A BEAM SHAPER FOR THE OPTICAL BEAMLINE OF RF PHOTOINJECTORS

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Abstract

The paper reports on first results on beam shaper for the generation of a flat-top beam profile in the ultraviolett (UV). The shaper can be integrated into the optical beamline of the PITZ facility [1]. This will improve the efficiency of the optical beamline significantly.

INTRODUCTION

A high performance of SASE FELs requires a low emittance of the electron bunches that emerge from the photoinjector. This in turn can be favoured by irradiating the cathode by a laser beam with a spatial and temporal flat-top profile [2]. A simple way to illuminate the photocathode with a uniform beam profile is to strongly expand the laser beam with a telescope and select the very central region of the magnified beam by means of a small “beam shaping aperture”. This method which is presently implemented at PITZ, inherently gives rise to a large loss of the incident UV-laser power. At PITZ the transmission amounts to approximately 20%, and 80% of the UV laser radiation are lost at the beam shaping aperture.

Thus, a more efficient technique for optical beam-shaping is desirable.

BEAM SHAPING TECHNIQUES

Conceivable technical solutions can be associated with one of the following methods:

Field mapping: The input beam is transformed into the desired output beam by refraction at appropriately designed aspherical surfaces in a prescribed manner. This technique works well for diffraction-limited beams and can be nearly lossless. A plane wavefront, i.e. a collimated beam can be generated at the ouptut of the shaper by adding a second aspherical lens. Both, the temporal shape of the pulse and the coherence of the laser beam are maintained, which is particularly important for the optical beamline of photoinjectors. Field mapping permits to precisely control the final intensity profile. For these reasons it is the method of choice for our beam shaper compared to the alternatives outlined below.

We suggest the setup of Fig. 1 for integration of the beam shaper into the optical beamline. Two magnifying telescopes are used to match the beam diameter to the requirements of the individual components. The former beamshaping aperture remains in place. It is needed to increase the edge steepness in the wings of the flat-top.

Another alternative are **beam integrators** which split the input beam by a lens array into a large number of facets. Subsequently, the energy within each facet is dispersed over the cross section of the desired output beam. The output profile is the sum of the diffraction patterns of each individual aperture of the lens array. That’s why the output beam exhibits strong, small-scale intensity modulations (speckles) and the beam integrators work satisfactory only for multimode beams. They are lossless as well.

However, due to their principle of operation they destroy the spatial coherence of the laser beam. There is also no condition of constant optical path, so some temporal broadening of the pulse duration results.

A third medthod is the **radial intensity filter** (RIF) [3]. This filter can be realized based on birefringent crystals with a curved surface that provides a radial variation of polarization retardation. One or more such radial birefringent elements in combination with polarizers form a RIF. They are lossy due the absorption of light in the polarizers. As a further disadvantage, flattening of the nearly Gaussian infrared (IR) laser beam can only approximately be obtained due to limited degrees of freedom in its design parameters.

Beam shaping elements based on by **internal conical refraction** are commercially available [4]. These systems require depolarized or circular polarized monochromatic radiation and contain a biaxial/trigonal crystal. The crystal

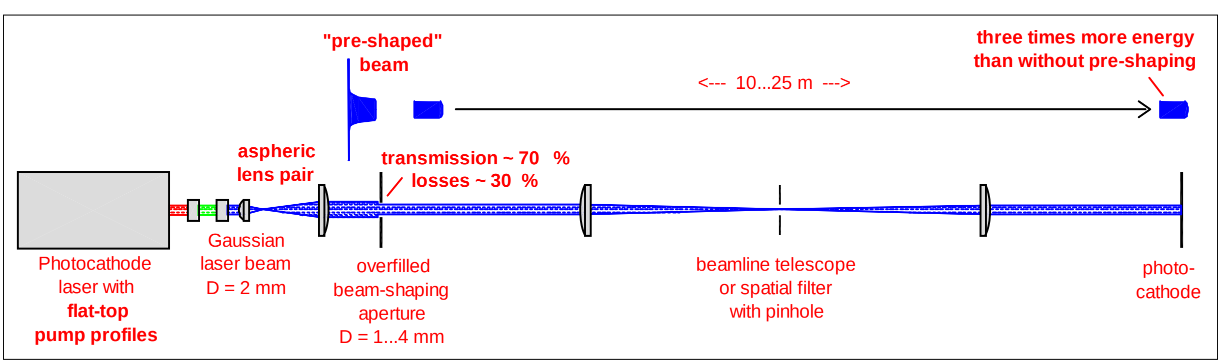

Figure 1: Proposed scheme of an optical beamline for the rf-photoinjector at PITZ that integrates a refractive beam shaper.

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length has to be adapted to wavelength and diameter of the input beam. Since no polarizers are needed, this system can be highly transmissive. Unfortunately, there are no suitable biaxial birefingent crystals available for the UV at present. That's why the technique cannot be used in the UV beamline of a photocathode laser.

EXPERIMENT

We have designed a beam shaper that consists of a Galilean telescope made of two refractive aspherical lenses. Fig. 2 shows how the input rays from the laser system are redirected into a uniform distribution within a Galilean telescope. The Fig. 3 shows our measured beam profiles at the input, in the middle and the exit of the lens pair when using a HeNe-laser. The absence of a focus between the aspheres is important for application at the PITZ beamline, since this excludes possible optical breakthrough due to high UV peak powers.

Our beam shaper is presently designed for 4 mm diameter (FWHM) of the flat-top and 2.8 mm ($1/e^2$) diameter of the Gaussian input. The aspheres are 100 mm apart. There diameters were chosen for a nominal power transmission of 99.9%. Following [5], a smooth Fermi-dirac profile instead of a step function was chosen to represent the flat-top profile, since this reduces diffraction effects along the propagation path of the output profile.

Sensitivity against beam size fluctuations

For application of the shaper in a beamline of a photocathode laser, the beam profile at the cathode should be stable as far as possible, even if the diameter of the input beam varies slightly. That's why we have carefully examined the sensitivity of of the otput beam against a 10% fluctuation of the input beam diameter for our spherical lens pair. The results are depicted in Fig. 4.

The amount of the deviations on the edge of the flat-top depends approximately linear on the dimensionless shape parameter ß of the Fermi-dirac profile. ß represents the ratio of the radius of the flat-top and the total width of the soft transition region where the intensity returns to zero [5]. With increasing ß the profile becomes gradually flat and square, approaching a step function as $ß \rightarrow \infty$. In the example shown in Fig. 4 the overshoot amounts to 15%.

We conclude from our experience with the current beam shaper that a design tolerant against fluctuation of the input beam diameter is more important than an almost perfectly flattened output profile with steep edges. This means that ß should be reduced considerably, a future value of $ß = 6$ seams to be suitable for our application.

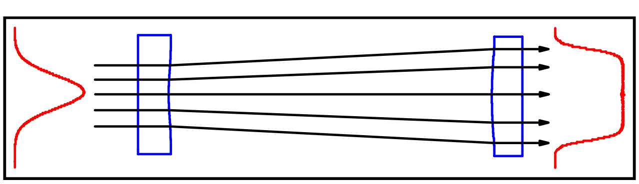

Figure 2: Basic scheme of the refractive field mapping beamshaper (Galilean design)

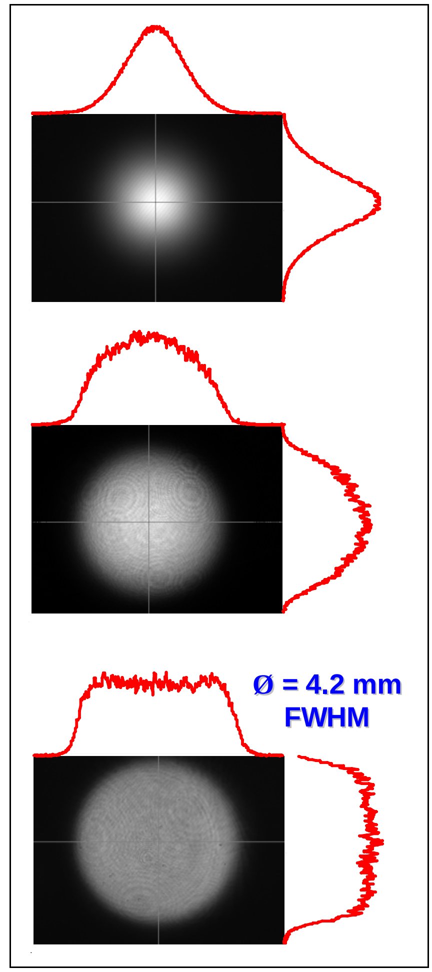

Figure 3: Mesasured beam profiles at the entrance, midway and at the exit of the beam shaper

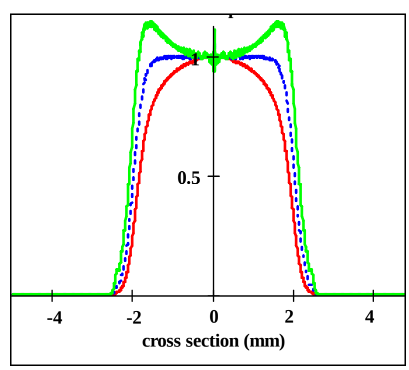

Figure 4: Output profile for varying beam radius w at the input (shape parameter $\beta = 16$): $w = 0.9 \cdot w_0$ (red), $w = w_0$ (blue), $w = 1.1 \cdot w_0$ (green), design value: $w_0 = 1.422$ mm ($1/e^2$)

With the additional option of a spatial light modulator that might preceed the aspherical lens pair the remaining error at the edges as well as some remaining radial variation of the intensity might be corrected.

Propagation of the UV beam

Fig. 5 shows the beam profile produced by the refractive beam shaper in a matched UV beam (left). The present realization of the nonlinear frequency conversion produces a slight elliptical beam in the UV. Its horizontal cross section is slightly larger than in the vertical direction. This is responsible for the observed overshoot in the horizontal cross section at the output plane of the aspherical lens pair. The beam profile was reasonable preserved by relay imaging over a distance of about 1 m, see Fig. 5 (right).

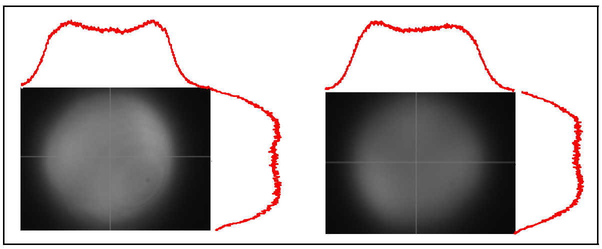

Figure 5: Output beam profile of the aspherical lens pair at 262 nm wavelength (left) and its relay image in a distance of approx. 1 m with (right).

CONCLUSION AND OUTLOOK

The suggested integration of a refractive beam-shaper into the optical beamline of the PITZ photocthode laser has the potential to form a flat-top beam profile and simultaneously improve the energy efficiency of the complete beam-line. Consequently, the application of an appropriately designed beam shaping system can lead to a significant reduction of the overall costs of the laser due to its reduced power requirements.

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