SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 5 | May 2026 - Peer Reviewed Journal

TECHNOLOGICAL INNOVATIONS AND PERSPECTIVES IN MODERN ENGINEERING EDUCATION: INTEGRATION OF FIBER-OPTIC LASER SYSTEMS IN THE PRACTICAL TRAINING OF BACHELOR STUDENTS AT NIKOLA VAPTSAROV NAVAL ACADEMY

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Article DOI: https://doi.org/10.36713/epra28028
DOI No: 10.36713/epra28028

ABSTRACT
This report explores the perspectives and technological possibilities of integrating modern fiber-optic laser cutting systems (model UG-1390FL-3000W) into the practical training of students and cadets in the engineering bachelor's degree programs at the Nikola Vaptsarov Naval Academy. The main areas for implementing the technology in the educational process are examined, encompassing the mastery of specialized Computer Numerical Control (CNC) software (CypCutE), the analysis of thermal processes during the machining of various metals (carbon and stainless steels, aluminum alloys) using auxiliary industrial gases, as well as key procedures for equipment calibration, diagnostics, and industrial maintenance. The analysis demonstrates that incorporating this equipment into the academic curricula provides an interdisciplinary approach that bridges the gap between theoretical knowledge and real-world industrial requirements, thereby significantly enhancing the competitiveness and practical competencies of future engineers.

KEYWORDS: *Fiber-Optic Laser, Engineering Education, Practical Training, CNC Control, Mechanical Engineering, NVNA*

1. INTRODUCTION

Modern engineering and maritime education are undergoing a dynamic transformation, driven by the need to adapt to rapidly emerging industrial innovations. According to international regulatory documents, including the STCW Convention (specifically the 2010 Manila Amendments), there is a requirement for continuous updating of competence standards for future specialists, with an explicit focus on emerging technologies and the introduction of new training methodologies [1]. Similarly, the International Maritime Organization's model courses (e.g., Model Course 7.04) emphasize the necessity of in-depth knowledge of material processing, the operation of complex machinery, and industrial safety [2]. In this context, the Nikola Vaptsarov Naval Academy (NVNA) strategically integrates high-tech solutions into its academic environment to meet these global requirements.

One of the key perspectives for enhancing the practical training of students and cadets in technical bachelor's programs is the implementation of modern Computer Numerical Control (CNC) systems and precision thermal metal processing. The subject of this report is the integration of a compact, fully enclosed fiber optic laser cutting machine – model UG-1390FL-3000W. This technology provides an excellent basis for interdisciplinary training, as its operation requires comprehensive knowledge of materials science, specialized software (CypCutE), mechanics, and the handling of industrial gases under pressure [3].

The aim of this report is to investigate and systematize the primary opportunities for implementing laboratory and practical sessions with the specified laser system in modern education at NVNA. Integrating such industrial equipment into the curricula will allow for a smooth transition from theoretical engineering concepts to real-world production simulations. Consequently, trainees will acquire critical skills for setup, safe operation in accordance with established codes of safe working practices [4], and technical maintenance of advanced equipment, thereby significantly increasing their competitiveness in the labor market.

2. TECHNICAL COMPETENCIES IN CNC PROGRAMMING AND SYSTEM CONTROL LOGIC

The pedagogical value of the UG-1390FL-3000W fiber laser system lies in its capacity to bridge the gap between theoretical geometry (CAD) and physical manufacturing (CAM). The core of this practical module focuses on the mastery of the CypCutE software environment, which facilitates the translation of complex vector designs into precise machine instructions [3]. This integration directly supports the requirements set forth in IMO Model Course 7.04, which mandates that engineering officers possess a high level of proficiency in workshop technologies and the operation of sophisticated mechanical equipment [2].

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The educational focus within this section is structured around three primary pillars:
Algorithmic Path Planning and Nesting: Trainees are required to perform advanced nesting and lead-line optimization. This exercise teaches students how to manage material efficiency through intelligent software algorithms, a skill that is critical for resource management and cost-effectiveness in maritime and industrial repairs [3].
Laser Physics and Real-time Parameter Modulation: Practical sessions involve the empirical calibration of laser power (up to 3000W), pulse frequency, and duty cycle. Students study these variables as dynamic functions of material thickness and thermal conductivity [3]. By observing the physical outcome of different software settings, they gain a deeper understanding of the thermal processing of materials, which is a fundamental component of modern engineering education.

Automated Feedback Loops and Mechatronics: A key part of the training is the configuration and monitoring of the capacitive sensing system (height controller). Students learn to calibrate the BCS100 system, which maintains a constant nozzle-to-workpiece distance with high precision [3]. This provides a practical case study in control engineering and automated feedback systems, allowing students to see how sensors interact with mechanical actuators to ensure process stability.

By engaging with these high-level control systems, students and cadets at NVNA develop the "technical acumen" required for the operation of automated machinery, ensuring they are prepared for the "emerging technologies" highlighted in the STCW Manila Amendments [1].

Graphical Model of the Practical Training Mechanism (CAD-CAM-CNC Cycle):

[1. Theoretical Assignment]
↓
[2. CAD Design] ——> *Creation of the part's vector geometry*
↓
[3. CAM Optimization] ——> *Working with CypCutE: Nesting, applying compensations, and path optimization [3]*
↓
[4. CNC Configuration] ——> *Modulation of laser parameters (power, frequency) and selection of assist gas based on the material [3]*
↓
[5. Mechatronic Feedback] ——> *Automated height control via the capacitive system (BCS100) during the cutting process [3]*
↓
[6. Quality Assessment] ——> *Analysis of the Heat-Affected Zone (HAZ) and cut quality against STCW competency standards [1]*

Table 1. Matrix of Formed Practical Competencies and Technological Parameters

Training Module	Software / Hardware Provision	Key Configuration Parameters	Formed Engineering Competencies
Algorithmic Path Planning	CypCutE Software	Lead-line, Nesting algorithms, Micro-joint	Resource optimization; material efficiency; spatial planning for industrial maritime repairs.
Laser Physics and Modulation	Laser source (up to 3000W) and gas console	Cut Speed, Peak Power, Duty Cycle, Gas Pressure	Understanding the thermal processing of metals; empirical calibration of energy systems according to material specifics [3].
Mechatronics and Feedback	BCS100 Capacitive System	Follow Height, Calibration curves	Configuration of automated feedback systems; sensor diagnostics; process stability control.

3. APPLIED MATERIALS SCIENCE AND THERMODYNAMICS OF LASER-ASSISTED MACHINING

The practical application of the UG-1390FL-3000W fiber-optic laser system offers an advanced pedagogical platform for empirical research in materials science. Unlike traditional mechanical cutting, the solid-state fiber laser operates at a wavelength of approximately 1.06 μm, which enables superior energy absorption rates in industrial metals [6]. Understanding the thermomechanical behavior of these metals under high-energy density irradiation is a critical competency for marine and mechanical engineers, directly correlating with the material properties syllabus outlined in the IMO Model Course 7.04 [2].

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By integrating this technology, students transition from theoretical metallurgy to applied thermodynamic analysis. The laboratory modules within this section encompass: Gas Dynamics and Exothermic Reactions: Trainees investigate the critical role of auxiliary industrial gases (assist gases) in the cutting process. They conduct comparative analyses between different gas dynamics: Oxygen (Reactive Cutting): When processing carbon steel, oxygen acts as an active assist gas, generating an intense exothermic chemical reaction with the hot metal. This reaction releases additional thermal energy, significantly increasing cutting speed and allowing the processing of thicker plates [7] [8]. However, students must analyze and account for the resulting oxide layer on the cut edge. Nitrogen (Inert Cutting): For stainless steel and aluminum alloys, high-pressure nitrogen is utilized to expel the molten material without chemical interaction. This produces a clean, oxide-free cut (bright edge) but requires rigorous parameter optimization to manage gas consumption efficiency and reduce operational costs [8] [9]. Thermal Footprint and Metallurgical Integrity: A primary academic focus is placed on analyzing the Heat-Affected Zone (HAZ). The HAZ is defined as the area of the metal that has not melted but has undergone thermally induced microstructural modifications due to the rapid heating and cooling cycles of the laser pulses [10].

Students evaluate how varying the laser's peak power and cutting speed impacts the HAZ width. For instance, in low-carbon steels, excessive heat accumulation can lead to microstructural transformations (e.g., from ferritic to pearlitic structures) and alterations in grain size [10].

Understanding these thermal effects is vital for preventing localized corrosion and metal fatigue in harsh marine environments. Through this empirical troubleshooting, cadets and students formulate a deep understanding of manufacturing tolerances and material limitations. They learn to balance cut speed, gas pressure, and thermal input, fostering the critical thinking and problem-solving skills essential for modern industrial and maritime workshop practices.

4. CONCLUSION AND STRATEGIC IMPLEMENTATION FRAMEWORK

The integration of the UG-1390FL-3000W fully enclosed fiber-optic laser cutting machine into the Nikola Vaptsarov Naval Academy's engineering curriculum represents a significant advancement in maritime and mechanical education. By effectively bridging the gap between theoretical materials science and hands-on industrial manufacturing, this pedagogical initiative directly answers the STCW Convention’s mandate for enhanced technological proficiency and familiarization with emerging technologies.

To ensure a systematic, safe, and academically rigorous integration of this equipment into the educational process, the following Step-by-Step Implementation Checklist is proposed as a standardized training mechanism for future marine and mechanical engineers:

Step-by-Step Pedagogical Implementation Checklist

Step 1: Occupational Safety and Equipment Familiarization (Pre-requisite)

- Review and apply industrial safety protocols in accordance with the Code of Safe Working Practices for Merchant Seamen (COSWP).
- Master the strict hardware initialization protocol (Turn on/Turn off order) and emergency stop procedures.
- Verify working environment requirements, including ambient temperature control and the preparation of the industrial water chiller.

Step 2: Software Proficiency and Digital Manufacturing (CAD/CAM)

- Import and modify engineering vector files within the CypCutE software environment.
- Execute material optimization techniques (Nesting algorithms, Micro-joints, and Lead-line placements).
- Perform virtual software simulations of the cutting path prior to physical execution to prevent hardware collisions.

Step 3: Applied Thermodynamics and Material Processing (Execution)

- Select and regulate the correct industrial assist gas: Oxygen (for exothermic cutting of carbon steel) or Nitrogen/Compressed Air (for inert mechanical expulsion in stainless steel and aluminum).
- Configure dynamic laser parameters based on material thickness (Cut Speed, Peak Power, Duty Cycle, and Focus Position).
- Execute the automated calibration of the BCS100 capacitive height controller to ensure constant nozzle-to-workpiece distance.

Step 4: Quality Assessment and Microstructural Analysis (Post-Processing)

- Inspect the physical cut quality, evaluating kerf width, dross formation, and edge smoothness.
- Conduct empirical analysis of the Heat-Affected Zone (HAZ) to understand the thermal impact on the metal's microstructural integrity and future corrosion resistance, fulfilling IMO Model Course 7.04 objectives.

Step 5: Preventive Maintenance and System Diagnostics (Ongoing)

- Perform routine diagnostic checks: inspect and replace bottom protection lenses, verify nozzle coaxiality, and clean the ceramic ring.

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- Execute schedule-based maintenance (e.g., draining the air compressor daily, cleaning the chiller) in alignment with the reliability principles of the ISM Code.

Final Summary - by adhering to this structured educational framework, cadets and students will not merely learn to operate a CNC machine; they will deeply comprehend the underlying laser physics, algorithmic software logic, and rigorous industrial safety protocols. This comprehensive, hands-on qualification ensures that NVNA graduates possess the high-level technical acumen required to excel in modern, automated maritime operations and advanced mechanical engineering sectors.

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