A Magnetic Tuning System for Dye Lasers

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Abstract. A new device for magnetically displacing the output mirror of a laser resonator and synchronously tilting an etalon in order to obtain single-mode tuning of a dye laser over a tuning range of at least 10 GHz is described. Comparatively large displacements with good linearity of a coil mounted on a membrane and placed inside the strong magnetic field of a ring magnet are obtained for currents in the order of several hundred milliamperes. Together with etalon flats of appropriate thickness and reflection mounted in the resonator of the laser a versatile instrument for application in intra and extra cavity spectroscopy has been developed.

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Modern tunable dye lasers contain, as tuning elements, piezoelectrically driven mirrors and air-spaced etalons. The length $L$ of the resonator determines the frequency $v$ of the possible dye laser modes which are separated by $\Delta v = c/(2L)$. The inserted etalon—adapted in free spectral range and reflection to the length of the resonator used and the wavelength desired—isolates one of the oscillating modes. Single mode tuning is achieved by applying voltages of appropriate size to the piezoelectric positioning elements. Since the transmission frequency of the etalon and the eigenfrequency of the laser resonator change linearly with the mirror distances, one simply has to apply a certain fraction $(L_{\text{etalon}}/L_{\text{resonator}}) \cdot U_{\text{resonator}}$ of the voltage at that piezoelement which drives the output mirror to the piezoelectric etalon spacer in order to obtain single-mode tuning. However, this method suffers from some disadvantages:

(i) The air-spaced etalon has, compared with etalon flats, two more surfaces. Thus, further losses in the resonator are introduced, even if the additional surfaces are coated with antireflection layers.

(ii) The thickness of the etalon spacer and consequently the free spectral range of the etalon is fixed. Change of the thickness necessitates tedious and time-consuming adjustment procedures since the transmission of the etalon is very sensitively dependent on the parallelism of the Fabry-Perot mirrors.

(iii) The application of piezoelectric elements for controlling the resonator length leads to rather lengthy stacks of piezo disks or rings in order to achieve the necessary large displacements at frequency tuning ranges over several GHz, the displacement $\Delta L = -(\Delta v/v) \cdot L$ being proportional to the resonator length $L$ for constant frequency detuning $\Delta v$. Effects like hysteresis, "creeping" and tilting occur.

There has been some effort in the past to use magnetic forces for tuning interferometers [1, 2], but no such experiments have been reported in connection with tunable lasers so far. In the following a tuning system is described on the basis of galvanometric deflection of coils in the strong field of a permanent magnet. Clearly, there arise new problems in verifying the concept of a combination of magnetic tuning and etalon flat tilting, one of which should be mentioned immediately: A change of $\Delta L$ of the resonator length changes the laser frequency linearly. But the transmission frequency of the etalon changes quadratically with the tilt angle $\theta$ according to $\Delta v = v \cdot \theta^2/(2n^2)$ ($v$: optical frequency, $n$: refractive index of the etalon flat). It should be noted, however, that the thickness of the etalon does not enter...
Mechanical Device for Magnetic Tuning

The arrangement for magnetic displacement of the mirror and tilting the etalon are based on the construction principles of a loudspeaker. Figure 1 shows the device for the linear movement of the output mirror. For the magnet a loudspeaker ring magnet with a field of 8000 Gauss over a gap width of 1.3 mm is used. If a current passes through the coil it is pulled into the slit of the magnet, thereby deforming a membrane of bronze of 0.4 mm in thickness and 60 mm in diameter. A borehole in the magnet of 7 mm in diameter allows the light to pass on the mirror. With this membrane a displacement of 1.5 μm/100 mA is obtained. The arrangement for tilting the etalon is seen in Fig. 2. Magnet and coil arrangement are the same as in Fig. 1.

Electronic Control Unit

Figure 3 shows the diagram of the electronic circuit for driving and synchronizing the movements of output mirror and etalon. A sawtooth generator with variable scan time and amplitude can be operated in the two modes “single sweep” and “periodically”. Its output drives an amplifier with variable amplification and offset. Then the circuit is divided into two branches. The first branch supplies the current for the displacement of the coil carrying the output mirror of the cavity. The current is amplified via a square module in order to ensure linear frequency tuning with respect to the tilted Fabry-Perot etalon which is driven by a linear current (second branch) and has a quadratic dependence of the etalon transmission frequency on the tilt angle. In order to take into account the heating of the coil depending on amplitude and time of the tuning process, which affects the membrane temperature and consequently the resonator length, a second bifilar winding of equal resistance as the main coil is wrapped on the coil carrier. An analog device consisting of square—difference—and square root amplifiers supplies a current $I_{\text{heat}}$ so that the loss power $(I_{\text{cavity}}^2 + I_{\text{heat}}^2)R$ is constant and thereby—after a setting time of 20 min after turning on the power—the temperature of the membrane.

Synchronization and Tuning

After coarse adjustment of the dye laser frequency with a prism as the only dispersion element in the resonator the etalon is inserted. The “common offset” is put to zero, by adjusting the “etalon offset” to a small value. The etalon is tilted perpendicular to the laser beam, thereby electronically defining the tilt angle $\theta = 0$. This can be easily observed as the etalon is coupled to the laser. Thereafter the etalon offset remains unchanged. With the circuit described above we have realized the following proportionalities

$$\Delta V_{\text{Etalon}} = \theta^2 \frac{v}{2n^2} \sim I_{\text{Etalon}}^2 \sim U_{\text{common}}^2$$

$$\Delta V_{\text{cavity}} = -\Delta L \frac{v}{L} \sim I_{\text{cavity}} \sim U_{\text{cavity}}.$$

In the place of the micrometer in common tilting devices one has here an adjustable spring of steel whose elongation compensates the magnetic force acting on the coil. A tilt angle of 1° is obtained by a current of 500 mA, the gap of the magnet being wide enough to allow the corresponding tilting of the coil.