DESIGN AND COMMISSION OF THE DRIVEN LASER SYSTEM FOR ADVANCED SUPERCONDUCTING TEST ACCELERATOR*

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Abstract

Currently an advanced superconducting test accelerator (ASTA) is being built at Fermilab. The accelerator will consist of an photo electron gun, injector, ILC-type cryomodules, multiple downstream beam lines for testing cryomodules and carrying advanced accelerator research. In this paper we will describe the design and commissioning of the drive laser system for this facility. It consists of a fiber laser system properly locked to the master frequency, a multi-pass amplifier, several power amplifier and final wavelength conversion stage. We will also report the initial characterization of the fiber laser system and the current commissioning status of the laser system.

INTRODUCTION

A future superconducting RF accelerator test facility is currently being commisioned at Fermilab in the existing New Muon Lab (NML) building. The designed accelerator will consist of a photoinjector, two booster cavities, beam acceleration section consisting of 3 ILC-type cryomodules, multiple downstream beam lines with various diagnostics to conduct beam tests, and a high power beam dump[1, 2]. In this paper we will describe the design and commissioning of the drive laser system for this facility. One of the goals is to realize a long pulse train operation (up to 1000 individual pulses with 1 μs apart or 3000 pulses with 330 ns apart) which is essential for the newly built ASTA facility in Fermi lab.

Our new laser system is based on the design for the old laser system used at A0 photoinjector[3]. One of the disadvantages of the A0 laser system design is the low efficiency of the gain medium, Nd:Glass, used in the amplifying structure. Couples with the fact of the instability of the flash lamp used to pump the gain medium it's very difficult to realize long pulse train operation as required in the new facility[3]. In order to address those issues we decided to use Neodymium-doped yttrium-lithium fluoride (Nd:YLF) as our new gain medium to replace the Nd:glass used in current A0 laser amplifier chain. Nd:YLF is a very efficient material that can be pumped by either flash lamp or diode laser. In addition the induced emission cross section is large enough to produce a single pass amplification up to 10. At the same time we will also upgrade our flash lamp pump to fiber coupled laser diode pump to get better stability and higher reliability. Using optical fiber to deliver the pump to the end-pumped active medium has several practical advantages:

- The pump beam at the end of the fiber has a high quality, central symmetrical profile.
- The radial size of the beam can be easily scaled up or scaled down with high quality optics.
- A fiber connection provides a simple and virtually lossless interface between the pump source and the active medium.
- Both the pump source and active medium can be changed simply by reconnecting the fiber between them.

In addition to the change of the amplifying chain we also replaced the solid state seed laser used at A0 laser structure with a fiber laser based seed system. Figure 1 is the designed flow chart of the whole photocathode laser system. The top box is a fiber based seed laser locked directly to the master oscillator and the bottom box includes a solid state based amplifier chain and frequency conversion stage.

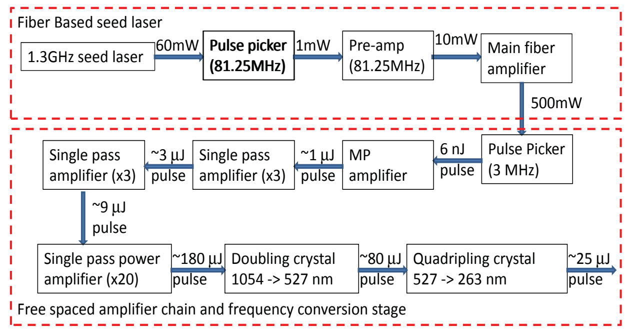

Figure 1: Designed flow chart of the whole photocathode laser system. The number is the expected power level at each stage.The top box is the fiber based seed laser stage and the bottom box is solid state based amplifier chain.

COMMISSIONING AND PRELIMINARY TEST OF THE ASTA LASER SYSTEM

The laser room at ASTA facility is finished at the beginning of the August, 2012. We are in the early stage of commissioning the laser system. In this part we will go over some of the preliminary test done in the fiber based seed laser system and diode pumped multi-pass amplifier system.

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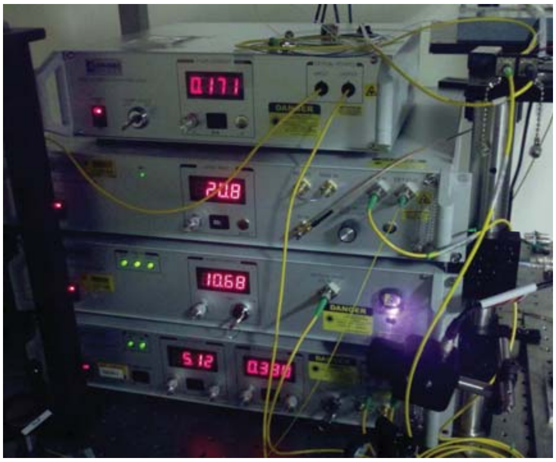

Figure 2: Picture of the fiber based seed laser setup the bottom to top it's seed oscillator, power amplifier picker and preamplifier respectively.

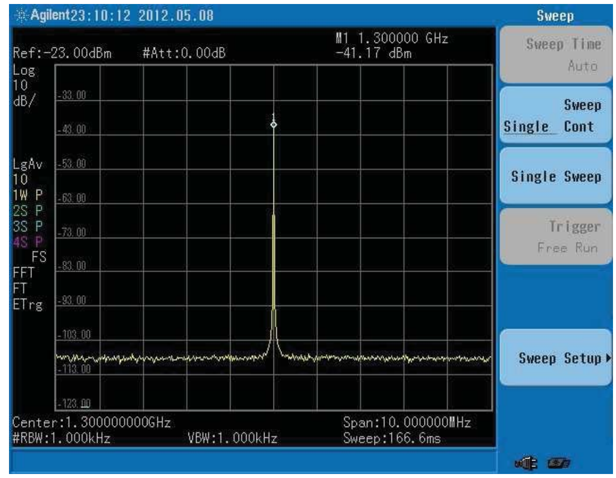

Figure 3: RF spectrum of the seed laser locked at at 1.3GHz.

Fiber based seed laser system

This system is designed and built by Calmar Laser Inc. Figure 2 is the picture of the whole system. The seed laser is a active mode locked Yb-fiber laser system center at 1054nm. The laser cavity consists of YDFA, output coupler, electro-optics modulator, tunable filter and fiber that connect these devices together. A piezo stage is used to adjust the cavity length to achieve stable mode-locking. The pulse width is 3.2 ps RMS with our auto-correlation measurement. The laser is locked to 1.3GHz signal from master oscillator. The modulator bias voltage needs to be adjusted to a proper DC value to ensure proper mode-locking. Normally the modulator bias point can drift over time. Thus the modulator bias voltage may need to be adjusted from time to time by the users. In order to keep the laser running continuously a feedback system is designed to adjust the modulator bias automatically to stay at the optimum value without tuning by the users. A typical RF spectrum is shown in Figure 3. The signal noise ratio is about 70 dB. Jitter study using Agilent E5052B signal source analyzer resolve a phase noise less than 200fs integrating from 1Hz to 10MHz range.

After the fiber oscillator pulse was sent to a pulse picker (Calmar model EPG-01FML12), in which 81.25MHz pulse train was picked up from the 1.3GHz pulse input. The output is amplified in 2 stages to reach 5 nJ per pulse level. In figure 4 we plotted the measured seed pulse phase over 14 hours after 4 hours warm up. We can see when the laser phase only drift around 2 ps total in a 14 hours span. The standrad deviation during this span is less than 0.3 degrees, which is much better compared to the same measurements with similar setup on the GE-100 manufactured by Time-bandwidth Inc or Tsunami Laser system manufactured by Spectra-physics.[4]

Output from the seed laser will then go through a pulse picker unit (Con-optics) and be picked up 3MHz train as required in our application. The pulse train can be up to 1ms long in time. The extinguish ratio through the pulse picker is more than 120:1. The pulse-pulse amplitude fluctuations are less than 3%.

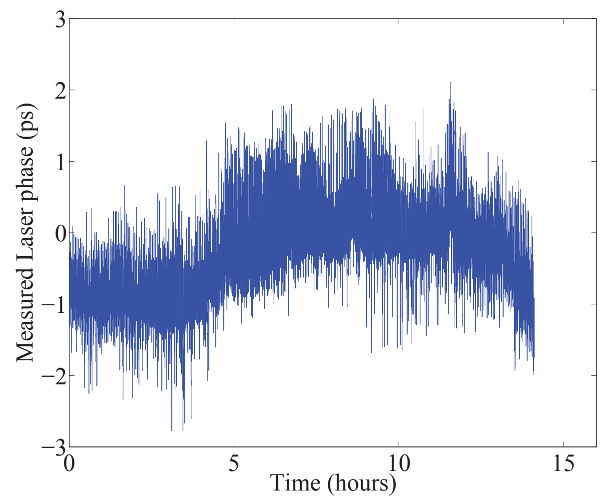

Figure 4: Laser phase measurement during a 14-hours span.

Diode pumped multi-pass amplifier

For the demonstration of a free running end pumped Nd:YLF laser we put the rod into a cavity with a length of 1.85 m as shown at the top of the figure 5. The cavity use a flat output coupler with the reflectivity of 90% and a high reflector with a curvature of 5 m. The lasing at 1053 nm is insured by the correct orientation of the Nd:YLF crystal using previous single-pass small signal gain measurement. And we also insert a brewster plate into the cavity which is used as our input and output port for our future MP structures. The existence of the brewster plate will also force

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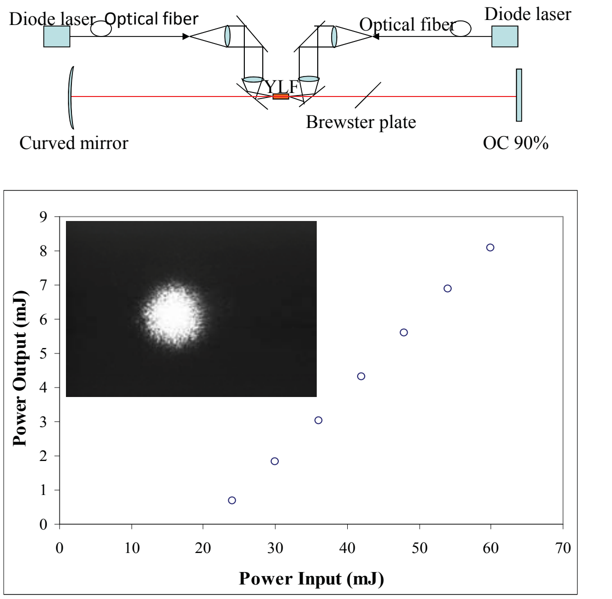

Figure 5: Top sketch is the end pumped 1053 nm Nd:YLl laser resonator layout. Bottom shows measured output en ergy vs. the pump energy. The inset shows the spatial pro file from our TEM00 mode captured using a CCD camera

the cavity lasing only at 1053 nm because it acts as a polar izer inside the cavity. The wavelength of the output lase radiation was also confirmed by a commercial optical spec trum analyzer. At the maximum one-sided pumping energy of 30 mJ, the free-running output was 3 mJ in the multi-longitudinal, fundamental TEM_{00} mode, which is 10% of the pump energy delivered to the Nd:YLF rod surface. At the maximum two-sided pump energy of 60 mJ, the free-running output was 9 mJ for the TEM_{00} mode, which is about 15% of the energy delivered to the rod surface. At the bottom of the figure 5 we plotted the resonator output vs the input energy for both side pump case. The inset is the image of TEM_{00} mode captured with a CCD camera. The highly symmetric image indicates a very good TEM_{00} mode. It's worth noting that we observed the good mode throughout the entire pump ranges without any transverse control inside the cavity. This could be explained by the fact that the end pumped cross section is smaller than the fundamental mode, which will function as an automatic mode control inside the cavity. The optical to optical differential efficiency in our case is 15%. In order to realize multi pass a Q-switch unit will be put in between the Brewster plate and the flat HR mirror. Initial test of the single pass operation with Q-switch unit resolve a gain of more than 4.

We tested the MP operation at another lab before moving. The results are shown in figure 6. The input of the 3MHz pulse train is shown on the top. The pulse energy at this point is about 1nJ per pulse. The output of the pulse from MP cavity is shown on the bottom of the figure 6. The output is pretty flat during the whole 1ms long period. The energy at this point is above 2μJ. So the total amplification

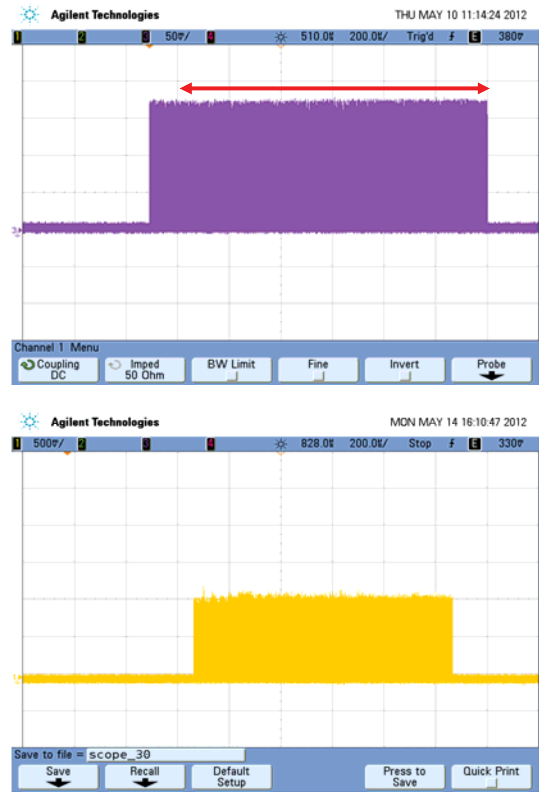

Figure 6: Scope image of the multi-pass input (top) and multipass output (bottom). The pulse energy is 1 nJ at the input and above 2μJ after the multi-pass cavity. The red arrow indicates a length of 1ms.

is about 2000 times with 14 round trips. It's worth pointing out that at this configuration the pulse is very close to the saturation stage, which means our MP operation is actually a regeneration process.

Summary

In conclusion we are in the process building a photocathode driver laser for the newly built Advanced Superconductor Test Facility. A fiber laser based seed laser has been commissioned. At the same time a diode pumped multi-pass structure is also disgned and tested to support long pulse train operation (3MHz pulse train up to 1 ms long). The whole laser system is being installed in the facility and will be operational in the near future.

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