SPATIAL AND TEMPORAL SHAPING OF PICOSECONDS DRIVE LASER IN PHOTOCATHODE RF GUN*

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Abstract

In this paper, we present the experimental spatial and temporal drive laser shaping results by using of a pi-shaper sample and an interferometer setup pulse stacking system. Based on the spatial and temporal shaping results, a scheme for quasi-ellipsoidal shaping and the evolution of critical parameters are also studied.

INTRODUCTION

In Photocathode RF Gun, the distribution state of electron beam emitted from photocathode is depended on the distribution state of drive laser. To reshaping the drive laser pulse as a uniform spatial and temporal distribution is beneficial for low emittance beam generation [1, 2, 3].

About the spatial shaping: H. Tomizawa et al presented the shaping methods and experimental emittance improvement results of ”micro lens array” and ” deformable mirrors” [4, 5, 6]; pi-shaper from Mol Tech [7] and shaper from Newport [8] are all very simple design, nearly perfect flattop profile was generated and emittance improvement was also measured [9, 10] by its application; besides, a more favorable design was proposed by Zhang [11].

Temporal shaping of laser pulses is mostly achieved by modulating the amplitude and phase in the spectral domain [12, 13] using optical devices such as a spatial light modulator, it is not suitable for picosecond laser pulse, because of the relative narrow width in the spectral domain. Although an acousto-optic programmable dispersive filter, commercially known as DAZZLER [14], has successfully shaped laser pulse in the picosecond regime, its use proved limited for low energy laser pulses operating at a repetition rate up to a few kHz. For low repetition rate picosecond laser pulse, pulse stacking technology is a feasible method, which has two different stacking way: interferometer setup [15] and Birefringence crystal [9].

After spatial and temporal shaping, a quasi-uniform cylinder pulse can be obtained, but the most perfect one is a uniform ellipsoidal pulse, the emittance value would be reduced by more than 40% from that obtained using uniform cylindrical shape laser pulses [16]. Ellipsoidal electron or laser pulse had been obtained with a femtosecond drive laser [17, 18, 19, 20].

SPATIAL SHAPING

Pi-shaper is an achromatic telescope of galilean type design, the input beam is requested as a collimated gaussian or similar intensity profile with specific beam diameter. The original pulse from our laser head is an elliptical spot with 1.55 mm and 1.4 mm length of major and minor axis respectively, a beam expander is used before the shaper to expand the beam size and collimate the pulse, as shown in Fig. 1(a). Fig. 1(b) show the measured beam profile at different longitudinal position from the shaper exit with a 4 times magnification beam expander, consisting of two plano-convex lenses of focal length 50 and 200 mm, respectively. The shaping results becomes distorting when the distance from the shaper exit exceed 150mm. From the fist two profiles in Fig. 1(b), we can find that the intensity of the left part of central area is a little lower than the other area. This problem still appear in the shaping result(the first profile in Fig. 1(c)) with a 3.57 times magnification beam expander, consisting of two plano-convex lenses of focal length 35 and 125 mm,respectively. We convince the possible reasons are: 1) the original elliptical spot; 2) the distorting of original gaussian distribution inducted by beam expander; 3)problem with pi-shaper sample .

The 6 mm diameter spot from the shaper exit is disadvantaged to acquire low emittance, so a suitable minification beam reducer is needed to match the demands of high quality beam generation. The beam profile at 100 mm distance from 3 minification(consisting of two plano-convex lenses of focal length 150 and 50 mm,respectively) and 5 minification(consisting of two plano-convex lenses of focal length 150 and 30 mm,respectively) beam reducer are all shown in Fig. 1(c).

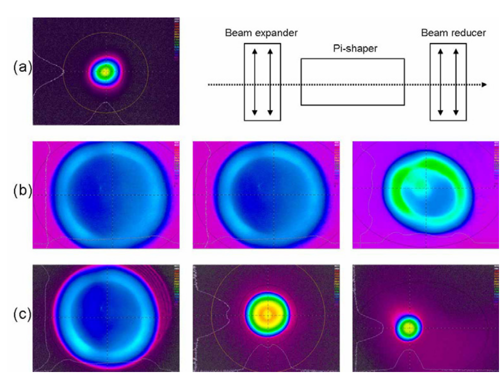

Figure 1: Measured beam profile (a) left: original pulse; right: optical line for spatial shaping. (b) out put profile with 4 times magnification beam expander, left to right: 50mm from shaper exit; 120mm from shaper exit; 400mm from shaper exit. (c) out put profile with 3.56 times magnification beam expander, left to right: 50mm from shaper exit; 120mm from 3 times minification beam reducer; 120mm from 5 times minification beam reducer.

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TEMPORAL SHAPING

A interferometer setup pulse stacking system is employed to reshape the temporal distribution of laser pulse, its schematic diagram is shown as Fig. 2. The polarization angle of input vertical polarization pulse is rotated 45 degree by a half wave plate; polarization beam splitter is used to split the input pulse to 2 micro-pulses, 2 pulses can be split similarly to 4 micro-pulses; then, the micro-pulses are stacked with specific interval, which is controlled by tuning the optical delay lines. Fig. 3 is the temporal distribution

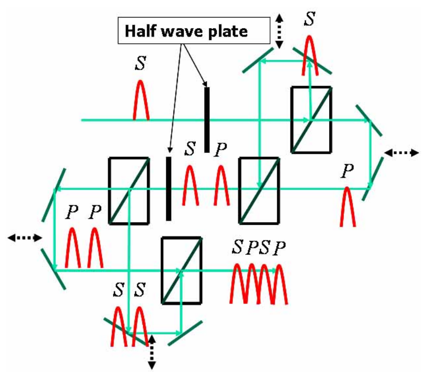

Figure 2: schematic diagram of temporal shaping.

profile of the laser pulse before and after temporal shaping, which is measured by a streak camera. Before shaping, the pulse is a gaussian distribution with $\sigma = 3.8ps$ FWHM pulse width; after shaping, the stacked pulse is a quasi-uniform distribution with some picoseconds rising and falling edge. Compared to Birefringence crystal stacking way, the interval between micro-pulses are continuous tunable with interferometer setup stacking way, but it has a more compact optical transport line. The emittance improvement of spatial and temporal shaping is simulated by program ASTRA [21], as shown in Fig. 4. The emittance will minimized greatly by spatial shaping and 4 pulses stacking temporal shaping, and 8 pulses stacking will be more favorable. The emittance can be improve furthermore by eliminating the rising and falling edge of stacked pulse.

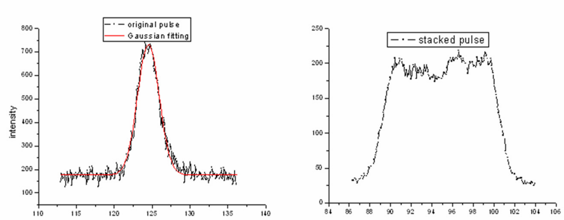

Figure 3: Temporal distribution of original pulse and stacked pulse.

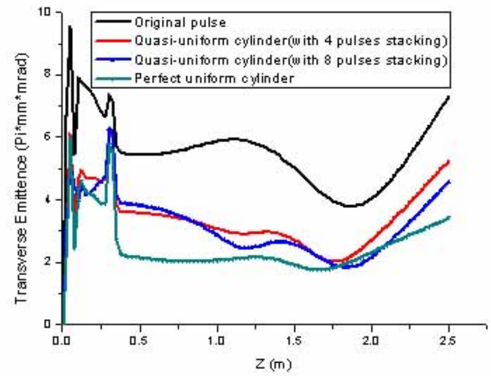

Figure 4: Emittance Vs longitudinal position at different pulse distribution state.

QUASI-ELLIPSOIDAL SHAPING

The ellipsoidal distribution is characterized with a constant charge density $(\rho(x, y, z) \equiv Constant)$ inside a volume that is bound by the following ellipsoid of Eq. 1 where r_{max} is the maximum radius and l is the half of the total bunch length

$$\frac{x^2}{r_{max}^2} + \frac{y^2}{r_{max}^2} + \frac{z^2}{l^2} = 1 \tag{1}$$

Charge and beam radius with longitudinal position is determined by Eq. 2 and Eq. 3:

$$Q(z) = Q(0) \cdot (1 - \frac{z^2}{l^2}) \tag{2}$$

$$r(z) = r_{max} \cdot \sqrt{1 - \frac{z^2}{l^2}} \tag{3}$$

Quasi-uniform ellipsoidal shaping based on spatial shaping and interferometer setup pulse stacking can be implemented, Fig. 5 is the sketch of optical transport line. To keep the uniform distribution of spatial profile during the quasi-uniform ellipsoidal shaping, an image relay system [9] for long distance transport should be emplaced before the system. Variable apertures are used to tune the beam size of micro-pulses, interval between micro-pulses is set at $\sigma \cdot C$ (C is the velocity of light) by tuning the optical delay lines. The radius of the 8 micro-pulses are set as: $r(1, 1') = r_{max}$, $r(2, 2') = r_{max} \cdot \sqrt{1 - \frac{(3/2 \cdot \sigma \cdot C)^2}{l^2}}$, $r(3, 3') = r_{max} \cdot \sqrt{1 - \frac{(5/2 \cdot \sigma \cdot C)^2}{l^2}}$, $r(4, 4') = r_{max} \cdot \sqrt{1 - \frac{(7/2 \cdot \sigma \cdot C)^2}{l^2}}$, where $l = 4 \cdot \sigma \cdot C$. Drawbacks of the quasi-uniform ellipsoidal shaping are: low efficiency and compact structure. Fig. 6 shows the side elevation and temporal current distribution of the quasi-uniform ellipsoidal pulse.

The evolution of emittance and current with different r_{max} are studied by using the program ASTRA, the results show as Fig. 7 and Fig. 8. Compare with quasi-uniform cylinder pulse with 8 micro-pulses stacking, the

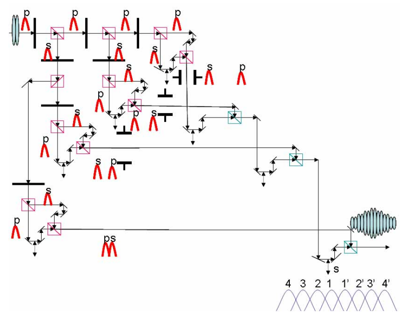

Figure 5: Sketch of quasi-uniform ellipsoidal shaping setup.

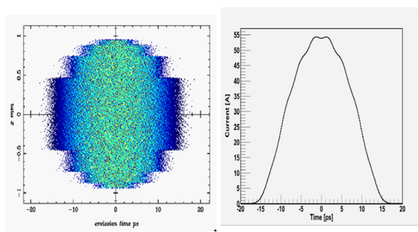

Figure 6: Quasi-uniform ellipsoidal pulse left: side elevation; right: temporal current distribution.

quasi-uniform ellipsoidal pulse can minimize the emittance by more than 30%. Optimized magnetic field intensity of the splenoid coil for low emittance generation are distinct at different r_{max}, whereas the inject phase is constant because of the same initial phase space. A smaller r_{max} is more benefit to get lower emittance. When r_{max} is growing up, the charge density is getting down, then the repulsive space charge force is also getting down, so, electron pulse with smaller longitudinal size, higher peak current and lower energy spread can be generated by the Gun.

Overall consideration, $r_{max} = 1.0mm$ is most benefit for high quality electron beam generation.

CONCLUSION

A relative ideal flattop spatial profile is generated by using of a pi-shaper sample, we analysis the experimental results and consider the practical application. With a interferometer setup pulse stacking system, quasi-uniform temporal distribution pulse is acquired. Besides, we propose a quasi-uniform ellipsoidal shaping method based on the spatial and temporal shaping results, the evolution of critical parameters are also be studied.

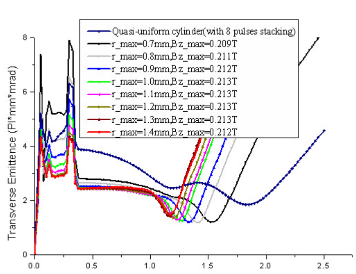

Figure 7: Emittence Vs longitudinal position at different r_{max}.

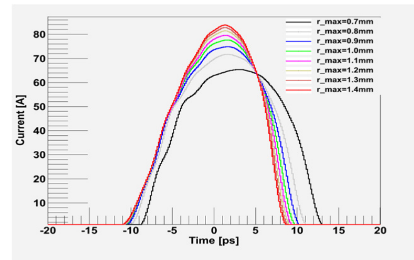

Figure 8: Current distribution of electron beam from the gun at different r_{max}.

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