser, two mode stabilized, beat frequency technique.

1. INTRODUCTION

The Frequency stabilized He-Ne laser has been widely used in the interferometry system. Most of stabilized laser system have been developed of the accuracy 10^{-8} – 10^{-10}. According to [1-4] accuracy of the laser depends on the feedback controlling techniques. There are two controlling techniques, Firstly, feedback controlling signal comes from beat frequency between two modes. Second technique use power difference between 2 modes to feedback control.

The most common stabilization technique is based on the principle of the orthogonal polarization properties which is controlled by the cavity length. However, some techniques obtain two orthogonal polarization of He-Ne laser by applying a transverse [5-6] and axial [7-8] magnetic field to the laser tube and this magnetic filed can split the spectral lines into 2 orthogonal polarization of different frequency.

Here, we describe the cavity length, L, as $L = n\lambda/2$ and the frequency, ν, as $\nu = nc/2L$ where λ is wavelength, c is speed of light and n is an integer number of longitudinal modes. Therefore, the difference frequency of two neighboring mode or mode spacing can be defined as $\Delta\nu = c/2L$. To obtain the stabilized frequency (wavelength) of laser, we need to control the cavity length of the laser tube.

In this paper we present the development of the stabilized laser at 633 nm based on two polarized modes locking technique. The temperature at anode and cathode of laser tube were measured by using thermistor thermometer. The laser power of the vertical and the horizontal polarization were reported as well. The frequency stability of stabilized laser results were measured with tractability to the SI unit.

2. DEVELOPMENT OF STABILIZED LASER

The internal mirror of the He-Ne laser tube has a cavity length of 265 mm. Therefore mode spacing $c/2L$ = 565 MHz. Thus it may has two modes on the Doppler half-width of gain curve of laser is 1600 MHz [9]. Its total output power is 2.8 mW.

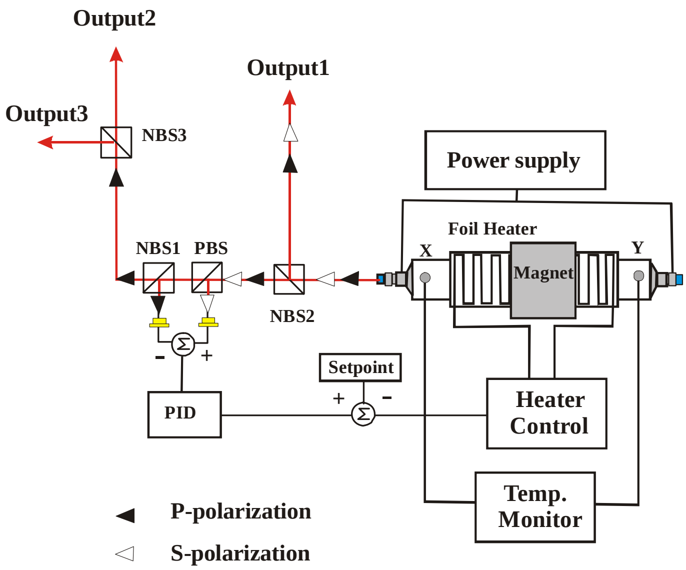

Fig. 1. Setup diagram for stabilized He-Ne laser system

In our system, most of laser beam pass through the output coupler. The thermo foil heater was entwine the laser tube to control the laser cavity by applying voltage at 6 V. Two orthogonal polarization beam was produced by using 0.3 T permanent magnet, diameter 50 mm The beam was sent through a non polarizing beam splitter (NBS1) as an output 1 for laser power measurement. Then the beam go to the PBS1 where the horizontal polarization beam to the photodetector (PD1). First part of the vertical polarization beam was sent to photodetector (PD2) by the non-polarizing beam splitter (NBS2). The second part was splitted at NBS 3 as an output 2 and an output 3 for to wavelength meter and beat frequency measurement respectively as shown in figure 1.

Signals from PD1 and PD2 were converted into voltage and were amplified by the operational amplifiers. The voltage difference between two amplified signals is called an error signal which was sent through the proportional, intergral and derivative circuit (PID) controller. Then it was compared with the set point or the desired value. The deviation of the error signal from the PID from the set point was send as a feedback to control power of the heater that control the length of the laser cavity.

To prevent disturbances of the air, due the large temperature difference between the laboratory temperature (20 ^{O}C) and the laser operating temperature (~ 50 ^{O}C), the laser system was covered by the housing.

3. THE PERFORMANCE RESULTS OF LASER

The performance of stabilized He-Ne laser were investigated by measure the laser tube temperature, laser power of two orthogonal polarization and frequency stability in long-term.

3.1 Laser tube temperature

3.1.1 Temperature stability

The temperature of laser tube were measured by using thermistor thermometer (Cole-Parmer, model : YO-08502-12). Two thermistor thermoeters were attached on anode (position Y) and cathode (position X). The temperature has been raised for 45 minutes from laboratory temperature 20 ^{O}C to the equilibrium state temperature at 48 ^{O}C and 51 ^{O}C at the anode and the cathode respectively.

The temperature stability in 2 hours at anode and cathode area are 0.1 ^{O}C and 0.2 ^{O}C respectively.

3.1.2 Increasing length of laser tube

The increase in length of laser tube (ΔL) is depended on the increasing temperature during the period of warming up time. The increase in length of laser tube is calculate from $L\cdot\alpha\cdot\Delta T$, where L is the laser cavity at room temperature, α is the thermal expansion coefficient of Pylex glass (3.3 x10^{-6} /^{O}C) and ΔT is the increasing temperature of laser tube. Since the temperature of laser tube was increase by 31 ^{O}C at cathode area, the ΔL is 2.71 x 10^{-5} m.

The increase in length of laser tube can also be determined from the mode-sweeping data that occurred during the warm up process. The mode sweeping can measured by using wavelength meter. The laser output 3 (see figure 1) was launched to the measuring system. The system comprises a wavelength meter, a stabilized laser beam, an optical isolator and an objective lens with an optical fiber. The stabilized laser beam 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 amount of the longitudinal mode is related to the intensity of laser.

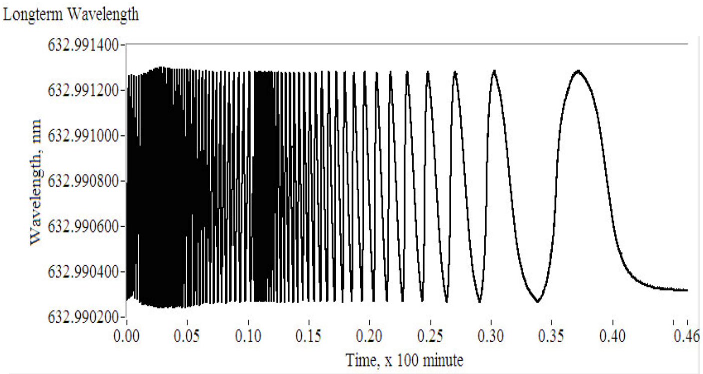

Fig. 2. Mode sweeping measured by wavelength meter.

When the laser was stabilized, the amount mode sweeping that was observed by the wavelength meter is 87 modes when it was stabilized. Therefore the increase in length of laser tube that corresponding to mode sweeping is 2.75 x 10^{-5} m (as $\Delta L = n\lambda/2$).

Figure 3 illustrated the ΔL that calculated from the temperature change and that calculated from mode-sweeping data during the warming period.

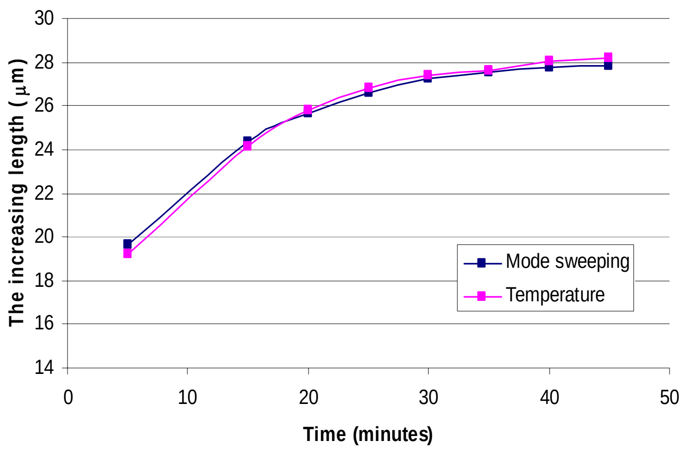

Fig. 3. Comparison of the ΔL **obtained from temperature and mode-sweeping**

3.2 Laser power stability of stabilized He-Ne laser.

The power stability of two orthogonal polarization of the stabilized He-Ne laser were measured simultaneously by using 2 optical power meters. Laser beam from output 1 was splited into two beam by polarizing beam splitter. Vertical polarization beam was sent to optical power sensor, OPM1 (Yokogawa: AQ2200-231) and horizontal polarization beam was sent to another optical power sensor, OPM2 (Advantest: 82017A) as shown in figure 4.

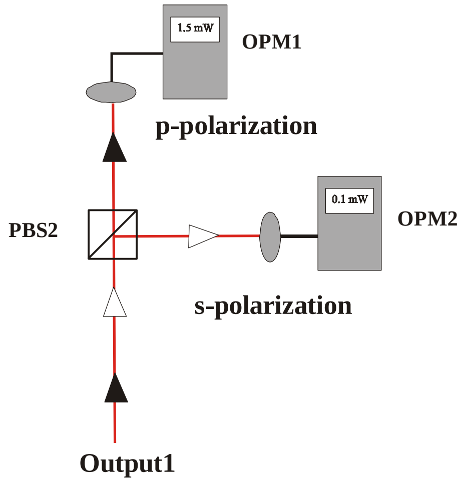

Fig. 4. The laser power measurement of two orthogonal setup

Both OPMs had been validated and compensated to read the same value of power for the same polarization. Therefore the power measurement is reliable.

The laser power of the vertical polarization is much higher than the horizontal polarization as illustrated in figure 5. It should be noted that trend of both are very similar.

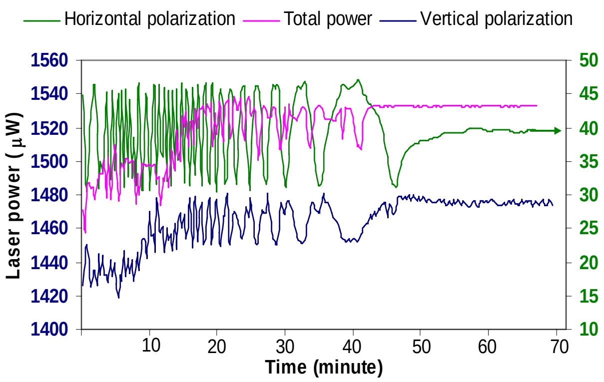

Fig. 5. The laser power measurement of laser : total power (red), vertical polarization power (blue) and horizontal polarization power (green)

The stability of the overall was measured power of the output 1 laser beam (see figure1).The optical power sensor, OPM2 (Advantest: 82017A) was used to measured the stability of 26.1 μW was observed after monitoring the stabilized laser for 2 hours.

3.3 Frequency Stability of the stabilized laser

Stability of the vertical polarization beam of the stabilized laser was measured by using beat frequency techniques which is national tractability to the SI unit [11].

Principle of the beat frequency technique is to measure the frequency difference between the iodine stabilized He-Ne laser which is the primary standard according to advise from the Comité Consultatif pour la Définition du Métre (CCDM) for the revisions of the *mise en pratique* in Recommendation 1 (CI-2002) [12] in 2002.

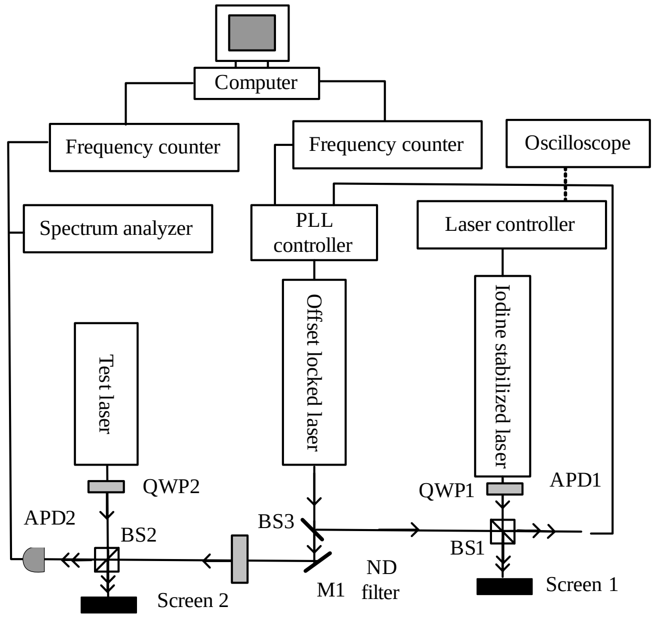

Fig. 6. The beat frequency measurement set up

Figure 6 demonstrated the beat frequency setup to measure the frequency difference between the iodine stabilized He-Ne laser as and the stabilized laser as the under-tested. The laser beam from the primary standard NIMT-1 (NF, model : NEO-92SI-NF-P) and the laser beam from the offset lock laser (NF, model : NEO-OL101K) were optically mixed at the surface of a beam splitter (BS1) and were directed on the surface of an avalanche photodiode - APD1 (Hamamatsu, model : C5658) . The frequency offset between the NIMT-1 and the offset lock laser was controlled by a Phase Lock Loop (PLL) controller. Normally, the offset lock laser can set the stabilized beat frequency in the range of 200 – 500 MHz. In our case, we set 400 MHz at the beat frequency stabilized of the primary standard. The beat frequency was measured by the frequency counter (Hewlett Packard, model : HP 53151A).

Laser beam from the under-tested and that from offset lock laser were optically mixed on the surface of an avalanche photodiode - APD2 (Hamamatsu, model : C5658). The beat frequency was measured by the frequency counter (Hewlett Packard, model : HP 53151A)

Beat frequency results were recorded to the personal computer by both frequency counters. The tested laser wavelength was calculated and the display gate time interval has also set by the same LabVIEW program

The spectrum analyzer (Hewlett Packard, model : HP 8590L) was used to monitor the spectral accuracy and the signal-to-noise ratio of the input signal.

We also used the oscilloscope (Iwatsu, model : SS-7821) to connect the iodine stabilized He-Ne laser controller to monitor the iodine component signal , a neutral density filter to adjust the offset lock laser's laser power and a screen to block the laser beam.

We determined wavelength of the stabilized laser by using **d**, **e**, **f** and **g** hyperfine of the iodine spectra.

Wavelength stability of the laser was also monitored every 10 seconds for 12 hours by tracking at the **f**-component. Long term stability is in order of 10^{-8} or 57 MHz as shown in Fig.7.

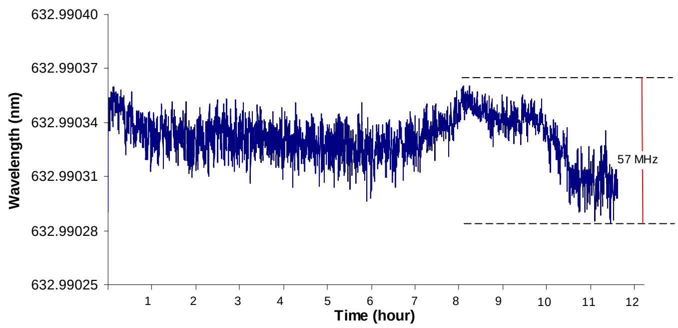

Fig. 7. Long-term frequency stability of stabilized laser by using beat frequency technique.

4. DISCUSSION AND CONCLUSION

The performance of the developed stabilized laser was investigated by monitoring the temperature of laser tube, the mode sweeping and the laser power of two orthogonal polarization. Laser power of both vertical and horizontal polarization beams have the similar behavior. We observed some fluctuation of temperature and laser power prior to the laser stabilization. After laser went to stabilized state, both of temperature and power were at the equilibrium state. The temperature stability at the anode and the cathode are 0.1 ^{O}C and 0.2 ^{O}C, respectively. The 26.1 μW was obtained from stabilized laser.

The increase in length of the laser tube obtained from the temperature dependence and that from the mode scanning dependence are 2.71 x 10^{-5} m and 2.75 x 10^{-5} m respectively. Comparison between 2 techniques shows a the cavity length measurement and the exact increasing temperature of capillary of laser tube for instance.

The beat frequency technique was used to investigate the long-term stability of the developed stabilized laser. The frequency variation in long-term of the vertical polarization is 57 MHz.

In this work, the stabilized He-Ne laser was stablized by using two polarized mode locking method and its longterm stability is in the order of 10^{-8} or 0.01 ppm. It can be used as a 633 nm standard wavelength for short gauge block interferometer where the main source of the measurement uncertainty is temperature as reported in [10]. In future, the stabilized He-Ne laser will be used in our short gauge block interferometer.

The disadvantage of the developed stabilized laser is that it takes long time to reach the stabilized state (~ 45 minutes). We have plan to improve the system in order to shorted warm up time. Investigation of the difference frequency between two polarized modes will done in our further work.

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