④ Longitudinal Modes and Their Significance for Stabilized HeNe Lasers

We assume familiarity with general laser mode principles. For an introduction to HeHe lasers and longitudinal modes, see Theory of Operation, Modes, Coherence Length, On-Line Course.

For everything that follows, it is assumed that the spatial mode structure of the HeNe laser is near pure TEM00 resulting in close to a Gaussian beam profile. We are not aware of any stabilized HeNes using multi-spatial mode tubes.

Lasing is determined by the round trip gain at the laser's optical frequency or wavelength, and resonance wihin the laser cavity. For everything in this chapter, we assume a linear "Fabry-Perot" cavity - the classic "gain medium between mirrors" laser - and the one used in virtually all HeNe lasers and even close to all stabilized HeNe lasers. But ring and other geometries would have similar constraints.

As with any resonant structure, there will be a fundamental frequency at which it can respond (n=1), as well as an inifinite range of harmonics (n=2,3,4.....infinity). For an organ pipe or violin string resosnance is at its fundamental and several harmonics. However, due to the short wavelength of light and relatively large resonant cavity length, for a HeNe laser, there is no fundamental and the harmonics have values of n in the hundreds of thousands or more.

In order to sustain laser oscillation, the round trip gain must exceed losses for photon at an optical frequency that is close to a cavity resonance as defined by n*c/2L. L is the distance between the mirrors, c is the speed of light, and n is an integer that results in the equation being equal to an optical frequency with a net gain greater than one for the lasing medium gain and cavity geometry.

For a red (633 nm) HeNe laser, the Neon Gain Curve (NGC) has a width of 1.5 to 1.6 GHz FWHM and is centered at around 474 THz. (We will have much more precise values later.) As an example, for a cavity length of 200 mm, c/2L is around 725 MHz. Thus, 1 to 3 modes may oscillate at the same time depending on their precise position within the NGC, but never more than that. Typical values for n in this case would be successive integers near 987,500. (There are other more subtle effects such as mode pulling and mode pushing that offset the actual optical frquencies by a small amount, but for now, the exact cavity resonances are sufficiently accurate.)

Higher power longer tubes will support more than 3 modes. And due to the shape of the NGC, the power in the strongest mode increases sub-linearly with tube length. So even if it could be isolated for a single frequency laser (which beyond 3 is not really practical), its power would not be that high, perhaps 6 mW for a tube outputting 35 mW . Further, due to mode competition, the power in each mode in longer tubes tends to fluctuate at random among them and stabilization doesn't help. This can be an issue even with the tube used in three mode stabilization.

When a HeNe laser is powered, whichever cavity resonances – also called "cavity modes" are within the NGC and have sufficient round trip gain will lase. These are the longitudunal or axial modes of the laser. Each of these "lasing lines" is a very nearly pure optical frequency in a HeNe laser, with a bandwidth of under 1 kHz and possibly as low as a few Hz or less. Thus, the term "single frequency" is appropriate (except for the most die-hard purists) where one of these modes is the output of a stabilized laser.

If the distance between the mirrors changes, the position of the modes will drift through the NGC. For large frame laboratory HeNe lasers, the resonator structure is designed to have a very low coefficient of thermal expansion. However, for common HeNe laser tubes of the type used in most stabilized HeNe lasers, the heating effects of the plasma discharge will cause the distance between the mirrors the change. As this occurs, the longitudinal modes will drift through the NGC. A mode at the high frequency-end will eventually disappear and be replaced by a new one appearing at the low-frequency-end. This is "mode sweep". An animation of the mode behavior of a tube similar to those used in many stabilized HeNes can be found at HeNe Laser Mode Sweep: 200 mm (~8 inch) Cavity Length. Of course, the movement is continuous but it's tiring to create an infinite number of slides. ;-)

To stabilize such a tube, the cavity length needs to be controlled in a feedback loop. A variety of means can be used to affect cavity length. A heater wrapped around the tube is most common, but others include an internal heater wrapped around the bore, an induction heater on one of the mirror mount stems, or the use of a PeiZo Transducer (PZT) behind one of mirror. It's even possible to use a magnetic actuator to press on one of the mirror mounts. With stabilization, the longitudinal modes can be precisely "parked" on the NGC. It's possible to do this in the animation by careful use of the left and right arrow keys to keep one mode centered. Fortunately, analog or digital electronics is much more effective and doesn't get tired as easily. ;-)