DEVELOPMENT OF AN ACCELERATOR-READY PHOTOCATHODE DRIVE LASER AT CEBAF

S. Benson and M. Shinn, Continuous Electron Beam Accelerator Facility, Newport News, Virginia 23606 USA

Many injector designs for free-electron lasers and linear colliders use photocathode sources in lieu of a thermionic cathode. These designs require mode-locked lasers with very tight phase and amplitude jitter specifications to achieve the electron beam quality needed for these applications. We have characterized the long term stability of a mode-locked laser for use in the injector test stand at CEBAF. The sources of drift and instabilities were studied and characterized. Initial results indicate that the most important source of drift is a change in the effective cavity length. A possible design for automatically optimizing the length is presented.

I. INTRODUCTION

Many proposed high-brightness sources for driving linear colliders and free-electron lasers plan to use a photocathode injector [1]. At CEBAF we will use a modelocked laser with a dc gun [2] to provide a bright source for a free-electron laser (FEL) driver accelerator [3].

In contrast to general research laboratory use, an accelerator-based laser must generally run unattended for long periods, with remote control and monitoring. The phase and amplitude stability should be comparable to rf sources and the laser phase must be locked to the accelerator master oscillator. The laser output must be remotely controllable to match accelerator conditions and photocathode quantum efficiency. To date no modelocked laser has exhibited performance which would meet these requirements.

Though Q-switched lasers have proven sufficiently stable to operate as part of an accelerator injector for the SLC polarized source [4], a modelocked laser is inherently less stable than a Q-switched laser. It is possible to use feedback techniques to stabilize the laser against amplitude and phase oscillations [5] but passive systems are always preferred due to their reliability.

To drive the CEBAF injector test stand we have purchased a frequency doubled Antares™ modelocked Nd:YLF laser from Coherent , Inc. Though our stability specifications for the laser were quite stringent, the laser has met them. Standard diagnostics were used to monitor the laser. A photodiode with a 65 psec risetime was used to monitor the time structure of the infrared light leaking from the cavity high reflector. Both slow and fast power meters were used to monitor the second harmonic generated (SHG) power and laser power fluctuations. A pickoff plate directed 3% of the laser light to an autocorrelator which monitored the pulsewidth of the second harmonic.

II. DIFFICULTIES IN USING MODELOCKED LASERS

A. Sensitivity of laser parameters to cavity length

Since the performance of a modelocked laser is quite sensitive to the cavity length, the Antares™ laser cavity was designed to have a particularly stable length. All components are mounted on a 5 cm diameter Invar rod to reduce temperature effects. To augment the stability, Coherent has used a Mefferd Thermal Compensator [6]. Using this compensator it is possible to cancel out all linear temperature dependence in the cavity round trip time. Note that, even if the Invar rod had no temperature coefficient, the laser would still have some temperature dependence in the round trip time due to changes in the refractive index of air with temperature and to changes in the size of the elements mounted on the Invar bar.

To indicate how critical the cavity length is we show in figure 1 the dependence of the SHG power and the full width at half maximum pulsewidth as a function of cavity length. A typical pulsewidth curve is shown. The shape of the power curve drifts considerably over time. The error bars on the power curve indicate the changes in the power dependence from measurement to measurement. Further work is necessary to characterize the source of this drift. The laser does not modelock stably outside of the range of cavity lengths shown. Note the very narrow maximum in the power and narrow minimum in the laser pulse length. The infrared laser power is not very sensitive to the cavity length and so variation in the SHG power is mainly due to the change in the pulsewidth.

B. Sensitivity to other variables

We looked at the dependence of the laser on other parameters as well. The feedback for the laser head closed loop cooling system has a gain of 9 so the coolant temperature is dependent on the primary loop water temperature. We measured the sensitivity of the power to the primary water temperature and found that the power varied 0.5% for a 1 °C primary water temperature change. The water temperature must therefore remain constant to ±1°C.

The refractive index of air changes with barometric pressure and relative humidity [7]. This will not be compensated by the Mefford compensator. The sensitivities are 0.36 parts per million (ppm)per mm-Hg and 0.01 ppm per % change in relative humidity. The dependence on humidity in an air conditioned environment should be negligible. A 10 mm-Hg change in barometric pressure, resulting in an effective cavity length change of 7 µm, is possible when a weather front passes through. From figure 1, it is obvious that this would cause a major change in the laser performance.

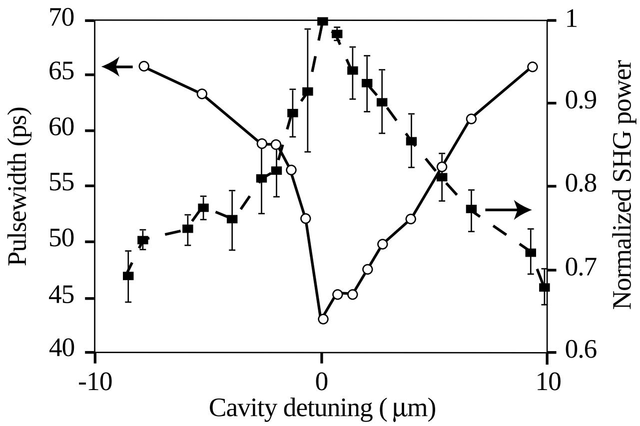

Figure 1: Power and FWHM pulse width vs. laser cavity length. The pulse width is a typical curve. The normalized power curve varies over time. The variation is indicated by the error bars.

III. NOISE RESULTS

Solid-state, lamp-pumped, modelocked lasers inevitably have phase and amplitude noise caused by the water cooling channels that must have turbulent flow to remove the heat from the lamps. Broadband turbulence-induced vibrations can cause phase noise either by vibration in the mirrors causing changes in the cavity length [8] or by acoustically induced changes in the refractive index of the laser rod.

The noise in the laser as a function of cavity length is shown in figure 2. Phase noise was measured on only one side of the cavity length detuning curve. In general it is found that the phase noise levels are highest near the peak in the power curve. Despite this the rms timing jitter in the frequency range of 10 Hz to 5 kHz is on the order of 1 ps. There is an intermittent laser instability which creates higher levels of timing jitter at cavity lengths slightly shorter than the optimum.

The phase noise spectrum is shown in figure 3 for operation at maximum SHG power. There is a general 1/f falloff for the broadband noise between 100 Hz and 100 kHz and broad features at 250 Hz, 500 Hz, and 1000 Hz. These features could be due either to acoustic resonances in the laser head or to noise from the master oscillator which is amplified by poles in the laser gain response. No sharp features were seen in the spectrum of the local oscillator.

Although not a minimum, the 1% peak to peak noise at maximum power meets our specification for the laser. Also shown in figure 2 is the noise monitor output from the laser. This monitors the amplitude noise of the fundamental. It is small and constant over most of the peak in the cavity detuning curve. Note that amplitude noise is not as serious as phase noise since it can be removed with an acousto-optic attenuator in a feedback loop.

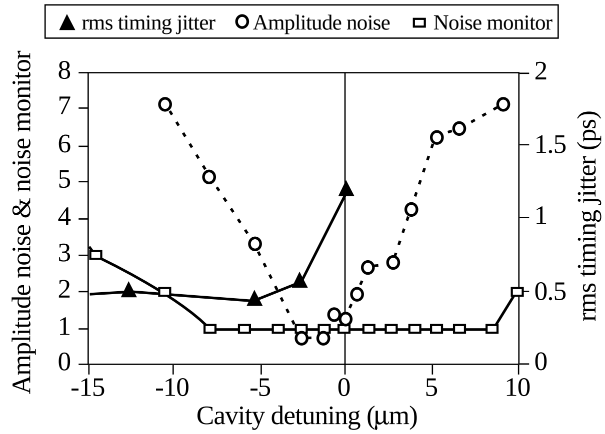

Figure 2: Noise in the drive laser vs. cavity length. The maximum phase noise is at the peak of the power vs. cavity length curve.

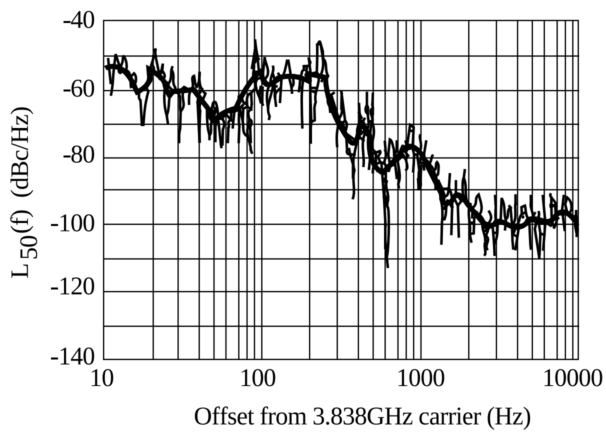

Figure 3. Typical phase noise spectrum measured at the 100th harmonic of the mode-locker frequency.

Although the spectrum in figure 3 is typical, we occasionally noticed that the phase noise increased dramatically at high frequencies. Peaks at 8 kHz and harmonics appeared. The fundamental noise level rose when this spectrum was present. The laser persisted in this state for up to several hours. We do not know the cause of this condition but intend to study it to determine which parameters, if any, are out of their typical range when the noisy spectrum appears.

IV. STABILITY WITH TIME FOR ANTARES LASER

As figure 1 shows, very small changes in the effective cavity length can cause large changes in the SHG power and pulsewidth. We carried out several endurance runs during which the second harmonic power, fundamental power, second harmonic pulsewidth, phase noise, fundamental power noise, and temperatures of the coolant water and the ambient temperature were recorded. We discuss here the results of one of these runs.

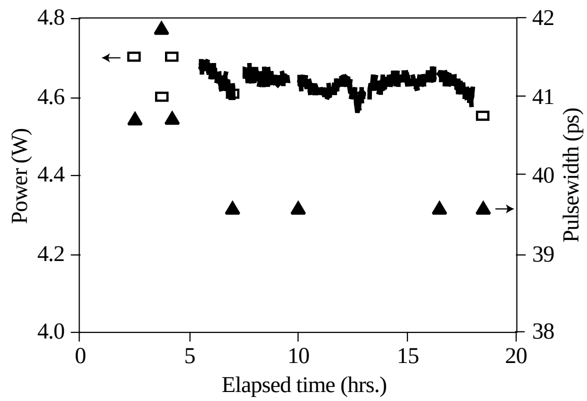

Figure 4 Power and pulse width vs. time during a long laser run. Note offset vertical axis.

After an initial warm up time of about six hours, the ambient temperatures stabilized at values of 29.4 °C in the laser head and 27.1°C outside the laser head. The temperature remained constant to better than ±1°C over the rest of the endurance run. During the warm up period, the fundamental noise and the SHG pulsewidth also varied. After this period the laser was quite stable for a period of 12 hours. The power and pulsewidth vs. time over this endurance run are summarized in figure 4. This performance is adequate for accelerator operations.

V. CONCLUSIONS

Although the performance shown in figure 4 is quite adequate for acceleration operation, other endurance runs had occasional periods of drift and instability. Furthermore, the occasional periods of large phase noise would be quite unacceptable for accelerator operations.

In general, the only adjustment which must be made over any 24 hour period is to the cavity length. One might think that a feedback loop should be able to hold the cavity at the optimum length. One parameter which may be ideal for this purpose, due to its linear dependence on cavity length, is the timing offset between the laser pulses and the master oscillator, shown in figure 5. We plan to study the possibility of using this signal in a simple feedback loop to maintain the laser at the peak in the curve. Note that the timing for optimum power may be dependent on other parameters as well. It is necessary to characterize the laser using the timing as a diagnostic while other parameters are varied so find out how useful this parameter is as a control variable.

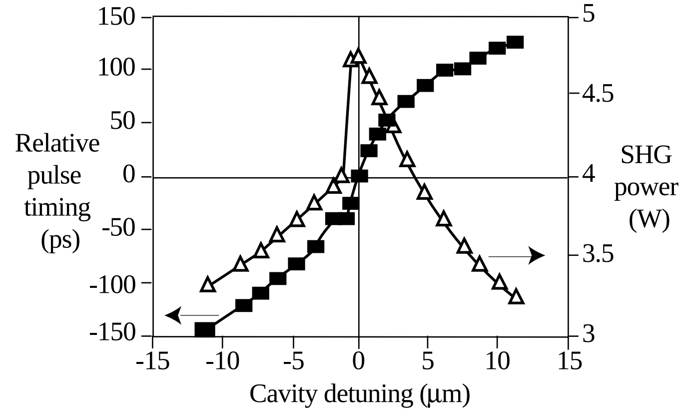

Figure 5. Power and relative phase of the light pulses with respect to the modelocker drive.

ACKNOWLEGEMENTS

We would like to acknowledge the helpful efforts of Dave Engwall and Gary Slack. This work was supported by the Virginia Center for Innovative Technology and DOE Contract # DE-AC05-84ER40150.

REFERENCES

1. C. Travier, Nucl. Inst. and Meth. **A304** (1991) 285 has references to 21 proposed or operating photocathode rf guns.

2. P. Liger et al. *1992 Linear Accelerator Conference Proceedings* (AECL-10728) 85.

3. H. Liu et al., “Design of a High Charge CW Photocathode Injector Test Stand at CEBAF”, these proceedings.

4. J. E. Clendenin et al., *1993 IEEE PAC proc.* (1993) 2973.

5. M. J. W. Rodwell, D. M. Bloom, and K. J. Weingarten, IEEE J. Quant. Elec. **25** (1989) 817.

6. For more information on the Mefferd Compensator, contact Coherent Laser Group, P.O. Box 54980, Santa Clara CA 95056 USA

7. F. Jones, “The Refractivity of Air,” J. Res. Natl. Bur. Stand. **86**,(1981) 81.

8. S. B. Darack, D. R. Dykaar and G. T. Harvey, Opt. Lett., **61** (1991) 1677.