MASTER OF SCIENCE
IN
APPLIED PHYSICS

THE SHIPBOARD EMPLOYMENT OF A FREE ELECTRON LASER WEAPON SYSTEM

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A megawatt (MW) class Free Electron Laser (FEL) shows promise as a new weapon for anti-ship cruise missile defense. An FEL weapon system delivers energy at the speed of light at controllable energy levels, giving the war fighter new engagement options. Considerations for this weapon system include employment, design, and stability. In order to reach a MW class laser, system parameters must be optimized and the high power optical beam must be appropriately managed.

In a high power FEL, the optical beam could heat and ultimately damage the optical cavity mirrors. One proposed solution is a short Rayleigh length design, which lowers the intensity on the mirrors, but increases sensitivity to vibrations. This thesis shows a that short Rayleigh length FEL will remain stable using current technology and can be designed to achieve a MW of power. Scenarios are then presented to explore some of the engagement options associated with this weapon system.

KEYWORDS: Free Electron Laser, Short Rayleigh Length, Directed Energy, Mirror Stability

WIRELESS IR IMAGE TRANSFER SYSTEM FOR AUTONOMOUS VEHICLE

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A wireless IR image transfer mechanism was developed and tested for eventual employment on the NPS autonomous ground vehicle. Tests were conducted inside a building as a rough simulation of an urban environment. Two common ISM frequency bands were explored. Experiment results proved that the 915 MHz band was best suited for this effort. Data revealed that minimal signal loss occurs at Line of Site out to several hundred meters. Signal loss through obstructions (cement, wood, and metal) proved significant, on the order of 10 –15 dB per obstruction. But the image transfer was successful through multiple obstructions at a range of 400 meters. Further work includes integration into the autonomous vehicle and testing of the performance.

KEYWORDS: IR Image Transfer, Antenna Polarization, Serial Communication, Wireless Communication, Received Signal Strength

HIGH POWER OPTICAL CAVITY DESIGN AND CONCEPT OF OPERATIONS FOR A SHIPBOARD FREE ELECTRON LASER WEAPON SYSTEM

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A megawatt (MW) class Free Electron Laser (FEL) as a point defense weapon system may lead to a revolution in anti-ship missile defense. Deep magazine, low cost, proportional engagement capability, and speed of light energy delivery provide the FEL with unmatched advantages over kinetic energy weapon systems. Before a FEL is made fleet deployable, stability, system parameter optimization, and operational utility all must be taken into account.

A short Rayleigh length FEL design is being considered in order to reduce system size and mitigate resonator mirror damage. A short Rayleigh length though, can lead to vibrational sensitivities which must be studied. This thesis demonstrates that utilizing currently available technology and properly defined parameters, a short Rayleigh length FEL should be able to achieve a MW of power.

This thesis will also establish the viability of the FEL as a fleet deployable point defense weapon system through the development of a Concept of Operations (CONOPS) which draws from current naval warfare doctrine.

KEYWORDS: Free Electron Laser, Point Defense Weapon System, Shipboard Free Electron Laser System

TUNABLE BANDWIDTH QUANTUM WELL INFRARED PHOTO DETECTOR (TB-QWIP)

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In this thesis, a tunable bandwidth quantum well photo-detector (TB-QWIP) is fabricated and experimentally characterized. The designed detector is based on the Stark effect with two quantum step wells arranged opposite to each other to simultaneously achieve both blue and red shift of the absorption peak for either direction of the bias. The characterization of the TB-QWIP is based on absorption measurement with Fourier Transform Infra Red (FTIR) spectroscopy, current versus applied voltage (I-V) measurement with a semiconductor parameter analyzer, and photo current spectroscopy. The measured IR absorption peaks found at room temperature 8.8 μm and 10.0 μm are in good agreement with designed values. The dark current of the test detector was found to be 10^{-9} A and a background photocurrent was found to be 700 x 10^{-9} A at -4 V bias at 10 K. The background-limited performance of the device was found to be at 60 K. The peak responsivity of the detector was 0.39 A/W at 8.2 μm. The maximum normalized detectivity under background limited conditions D^*_{BLIP}, was calculated to be 3.5 x 10^{11} $\mathrm{cm}\sqrt{\mathrm{Hz}}/W$. The bandwidth of the detector tuned with bias from 1.8 μm at -1 V to 2.7 μm at -4 V, which amounts to 50% higher bandwidth than the original. Further tuning of TB-QWIP parameters based on the analysis of this thesis hold promise for 100% increase of peak width by an applied biased.

KEYWORDS: Tunable Bandwidth Quantum Well Infrared Photo-Detector, TB-QWIP, Absorption, FTIR, I-V Characteristics, Photo Current, Responsivity, Dedectivity, Background Limited, Tunability

IMPROVEMENT OF THE PERFORMANCE OF A TURBO-RAMJET ENGINE FOR UNMANNED AERIAL VEHICLES AND MISSILE APPLICATIONS

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An existing turbo-ramjet engine was modified in order to increase the produced thrust and sustain combustion at increased freejet Mach numbers. The engine's afterburner fuel system was redesigned to improve the vaporization and atomization of the fuel. The engine performed satisfactorily at speeds up to Mach 0.3, producing 100% more thrust over the baseline turbojet. The data acquisition system of the turbo-ramjet engine's performance measurement in a freejet facility was also updated. Various computational fluid dynamics models of the flow through the turbo-ramjet engine were developed to visualize the flow and to predict the engine performance at different Mach numbers.

KEYWORDS: Turbo-Ramjet, Afterburner, UAV Propulsion, Missile Propulsion, Computational Fluid Dynamics, OVERFLOW, Freejet, Small-Scale Engines

DETERMINATION OF YOUNG'S MODULUS OF CARBON NANOTUBES USING MOLECUAR DYNAMICS SIMULATION

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Molecular dynamics simulations were performed to determine the Young's modulus of the single-walled carbon nanotubes (SWNT) and bamboo structural carbon nanotubes (BSNT) models generated from the basic structure characteristics of graphite. The empirical Tersoff-Brenner potential and freestanding thermal vibration methods proposed by Krishnan, et al., were used to determine inter-atomic forces and *rms* displacements of carbon atoms at room temperature ~300 K. The calculated average Young's modulus of SWNT and BSNT model were <Y> = 1.424 and 0.604 TPa, respectively. In particular, the calculated Y value of the SWNT model is in good agreement with the previous measurements. Although, the evaluated Y value of the BSNT model, which represents heterogeneous nanotubes, was less than the pure the SWNT model, it still has strong and stiff mechanical properties compared with other general bulk materials such as hardened steel (210 GPa). CNTs hold a promising future for the variety of potential applications in the nanotechnology field.

KEYWORDS: Molecular Dynamics, MDSS, Carbon Nanotubes, SWNT, BSNT, Young's Modulus, Equilibrium Analysis, Non-Equilibrium Analysis, CNT, Tersoff-Brenner Potential, Freestanding Thermal Vibration Method

ACTIVE VIBRATION CONTROL FOR FREE ELECTRON LASERS

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This thesis is concerned with active control methods for stabilizing the mirror vibrations of free-electron laser weapons on ships so that the laser continues to deliver full power. Alignment of the mirrors is critical

for proper operation because the electron beam and optical mode must substantially overlap. The alignment is expected to be difficult to maintain in a shipboard environment. A theory for controlling the vibrations of a single-degree-of-freedom system is developed and checked by numerical simulations. An apparatus consisting of a flexing aluminum strip was constructed in order to probe the fundamental behavior of actual systems which eventually become unstable as the control gains are increased. A computer data acquisition system (LabVIEW) was implemented so that experiments could be more efficiently and accurately performed. Proportional and derivative controls were used to stabilize the motion of the strip. Experiments reveal that the derivative control behaves according to the theory. In particular, the instability is understood as the result of positive feedback due to a phase shift of the unstable mode. However, the instability due to the proportional control does not behave according to the theory. Improvements that would allow for greater control gains and thus greater stabilization are suggested.

KEYWORDS: Free-Electron Lasers, Active Control, Vibration Stabilization

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ESTABLISHING A VIBRATION THRESHOLD VALUE, WHICH ENSURES A NEGLIGIBLE FALSE ALARM RATE FOR EACH GEAR IN CH-53 AIRCRAFT USING THE OPERATIONAL DATA

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Rotating machinery, such as gears, plays an important role in control of an aircraft. The health of this machinery is a key ingredient to both platform safety and mission success, especially in military operations. The purpose of this thesis research is to establish a vibration threshold level for each particular gear in CH-53 aircraft such that, while minimizing in-flight risk, a negligible false alarm rate is obtained. This study uses Box-Jenkins time series modeling (ARMA) with regression, Mahalanobis distance metrics, goodness-of-fit tests, and the Bonferroni correction to explore the structure of the historical acquisition datasets for particular gear type and aircraft, to set vibration threshold values for "Warning" and "Alarm" situations. Although 28 datasets could not be modeled because of small sample sizes, the other 224 data sets were successfully modeled using ARMA with regression modeling techniques. The Mahalanobis distance metric was then used to set a threshold value of "Warning" and "Alarm" for each gear type. These threshold values were then checked with new data: 200 outliers for "Warning" and 69 outliers for "Alarm" were detected. These outliers might be evaluated as false alarms.

KEYWORDS: Box-Jenkins Time Series Modeling, ARMA, Mahalanobis Metric, Goodness of Fit Tests, Bonferroni Correction