Stabilization of a multimode He-Ne laser using Thermal Feedback.

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The purpose of this experiment was to show that a multimode He-Ne laser can be stabilized using thermal feedback. A Melles Griot laser with an ouput of 5mW was used. The laser output was applied onto a photodetector and then passed through a circuit that analyzed the amount of fluctuations and correspondingly passed a certain amount of current through a heater coil attached to the laser tube. Once the feedback circuit is switched on there is a significant decrease in laser fluctuation. The standard deviation in the laser intensity is 3.4 mV for the free running case, with thermal feedback on this decreases to 1.0 mV.

INTRODUCTION

Inexpensive He-Ne lasers often exhibit large intensity fluctuations. In laboratories, this instability makes life complicated. Lasers such as the above mentioned are used for all sorts of purposes, such as reference lasers for wavelength meters, and more generally as light sources for various experiments in optics. Because of the instabilities, inaccurate results are often obtained. Although rapid sampling or modulation techniques can be used to overcome these fluctuations, they are still a serious hindrance. It was shown by Stahlberg[1], for single mode He-Ne lasers, and by Stanek[2], for multimode He-Ne lasers, that thermal feedback techniques can effectively stabilize such lasers. In this experiment, Stanek's experiment is replicated.

THEORY

Most commercially available 0.5 to 2 mW He-Ne lasers used in undergraduate labs have internal mirrors and are adjusted to operate in cylindrically symmetric axial modes TEM_{ooq}. The frequency of these modes is given by $\Delta\upsilon = qc/(2L)$, where L is the cavity length and q is an integer. For example, a Spectra Physics Model 155 He-Ne laser has a cavity length of 27.4 cm, and hence a frequency difference, $\Delta\upsilon$, between adjacent longitudinal modes of 548 MHz. Since the Doppler half width of the neon 633-nm line is about 1600 MHz[3], this laser operates simultaneously in two or three axial modes. After such a laser is switched on, there is a period of up to about an hour, during which the temperature of the glass laser tube rises so that the tube slowly expands longitudinally. The cavity therefore lengthens and this causes the axial modes to pass inside the Doppler line of the output. The total output intensity is affected little by this mode switching. If however the output beam is passed through a polarizer, then for particular orientations of the polarizer, substantial fluctuations are observed in the intensity transmitted through the polarizer. These fluctuations occur, because successive longitudinal modes are linearly polarized, with alternate modes following two perpendicular directions π and σ.

When a gas is irradiated by two oscillating linearly polarized fields of different frequencies well within the Doppler broadened width of the same absorption line, maximum absorption of both fields occurs when the two linear polarization's are perpendicular to each other. Consequently when a gas laser oscillates simultaneously in two or more longitudinal modes, oscillations in adjacent modes corresponding to orthogonal linear polariztions (π and σ), the passage of the modes within the Doppler line can cause intensity fluctuations as high as 40% of the mean intensity. The movement of modes inside the Doppler width of the laser line represents an instability which must be eliminated if the laser is to be used for precision length measurements. The thermal feedback loop that is attached to the output of the laser stabilizes the temperature of the tube, and its length L.

PROCEDURE

The equipment was setup as shown in figure 1[4].

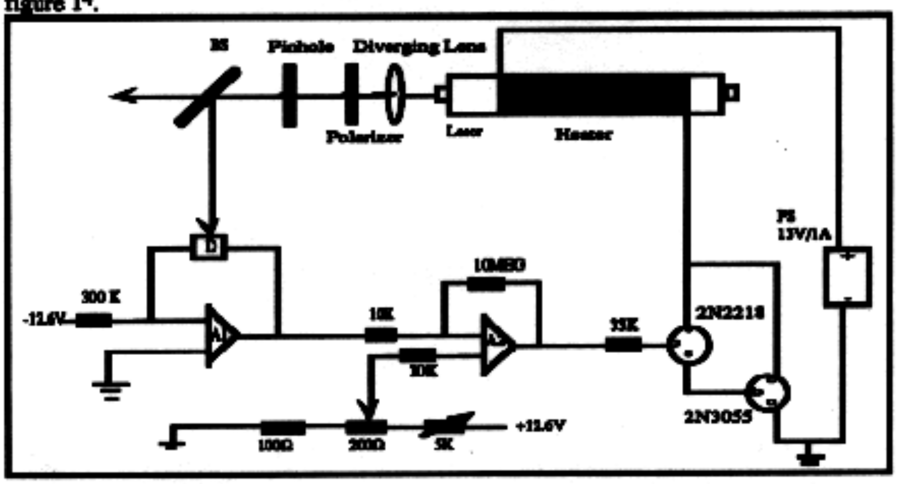

Fig 1: Experimental Setup

The beam from the laser falls upon a diverging lens, so that it can be widened. It then passes through a polarizer, and then through a 2 mm pinhole. The purpose of the pinhole is to block incoherent plasma emission. The beam then falls upon a 2% beam splitter. The diverted beam falls upon a Cadmium Sulfhide photocell, while the rest falls on a Graseby Optronics photo detector connected to a model 350 linear log optometer. The cadmium sulphide photocell has a large 0.07 sq inch active area, which is why the diverging lens is needed to make sure that the beam falls upon a large enough area. The photocell is current biased by op amp A1, a model 741 op amp. The polarity of the bias current is chosen to give the correct feedback sign, by applying the -12.6 volt input to the inverting input of A1. The voltage of A1 is positive and proportional to the resistance of the detector, and therefore inversely proportional to the light intensity.

The second op amp A2, also a 741, compares the detector voltage to a stable set-point voltage selected by the 200 Ω potentiometer. This voltage selects the operating point of the laser. The intensity of the stabilized laser has to be lower than that of the freely running laser, therefore the set point voltage is greater than the minimum detector signal obtained without feedback. The voltage is then amplified by -1000 and used to drive the two transistors which are connected as a Darlington pair.

The two transistors along with the 33k resistor form a voltage to current converter, and control the amount of current passing through the heater. Since the heater current can be close to 1A the second transistor is chosen to be a

2N3055 power transistor, and is mounted on a heat sink. The first transistor is chosen to be a 2N2218 transistor. The heating element consists of two Minco Inc thermo foils of 60 and 80 ohms respectively, wired together in parallel. These foils are bound to the center of the laser tube using scotch tape. A heat conductive compound (Wakefield Eng Part No0 120-2) is first applied to the tube and the foils to ensure good thermal conductivity between the foils and the tube. The heating coils are powered by an independent variable voltage source (Model H.P. 6216C Power Supply) set at 15 volts. The negative part of the power supply was connected to the emitter of the power transistor so that the large heater currents would not introduce spurious voltages in the circuit.

Once the circuit was set up, the potentiometers were adjusted so that the fluctuations in the laser output would produce the greatest change in the amount of current flowing through the coils while at the same time also letting the current go to zero when the output stabilized. The tube of the laser was also slightly "lagged" by wrapping some bubble wrap onto it. This was necessary because the room in which the apparatus lay had a powerful blower in the ceiling, blowing out cold air. This took away from the heating effect of the foils, until they were covered with bubble wrap.

The output of the optometer was connected to a H.P. 5460 A Oscilloscope, so that the fluctuations in the laser intensity could be viewed on the screen. The oscilloscope would collect a certain number of points and then determine the Vrms,Vavg and Vpp. The Vrms allowed us to determine whether or not the intensity fluctuations were decreasing or not.

DATA

The following is the data used

Vrms Circuit Off (mv)	Vrms Circuit On (mv)
9.56	8.89
13.32	6.97
11.22	7.6
12.08	8.01
10.6	8.17
10.98	8.48
14.87	7.24
15.06	10.56
10.18	7.26
14.69	7.22
8.53	7.44
10.09	7.35
12.33	7.37
14.2	7.65
10.99	7.91
11.36	7.03
9.35	7.36
10.47	7.03
18.65	10.73
10.18	8.06
9.56	7.77
9.32	8.37
9.11	7.33
16.11	7.34
13.08	7.28
24.06	7.45
12.96	8.49

Table 1: Data collected and used for analysis

The following plot (fig 2) shows a sample of data collected over a 15 minute period while the laser was running freely. The overlay plot shows, some data for when the feedback circuit was started. The difference in level of fluctuation can be seen clearly."Vrms circuit off" indicates the rms voltage given by the oscilloscope when the laser was running freely. As can be seen there is very little stability and the intensity fluctuates all the way from 8 to 24 mV. However once the thermal feedback circuit is started it can be observed as indicated by Vrms heat that the output stabilizes around 7.5 mV. There is still however an occasional peak in fluctuation, this being due to momentary increases in laser power. As can be seen in the statistics in table 2,3 for both the data runs, when the laser is running freely the standard deviation for the data is 3.4 mV. However with the

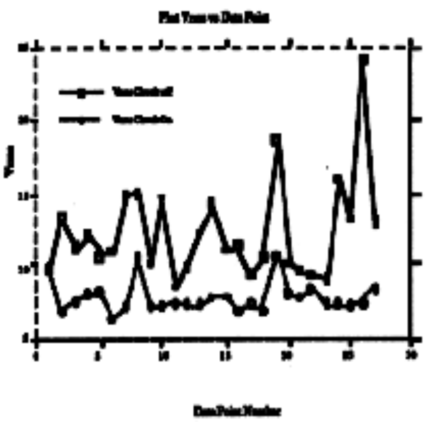

Fig 2: Comparison of Laser output with and without feedback circuit.

feedback circuit switched on we have a standard deviation of only 1.0 mV. The reason we get even a 1.0 mV deviation is due to the couple of times that the laser power increases. The difference between the minimum and maximum values obtained in the free running case is 15.6 mV, however with the circuit switched on it falls to 4.3 mV.

State Circuit	Off
Minimum	8.53
Maximum	24.06
Sum	332.89
Range	15.53
Mean	12.33
Median	11.22
St. Dev.	3.41
Variance	11.59
Count	27

Table 2: Statistics for laser intensity with circuit off.

State Circuit	On
Minimum	6.48
Maximum	10.73
Sum	211.55
Range	4.25
Mean	7.84
Median	7.37
St. Dev.	1.03
Variance	1.06
Count	27

Table 3: Statistics for laser intensity with circuit on.

The intensity stability is somewhat inferior to that shown by Stanek, but is nevertheless clearly visible.

CONCLUSION

The experiment demonstrated the stabilization of an inexpensive low power He-Ne laser using thermal feedback, a method used both by Stahlberg and Stanek. With thermal feedback turned on intensity fluctuations decrease within a minute or two, and this stability was held for 15 to 20 minutes. Due to lack of time, no method for automatically obtaining the Vrms could be developed, as a result the time period of data aquisition is only a couple of minutes. There can be a couple of improvements that could be made. The most important one is to develop a Lab VIEW module that could acquire the data from the optometer and display the Vrms, and Vpp and save the data to a text file, so that longer periods of time could be investigated. Another improvement could use smaller resistance thermofoils so that a greater area of the tube is covered. Improvements such as these could greatly improve the results of this experiment.

[1] B. Stahlberg, P. Jungar, and T. Fellman, "A very simple stabilized single mode He-Ne laser for student laboratories and wave meters" Am. J. Phys. 58, 878-881 (1990).

[2] Ferdinand Stanek, R.G. Tobin and C.L. Foiles "Stabilization of a multimode He-Ne laser: A vivid demonstration of thermal feedback" Am. J. Phys. 61 932-934 (1993).

O'Shea, Donald, <u>Introduction to Lasers and their Applications</u> (Addison-Wesley Publishing Company, MA, 1978).

Junior Independent Study Lab Manual, Spring 1995.

[3] G.A. Woolsey, M.Y. Sulaiman, and M. Mokhsin, "Correlation of changes in laser tube temperature, cavity length, and beam polarization for an internal-mirror helium-neon laser," Am. J. Phys. 50, 936-942 (1982).

[4] Figure showing experimental setup.