DEVELOPMENT OF A HIGH AVERAGE POWER LASER GENERATING ELECTRON BEAM IN ILC FORMAT FOR KEK-STF*

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Abstract

Aim of Super-conducting Test Facility (STF) at KEK is demonstrating technologies for International Linear Collider(ILC). In STF, one full RF unit, which is composed from one klystron, three Cryo-modules, and 24 RF cavities, will be developed and beam acceleration test will be made. In super-conducting accelerator, precise RF control in phase and power is essential because the input RF power should be balanced to beam accelerating power. To demonstrate the system feasibility and reliability, the beam acceleration test is an important step in R&D phase. To provide ILC format beam for STF, we develop an electron source based on photo-cathode L-band RF gun. In this article, the laser system generating ILC format beam is described. The laser system consists from Yb fiber oscillator, macro-pulse profiler, Nd:YLF amplifier and Harmonic Generations. The laser system is initially developed at Institute for Applied Physics(IAP), Nizhny-Novgorod, Russia and moved to KEK-STF, Japan for the experiment. The laser system meets the basic ILC requirements; One macro-pulse contains 2439 micro pulses with 369ns bunch spacing; The macro-pulse is repeated in 5Hz; The micro-pulse energy is 1.9μJ, which corresponds to 4.3nC assuming 1.0% quantum efficiency of cathode. We report the basic performance of the laser system from the accelerator technology point of a view.

INTRODUCTION

ILC is an high-luminosity($2.0 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$) electron-positron collider with 200-500 GeV center of mass, which is extend-able to 1.0 TeV[1]. Although several linear collider projects had been promoted by various laboratories, according to a report by ITRP (International Technology Recommendation Panel)[2], ICFA (International Committee for Future Accelerator) initiates a common project, ILC.

ILC consists from a couple of linear accelerators based on Super-Conducting RF Technology, one for electron and another for positron. 2K He cooled accelerating cavity made from Nb, is operated 31.5 MV/m field gradient In ILC, one macro pulse, which contains 2625 micro pulses, is repeated in 5 Hz. In a macro pulse, micro pulse spacing is 369 ns, which corresponds to 2.71 MHz repetition and a sub-harmonics(1/480) of 1.3 GHz, which is RF frequency of the main linac. The macro pulse length becomes 968 μs. One micro pulse (bunch) contains 3.2 nC charge and average beam current in a macro pulse is 8.7 mA.

To generate the electron pulse train in ILC format, a photo-cathode gun is employed. In the real ILC, the electron has to be polarized to determine the initial state and NEA GaAs cathode is used[1]. NEA GaAs cathode has been developed initially by SLAC[3] and is improved by introducing super-lattice structure[4][5], which yields 90% polarization. Because the polarization is not necessary for STF since the aim of STF is demonstrating SCRF for ILC, a wide variety of cathode materials are in a range of our selection. As electron source for STF, CsTe photo-cathode is finally selected. CsTe cathode[6] is now widely used because of the toughness and good performance. CsTe keeps 1.0% quantum efficiency during accelerator operation period more than one month[7].

CsTe requires UV light for electron generation. In STF, 4th harmonics of $1\mu m$ solid state laser is chosen because Yb fibre laser technology can be utilized. Yb fibre laser has a great stability and a large capability generating high power laser[8]. As a solution, the STF laser system employs Yb fibre laser as oscillator and Nd:YLF as amplifiers. From the amplified laser pulse train in IR wavelength ($\sim 1050\mathrm{nm}$), UV light pulse train is generated by harmonic generation. ILC requires 3.2nC bunch charge. Assuming 1% quantumf efficiency of CsTe cathode and 263nm laser wavelength, 1.5 μJ of laser micro pulse energy is required.

The electron source for STF is based on photo-cathode RF gun technology initially developed for FEL and now widely used for various applications[9][10]. In STF, 1.3 GHz L-band RF Gun cavity designed by DESY[11] and manufactured by FNAL is used. The CsTe cathode is formed on a molybdenum plug by evaporation in a vacuum chamber, which is specially designed for the cathode activation and is connected to the RF Gun cavity to transport the cathode plug without air exposure.

LASER SYSTEM

The laser system consists from Yb fiber oscillator(Pico-Second Master Oscillator, PMO), Macro-Pulse Profiler (MPP), Nd:YLF amplifier(YLFA), and Harmonic Generators (HG).

PMO is passively mode-locked laser generating contin-

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* Work supported by MEXT Quantum Beam Technology Program

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uous pulse train in 40.625 MHz repetition and 10 ps micro-pulse width. PMO is composed from Yb fibre laser pumped by 100 mW power LD and two mirrors forming optical cavity. One of the mirror is SESAM (Semiconductor Saturable Absorber Mirror) for the passive mode-locking. The mirror is mounted on a movable stage for a rough tuning on the mode-lock frequency. For the fine tuning, a piezo cylinder is implemented. The optical fibre winds around the cylinder and the optical path length of the fibre is modulated according to the drive voltage to the piezo actuator; The mode-lock frequency is then finely controlled by the piezo cylinder and the tuning range is 600Hz. The laser pulse train is extracted from the PMO through fibre output coupler and transported to MPP. Output of PMO is 1050nm in wavelength, 2.0mW in average power, and 50 pJ in micro-pulse energy. The power stability of PMO output is 0.5% in several hours. Stability of the repetition rate of PMO pulse train is 120 Hz/hour. It is even within the range of the rough abd fube tuning knobs, and the drift can be compensated by a feedback.

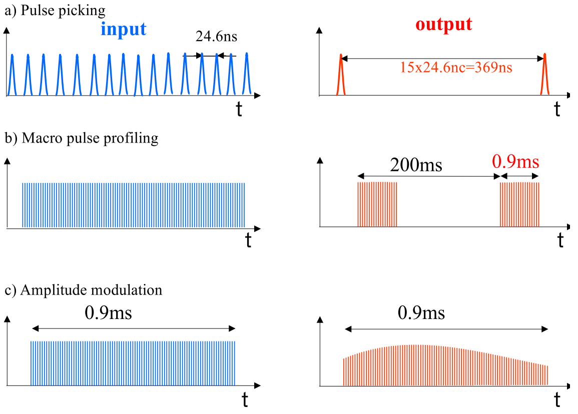

Figure 1: Function of MPP. (a) pulse picking, (b) macro pulse forming, and (c) amplitude modulation. For each figures, left side and right side show input and output signals, respectively.

Fig. 1 schematically shows the functions of MPP. Macro-pulse structure (900μs pulse width) is made by clipping it from the continuous pulse train generated by PMO. The macro-pulse length is shorter than the exact ILC format, 970μs, but it is close enough for the test in STF. Another function of MPP is decreasing the repetition frequency from 40.67 MHz, which is the repetition of PMO output, to 2.71 MHz, which corresponds to electron bunch repetition in STF/ILC. Picking up one micro-pulse in every 15 pulses by EO implements this function. In addition, MPP performs also an amplitude modulation within the macro-pulse as shown in Fig.1 (c). This amplitude modulation is made for compensating amplifier gain variation of YLFA within a macro-pulse. The amplitude modulation is optimized for uniform macro-pulse envelope of the temporal profile of YLFA output.

YLFA operates in a frequency of 5 Hz to ensure a macro-pulse duration of 900 μs with fairly stable amplitude of micro-pulses. To obtain 1.5 μJ micro-pulse energy in Fourth Harmonics (FH), YLFA should provide micro-pulse energy of ~ 10 μJ. The micro-pulse energy of MPP output is about 10 nJ and the gain coefficient of YLFA must be 10^3 or higher. YLFA consists from a couple of flash-lamp-pumped Nd:YLF laser with 5-mm-aperture developed by IAP/RAS. The amplifiers are placed in a two-pass geometry to provide an enough gain. The micro-pulse energy becomes 11 μJ at the output of YLFA. Fig. 2 shows the temporal gain evolution of two Nd:YLF amplifiers. Nd:YLF has a lifetime of the inversion population of 500 μs which is shorter than the macro-pulse length. To obtain a flat gain over 1 ms duration, we need very long pumping light and it would be costly. Instead of the strong pumping, we operate two Nd:YLF amplifiers with different gains and pumping timings, to ensure enough gain as shown in Fig.2. The total gain is kept more than the designed value (30) over 1ms. The gain is, however, not flat and the macro-pulse envelope is expected to be strongly distorted according to this gain evolution. The amplitude modulation in MPP is im-

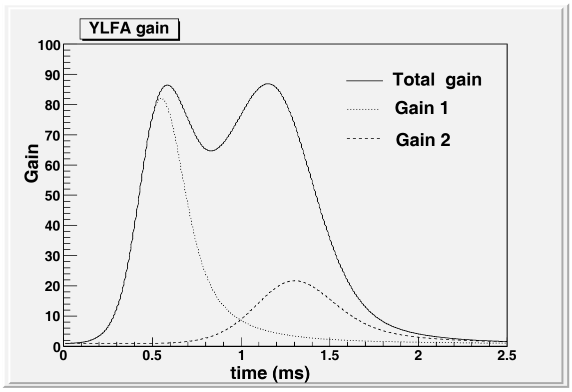

Figure 2: Temporal gain evolution of two Nd:YLF amplifiers. Gain 1 (dotted line) and Gain 2 (dashed line) show the gain curve of each Nd:YLF amplifiers. The total gain of this amplifiers is shown by a solid line, which keeps more than 30 (designed value) over more than 0.9ms.

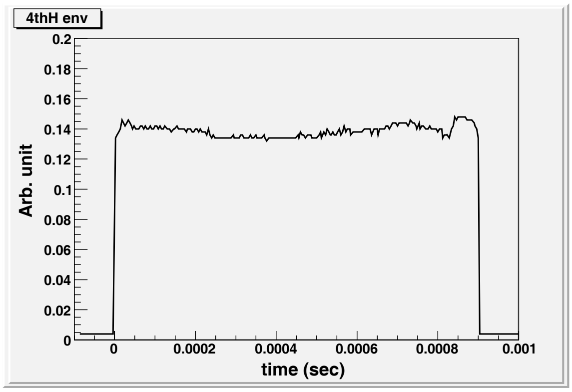

Figure 3: Envelop of a macro pulse in 4th harmonics. The relative flatness of the pulse envelop is 2.5% in rms.

plemented to compensate this distortion. The gain and timing of each Nd:YLF amplifiers are optimized to obtain a flat macro pulse envelop at the output of YLFA. Fig. 3 shows envelop of one macro pulse in FH. The strong distortion is compensated and 2.5% flatness in rms is obtained.

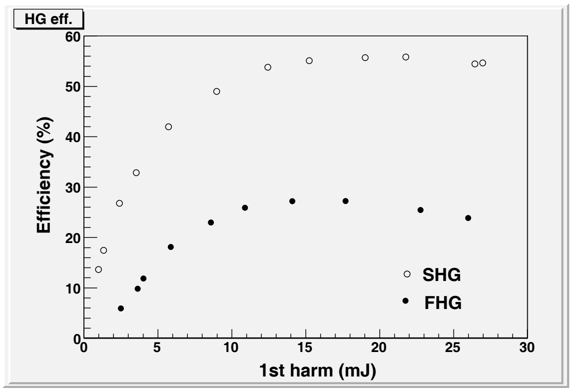

Figure 4: Conversion efficiency in % as a function of the the fundamenatl mode macro pulse energy.

The amplified pulse train in 1050nm is then converted to UV light by SHG (Second Harmonic Generation) and FHG (Fourth Harmonic Generation). According to our investigation among various birefringence crystals[12], KTP and BBO are chosen for SHG and FHG, respectively. KTP is 7.5mm crystal in type II phase matching and BBO is 10.0 mm crystal in type I phase matching. The total conversion efficiency expected to be as high as 30%. Fig. 4 shows the experimental results of the efficiencies of SHG (open circle) and FHG (closed circle) as a funtion of the fundamental pulse energy in mJ. More than 25% efficiency was obtained giving 1.9 μJ micro-pulse energy in UV. Fig. 5 is a histogram of the 4th harmonics power and shows the power stability in 10 minutes. It was 2.4% relative in rms, which satisfies the requirement, less than 3%. The similar data of the fundamental mode and 2nd harmonics were taken and the stability were 1.3% and 2.8%. The micro-pulse length is less than 8.5ps at SH due to the non-linear nature.

The system is initially developed in IAP/RAS, Nizhny-Novgorod, Russia. After the confirmation of the performance satisfying the basic requirements in Dec. 2009, the system is transported to KEK, Tsukuba, Japan in March 2010. In KEK-STF, a laser hut is constructed to accommodate this system in near of the injector. The system is reconstructed in the hut and the performance is finally reproduced in KEK, STF at the end of March 2010.

SUMMARY AND FUTURE PROSPECT

The laser system for KEK-STF is successfully developed as a result of collaboration among IAP/RAS, JINR, KEK, Osaka U. and Hiroshima U. It was confirmed that the system performance meets the basic requirements as the driver for the STF photo-cathode injector. Currently, the laser is a stand-alone system and any synchronization to master signal is not implemented at all. Synchronization to master RF signal is easily made by a phase-lock loop with the signal of PMO measured by Photo-Diode, which is already in use, and the fast control by the piezo cylinder. STF will perform the beam acceleration test in 2012. We plan the laser system would be ready for the beam test in this year.

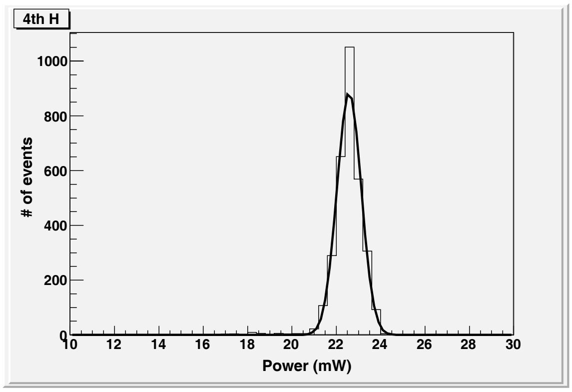

Figure 5: Power stability of the 4th harmonics. The data are accumulated 10 minutes and show the stability 22.57±0.54 (2.4%).

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