TWO-MODE FREQUENCY STABILIZATION OF AN INTERNAL MIRROR 633NM HE-NE LASER

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Abstract – A Commercial He-Ne laser was stabilized to about 1×10^{-9} for a two hour measurements and a frequency resettability of about 8.4×10^{-9} for three months of measurements. The stabilization process depends on the two-mode frequency method using the power difference between the two orthogonal linearly polarized modes of the laser as an error signal. A simple and inexpensive feedback circuit has been used to control the heater current, wrapped around the laser cavity to keep the difference in power between the two modes at constant value.

Keywords: Two-Mode Method, Laser Frequency Stabilization, 633nm He-Ne Laser.

1. INTRODUCTION

Since the development of He-Ne gas laser in 1960, optical interferometer with 633nm internal mirror type He-Ne laser has became one of the techniques widely used for precision length measurements. This is mainly due to the facts that it has intense, collimated beam, narrow bandwidth, highly stability and good visibility. To obtain high accuracy, the frequency of the laser source must be stabilized and calibrated by comparison with a reference laser with high stability in frequency. Frequency stability of about 10^{-9} is needed for accurate measurements which is difficult to achieve with common secondary laser frequency standard.

In the case of the slip (or block) gauges and their accessories, which considered as practical working standards of length used in industry, they must be verified interferometricly, that is in term of the wave length of light. Measurements of 1m length bars demand of the laser a relative frequency stability of about 10^{-9}, if the relative phase is to be measured to 1% which is difficult to achieve with the free running lasers (1).

Since the stabilization scheme was presented by Balhorn (2) and Bennet (3), polarization or (two-mode) stabilized He-Ne lasers have found a widespread use in applications, where simplicity of construction, mechanical robustness and good frequency reproducibility required. A variety of design and techniques for frequency stabilization of 633nm He-Ne lasers have already been discussed in many papers (4 -7). Such lasers have been used for interferometric

length measurement in the transportable absolute gravimeter and for accurate measurements of gauge blocks and surface roughness. Most of these lasers use a stabilization procedure which are; detection of shift of the position of the longitudinal mode within a gain profile photoelectrically as a change of the difference between the intensities of the two orthogonally polarized beams produced by polarization filtering of the laser output, or change in the frequency difference between Zeeman split components of the longitudinal mode. The shift of the longitudinal mode detected is fed as an error signal to the negative feedback loop of the circuit to control current in the heater wounded on the laser tube to keep the optical length of the resonator constant.

The Most stable and accurate frequency stabilized He-Ne lasers are those locked to an intracavity methane absorber. A stability of about 10^{-14} has been achieved with these arrangements. However, these extremely accurate systems have a drawback that they work with infra-red 3.39μm wavelength. In the optical region, He-Ne lasers stabilized by saturated absorption technique using hyperfine transitions in molecular iodine, which has stabilities about 10^{-11} are more convenient to use. It has frequency, stability and resettability high enough to make extremely small contributions to the error budget of even the most accurate interferometric measurements. However, it cannot be considered as a light source for precision interferometric measurements because it's output has relatively low power (typically 0.1mW). Another drawback of this system is that the external-mirror laser cavity with loss component requires critical mirror alignment and is vulnerable to mechanical vibration and chocks.

2. DESCRIPTION OF THE DEVICE

A commercially available laser Melles-Griot Model 05-SRR-810 was used for the experiment. It is a TEM_{00} internal mirror He-Ne laser operating at 633nm wavelength which is the same as the He-Ne Iodine stabilized laser, our primary standard. It shows a spectral line profile contain two axial modes orthogonally polarized to each other, and has a fixed direction of polarization. Typical operating conditions

for the discharge are a dc voltage of 1.2Kv and current of 4.5mA with output power of approximately 0.5mW.

To stabilize this laser a simple and inexpensive frequency stabilization system was described. Fig.1 shows the experimental setup for the frequency stabilization of this laser tube.
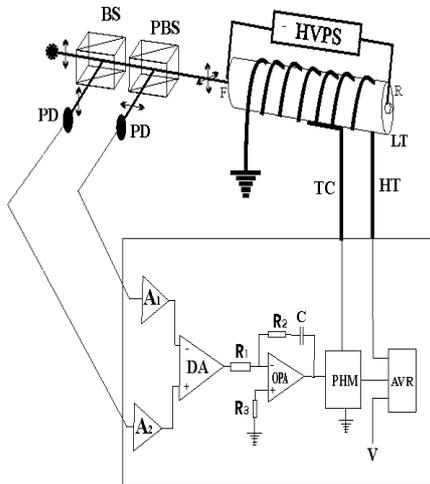

Fig.1. Stabilization system

1- PBS: Polarizing beam splitter; 2- BS: Beam splitter; 3- PD: Photodiode; 4-A1,A2: Amplifiers; 5- DA: Differential amplifier(AMP-01); 6- R: resistor; 7-Capacitor; 8- OPA: Operational amplifier(LF-356); 9- PHM: Pre-Heating module; 10- TC: Thermocouple; 11-AVR: Adjustable voltage regulator (LM317); 12- HT: Heater; 13-LT: Laser Tube; 14-HVPS: High voltage power supply

A thermofoil heater from Minco, Model No 5450, with resistance 16.1Ω and dimension 63.5 x 12.7mm wrapped around the tube to control the length of the cavity. A copper coil wrapped in the opposite direction to cancel the axial magnetic field produced by heating the foil. The two orthogonal polarized modes from the laser output (LT) were separated by a polarizing beam splitter (PBS). The component which is perpendicular to the axis of the laser tube falls directly on the photodiode (PD) and other one which is polarized parallel to the axis of the tube passes through a beam splitter (BS). One of the spited beams falls on the other photodiode (PD). The small photocurrent signals from the two detectors were amplified by the pre-amplifiers(A_1,A_2). The difference of the output power $I_\parallel$ - $I_\perp$ detected by the differential amplifier (DA) used as the error signal. A simple integral feedback circuit to control the current flowing the thin heating foil wound around the laser tube used. Since the variation of the cavity length due to thermal expansion is nonlinear, we used the integration method (8-9), this was done by making the gain high enough by integrating the feedback signal using the operational amplifier(OPA). The heater driver(AVR) provide a constant current to the heater until the tube reaches the desired temperature. The preheating mod-

ule(PHM) control this process and the temperature of the tube could be measured with type-K thermocouple connected directly on the tube glass.

After the tube reaches the desired temperature, the integrated feedback signal started to control the heater current through the heater driver (AVR), so that if the cavity length decreases, the frequency increase and the two modes shifted to right increasing the intensity of the left-side mode and decreasing the intensity of the right side mode, so the circuit produces positive feedback signal that provide heat to the laser cavity making it expands again, and return back to it's original position. If the cavity length increases, the frequency decrease and the two modes shifts towards the left decreasing the intensity of the right side mode and the circuit produces negative feedback signal that stops the heater and the laser cavity shrinks returning the frequency back into its original position.

3. EXPERIMENTAL WORK

The desired temperature at which the laser switches from the pre-heating mode to the stabilized mode is called preset temperature. The preset temperature could be obtained by determining a range of the preset temperatures at which the stabilized laser can operate without losing the stability, those temperatures chosen such that; They must be above the normal working tube temperature, the temperature due to gas discharge, to avoid losing stability if the tube reaches the normal working temperature during the stabilization process.
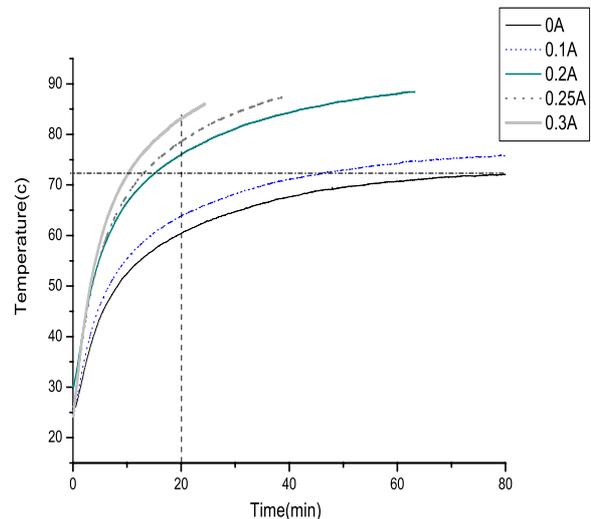

Fig.2. Tube temperatures at different applied heating current

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- They must be such that, the laser tube will, loss heat, and be cooled if the heater current disconnected and will warm, and gain heat, if the heater current increases.
- They also must not be so high such that the heat loss happened at high rate much more than the heat gain. Then measuring the stability of the laser tube at the selected preset temperature the best stability achieved. Fig. 2 shows the variation of the tube temperature with warming time at different values of current (0.1, 0.2, 0.25, and 0.3 A). We selected a preset temperature from 76 C° to 80 C° by the values from 0.2 A to 0.26 A keeping the time of the heating around 20 min and voltage 10 v, 12.5 v, 15 v and 17.5 v.

The frequency stability and repeatability for the constructed laser were studied and the beat value, were selected. The frequency stability may be defined as (10):

$$S_\nu = \frac{\nu_L}{\Delta\nu_L} \qquad (1)$$

Where ν_L is the average frequency generated by the laser, $\Delta\nu_L$ is a measure for frequency fluctuation during the period of observation. It is customary to characterize the stability of the stabilized oscillators by giving their long-term and short-term stabilities according to whether the period of observation is greater or less than some characteristic time. A quantity very closely related to frequency stability is frequency resettability R which is defined by (10):

$$R_\nu = \frac{\nu}{\Delta\nu} \qquad (2)$$

where $\Delta\nu$ is the deviation of a series of settings. The resettability describes the accuracy with which the frequency ν can be reproduced after the generator is perturbed and readjusted. The wavelength stability and resettability are synonymous with frequency stability and resettability by virtue of the relation

$$\frac{\lambda}{\Delta\lambda} = \frac{\nu}{\Delta\nu} \qquad (3)$$

Measurements have been done using the heterodyne system and a Winter Electro-Optic Model 100 He-Ne laser stabilized by absorption in iodine and has a power of about 100μW, wavelength 633nm and frequency stability 2.5 x 10⁻¹¹, as a primary standard.

The frequency stability and resettability for the unstabilized He-Ne laser were done after one hour of warm up, it was found that they are about 2.6 x 10⁻⁶.
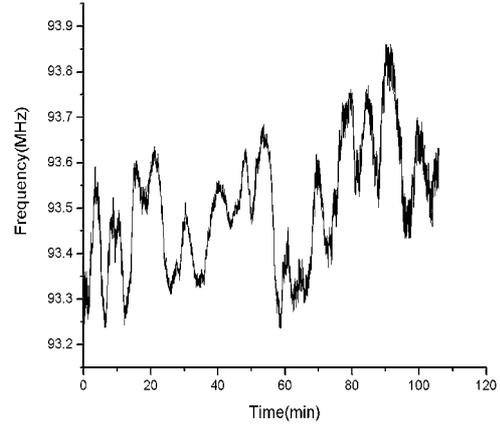

Fig.3. Frequency stability for 2h measurement

Fig. 3 shows the change in frequency with time for this laser. For the constructed stabilized laser, the frequency stability reached 1.09 x 10⁻⁹ when keeping the environmental temperature at 23 ± 1 C°, which is the normal laboratory temperature at heater voltage of 10V and when setting the tube temperature at 76 C°. The experimental results shown in Fig. 4
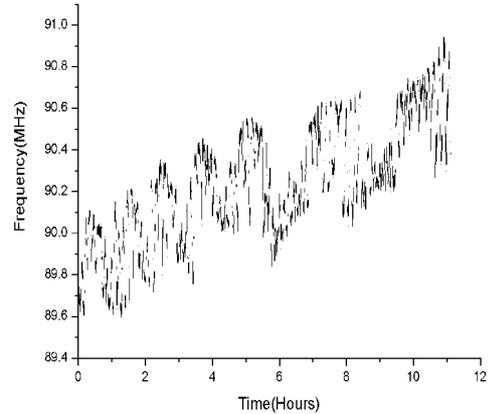

Fig.4. Frequency stability due to overnight measurements

However the resettability values increased to be about 8.4 x 10⁻⁹ during a period of observations through three months.

The power stability of the stabilized laser was also measured. The variation of the laser power stability measured within three hours shown in Fig.5, this variation is about ±0.25μW.
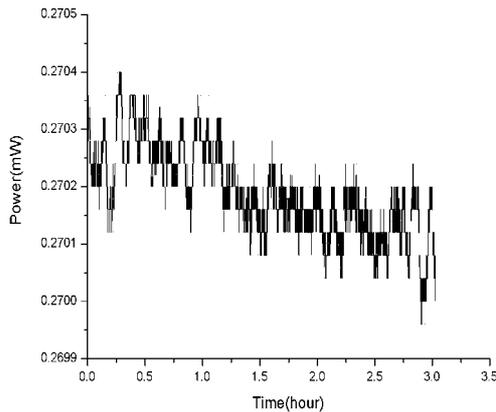
Fig.5. Laser power stability

The uncertainty in the measured frequency values was measured. The frequency measurements could be affected by a systematic component and a random component. The systematic error could be affected by reference iodine stabilized lasers, optical components (mirrors, lenses, a cousto-optic modulator and the photodetector) and other systems (differential amplifier, frequency counter and computer). Since it is difficult to determine the uncertainty due to every component separately, measurements have been made using another iodine stabilized laser. The uncertainty due to the systematic error was found to be ± 0.0117 MHz. The random component of uncertainty, which is due to the constructed stabilized laser frequency is about ± 0.0043MHz. The combined standard uncertainty for the frequency measurements

$$U = \sqrt{\sum_{i=1}^{N} U_i^2} = \sqrt{(0.117)^2 + (0.0043)^2}$$
$$= 0.124 \text{ MHz}$$

Since the uncertainty is usually stated with 95% (11) level of confidence so it has to be multiplied by coverage factor of k=2 to assure this level of confidence then U_{95} = 0.0248 MHz.

4. CONCLUSION

Although other stabilized scheme exists for He-Ne lasers, we feel that our design is practical and interesting alternative for applications requiring a secondary optical frequency standard with a stability 10^{-9}. This Paper describes a method to stabilize the 633nm He-Ne laser. The results of absolute frequency of the stabilized laser as well as the resettability were measured. It was found that the stability ≈ 1 x 10^{-9} and resettability 8x 10^{-9} for three months measurements keeping the preset tube temperature at 76C^o and room temperature 23 ± 1C^o.

We have engaged in developing a two-mode stabilized He-Ne laser at 633nm using a simple and in-

expensive feedback circuit, its frequency could be used as light source for a gauge block interferometer at the National Institute of Standards, NIS, Giza, Egypt.

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