DEVELOPMENT OF ADAPTIVE FEEDBACK CONTROL SYSTEM OF BOTH SPATIAL AND TEMPORAL BEAM SHAPING FOR UV-LASER LIGHT SOURCE FOR RF GUN

H. Tomizawa[1], H. Dewa[1], T. Taniuchi[1], A. Mizuno[1], T. Asaka[1], K. Yanagida[1], S. Suzuki[1], T. Kobayashi[1], H. Hanaki[1], and F. Matsui[2],
Accelerator Division, Japan Synchrotron Radiation Research Institute (SPring-8), 1-1-1 Kouto, Mikazuki-cho, Sayo-gun, Hyogo 679-5198, Japan[1]
Creative & Advanced Research Department, Industrial Technology Centre of Fukui Prefecture, 61 Kawaiwashiduka-cho, Fukui City 910-0102, Japan[2]

Abstract

We have been developing a stable and highly qualified UV-laser pulse as a light source for the rf gun, which is a potential injector for future light sources. Our gun cavity is a single-cell pillbox, and the copper inner wall is used as a photo cathode. At present, the short pulse energy stability of laser has been improved, with a reduction to 1.3~1.5% (rms) for third harmonic generation.

In this improvement we only passively stabilized the system. We considered environmental controls in the clean room to reduce optical damage accidents and constructed a new humidity-controlled clean room in 2003. We then re-installed the entire laser system in this room in 2004. The relative humidity of this new clean room at room temperature is in the region of 50~60%, with a stability less than 2% (peak-to-peak). On the other hand, the ideal spatial and temporal profiles of a shot-by-shot single-laser pulse are essential in order to suppress the emittance growth of the electron beam from an rf gun.

This laser-shaping project has proceeded in two steps since its inception in 2002. In the first successful test run in 2002, with a microlens array as a simple spatial shaper, we obtained a minimum emittance value of 2π mm•mrad with a beam energy of 3.1 MeV, holding its charge to 0.1 nC/bunch. In the next test run in 2004, we prepared a deformable mirror for spatial shaping and a spatial light modulator based on fused-silica plates for temporal shaping. We are applying both types of adaptive optics to automatically shape both the spatial and temporal UV-laser profiles simultaneously with a feedback routine. We report here the principle and developing process of our laser beam quality control system.

INTRODUCTION

We have been developing a photo-cathode rf gun [1] as a highly qualified electron beam source to achieve future X-ray light sources (FEL (free electron laser), Compton back scattering, etc.) since 1996 in a test facility at the SPring-8 site. Future X-ray light sources will require an electron beam source with a low emittance of ~1 π mm•mrad. Our development of this type of gun is oriented toward a long-lived stable system for user experiments. It is necessary for the copper cathode of the rf gun to have a UV-laser pulse with a pulse width of ~10 ps and a photon energy of ~4 eV.

Since we started to develop the test facility, two issues regarding the laser light source have appeared. One is the energy stability of the UV-laser light source. The other concerns the spatial and temporal laser profiles. The quality of the laser beam is essential to stabilization and generation of a low-emittance electron beam.

We passively stabilized the system. Environmental controls were considered in the clean room to reduce optical damage accidents, and a new humidity-controlled clean room was constructed (relative humidity at room temperature: 50~60%). The pumping source of the laser system was stabilized with a temperature-controlled base plate. As a result of the passive stabilization, the pulse energy stability of the laser has been improved with a reduction to 1.3~1.5% (rms; 10 pps; 10000 shots) for third harmonic generation (THG).

On the other hand, optimal spatial and temporal profiles of a shot-by-shot single laser pulse are essential in order to suppress the emittance growth of the electron beam from a photo-cathode rf gun. This laser-shaping project has proceeded in two steps since its start in 2002. Specifically, higher stability of the pulse energy is required and homogeneous Silk-hat (cylindrical flattop) spatial and rectangular temporal profiles of the UV-laser light source must be generated.

In the first spatial shaping test run, we shaped the laser spatial profiles with a microlens array. Consequently, the horizontal emittance was significantly improved from 6 to 2 π mm•mrad at a beam charge of 0.1 nC/bunch. This experimental data represents a new record for the minimum emittance of an electron beam from a single-cell-cavity rf gun [2].

In the next test run, we applied both types of adaptive optics to automatically shape both the spatial and temporal UV-laser profiles with a feedback routine simultaneously. We prepared a deformable mirror for spatial shaping and a spatial light modulator based on fused-silica plates for temporal shaping. Both adaptive optics were installed in the UV-laser optical transport. The development process of our beam quality control systems are reviewed in the remainder of this paper.

EXPERIMENTAL SET-UP

Configuration of CPA - Ti: Sa Laser System

The UV-laser light source for the rf gun consists of a mirror-dispersion-controlled Ti: Sapphire laser oscillator (Femtolasers Produktions GmbH) operated at a repetition rate of 89.25 MHz, a chirped pulse amplification system (Thales Lasers Co., Ltd.) operated at a repetition rate of 10 Hz, and a third harmonic generator system. The fundamental laser oscillates at a central wavelength of 790 nm with a spectral bandwidth (FWHM (full-width at half maximum)) of 50 nm. The pulse energy of the fundamental laser is 30 to 60 mJ/pulse after the multi-pass amplifier. After the third harmonic generation (central wavelength: 263 nm), the laser pulse energy is 200 to 400 μJ/pulse with a repetition rate of 10 Hz. The best pulse energy stability of the original laser system was 2% for generation of the fundamental harmonic and 3% for the third harmonic. This original system cannot keep the laser spatial profile homogeneous for long periods of operation due to damage and misalignments.

Environmental Control System for the Laser

In principle, we planned only passive stabilization of the system. We considered environmental controls in the clean room to reduce optical damage accidents and then constructed a new humidity-controlled clean room in 2003. The relative humidity of the new clean room at room temperature is in the region of 50~60% with a stability of less than 2% (p-p). The temperature was kept constant at 21 ℃ (±0.3 ℃) on the laser table. Also, the laser pumping sources are stabilised with a water-cooled base plate. As a result, the short pulse energy stability of laser has been improved, with a reduction to 1.3~1.5% (rms; 10 pps; 10000 shots) at the THG (263 nm).

At the present state of development, long-term stability depends only on the stability of mode locking at the oscillator laser. If the oscillator is stable without out-of-mode locking, the overall laser system can be stable for long-term operation with short pulse energy stability as mentioned above.

Figure 1: New humidity-controlled laser clean room.

Tested Optics for Laser-Profile Shaping

Microlens array as a spatial homogenizer - This laser system produces an inhomogeneous spatial profile. Therefore, we used several microlens arrays as a homogenizer for the first test run [2]. This microlens array is a collection of small hexagonal convex lenses with a pitch of 250 μm. The transmission of this optical array is about 80% in the ultraviolet region. This makes it possible to shape any laser spatial profile as a Silk-hat (cylindrical flattop) by combining with a convex lens. The main difficulty in utilizing this optical system is the manner in which the homogenized laser profile transports toward the cathode surface while focusing. Even if the entire wave front of the laser does not reach the cathode at the same time, the laser spot on the surface should be within the depth of focus.

Deformable mirror and SLM - Consequently, we used a deformable mirror (left upper in Figure 2) as a spatial shaper for the second test run. This deformable mirror consists of an aluminium-coated, multilayer silicon nitride membrane and 59 small hexagonal mirror-actuators behind the reflective membrane with a center-to-center distance between the actuators of 1.75 mm. The outermost layer of the reflective membrane is protected with an MgF_2 coating to keep reflectivity at about 70% in the ultraviolet region. Adjusting the voltages between the control electrodes on the boundary actuators performs fine adjustment of each mirror-actuator. The adjustable region of the control voltages is between 0 and 255 V with a step of 1 V. This makes it possible to shape any laser spatial profile with a total forming possibility of 256^{59}($\sim 10^{110}$). However, such a high adjustability makes manual as well as simple algorithm adjustment impossible. Thus, this spatial shaping method needs a sophisticated algorithm. One concept for a sophisticated program based on this genetic algorithm for a deformable mirror has been developed through a joint project [3].

Figure 2: Adaptive-optics complex for shaping both spatial and temporal laser profiles.

To control the temporal parameters of the laser pulses, we are preparing a programmable pulse shaping system in the fundamental wavelength region using a spatial light modulator (SLM) based on fused-silica plates (Cyber Laser Inc.: right in Figure 2). The temporal profile is measured with a streak camera.

We installed a deformable mirror and an SLM in the UV-laser transport while developing a sophisticated program to examine the spatial and temporal shaping ability of inhomogeneous original UV-laser profiles.

EXPERIMENTAL RESULTS FOR SPATIAL SHAPING

Results and Effects of Spatial Shaping with Microlens Array (In First Test Run)

The laser spatial profile without homogenization is shown on the left-hand side in Figure 3. The profile was spatially shaped by a microlens array as a quasi-Silk-hat profile (see the right-hand side of Figure 3). These profiles were measured with a laser beam profiler (Spiricon Inc., LBA300-PC). By spatially homogenizing, the emittance improved from 3.3 to 2.3 π mm•mrad at a beam charge of 0.1 nC/bunch. While it was not perfectly Silk-hat-shaped, laser profile was greatly improved.

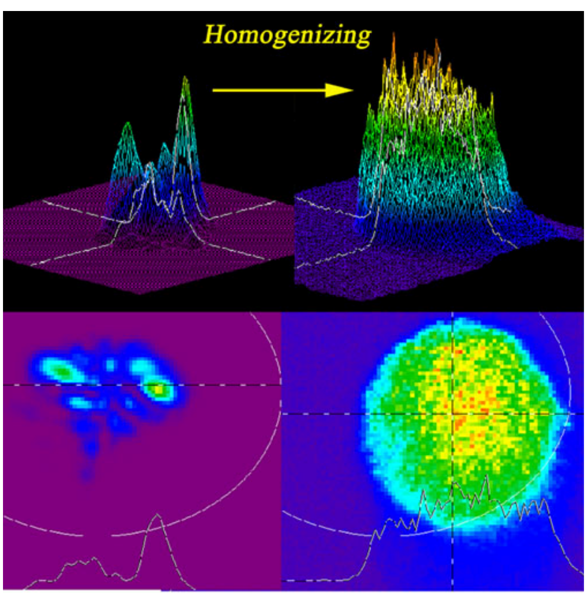

Figure 3: Homogenization results with microlens array.

Result of Spatial Shaping with Deformable Mirror (In Second Test Run)

The laser spatial profile was shaped manually for test purposes with the deformable mirror. The profile was spatially shaped by a deformable mirror as a quasi-Gaussian profile (Figure 4). This profile was also measured with the laser beam profiler. While the laser spatial profile was improved by this shaping technique, it was far from Silk-hat-shaped in this test. For perfectly Silk-hat-shaping, the amount of deformation possible with this mirror is not large enough.

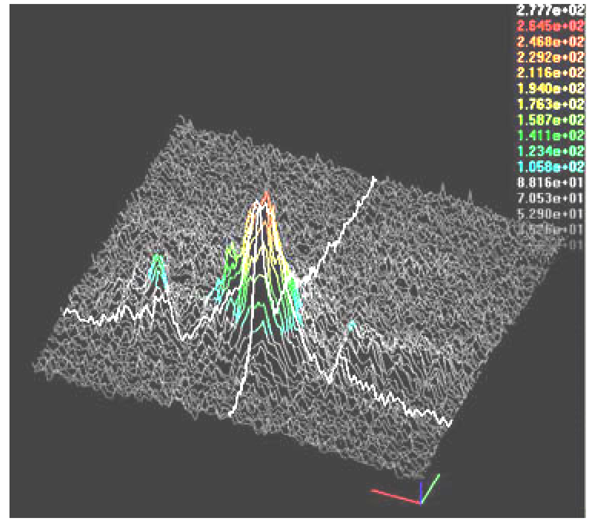

Figure 4: Spatial shaping result with a deformable mirror.

FUTURE PLANS AND DISCUSSION

Comparing the results of the spatial profiles between the two different test runs shown in Figures 3 and 4, we can see that both spatial shaping methods were successful. Especially in the shaping with the microlens array, the horizontal emittance significantly improved from 6 to 2 π mm•mrad at a beam charge of 0.1 nC/bunch. However, the amount of deformation with this type of deformable mirror (electrostatic actuator) is not large enough. For perfect Silk-hat-shaping, it is necessary to combine the method with aspheric lenses. A sophisticated program to control the spatial and temporal shaping is under development. However, the shot-by-shot optimization of each laser pulse profile can be difficult. Thus, the laser system should first be passively stabilized by environmental controls. At present, the short pulse energy stability of the laser has been improved to 1.3~1.5% at the THG (263 nm). This stability is sufficient for shot-by-shot automatic optimization with adaptive optics. The long-term stability depends only on the stability of mode locking of the oscillator laser.

In the future, we intend to shape both profiles of each electron beam bunch generated by each UV-laser pulse. An OTR monitor will be used to measure the electron beam profiles. The profile data will be used for the feedback routine to automatically optimize the electron beam pulse profiles. With this procedure, ideal electron beam profiles can be generated with compensation for some of the optical distortions and the inhomogeneous distribution of the quantum efficiency of a cathode.

REFERENCES

[1] T. Taniuchi et al., Proc. of 18th. Int. Free Electron Laser Conf., Vol. 2, 137, Rome, 1996.
[2] H. Tomizawa et al., Proceedings of the 2002 European Particle Accelerator Conference, 1819, Paris, July 2002.
[3] T. Itatani, AIST Today, p. 18, April 2003.