30: Reverse Incremental Efficiency of HeNe laser?

You say: "Huh, what?". ;-) Until recently, it never occurred to me to even think about how the HeNe lasing process and electrical input might be related other than that the HeNe laser is extremely inefficient. Then someone asked the obvious question: "Does the power input to the laser depend on the output power in the beam?". With a bit of thought, it should be obvious for there to be *some* relationship. But even for other types of lasers, this is not something that is often considered. The *slope efficiency* is an important measurement for any laser, being how the laser output changes as a function of the electrical (or other) input. For example, with a laser diode, all that is needed is to measure the input electrical power and output optical power at two points where lasing is occurring and calculate the ratio of the differences. But this is from *input* to *output*. For a HeNe laser, such measurements can be done over a portion of the range where the power supply is stable resulting in a typical value of 0.3 mW/W or 0.3 percent, similar to the pathetic absolute efficiency for the HeNe laser!

But what we want here is the opposite - how the input power is affected by the laser output, which I'll call the "Reverse Incremental Efficiency" or RIE. In other words, compare the input power with the laser operating normally and with the output suppressed, for example, by misaligning a mirror. For a HeNe laser, would there be a detectable change in input power if this were done? With a normal constant current HeNe laser power supply, the result should be a change in tube voltage. If for want of a better term, the "reverse slope efficiency" were 100 percent, then "spoiling" the beam of a 1 mW laser should result in a reduction of 1 mW in power consumed *by the tube*.

So I did an experiment using a high-mileage JDS Uniphase 1145P laser head with a Melles Griot 05-LPL-915 power supply set at 6.5 mA. The lasing was spoiled using a tube-type Nylon mirror adjuster pushing on the OC mirror mount to kill lasing in a totally reversible manner. Measurements were made while the laser was warming up and outputting 12 mW and then once fully warmed up and outputting 19 mW. The results were rather intriguing:

ΔPo	ΔVt	ΔPt	RIE
12 mW	4.1 V	26.65 mW	45.0%
19 mW	5.2 V	33.80 mW	56.2%

ΔPo is the output power, ΔVt is the change in tube voltage from 0 mW to ΔPo, and ΔPt is the corresponding change in the tube's power consumption.

At first, my measurements were made with a DMM with only 4 digits of resolution and it appeared as though the the RIE might be exactly 50 percent, which could have had some cosmic significance. :) But it wasn't to be. With the full 5 digits of a Fluke 87, while the RIE isn't far from 50 percent, it isn't 50.00000000%. Too bad. But what this does say is that the incremental efficiency of getting coherent photons out the front of a HeNe laser once it's running at the normal voltage and current and outputting near rated power is order of 50 percent, not a miniscule value like that 0.3 percent! Note that the results depend on whether the laser is running at reduced and full power. If this had been some obscure effect of mechanical stress on the discharge voltage, then the change in tube voltage would be about the same at both output powers. And pushing on the mirror mount beyond where lasing ceases has no effect on tube voltage. At least until it breaks off. :)

To further confirm that this is a true lasing effect, I repeated the experiment with a Melles Griot 05-LHB-570 one-Brewster laser where lasing could be suppressed simply by poking something in the cavity between the tube and OC mirror:

ΔPo	ΔVt	ΔPt	RIE
2.55 mW	0.9 V	5.85 mW	43.6%

Even at this much lower output power, the RIE is still fairly high, though uncertainly is greater due to the much lower power and corresponding change in tube voltage.

Then, I did multiple sample points while a like-new 1145P head was warming up:

ΔPo	ΔVt	ΔPt	RIE
6 mW	4.8 V	32.1 mW	21.0%
10 mW	5.7 V	37.1 mW	27.0%
14 mW	5.8 V	37.7 mW	37.1%
17 mW	6.0 V	39.0 mW	43.6%
19 mW	6.3 V	41.0 mW	46.3%
21 mW	6.3 V	41.0 mW	51.3%
24 mW	6.4 V	41.6 mw	58.0%

Just when I thought this was making some sense, these data appear to show an unexpected very non-linear relationship. Most of the voltage change occurs between 0 mW a few mW, and it is then nearly constant, perhaps due to the gain saturating. There is still significant uncertainty as the measured values for both absolute tube voltage and the voltage difference fluctuate over time.

And finally on the same head when fully warmed up with a stable 24 mW of output power undisturbed, with controlled misalignment of the OC mirror to generate a few intermediate values:

ΔPo	ΔVt	ΔPt	RIE
1 mW	1.3 V	8.5 mW	12.0%
6 mW	4.4 V	26.8 mW	21.0%
9 mW	5.2 V	34.5 mW	26.1%
24 mW	6.3 V	41.0 mW	58.6%
″″ mW	6.5 V	42.3 mW	56.8%
″″ mW	6.8 V	44.2 mW	54.3%

These are generally similar to the measurements during warmup. The last two full power entries reflect the variation that may be present even when the laser is in thermal equilibrium. Even so, there can be small changes in the longitudinal mode positions and thus relative efficiencies of the lasing lines or something. :)

A reference to this phenomenon can be found on page 38 of an old NASA report: An Experimental and Theoretical Investigation of Striations in a HeNe Laser. (If this link should decay, simply search for the title.) I'm sure there are many more in depth studies but locating them is left as an exercise for the student. :)