ADVANCED LONGITUDINAL DIAGNOSTIC FOR SINGLE-SPIKE OPERATION AT THE SPARC FEL*

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Abstract

Ultra-short, very low charge beams will soon be used to drive short wavelength single-spike operation at the SPARC Free Electron Laser (FEL) [1]. This paper explores the development and construction of a longitudinal laser pulse diagnostic capable of completely characterizing the radiation based on the Frequency-Resolved Optical Gating (FROG) technique. In particular, this paper explores a geometry based on a Transient-Grating (TG) nonlinear interaction and includes studies of start-to-end simulations for pulses at the SPARC facility and reconstructed using the FROG algorithm. The experimental design, construction and initial testing of the diagnostic are presented.

INTRODUCTION

The recent developments made in the FEL community are beginning to have a large impact on end-user groups where researchers from many scientific disciplines seek to utilize the unique features of these robust light sources [2]. However, full pulse characterization, including pulse length as well as full phase information, has been somewhat difficult to acquire. Pulse amplitude information can be obtained through a simple autocorrelation but the phase information ultimately is lost due to the nature of the autocorrelation signal and the one-dimensional phase retrieval problem. Some experiments have succeeded at retrieving the phase information, and thus a full pulse reconstruction, using a process called Frequency-Resolved Optical Gating [3]. Many of these FROG diagnostic geometries were complicated and operated only for small bandwidth. This paper explores the implementation of a new geometry based on the Transient-Grating (TG) nonlinear interaction [4]. The geometry has minimal alignment degrees of freedom and has the added advantage of operating from frequencies ranging in the ultraviolet (UV) to the infrared (IR). The design of such a geometry is studied with start-to-end simulations of low charge, ultra-short pulses where the wavelength of operation is 400 nm at SPARC, which has been simulated using PARMELA [5], ELEGANT [6] and GENESIS [7] and reconstructed using Femtosoft Technologies FROG software [8]. The experimental design, construction and initial testing of the diagnostic are also discussed.

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FROG

The FROG pulse reconstruction technique involves using a nonlinear optical process to obtain an autocorrelation signal, which is then spectrally resolved to yield a spectrogram, or FROG trace [9]. The phase information, which is vital to full pulse reconstruction, is stored within this trace and is retrieved using inversion algorithms. There are many different geometries that utilize various nonlinear processes to obtain the FROG trace. Two characteristics are desirable for the purposes of investigating FEL signals; 1) The geometry should operate on a single shot basis to investigate pulse to pulse variability and 2) should work for a wide range of frequencies to account for the tunability of the FEL.

FROG Diagnostic Geometry

The geometry developed by Dongjoo Lee *et al.* (Fig.1) meets these criteria. First, the pulse obtained from the transport is expanded and passed through a mask to split it into three beamlets. These beams then pass through a cylindrical lens, which brings each beamlet to a line focus within the nonlinear medium. Before reaching the medium the beamlets pass through a fresnel bi-prism, which crosses interfering beams at a relatively large angle. Crossing the beams at an angle maps a relative delay along one of the beam's transverse dimensions, here along the vertical axis. This particular geometry operates on a single shot basis and does not require any additional delay lines. A major advantage of the bi-prism is that it is aligned in space and time. The interaction of the three beamlets within the crystal generates an autocorrelation signal, which is selected by the output mask. The signal is then spectrally resolved by passing it through a custom fabricated spectrometer (consisting of a collimating lens, diffraction grating and focusing lens). Imaging the spectrally resolved signal pulse along the horizontal transverse dimension into a CCD yields a FROG trace.

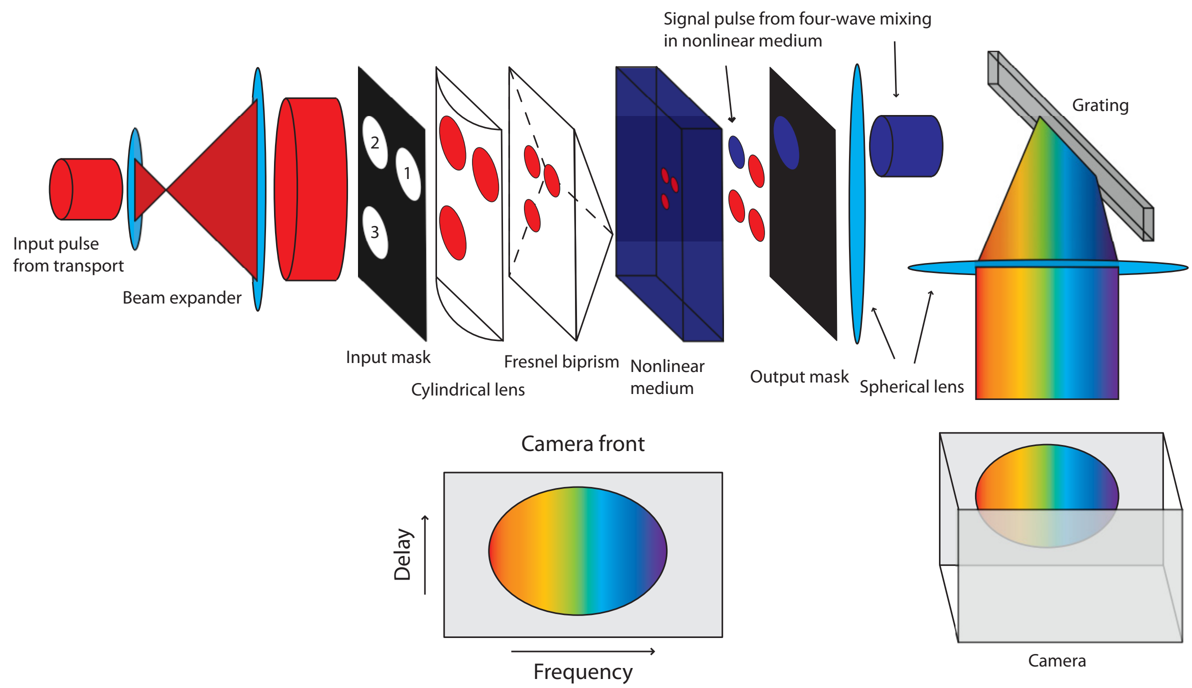

Figure 1: Transient-grating FROG geometry proposed for SPARC FEL as described in Ref. [4].

SIMULATION

Start-to-end simulations of low charge, ultra-short beam pulses lasing at 400 nm at the SPARC facility were investigated. Beam creation and propagation were simulated using PARMELA and ELEGANT while FEL operation was simulated using GENESIS. FROG traces were also generated from these simulations and were analyzed using Femtosoft Technologies FROG software. The FROG trace generated by GENESIS as well as its reconstruction for the 400 nm simulation are pictured in Figure 2. There is reasonable agreement between the original trace and the reconstruction for the simulated scenario.

The reconstructed temporal and spectral profiles can be seen in Figure 3. The reconstructed images and their GENESIS counterparts for both the longitudinal and spectral intensities are in good agreement. The amplitude and full phase information of the pulse was extracted successfully in the reconstruction process.

EXPERIMENTAL DESIGN

A commercially available cage assembly system was employed for the experimental layout. The cage system takes full advantage of the linear geometry and allows for the quick alignment of optical components along the direction of propagation (Fig.4). The layout of the device follows the description of Fig.1.

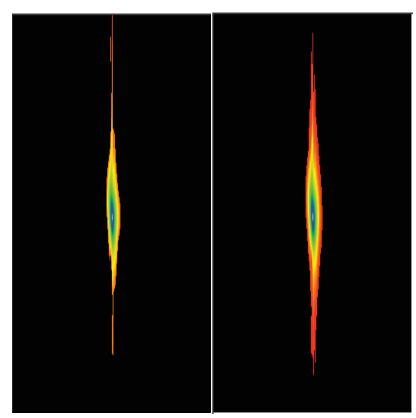

Figure 2: FROG trace from simulation (left) and its reconstruction (right) for the 400 nm case at SPARC.

The bi-prism was mounted on a kinematic cylindrical lens mount which in turn was mounted on a micrometer. This allowed for alignment in all directions made necessary by the sensitivity of the nonlinear signal to the position of the bi-prism. The 1200 line/mm groove-density grating was placed on a swivel mount to control the incident and reflected angles of the signal which were focused into a CCD camera.

Initial Testing

The initial testing of the TG FROG device is currently underway at the Pegasus laboratory using a state of the art

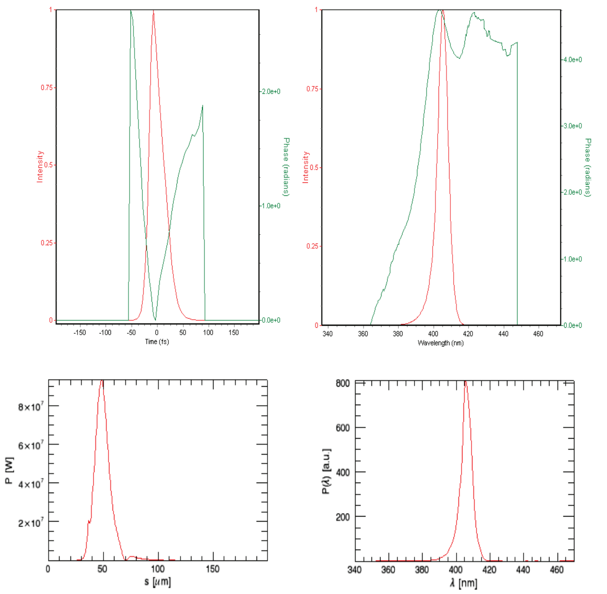

Figure 3: Above: the reconstructed temporal intensity and phase plots (left) and the spectral intensity and phase plots (right). Below: corresponding plots generated by GENESIS simulations.

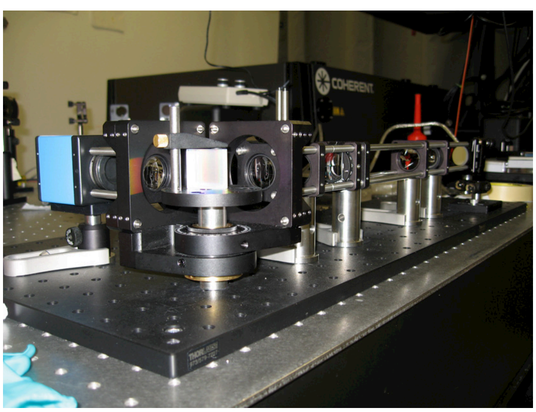

Figure 4: Photograph of the TG FROG layout in the Pegasus lab.

all diode pumped Titanium:Sapphire based laser system capable of generating sub 50 fs pulses. Figure 5 shows a false color image of a FROG trace of one such pulse. The plot shows the signal spectrum vs. time delay. The lack of structure in both the horizontal and vertical directions indicates similar characteristics in the longitudinal profile and spectrum. The time and frequency calibration of the diagnostic is currently under study.

CONCLUSION

A relatively simple, broadband TG FROG device is the most efficient and effective way to longitudinally characterize FEL pulses at the SPARC facility. The TG FROG beam

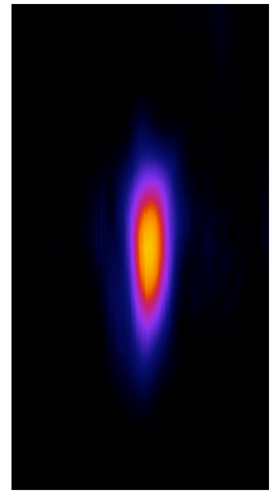

Figure 5: FROG trace of a 400 nm pulse from the Pegasus photoinjector drive laser

geometry has the ability to operate in both the UV and the IR without requiring the change of any optical components. It is specifically designed to operate at two wavelengths of special interest at SPARC, namely 400 nm and 800 nm. Start-to-end simulations were carried out for 400 nm with successful reconstructed results. The spectral and temporal profiles successfully replicated the corresponding plots generated by GENESIS.

Construction of the diagnostic is complete with initial tests currently being performed at the UCLA Pegasus laboratory. Initial results show pulse structure that is congruent with expected results. Further investigation is underway to calibrate the frequency and time domains with the ultimate goal of full phase recovery and pulse reconstruction. Future work includes upgrading the dispersive optics to reflective optics and testing the diagnostic over a range of wavelengths.

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