DESIGN AND STATUS OF THE VISA II EXPERIMENT

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Abstract

VISA II is the follow-up project to the successful Visible to Infrared SASE Amplifier (VISA) experiment at the Accelerator Test Facility (ATF) in Brookhaven National Lab (BNL). This paper will report the motivation for and status of the two main experiments associated with the VISA II program. One goal of VISA II is to perform an experimental study of the physics of a chirped beam SASE FEL at the upgraded facilities of the ATF. This requires a linearization of the transport line to preserve energy chirping of the electron beam at injection. The other planned project is a strong bunch compression experiment, where the electron bunch is compressed in the chicane, and the dispersive beamline transport, allowing studies of deep saturation.

INTRODUCTION

The development of a source of high brightness x-rays is an important instrument for studying structural dynamics at the atomic level. The fundamental time scale for atomic motion is on the order of tens of femtoseconds [1]. A single pass self amplified spontaneous emission (SASE) free electron laser (FEL) has the capability to bring about such short pulse x-ray lasers [2]. One way to achieve such high frequency resolution, is to chirp the radiation pulse, then compress the pulse using diffraction gratings. This would reduce the pulse length to the order of tens of femtoseconds [3]. Radiation pulse chirping can be obtained by injecting a chirped electron bunch into the undulator. Theoretical studies have shown that the coherence time is independent of chirp [4], but have yet to be verified experimentally. Another method to drive an x-ray FEL is to inject a short compressed pulse into the undulator.

EXPERIMENTAL OVERVIEW

Summary of VISA I Results

The succesful VISA I experiment was designed to investigate physical properties of SASE-FEL as it relates to future LCLS operation. Saturation was achieved at 840 nm with a SASE power gain length of 17.9 cm and total gain of 10^8. A novel bunch compression mechanism was developed during the VISA I experiment. This scheme utilized second order momentum error effects in the dispersive line. The proper choice of linac phase detuning and quadrupole settings yielded strong longitudinal bunch compression, and as a result, much higher current [5].

Another achievement of the VISA I experiment, was the development and deployment of a start-to-end (cathode to undulator) computational model. The computational effort involved employing UCLA-PARMELA for gun and linac calculations (emittance, charge, energy, energy spread), ELEGANT for transport lattice calculations (bunch length, beam size, emittance growth after dispersive line), and GENESIS 1.3 for undulator studies (gain length, saturation, angular wavelength, and spectra). This computational undertaking, compared with the detailed experimental data, yielded new levels of insight into the dynamics of SASE FEL processes. The same numerical tools will continue to be used for VISA II.

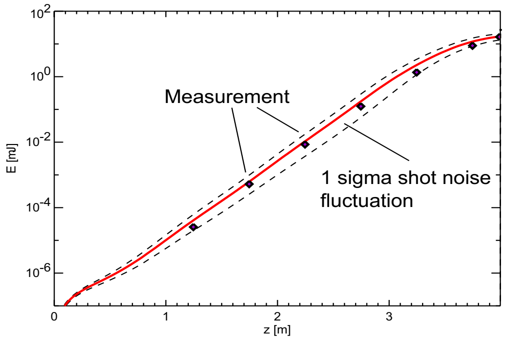

Figure 1: VISA I saturation curve. Measured data is consistent with theoretical calculations.

Experiment Setup

VISA II will encompass a number of hardware changes to investigate the different regimes mentioned above. The undulator and diagnostics will remain unchanged.

Chicane: The chicane compressor consists of four dipole magnets with a nominal field of 0.2 T. The dipoles have a bend radius of 1.2 m and a length of 41 cm. The effective magnetic length is 44.6 cm, with a path length of 41.89 cm. Once the chicane is installed, the electron bunch is expected to compress from 300 μm to less than 30 μm [6]. The current of the bunch is projected to increase from 60 A (VISA I uncompressed running conditions) to 1 kA. Simulations also show that coherent synchrotron radiation

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(CSR) may amplify during compression and in the process microbunch the electron beam. Emittance degradation of 4-10 mm mrad is anticipated [7].

The initial experiment to be performed at VISA II is running the FEL with a short compressed beam (current of 1 kA, charge of 200 pC). According to GENESIS 1.3 simulations, the short compressed bunch should produce extremely high gain. Saturation is expected by the 3rd meter of the 4 meter long undulator (Fig.2). With additional compression, the slippage can be so severe that the gain may not be purely exponential.

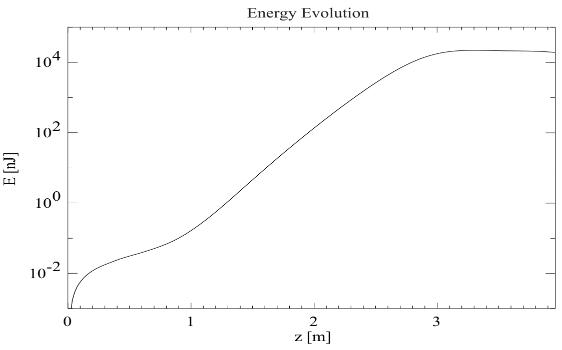


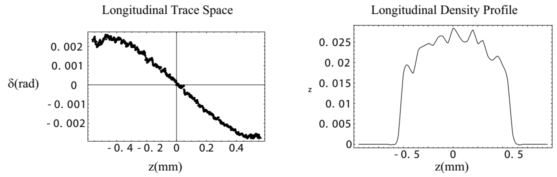
Figure 2: GENESIS 1.3 simulation of the energy evolution within the undulator. Saturation is reached at approximately 3 m, well before the undulator end.

Linearization of Transport: In order to maintain a chirped electron bunch from the linac to the undulator, the transport to beamline 3 must be linearized. Linearization requires a stronger control of the dispersion along the dog leg. The addition of sextupoles will allow VISA II to run in two distinct modes. By diminishing the T_{566}, the linear phase space chirp is maintained, as is illustrated by the ELEGANT simulations in Fig.3. The sextupoles are 5 cm long and have a calculated gradient of 22.0 T/(m^{2}A) [8].

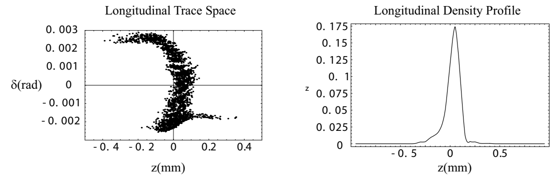
Undulator: The VISA undulator is 4 m long and divided into 4 sections. There are a total of 220, 1.8 cm long periods. The on-axis peak field is about 0.75 T. The undulator has a superimposed quadrupole focusing channel (FODO lattice) throughout the length of the undulator. The electron beam walk-off tolerance inside the undulator is approximately 80 μm [9]. The quadrupoles were aligned so that the beam trajectory would meet this tolerance . Undulator alignment is conducted via a CCD based optical monitoring system [10].

There are eight intra-undulator diagnostics located 50 cm apart. Each port has a double-sided silicon mirror which leases the ability to measure both SASE radiation properties, by reflecting FEL light into the diagnostics, as well as electron beam position and envelope outline, by generating optical transition radiation (OTR) for the beam imaging diagnostics [11].

a) Initial Trace Space after linac.



b) Final Trace Space after dispersive section (without sextupoles).



c) Final Trace Space after dispersive section (with sextupoles).

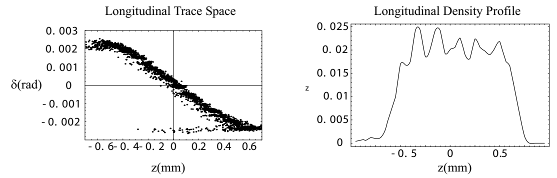


Figure 3: ELEGANT simulations of electron beam linear chirp preservation through dispersive line. VISA II can be run in two distinct modes: the compressed case, due to the natural R_{56} of the dog leg, and the energy chirped case, where the sextupoles are turned on.

CHIRPED PULSE MEASUREMENTS

Conditioning

By accelerating the electron beam at an off-crest RF phase, a linear chirp (energy spread - longitudinal position correlation) may be imparted onto the beam. Once sextupoles are utilized the T_{566} component of the transfer matrix can be minimized, allowing control of the linear chirp throughout the beamline. The input linear chirped phase space will be preserved and injected into the undulator. This will allow control of the frequency distribution of the generated radiation pulse. The natural negative R_{56}, discovered from the original VISA runs, stretches the pulse slightly. However, altered compressor settings can make the R_{56} positive. Experimental and computational analyses will determine various modes of operation, balancing compression, linearity, and degree of chirping. The initial measurement for VISA will be to run with the largest possible chirp obtainable, without degrading the FEL gain. Preliminary calculations show that this chirp is on the order of 4-5 %. In addition, the beam may be partially precompressed in the chicane, without removing its chirp, to raise the current in a chirped beam expertiment.

Simulation Results

Numerical studies have been conducted on the spectral response of a driving initially chirped electron beam. Simulations show that total energy at saturation is not affected by chirping up to 4 % (no gain degradation), even for the case of the 60A (uncompressed) beam. It is necessary to exceed 2 % chirp to overcome the intrinsic frequency width of the FEL amplification in order to achieve a measureable correlation between frequency and time.

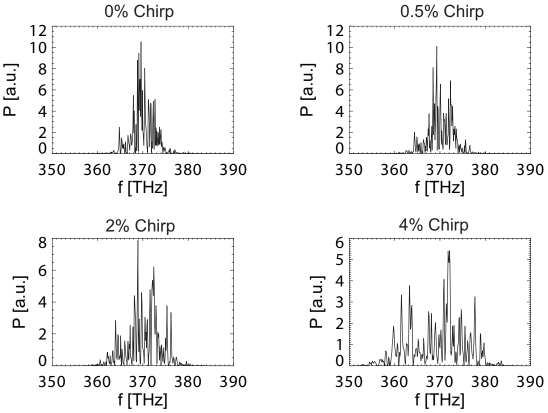


Figure 4: GENESIS 1.3 simulations of chirped pulse radiation spectrum (frequency domain) for varying degrees of chirping.

Proposed Measurements

The goals of the chirped beam experiment are to determine the gain length as a function of degree of chirping, and to measure the spectral correlation of the output beam. Theoretical studies show that the effects of the electron beam chirp on FEL is small if the resonant radiation frequency change within a cooperation length is small [4]. These results must be verified experimentally. FEL properties to be measured include saturation power, intenstiy fluctuations, and spectral and angular properties of the chirped radiation.

The wavelength chirping of SASE radiation can be used to make pulses on the order of 100 fs. Using a monochromator and double diffraction grating the radiated output can be compressed. This encompasses a few experimental complications. Creating short pulses on the order of 10 fs from pulses already on the order of 10 ps, is an experimental challenge. Measuring such short pulses requires reliance on nonlinear effects in materials.

The proposed scheme to measure this output is named Frequency Resolved Optical Grating (FROG) [12]. The signal is split and recombined to overlap at different times in a nonlinear, frequency doubling, crystal. The doubled output light has a time dispersed axis and is sent to a spectrometer which disperses frequency in the other dimension. Standard algortihms are used to reconstruct amplitude and phase informatin of the input radiation. A simplified FROG device (Grenouille), using a thick nonlinear crystal and a Fresnel biprism, yields a simplified single-shot, ultrashort-pulse intensity-and-phase reconstruction device [13]. The measurement of the epxected pulses will be simplified in operation by the use of Grenouille.

EXPERIMENTAL STATUS

The VISA II program is in its initial stage. The Particle Beam Physics Lab (PBPL) of UCLA has developed and is presently installing a chicane compressor for the ATF at BNL. The chicane magnets, vacuum vessel, and coherent synchrotron radiation (CSR) diagnostics have been developed at UCLA. The hardware installation of the chicane is nearing completion. The improvements to the diagnostics on the dispersive line and the mathcing line are underway. The addition of sextupoles will take place in the early summer of 2003, coincident with the chicane dipole installation.

Initial runs for VISA II are dedicated to bringing the beam up to successful operating conditions. The upgraded facilities of the ATF require revising the original run settings; technicalities must be addressed to reestablish high gain lasing conditions. Preparatory runs have yielded successful characterization of beam envelope evolution, and emittance measurements, utilizing the quadrupole scanning technique, are imminent. Optical methods have been used to measure the undulator alignment, however, they have been indeterminate as to whether undulator alignment is adequate. Undulator electron beam trajectory measurements are forthcoming and will be used to confirm alignment before any attempts to re-align are undertaken.

ACKNOWLEDGEMENT

This work is supported by ONR Grant # N00014-02-1-0911.

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