Chapter 10

Instrumentation and Control for Laser

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10.1 Introduction

In order to control various parameters of a laser like wavelength (λ), power during its operation, it is required to measure them accurately using suitable instruments and then control them using closed loop feedback. In this chapter, some of the laser parameter measuring techniques and their control are described.

10.2 Wavelength Stabilization System for SLM Dye Laser

Dye Lasers are the most widely used tunable lasers. Their various properties like efficient narrowband operation, continuous tunable range, and wide spectral range have made them very popular in various research and scientific applications. Laser cavity, lasing media and pump laser characteristics decide the wavelength that can laze within the cavity. In case of tunable laser the cavity length can be changed to tune the laser to a desired wavelength within its emission spectrum by using frequency selective elements within the cavity. However, it is not sufficient to tune the laser to the desired wavelength, it is also essential to maintain the set wavelength precisely within an acceptable band of fluctuation for the duration of an experiment.

Spectroscopic experiment like laser isotope separation requires precisely tuned lasers for selective ionization. A slight detuning of the wavelength of the laser can cause the unwanted isotope to get excited and thus totally destroying the purpose of the experiment. Hence stability of the wavelength of laser is extremely important for the success of the experiment. Long hours of experiment causes wavelength of the laser to drift away from the desired value due to the presence of thermal and mechanical disturbances. Passive stabilization alone cannot be sufficient to control the wavelength fluctuations. An active wavelength stabilization system is therefore essential to reduce the fluctuations and keep the wavelength stable.

10.2.1 Generation of single longitudinal mode laser

The principle of a cavity resonator is that only that wavelength can be present inside the cavity for which the cavity length is integral multiple of half wavelengths, i.e.

$$L = N\frac{\lambda}{2} \tag{10.1}$$

In terms of frequency (ν), only those frequencies can exist within the cavity which satisfies,

$$\nu = \frac{Nc}{2L} \tag{10.2}$$

The different longitudinal modes are supported by the cavity is as shown in the Fig. 10.1. A gain medium (dye solution) is placed within the cavity which has a spectral response according to which it selects the cavity modes that comes under its gain bandwidth product as shown in the Fig. 10.2a. The tunability range of typical dye solutions are 50-100 nm. To tune the wavelength of the dye solution, frequency selective losses are introduced into the

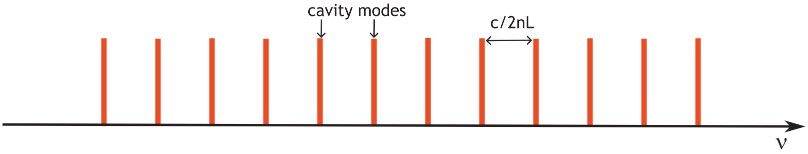

Figure 10.1: Longitudinal modes supported by the resonating cavity.

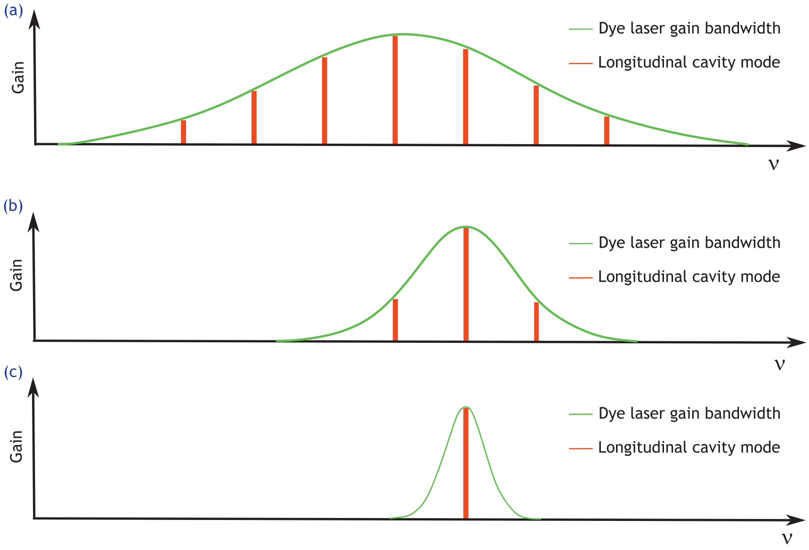

Figure 10.2: Gain vs frequency plots: (a) longitudinal cavity modes supported by Dye laser gain bandwidth, (b) cavity modes selected by diffraction grating, and (c) single cavity mode supported by intracavity etalon.

cavity. Dispersive optical elements introduce frequency selective loss inside the resonating cavity. Diffracting grating can select a band of wavelength within the gain bandwidth of the dye medium and this gives a multimode output as shown in Fig. 10.2b. Frequency selective elements such as etalon having passband which is smaller than the intermodal spacing of the cavity modes is required to generate single longitudinal mode output as shown in Fig. 10.2c. Figure 10.3 shows the schematic diagram of a laser cavity generating single longitudinal mode at the output. It consists of a dye cell housing the dye solution which is optically pumped by copper vapor laser (CVL), a diffraction grating, a narrowband etalon and a prism beam expander. The diffraction grating can be tuned to shift its passband using a piezo-electric translator (PZT) to generate a multimode output. The etalon is used to generate the SLM output. Its passband can be tuned using another PZT.

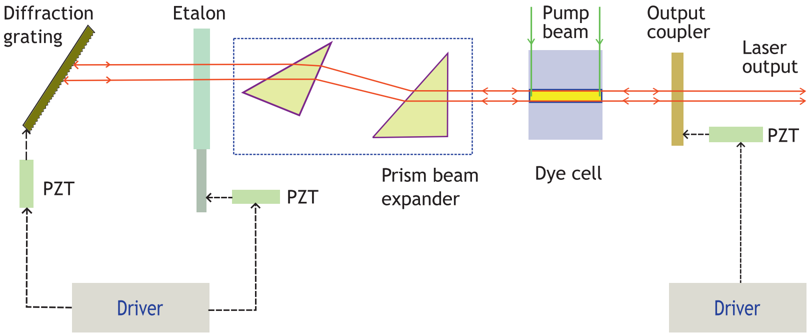

Figure 10.3: Schematic diagram of a typical SLM dye laser cavity with controls.

10.2.2 Wavelength stabilization principle

Thermal disturbance acting on the laser cavity due to heat dumped by the pump pulses, frictional heat dumped by dye circulation system and fluctuations in the ambient temperature causes drift in the wavelength of the laser by changing the optical path length of the laser cavity. Optical path length (i.e., n L) is the product of geometrical path length (L) and refractive index (n) of the cavity medium. Wavelength of the laser inside the cavity should satisfy, $\lambda = \frac{2nL}{k}$, k being the mode no. Thermal expansion of cavity elements leads to change in the geometric length of the cavity. Temperature variation leads to change in refractive index of cavity elements. The variation in wavelength due to L and n is given by,

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta n}{n} + \frac{\Delta L}{L} \tag{10.3}$$

The wavelength stabilization system is composed of two components:

a) Cavity length stabilization;

b) Mode control.

The drift in the wavelength of laser due to thermal disturbances can be controlled by using an active cavity length stabilization method. Thermal disturbances cause changes in the cavity length which results in drift in wavelength. This is detected by the wavelength meter. A PC based control algorithm computes the error in wavelength and generates the control signal which is applied to PZT coupled to the output coupler which corrects the wavelength error by tuning the cavity length. The cavity length stabilization method (Fig. 10.4) can maintain the wavelength of laser within the desired tolerance band as long as the center frequency of

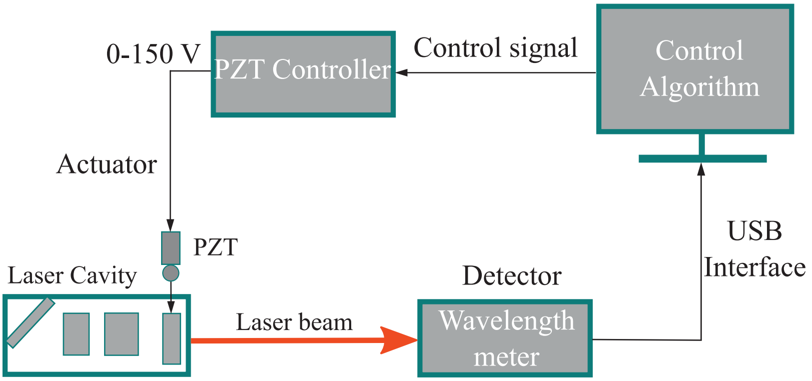

Figure 10.4: Cavity length stabilization system.

the single mode remains within the passband of the intracavity etalon.*If the transmission peak of the etalon passband gets drifted more than half the cavity mode spacing (1/2 of c/2L) the total gain becomes more favorable for the next cavity mode, and the laser wavelength will jump to the next cavity mode.* This condition is referred to as mode hopping. This implies that the optical path length of the etalon must be stable so that peak transmission drifts by less than c/4L.

Etalon dither and lock technique (Fig. 10.5) is used to control the occurrence of mode hop and works in sync with the cavity length stabilization system to maintain single mode operation for long durations. A low frequency modulation signal is used to dither the etalon passband. The laser intensity signal is detected by a photodetector. This signal is then processed by a phase sensitive detector. There is a modulated signal when the passband of the etalon is on either side of the cavity mode. From the phase and magnitude of this modulated output one can find out whether the cavity mode is on the longer or the shorter wavelength side of the etalon passband as well as how much it is detuned from the transmission peak of the etalon passband. When the transmission peak of etalon coincides with the cavity mode there is no modulated output.

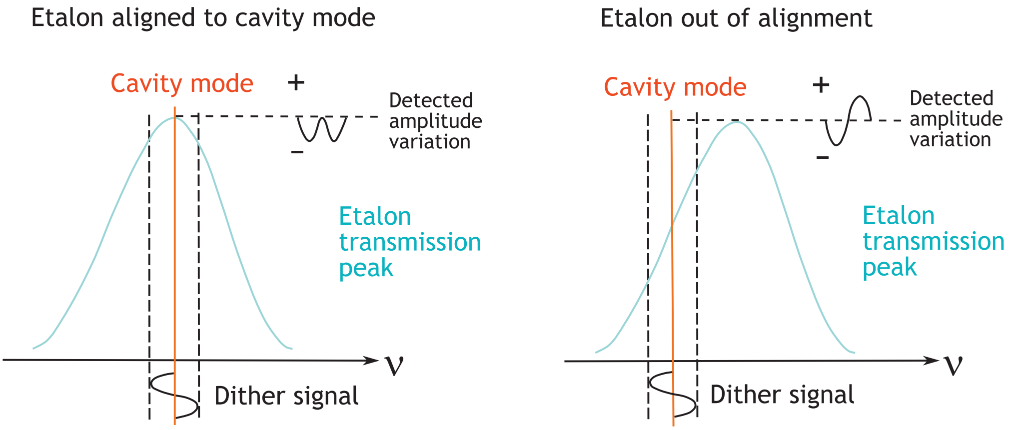

Figure 10.5: Phase sensitive detection principle.

10.3 Drift Control System

The drift control system is designed to control the drift in propagation delay of CVL laser power supply. The drift in propagation delay causes uncertainties in arrival time of optical output pulse with respect to input trigger pulse of CVL laser. When CVL lasers are operated in master oscillator power amplifier (MOPA) configuration, the drift affects the synchronization between two stages of CVL MOPA chain which eventually cause reduction in total optical output power. The technique utilises optoelectronic inter conversion of the current pulses of CVL system as a feedback signal. The feedback signal is given to the Drift control unit which compares the propagation delay of the received signal with the reference value fed to the controller of the unit. The error generated is then used to control the output signal fed to the trigger input of the CVL system. This methodology provides electrical isolation from pulse generation unit and trigger generation unit and ensures fail safe mode of operation of the system. The drift control system reliably keeps the propagation delay within the error band of 5 nsecs. Thus, helps in maintaining synchronization in MOPA chain and effectively restricts power droop rate

10.3.1 Working principle

The schematic of drift control system is represented in Fig. 10.6. Trigger signal from trigger generation unit instead of directly applying to the pulse generating unit (PGU), it is delayed controllably by drift control unit and then applied to PGU of CVL laser. This delay is actively controlled by monitoring feedback signal from the laser head discharge pulse using current transformer (CT). The basic aim is to maintain a constant time delay between the laser trigger pulse and the laser output pulse. The Fig. 10.7 shows working principle of drift control system in terms of waveforms. Here, T represents trigger pulse, D represents delayed trigger pulse generated by drift control system and C represents laser output pulse. If there is change in prorogation delay, i.e. position of C with respect to T in either direction, control system will adjust delay between T and D in order to keep delay between T and C constant.

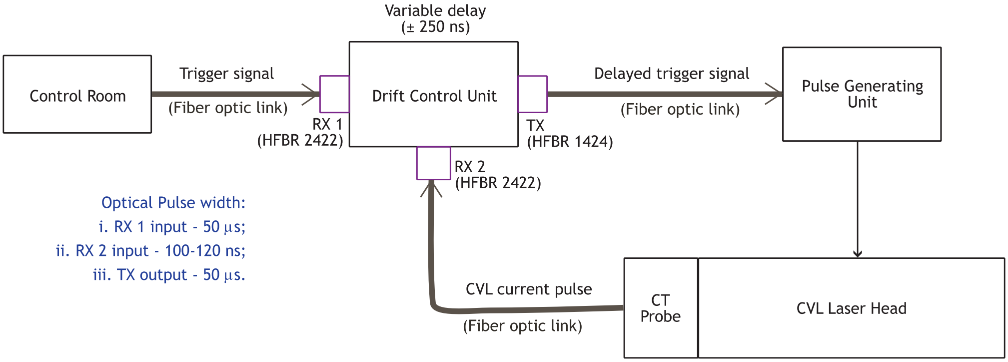

Figure 10.6: Schematic of CVL system with drift control and feedback units.

10.4 Online Laser Power Monitoring System

It is important to monitor the average power levels of each pulsed laser system, i.e. CVL, DPSS lasers and Dye lasers to conduct successfully experiments involving large number of

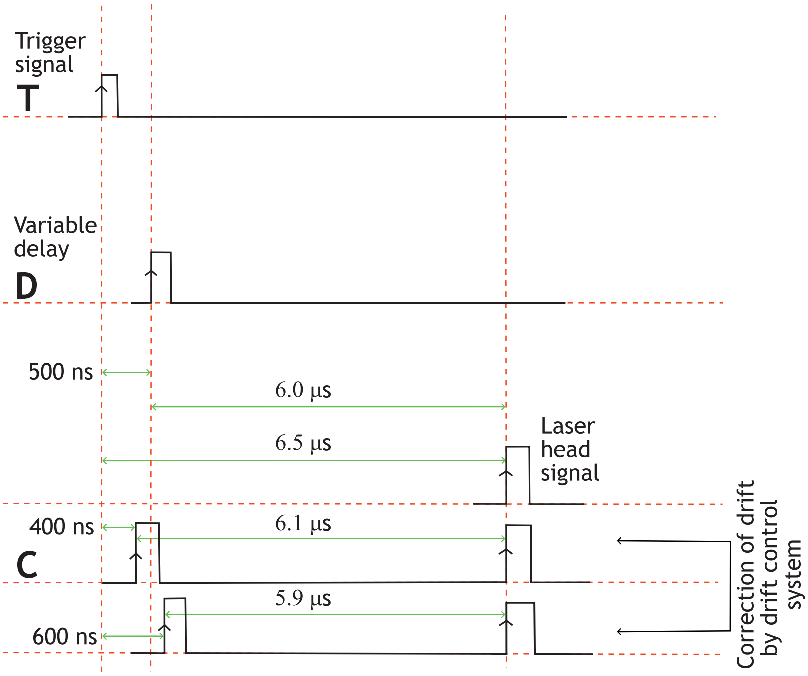

Figure 10.7: Waveforms indicating working principle of drift control system.

lasers. For this purpose, a photodiode based measurement scheme is used. Since photodiodes saturate at low intensity of laser power hence leakages from mirrors are tapped avoiding the need to block the main laser beam. If laser beams are multiplexed in time domain to form a composite optical beam then by synchronizing the electrical power measurement circuit with the laser triggers pulses it is possible to indicate the power of individual beams. Figure 10.8 shows a typical block diagram of an Online Power monitoring System.

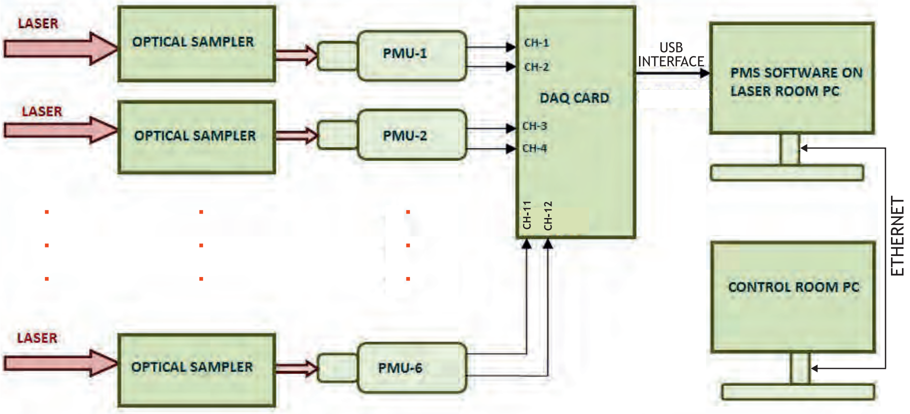

Figure 10.8: Block diagram of the online power monitoring system.

10.5 Conclusion

Laser wavelength monitoring and control, power monitoring and control have been explained. The single mode operation of Dye laser is very important for isotope separation and it is achieved using precise control elements like Diffraction grating and etalon which also helps in its stabilization. The power stabilization of CVL laser is achieved by implementing drift control system which adjust the delay between the trigger signal from control room and the high current pulse at laser head to synchronize current pulse with optical pulse for maximum gain operation. In the power monitoring system, the laser pulse power is measured at different locations and transmitted in real time for display on an online monitoring system.

Frequently Asked Questions

Q1. What do you understand by the term mode number of a laser? How is it related to the wavelength?

Q2. Which element in laser cavity ensures single mode operation of a Dye laser?

Q3. How is the electrical pulse synchronized with the optical pulse at CVL laser head?

Q4. Why is the electrical pulse synchronized with the optical pulse at CVL laser head?

Suggestions For Further Reading

a) **Wavelength stabilization system** [117–121]

b) **Drift control** [100, 122–126]

c) **Online Power Monitoring System** [127–131]