MASTER OF SCIENCE
IN
APPLIED PHYSICS

SIMULATIONS OF THE TJNAF FREE ELECTRON LASER WITH A NEGATIVE TAPER AND LASER DAMAGE STUDIES
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The Free Electron Laser (FEL) is a candidate for a future close-in weapon system that will provide a longer protective range for missile destruction. The FEL is also tunable to wavelengths that would give good atmospheric transmission and optimal target absorption characteristics at the target. This thesis describes single-mode and multimode simulation results of the Thomas Jefferson National Accelerator Facility (TJNAF) FEL operating at far infrared wavelengths. The TJNAF FEL uses inverse tapering and is driven by 34.5 MeV and 47.5 MeV energy electron pulses. Steady-state power, weak-field steady state gain, electron beam energy spread and optical spectrum widths were explored as a function of the desynchronism and tapering rate. The simulations described FEL pulse evolution and short pulse effects. The simulation results have been presented at an International Conference held at Duke University, Durham, NC in August 2000. In addition, the results of damage to Slip-cast Fused Silica samples by the TJNAF FEL, with and without the effect of airflow are analyzed. A comparison with older damage experiments was done in order to develop scaling rules in the future.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Free Electron Laser, Undulator, Negative Taper, Close-in Weapon Systems

SINKING A BODY WITH BUBBLES IN CLOSED AND OPEN ENVIRONMENTS
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The presence of bubbles in a liquid decreases the average density, and thus decreases the buoyant force on a floating body. Competing with the decrease in buoyancy is an upward drag due to the bubble motion and entrained liquid. This thesis presents investigations of the critical average density required to sink a buoyant body in water with bubbles in closed and open environments. A *closed* environment is where bubbles fill the container, in which case there is expected to be little if any upward flow of water at the body. An *open* environment is where the bubbles exist over a small cross-sectional area compared to the total cross-sectional area of the container, which models the effect of a methane eruption from the ocean floor. In this case, a substantial upward flow of water is entrained in the region of the bubbles, and a downward flow consequently occurs outside this region. Experiments for both closed and open environments are reported, where the average specific gravity of the body is varied. The closed environment data significantly deviate from a quantitative theory, and the open environment data are not in accord with a qualitative theory. Possible explanations for these deviations are offered.

DoD KEY TECHNOLOGY AREA: Other (Fluid Dynamics)

KEYWORDS: Water, Density, Specific Gravity, Volume Fraction, Bubbles, Buoyancy, Nonnewtonian Fluid

TESTING AND DEVELOPMENT OF A SHROUDED GAS URBINE ENGINE IN A FREEJET FACILITY

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Testing and analysis of a shrouded turbojet engine with possible application for high speed propulsion on low cost Unmanned Combat Aerial Vehicles (UCAV), Unmanned Aerial Vehicles (UAV) and missiles was the subject of this thesis. The possibility of a turbojet providing thrust at subsonic conditions and the ramjet section providing the thrust in the supersonic regime exists. The combined cycle engine (CCE) could be incorporated into a variety of applications.

The building of a new freejet facility and engine test rig at the Naval Postgraduate School enabled dynamic testing of the ongoing development of a turboramjet. The freejet facility and new engine stand performed without exception. The shrouded engine was dynamically tested in a freejet up to Mach 0.4. The engine performance measurements closely matched those predicted by a cycle analysis program, GASTURB.

Computational fluid dynamics (CFD) was used to analyze the supersonic inlet at a design point of Mach 2. The results provided by the CFD code, OVERFLOW, matched theoretical flow parameters. The intake design was slightly modified to enhance performance of shock waves in the supersonic flight regime.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: Micro-Turbojet, GASTURB, Engine Shroud, Turboramjet, Sophia J450, Microturbine

RADIATION EFFECTS ON InGaAs p-i-n PHOTODIODES

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This thesis identifies, characterizes, and identifies a method to predict the dark current degradation of InGaAs p-i-n Photodiodes caused by exposure to 55 MeV protons, 12 MeV protons, and 90 MeV electrons. Experimental proton and electron fluence levels (particles/cm^2) were calculated and correlated to fluence levels for a 1 MeV neutron in silicon by equating the amount of physical damage incurred within the device. Physical damage was quantified as a displacement damage dose (D_d), which is simply the fluence level multiplied by the appropriate value for the material's non-ionizing energy loss (NIEL). Photodiodes were then irradiated and dark current data was collected. The resulting data were fitted into the three-term diode equation, and current coefficients were obtained. Proton data were used to document device performance, and to examine the relationship between fluence levels and changes in the current coefficients. Additionally, these data were used to verify that it is appropriate to use NIEL and D_d for the correlation of 55 MeV and 12 MeV protons. Electron data were also used to document device performance, but failed to demonstrate the ability of NIEL and D_d to accurately match the predicted changes in device performance caused by 90 Mev electrons and 55 MeV protons.

DoD KEY TECHNOLOGY AREA: Electronics, Other (Radiation Effects)

KEYWORDS: Radiation, InGaAs Photodetectors

DESIGN AND DEVELOPMENT OF THE IMAGE SCANNER FOR LINEATE IMAGING NEAR ULTRAVIOLET SPECTROMETER (LINUS)

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The Lineate Imaging Near Ultraviolet Spectrometer (LINUS) is a spectral imager that works in the ultraviolet region of the spectrum, and its purpose is to study atmospheric gas plumes. This thesis project is part of an ongoing effort to field-test the first version of LINUS by mid-2001. It concentrates in the development of the ultra-precise servo system that controls the pointing/scanning system of the instrument. The closed-loop angular-position servo is controlled by a dedicated motion controller board that is installed in the host computer. Control of the servo is achieved through proportional-integral-derivative (PID) algorithms built into the hardware and firmware of the motion controller board. The servo has been designed to an angular resolution of 9 seconds of arc, and was tuned for a step of 1000 counts. Static and dynamic tests were conducted and showed that the servo is stable and accurate. The tested accuracy of the servo is well within the design goal of one half encoder count.

DoD KEY TECHNOLOGY AREAS: Chemical and Biological Defense, Environmental Quality, Sensors

KEYWORDS: Sensors, Spectral Imaging, Spectrometer, Remote Sensing

SIMULATIONS OF THE TJNAF FEL WITH A TAPERED UNDULATOR AND EXPERIMENTAL RESULTS OF LASER DAMAGE

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The modern maritime battlefield is dominated by the new generation of sea-skimming, high-speed, stealthy and highly agile anti-ship missiles. Anti-ship cruise missile technology continues to evolve, overcoming the performance of the existing ship self-defense weapon systems. The Free Electron Laser (FEL) could be the ultimate speed-of-light hard kill weapon system, offering unique features such as tunability, high power, pinpoint accuracy and infinite magazine. Multimode computer simulations were used to explore the operation of the Thomas Jefferson National Acceleration Facility (TJNAF) FEL with untapered and positively tapered undulator. The final steady state power, the steady state gain and the electron energy spread as a function of desynchronism were determined for both 34.5 Mev and 47.5 Mev electron beam energies.

This thesis also includes an experimental study of damage induced to Polyimide Fiberglass and F2 Epoxy samples, by the TJNAF FEL. Irradiations of the samples were conducted changing various parameters, such as the wavelength, average power, pulse repetition frequency, cross wind and spot size in order to explore the damage mechanism. At this stage of evolution, TJNAF FEL is capable of 500 W output average power, and in order to achieve the required intensity of 10 kW/cm^2 the beam was focused to a small radius. Scaling guidelines were developed in order to predict the damage caused by a high power laser over a large area.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Free Electron Laser, Ship Self-Defense, Tapered Undulator, Laser Damage Experiments

EFFECTIVENESS OF MODELING A HIGH POWER RADIO FREQUENCY (HPRF) WEAPON SYSTEM (U)

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The objective of this research was to model the electromagnetic output of a proposed High Power Radio Frequency (HPRF) weapon system. The antenna data was generated using GNEC, a method of moments computational electromagnetic code. The impulsive excitation and resultant transient near-fields were modeled using electrical circuit analysis and inverse Fast Fourier Transformation programmed in MATLAB 5.3. The peak amplitudes and waveforms were the primary focus of this study

DoD KEY TECHNOLOGY AREAS: Electronic Warfare, Directed Energy Weapons, Modeling and Simulation

KEYWORDS: Electronic Warfare, Directed Energy Weapons, Antenna Design, Antenna Modeling, Electromagnetic Simulation

ADVANCEMENTS IN BURIED MINE DETECTION USING SEISMIC SONAR

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Buried mines continue to disrupt the U.S. ability to project naval power ashore, conduct amphibious assaults, and wage land campaigns. This thesis describes advances in the development of a seismic sonar research tool that resulted in the successful detection of a Mk-63, 1000 lb, mine shape and a M-19, 20 lb, anti-tank mine. This seismic sonar research investigates the concept of using echo returns of a particular seismic interface wave, known as a Rayleigh wave, to detect buried mines. Rayleigh waves are unique in that they have elliptical particle motion that allows one to use vector polarization filtering to separate Rayleigh wave target reflections from other body waves with linear particle motion. A new source design employed in an array of seven elements has been shown to form a narrow beam of Rayleigh wave energy in a sand medium at the navy beach test site. This source beam, coupled with the receiver beam formed by an array of five three-component seismometers has provided a successful bi-static seismic sonar configuration. Signal to noise ratios of 21 dB for the Mk-63 mine shape, and 9 dB for the M-19 anti-tank mine were observed in the target echoes. These experimental results suggest that the seismic sonar is a very promising concept for buried mine detection.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Mine Warfare, Buried Mine Detection, Seismic Sonar, Surface Waves

MODELING SECOND GENERATION FLIR SENSOR DETECTION RECOGNITION AND IDENTIFICATION RANGE WITH POLARIZATION FILTERING

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The influence of polarization filtering on maximum detection, recognition, and identification ranges of a generic second generation FLIR sensor is examined with a computational model. The scenario studied represents a second generation FLIR sensor mounted on an aircraft in level flight at 300m approaching a ship target. The target ship radiant signature is modeled with an advanced infrared signature prediction program, MuSES (Multi-Service Electro-Optic Signature). A weather file representative of Midlatitude Summer at sea conditions was utilized. Polarized sea background and path radiance calculations are performed with a polarized version of the SEARAD Radiance and Propagation Code. Results showed that there is an improvement in maximum range of the sensor for detection, recognition, and identification tasks when a horizontal filter is included, provided that the target does not have a negative degree of polarization. For detection task the improvements were found to be 33.48%, 35.65%, and 39.78% when the target has 0%, +2%, and +8% degree of polarization respectively. A better modeling of Apparent Temperature Difference (ATD) calculation is also developed. To improve the model use of polarized target model is recommended.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Thermal Imaging Systems, Minimum Resolved Temperature Difference, Polarization Filters

APPLICATION OF THE ROBUST SYMMETRICAL NUMBER SYSTEM TO HIGH RESOLUTION DIRECTION FINDING INTERFEROMETRY

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This research has examined the benefits of using the Robust Symmetrical Number System (RSNS) to resolve ambiguities in phase sampling interferometry. A compact, high resolution direction finding antenna architecture based on the RSNS was developed to demonstrate experimentally the elimination of phase errors using a minimum amount of hardware. Previous work has determined that phase errors in the system will degrade the system performance. Several improvements were made to the original RSNS prototype antenna to provide enhanced performance. Adding isolators and supplementing the ground plane with copper tape (between the antenna elements), a reduction in the mutual coupling effects was accomplished. Mounting the microwave components on a brass plate also reduced errors contributed by vibrations and temperature. Tailor cutting all semi-rigid coaxial lines also helped reduce the number of connectors required to assemble the microwave circuit, also a source of phase errors. Matching the front-end amplifiers in each amplification stage rather than matching the characteristics of two cascaded amplifiers in each signal line has reduced relative phase errors between channels as well as matching the power outputs of the amplifiers. Two printed circuit boards were designed and built for the RSNS signal processor. The printed circuit boards provide a decrease in the electrical noise floor over the original design (assembled on breadboards). The new design has reduced the phase errors that were present in the

first prototype system. The RSNS signal processing technique is able to provide a high-resolution phase sampled direction finding capability with an angular resolution of 1.9 degrees by using only three receiving elements (two interferometers).

DoD KEY TECHNOLOGY AREAS: Sensors, Electronic Warfare

KEYWORDS: Robust Symmetrical Number Systems, Optimum Symmetrical Number Systems, Phase Sampling Interferometry, Direction Finding, Ambiguity Resolution