A PHASED-LOCKED S.A.M MODE-LOCKED LASER FOR THE ELSA PHOTOINJECTOR

Vincent Le Flanchec, Pascal Balleyguier, Johanne Treuffet, CEA/DPTA Bruyères-le-Châtel, France

Abstract

A new laser oscillator has been developed for the ELSA photo-injector. It is a fibered-diode-pumped mode-locked Nd:YVO_4 laser, with a completely passive cooling design. Mode-locking is achieved by a saturable absorber mirror (SAM). Such a passive laser oscillator must be synchronized with the ELSA electron bunches. A phased-locked loop (PLL) has been developed for that purpose. We present the main design aspects resulting from the high stability requirement of ELSA [1].

INTRODUCTION

In the ELSA photo-injector, the electron beam consists of pulse trains that are produced by short light pulses (20-100 ps) from a drive laser system onto a photo-emitter. It consists of an actively mode-locked laser source, a pulse compression stage with a mono-mode fiber and gratings, an amplifier chain, several Pockels cells to shape the pulse trains (repetition rate : 1-10 Hz, train duration : 1-1000 pulses @ 72.222 MHz), a frequency conversion stage to produce photons in the visible range by second harmonic generation, and a beam injection system which shapes the beam transverse beam profile and sends the photons onto the cathode. The performance of the linac depends critically on the stability of the laser since the electron bunches are the image of the photon bunches.

NEW LASER OSCILLATOR

We developed a new oscillator to improve the stability of our drive laser system. While the old oscillator is Nd:YAG based, flash-lamp pumped and cooled by water flow, we chose Nd:YVO_4 as the amplifying medium because it has a much larger gain and produces a naturally polarized laser emission (stress induced birefringence has no consequence as opposed to the Nd:YAG case). It is pumped by a fibered laser diode @808 nm through a dichroïc mirror inside the laser cavity. The fiber numerical aperture is 0.22 and the core diameter is 200 µm. Particular attention is given to the quality of the beam imaged into the 4x4x6 mm^3 crystal, because the gain zone must be as homogeneous as possible to avoid spherical aberration inside the amplifier that would degrade the oscillator mode locking. So the optics were chosen to minimize the spherical aberrations, and constraints were applied to the fiber itself to ensure that the light repartition at the very end of the multimode fiber is homogeneous. This is simply done by diminishing the curvature radius slightly under the minimum recommended by the laser diode supplier,

The diameter of the pumped zone is 800 µm, and most of the pump is absorbed in the first 2 mm. Since less than 5 W are injected in the active medium, there is no need to use any active cooling system. The heat is simply conducted into the table by the aluminum mount. The folded-cavity round trip time is adapted to the accelerator frequency synthesizer 72.222 MHz (i.e. ~2 m long). A piezo-electric actuator is used to fine tune the cavity length. Figure 1 shows our laser configuration.

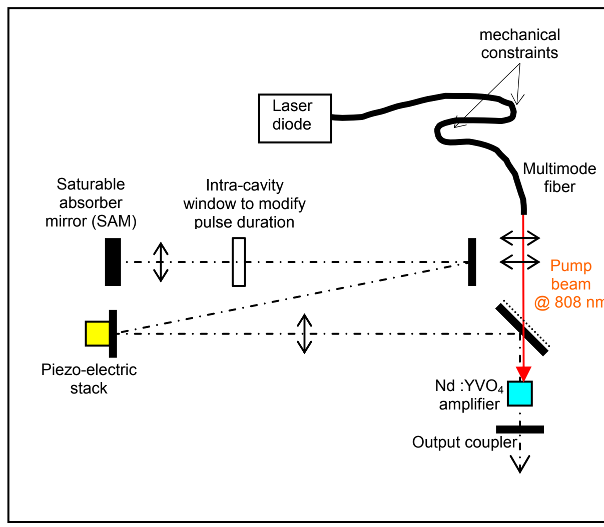

Fig.1. New laser configuration

SATURABLE ABSORBER MIRROR

The laser is mode locked by a semi-conductor saturable absorber mirror (SAM), placed at the end of the cavity. This device is a Bragg mirror structure with an incorporated thin absorber layer. The reflectivity depends on the fluence on the surface of the SAM. The saturation fluence of our SAM is 70 µJ/cm². The non-saturable losses are less than 0.3% and the saturable absorption is 4%. This means that for a low fluence, the SAM absorbs 4% of the incident beam and that for a high fluence, it acts like a good laser mirror. When multimode lasing just begins to occur inside the cavity, the SAM acts like a spike selector, so that all the longitudinal modes are in phase in a few roundtrip to produce the sharpest pulses as possible for the given spectral width of the amplifier gain. The critical parameter is the size of the laser spot on the SAM inside the cavity. It must be small enough to reach the high fluence regime, without exceeding the damage threshold. Considering our cavity design, the spot size can be slightly varied by adjusting the distance between the SAM and the last lens inside the cavity. To make more drastic changes to the spot size, the lens itself has to be changed, but the cavity dynamics remains the same, since the beam is nearly parallel between the two cavity lenses.

This design allows to have much more stable mode-locked pulse train, than in our old actively mode-locked oscillator.

The laser delivers 250 mW cw. The pulse duration is 25 ps @1064 nm (full width at half maximum FWHM). It is further shortened by the frequency conversion stage, so that the actual pulse duration on the photo-cathode is 17 ps @ 532 nm.

One important advantage of this new oscillator, besides the fact that SAM mode-locking is more stable than active mode-locking, is that the pulse compression stage is not needed anymore, thanks to the natural shorter duration of the pulses. The compression stage used to induce important instabilities due to alignment variations into the mono-mode fiber (thermal drift and mechanical perturbations).

For ELSA applications, it is convenient to be able to change this pulse duration from 25 ps to more than 100 ps. This can be done by placing simple cheap plano/plano windows with no surface treatment right inside the cavity (often referred as Fabry-Perot etalons), preferably where the beam is nearly parallel. The plane parallel window then acts like a spectrum narrower (Fabry Perot with a very low finesse), thus widening the pulse duration. We obtained pulse widths up to 140 ps with a 2 mm window, without having to use SAMs with different characteristics. The lens near the SAM had to be changed to accommodate the different peak-power levels corresponding to the different pulse width for a same average power.

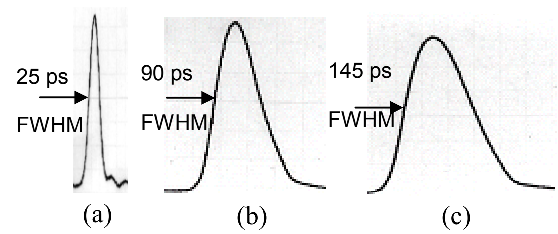

Fig.2. Sampling oscilloscope traces of different pulses obtained with different intra-cavity windows. (a) no window, (b) 1-mm window, (c) 2-mm window. Detector rise time=12 ps, sampling head BW=20 GHz.

PHASE-LOCKING

The optical pulse train has to be synchronized with the accelerator by a feedback loop.

As the laser repetition rate depends on the optical length of the cavity, we mounted one of the folding mirrors onto another low voltage piezoelectric stack. It is directly glued on it to reject the piezo-electric resonance to high frequencies (10 kHz in our case). Voltage applied on this crystal permits to vary the position of the mirror over a 15 µm range. The train of optical pulses is picked up via a semi reflecting plate (10%), detected by a photodiode, and filtered by a 72 MHz band-pass filter. After amplification, this RF signal is compared to the frequency reference in a double balanced mixer used as a phase comparator. The resulting error signal is then amplified and sent to the input of the piezoelectric crystal command (-20; +120 V).

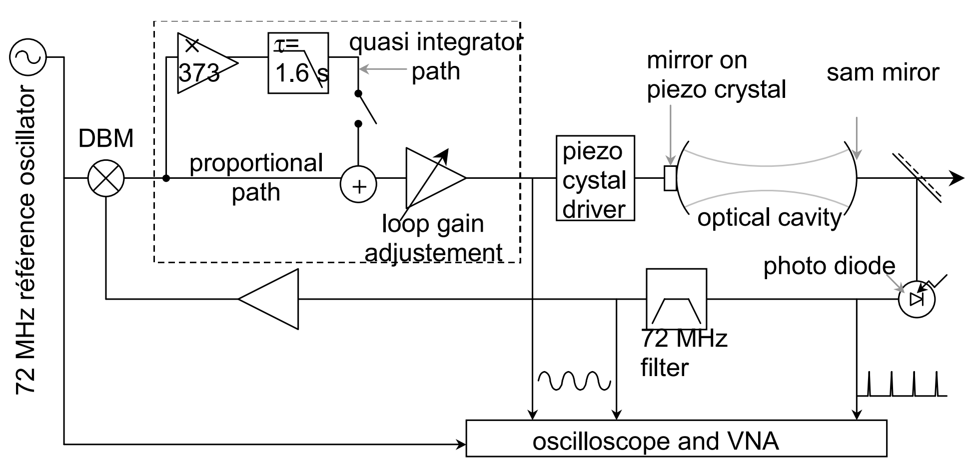

Fig.3.Phase-lock loop for frequency control of the laser oscillator

Before closing the loop, the optical cavity length is adjusted manually to bring its frequency close to the reference. The loop gain is kept below the self-oscillation threshold. To compensate slow frequency drifts, a "quasi-integrator path" was added to the loop.

It is a low pass first order filter (f_c=0.1 Hz) with a DC gain +51 dB above the proportional path.

Figure 4 shows a streak camera image of a typical 70 µs train @ 532 nm, with two temporal axes (slow axis : horizontal, fast axis : vertical). The intra-train jitter is 1 ps rms.

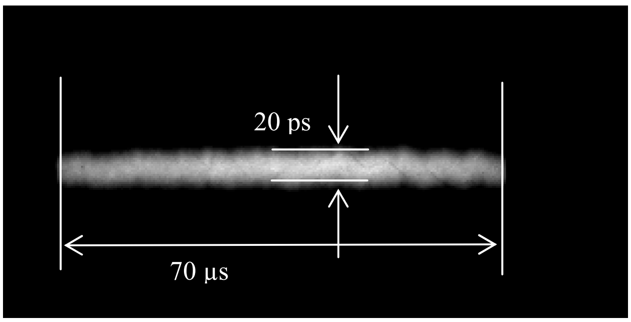

Fig.4. Streak camera image of one 70 µs pulse train. Slow axis : horizontal, fast axis : vertical

The mid term timing fluctuations from train to train (macropulse to macropulse) over a few seconds were recorded in time domain by a digital oscilloscope up to the limit bandwidth of the piezo command (1 kHz). The two traces on the oscilloscope show the reference signal (max gain on the oscilloscope channels) and the filtered and amplified photo-detector signal. The width of the green trace gives a good estimate of the timing fluctuation in the time domain. A typical 6-ps rms fluctuation was recorded as shown in figure 5.

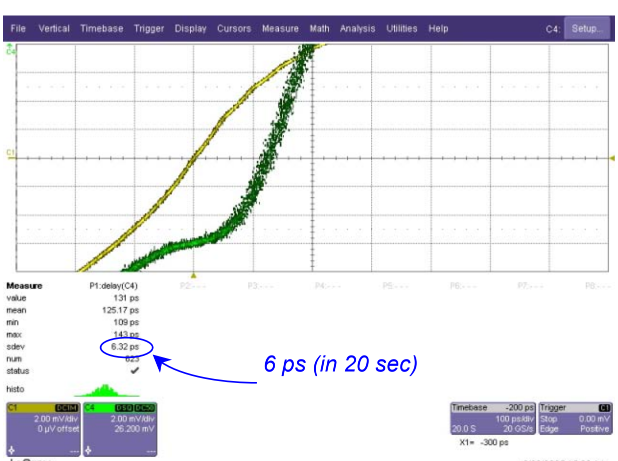

Fig.5.Time domain recording of the short term phase jitter

To test the long term stability of the loop, the 72 MHz RF signal issued from the photodiode was recorded with a vectorial network analyser (VNA), using a 10 Hz IF bandwith. To show the importance of the quasi-integrator path, it was switched-off at mid-time of the 180-s record. (fig. 3). When swicthed on, as long as the amplitude of the signal issued from the photo-detector is constant, the phase drift is kept below a few picoseconds.

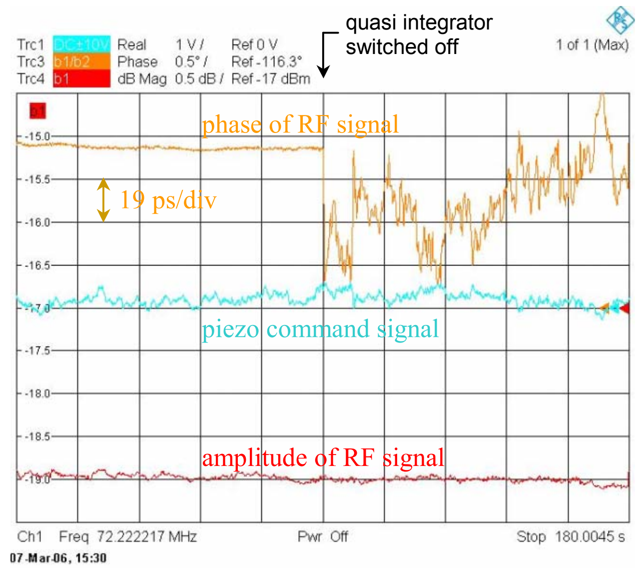

Fig.6.The mid term phase stability is dramatically improved by the quasi integrator path

CONCLUSION

We took advantage of the most recent advances in lasers to develop the new oscillator of the ELSA accelerator. It is now laser-diode-pumped, completely passively cooled and mode-locked by a SAM device. The result is a much more stable and robust laser system, with much less human interventions needed during ELSA runs. Moreover, the fact that we developed our own laser allows us to keep a very important feature for ELSA users : the flexibility in terms of electron bunches duration.

The authors thank A. Tocino for producing all the mechanical mounts for our laser.

REFERENCES

[1] JL.Lemaire "Gamma and X-rays Production for Experiments at ELSA Facility", Linac 2004, Lübeck, Germany.