LASIMO

Laser Simulation and Optimization

ELECOMP Capstone Design Project 2018-2019

Sponsoring Company:

Iradion Laser, Inc.
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http://www.iradion.com

Iradion Laser is continuing their support of the Program they initiated last year

https://web.uri.edu/elecomp-capstone/project-details-by-team/iradion/

Team Iradion won 1st prize at the 2017 December ELECOMP Capstone Symposium and
1st prize *again* at the 2018 May ELECOMP Capstone Summit

Company Overview: Iradion Laser, Inc. is focused on the design and manufacturing of patented, RF excited, ceramic core CO_2 lasers. The technology is derived from sophisticated military, aerospace and atmospheric monitoring systems and has been commercialized to serve the wider industrial laser market. Iradion's CO_2 laser products are available with power ranging from 30 to 250 W. Applications include direct materials processing (cutting, welding, marking, coding and drilling) as well as select processes in the medical and semiconductor fields. Iradion distributes products worldwide through direct sales and representative organizations. Iradion Laser, Inc. is incorporated in Delaware, USA with corporate headquarters and manufacturing facility in Uxbridge, MA, USA.

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Project Motivation:

Laser light is produced by stimulated emission of photons within an energized medium. Mirrors positioned at opposing boundaries of the medium are used to provide optical feedback, which is required for stimulated emission. Together, the energized medium and end mirrors form a laser resonator, or laser cavity, that can produce an extremely bright and well collimated beam of light. Optimal construction of the laser resonator relies on careful experimentation and optical modeling to understanding critical design parameters and tolerances. Ultimately, experiment and model must converge to successfully understand laser performance.

Despite ubiquitous use in industry, CO_2 lasers are actually not as well modeled and analyzed in scientific literature as other types of lasers and optical systems. This is especially true for the type of CO_2 laser that Iradion produces: the hybrid waveguide/confocal unstable resonator. A major part of the challenge is that the normal modes (spatial intensity distributions) of this type of resonator lack a closed-form, analytical solution. Predicting the output beam requires beam propagation simulation through the resonator using ray trace software, diffraction integral calculations, or a combination of the two.

The aim of this project is to accurately model the optical performance of Iradion's industrial CO_2 lasers. The team will verify model fidelity through careful comparison to laser performance measurements. The model should enable (1) prediction of output beam quality versus modifications to resonator design and (2) tolerance studies for errors in alignment and dimensional errors in constituent components. Ultimately, the product of this effort will be a functional design tool for Iradion's R&D staff.

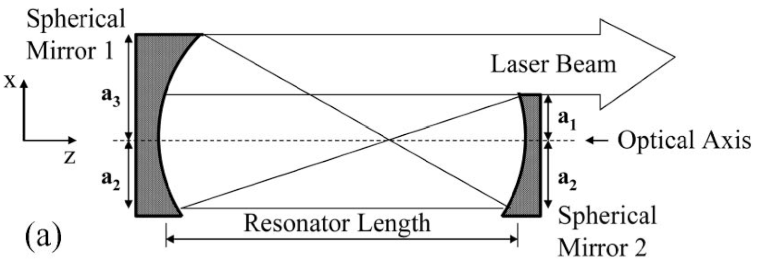
Anticipated Best Outcome:

The best outcome would be an easy-to-use software package that can accurately model the negative-branch, confocal unstable resonator used in Iradion's industrial CO_2 lasers. Performance predictions from the software must converge with physically measured laser performance. The model should be adaptable to design changes, e.g. larger or smaller resonators, folded geometries and component substitutions.

Project Details:

The concept for the project is to build an easy-to-use optical modeling package for the Iradion CO_2 laser resonator. The simulation software package can include commercial optical design software (such as ZEMAX: https://www.zemax.com/products/opticstudio) and/or original simulation programs based on known diffraction integral calculation methods. Evaluation and down-selection from these options are critical early tasks for the project. The key output from the modeling package will be near-field and far-field power intensity distributions of laser light (graphical plots and data arrays).

There are several examples in the literature of similar modeling projects. For example, Hall, et al.[1], modeled the performance of a full negative-branch, confocal unstable resonator. The figure below shows a simplified two-dimensional schematic (XZ plane) of the resonator design. Unlike a stable confocal resonator, here the mirrors have different radii of curvature, hence there is magnification. Hence the beam builds inside the resonator and is magnified until a portion of the beam leaks out over the cut-away section of Mirror 2.



The authors of that paper calculated the output beam using the numerical technique originally developed by Fox and Li[2] to solve the Fresnel-Kirchhoff integral equations. Their results for the near-field and far-field power distributions are shown in the figure below. It is anticipated that

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[1] T. Hall, et al., "Modified negative-branch confocal unstable resonator," Applied Optics 45, 8777–8780 (2006).

[2] A. G. Fox and T. Li, "Resonant modes in a maser interferometer," Bell Syst. Tech. J. 40, 453–488 (1961).

the present project will achieve similar modeling capability, albeit with results specific to the Iradion laser resonator designs.

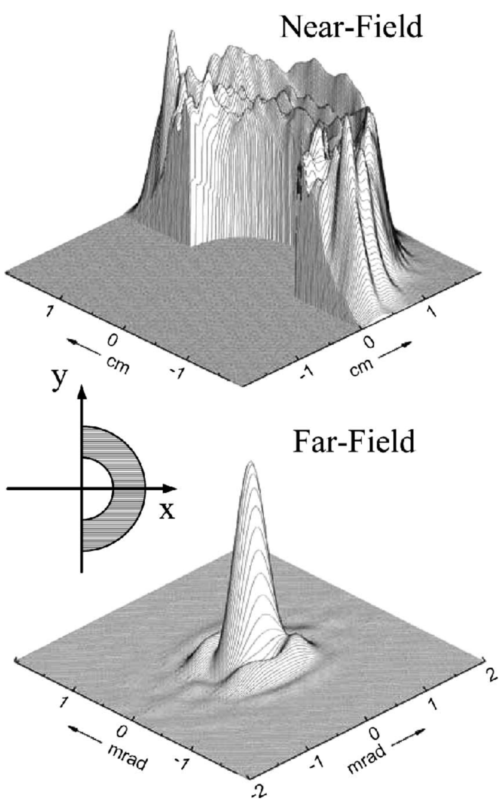

Fig. 5. Calculated near- and far-field distributions of the MNBUR.

With assistance from the Iradion R&D staff, the capstone team will verify model accuracy by measuring actual laser performance and comparing model and experimental data. After baseline validation is confirmed, adaptability and tolerance studies should be performed by changing components (such as alternative mirrors) and varying alignment of the optical elements of the resonator (such as mirror angle). These will also be compared to experimental measurements.

Some specific tasks that are anticipated for the project team are listed below.

Mathematical tasks include:

- Develop basic competency in geometrical and diffractive optics principles
- Apply these skills to understanding negative-branch, confocal unstable resonator operating principles
- Analyze computer simulation approaches to predicting output beam qualities

Software tasks include:

- Develop competency in commercial software (e.g. ZEMAX: https://www.zemax.com/products/opticstudio) and/or scientific programming environment (e.g. Matlab)
- Down-select and demonstrate the modeling tasks that will be performed in each software component
- Create the algorithms and write the programs for the beam propagation model
- Test robustness of the simulations against parameter perturbations
- Compare simulation results against experimental measurements of real lasers

Experimental tasks include:

- Develop basic hands-on laser measurement competency
- Work with Iradion R&D staff to determine best measurements and metrology for comparison data
- Build portfolio of laser measurements for analyzing efficacy of the resonator simulation software

Composition of Team:

2-3 electrical/computer engineers who will share the following duties.

- Learning laser physics and laser beam attributes
- Evaluating commercial software options versus creating new programs for beam simulation
- Developing and validating the software modeling package from commercial optical design software and/or original numerical simulation programs
- Benchmarking simulation results against measured laser performance data
- Training Iradion R&D staff in use of the software

Skills Required:

Successful completion of this project will require considerable creativity, analytical thinking and resourcefulness. The tasks will be multidisciplinary in nature and will compel project engineers to work and communicate effectively with Iradion's laser scientists and mechanical engineers. It is anticipated that many new skills will be developed during the project execution, including how to execute basic laser performance measurements. Nonetheless, the specific skills listed below are necessary for the team to begin the project.

Electrical Engineering Skills Required:

- Knowledge of fundamental electromagnetism principles *(preference will be given to seniors enrolled concurrently in ELE423: Electromagnetic Fields II)*
- Ability to keep a good laboratory notebook and record and process measurement data
- Discipline to follow general laboratory protocols for safety and proper use of precision equipment

Computer Engineering Skills Required:

- Solid grasp of algorithms and the fundamentals of computer science
- Competency in mathematical programming environment, e.g. Matlab, C++, or similar
- Some experience in creating simple graphical user interfaces
- *(preference will be given to seniors who have previously completed or are currently enrolled in additional mathematics courses beyond the scope of their curriculum)*

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

Computer modeling of the CO_2 laser resonator has been a gap in Iradion's design capability since the company was founded. Our products have been successfully designed using empirical knowledge and rules of thumb gleaned from prior art. While this has worked in the past, and enabled a rapidly growing business, we know that developing the best possible laser products requires high competency with all the design tools available.

We anticipate that implementation of the LASIMO modeling software will allow us to explore multiple design possibilities quickly and without the time and expense required to experimentally test all those possibilities. Whereas today we have developed products that are 'good enough,' using numerical simulation of potential resonators will enable 'best possible' designs to emerge from the design landscape. Success in this project will directly impact the growth trajectory of the company.

Broader Implications of the Best Outcome on the Company's Industry:

CO_2 lasers are the oldest type of industrial laser, with high power laser cutting, welding and marking systems deployed in global factories for decades now. Nonetheless, we are in a renaissance period of new applications and new markets for CO_2 lasers. The emergence of fiber lasers for high power cutting has put performance and reliability pressures on CO_2 laser manufacturers. Simultaneously, the far infrared wavelength (10.6 microns) exclusively provided by CO_2 lasers has found broad appeal in brand new markets for lasers, such as high fashion fabric patterning and trimming plastic films for consumer electronics.

Many of the new applications require lower cost and higher consistency from CO_2 lasers. We expect that the LASIMO project will enable faster pace of advancement in laser design and ultimately lead to deeper understanding of fundamental laser performance. These improvements will make the technology more accessible to new applications and types of users. In the long run, we can see a future where CO_2 lasers become accessible to the average home improvement do-it-yourselfer.