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ALGORITHM DEVELOPMENT FOR TOOL PATH GENERATION AND PARAMETERS VARIATION IN LASER MICROMACHINING PROCESSES

Antonio Carlos Haidamus Monteiro Filho
João Henrique Telles de Carvalho
PET-MA – Tutorial Education Program of Metrology and Automation - Fundação CERTI - Universidade Federal de Santa Catarina
Florianópolis CEP 88040-970 - Santa Catarina – Brasil
antoniochmf@gmail.com
joaotcarvalho28@outlook.com

Manoel Kolling Dutra
Claudio Abilio da Silveira
Milton Pereira
LMP – Precision Engineering Laboratory – EMC – CTC - Universidade Federal de Santa Catarina Florianópolis CEP 88040-900 – Santa Catarina – Brasil
manoel.kolling@posgrad.ufsc.br
claudio.silveira@posgrad.ufsc.br
eng.milton@gmail.com

Abstract. *In the context of contemporary manufacturing, lasers have emerged as a versatile and accurate method, making it important to study the influence of each of its parameters. This can be done by introducing a parametric test matrix approach (also called layer-by-layer). However, due to the large number of parameters that can be adjusted, the construction of the test matrix is exhaustive and inefficient. This paper presents the development of a software tool aimed to optimize the parametric test matrix generation, without the complexities of traditional G-code programming. The study encompasses the analysis of a laser machine and its parameters, a G-code generator software design, and system testing. The software, developed in Python, features a modular structure and a user-friendly graphical interface for parameter selection. It enables various laser movement patterns and many G-code syntaxis. Simulations were conducted to validate the software's accuracy and reliability, aligning user-defined patterns with simulated trajectories. This tool has potential to streamline laser processing tasks across diverse materials, machines, and applications. While limitations in syntax integration and in testing are noted, the software emerges as an asset in advancing laser-based manufacturing, offering accessible parameter optimization and comprehensive data management.*

Keywords: *CNC laser machine, G-code, Laser processing, Test Matrix, CAM*

1. INTRODUCTION

The adoption of lasers as a tool for materials processing has consolidated its status as a cutting-edge manufacturing process nowadays. It has gained a lot of interest in industry and in the academia, proving to be a highly advantageous alternative to conventional manufacturing techniques (Oliveira, 2019; Steen, 2003). Its notoriety is due, among other factors, to its enormous versatility, allowing application on different types of materials and under different environments (including vacuum, air, or liquid), because the laser beam loses almost no energy on its way toward the workpiece (Mishra; Yadava, 2015). In addition, its high resolution, attributed to its excellent focal capacity, has made it possible to obtain extremely refined surface finishes (Mishra; Yadava, 2015). All these factors have propelled it to a prime position in various industry sectors, including the automotive industry, telecommunications, biomedicine, the military, printing technology, semiconductors, among others (Baumgratz, 2022).

The results that can be obtained in each laser processing operation will depend on numerous parameters, such as the ones assigned to the CNC laser machine and to the optical and thermophysical characteristics of the workpiece (Mishra; Yadava, 2015). The main parameters controlled are power, pulse repetition rate (pulse frequency), pulse width (pulse duration), scanning speed, spot size (focal diameter), lateral overlap, and the number of pulses (Baumgratz, 2022). In this sense, the values assigned to each of these parameters and the results obtained from the processed workpiece will be the main data analyzed when it is desirable to study optimal parameters. It is important to notice, however, that the optimum combination of parameters is an interpretation made by the operator, who will evaluate the results they want to obtain for the conditions and processes they want to analyze.

To evaluate the optimum parameters for a given process, a 2D parametric test matrix is used, consisting of a laser-processed table where each element is a result from a different combination of parameters. The work carried out by

Baumgratz (2022), with the aim of understanding the influence of parameters on the resolution and quality of three-dimensional laser processing, adopted this method.

The process of building these test matrices is extensive and not very intuitive. This is because it is currently only possible to build them by constructing a model of the test matrix in CAM software and then generating the corresponding G-code, which will finally be inserted into the CNC for laser processing. Based on that, despite being widely used to generate complex G-codes with many parameterizations, these software are very generalist, in a way that they can be used in as many processes as possible. This makes them very complex and generic, increasing the difficulty in learning how to use them and not reaching all the specifications that a particular manufacturing process may require (Prujanski, 2021).

The present work describes the development of a more compact, didactic, modular, and open software for the automatic generation of the G-code for a parametric test matrix. This tool for generating trajectories and varying parameters will enable a small sample of material to be quickly processed and studied, without the need to use traditional methods for G-codes programming and generating.

2. MATERIALS AND METHODS

The project was divided into two main parts: the analysis of the model machinery and the development of the G-code generator software.

2.1 Analysis of the model machinery

The model machinery is the equipment for which the project was primarily conceived. Its analysis involved understanding its operating mechanism and constraints. However, the software also fulfilled the objective of being easily adaptable to others laser processing equipment.

The machine analyzed, named SL2 (Laser System 2), is based on the integration of systems supplied by different manufacturers. The handling system is supplied by Aerotech™ and consists of a 5-axis handling system. The galvanometer axes A and B, specification AGV14HPO, allow a stroke of up to 110 mm and a speed of up to 8000 mm/s (Aerotech, 2020). The PRO115SL Z-axis allows vertical movement of up to 300 mm and a speed of up to 300 mm/s (Aerotech, 2021). The ECO165LM X and Y axes are not used, although they make up the equipment.

The laser sources are manufactured by IPG Photonics™, and comprise a continuous source and a pulsed source. The continuous-emission laser source, named YLR-400-AC-Y14, has a maximum power of 400 W and emitted wavelength is centered at 1069.9 nm (IPG, 2014; IPG, 2015; IPG, 2020). The pulsed-emission laser source, named YLPN-1-1x120-50-M, has a maximum power of 50 W, the emitted wavelength is centered at 1061.3 nm, and it allows the adjustment of pulse width in 8 positions between 1 ns and 120 ns (Silveira, 2020). The system also has a F-theta JENar™ lens attached, with a focal length of 170 mm and a focal point diameter of 58 µm (Jenoptik, 2019). The laser source can also be modulated, allowing it to emit pulses of a certain duration and at a certain frequency.

The support structure, enclosure and electrical cabinet were designed through developments at the Precision Engineering Laboratory (LMP). Figure 1 shows the integrated structure:

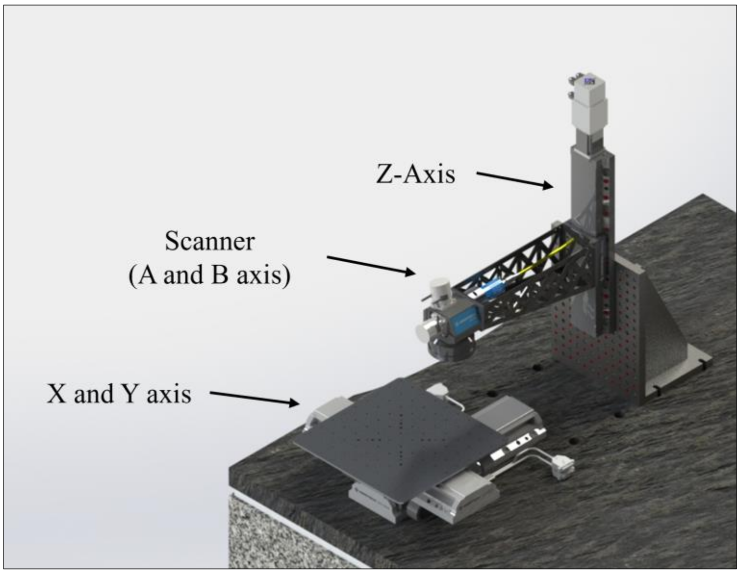

Figure 1. Laser system LS2 without enclosure.

The A3200 Motion Composer software, developed by Aerotech™, is used for operating the system, editing programs, controlling in- and outputs and visualizing program variables (Aerotech, 2019). Its interface allows G-code programming in Aerobasic syntax, developed by the company itself. Figure 2 shows the software interface:

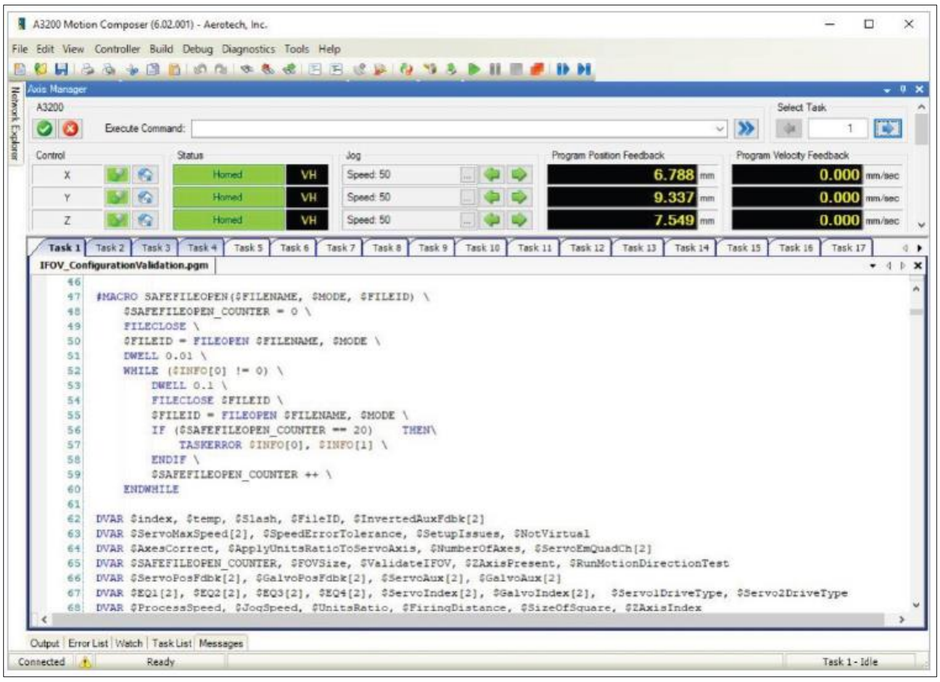

Figure 2. Aerotech A3200 software interface.

The software has no integration with external programs but allows G-codes in text files to be imported.

2.2 Program development

The code was entirely developed in the Python programming language, using the following libraries: PySimpleGUI, for developing and generating a graphical user interface (GUI); matplotlib for building graphics; Reportlab for creating PDF files; Numpy, Random and Os for general operations.

The software is modular, so that it can be adapted to different machines and different G-code syntaxes. To do this, the code was divided into individual modules and functions, each of which is responsible for different features and independent of the rest of the code.

The first module created is related to the GUI. It has four functions, each responsible for a screen. The first and second screens are the initialization, as shown in Figure 3, where the user fills in information about the test, such as the date, file name and save directory. The third is for filling in input parameters. The user chooses which parameters will vary and their respective values, the direction, the size of the test matrix, the syntax of the G-code and the type of movement made by the laser. The last screen confirms the parameters entered before running the program. Figure 4 shows the interface for the third and fourth screens.

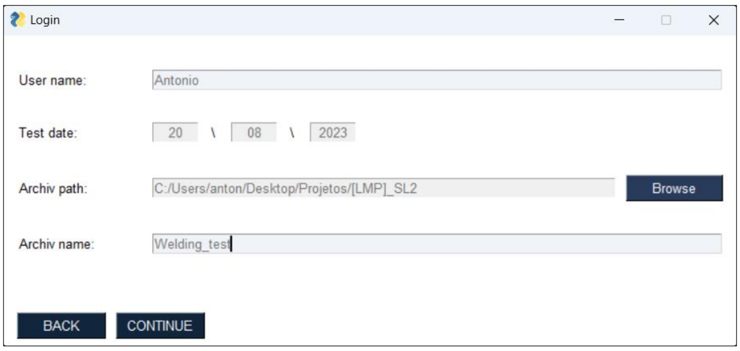

Figure 3. Software interface for Login screen.

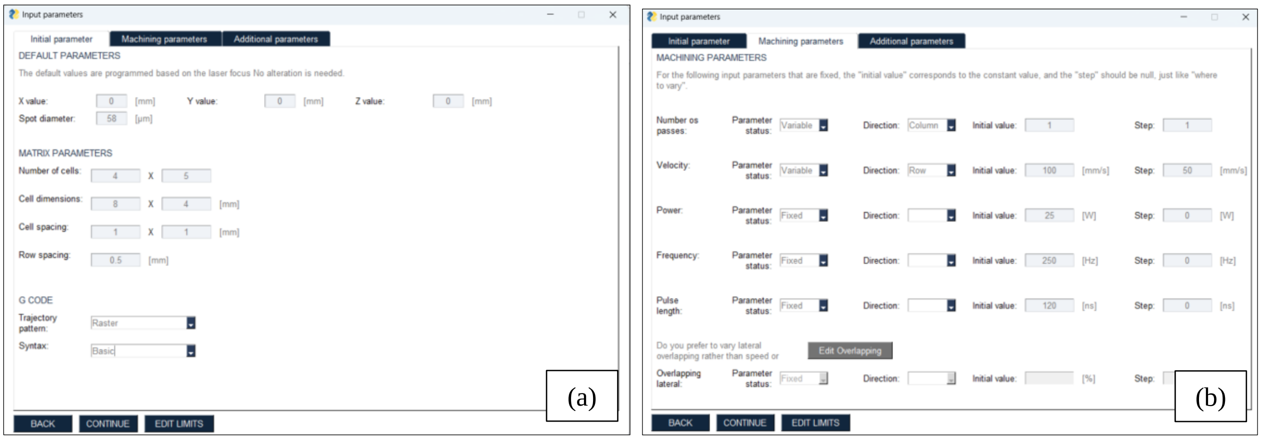

Figure 4. Software interface for (a) Test matrix parameters screen and (b) Machining parameters screen.

The second module includes laser movement functions, which generates various trajectory patterns that the laser beam can follow during processing. In the raster-type movement, the laser beam travels across the surface of the material in adjacent horizontal lines. In the zig-zag movement, the laser beam travels along the surface of the material in diagonal lines, changing direction after each line. By accessing the software's backend, it is possible to create more movement patterns. Figure 5 shows the two movement patterns.

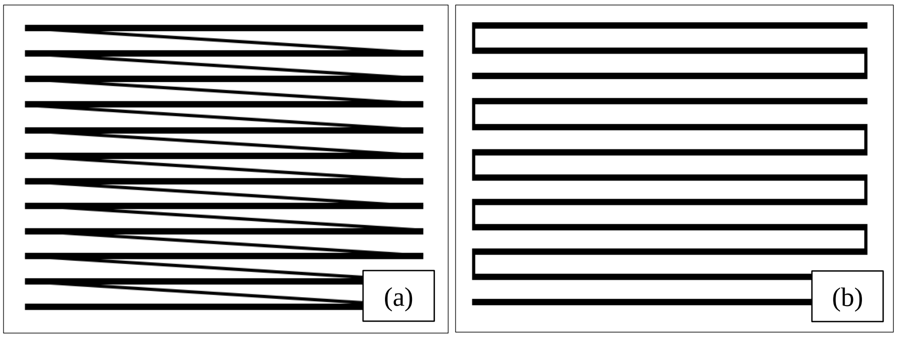

Figure 5. Trajectory patterns (a) Raster and (b) Zig-zag.

The third module is the software's post-processor. It converts the data entered by the user in the graphical interface into a G-code to be sent to the CNC laser machine. As the project is modular and CNC machines vary in terms of their architecture and programming language, this module comprises three initial functions, each of which translates into a different G-code syntax. The first uses the universal G-code syntax (accepted by most machines). The second also uses the universal syntax, but with its axes adapted to the galvanometric axes (A, B and Z axes are used instead of X, Y and Z). The third adapts the G-code to the syntax of the A3200 software. By accessing the software's backend, it is possible to create more translators for other syntaxes.

The fourth and final module of the program comprises the other results generated by the program, shown in the following section. The first function of this module is responsible for creating a PDF file with all the information indicated by the user in the graphical interface. The second function transforms the test matrix geometry data into a curve of points. These points will be used both to generate a graph representing this geometry and for the post-processor to indicate the laser movement points, in CNC language.

3. RESULTS AND DISCUSSION

The results obtained from several tests of the software on different platforms were analyzed for consistency and accuracy. These results will be presented and discussed in this section.

3.1 Software contents

The first file generated by the software is a text document, which contains the G-code that will be sent to the CNC laser machine. The evaluation and discussion of the efficiency of the G-code will be described in more detail in the next section. The second file generated is a graphical representation containing the software's prediction of the test matrix's visual attributes. It shows the geometric aspects of the test matrix (number of rows and columns, and the size of the elements, in scale) indicated in the system. The third and final file generated by the program is a PDF report. In this file, there is a compilation of information relating to each parameter indicated in the interface, serving as a repository for all the test data. Figure 6 shows the layout of the three files generated.

200823AW79 - G Code - Basic Syntax	20/08/2023 21:01	Documento de Te...	107 KB
200823AW79 - Graphic	20/08/2023 21:01	Arquivo PNG	9 KB
200823AW79 - Report	20/08/2023 21:01	Documento do Ad...	5 KB

Figure 6. Files generated by the program.

A final important factor to consider is the machining code. This alphanumeric sequence appears not only in the filenames generated by the software, but also on the surface of the test matrix. By referring to the code on the test matrix, it is possible to locate and access the corresponding files on a computer. This method provides a well-structured means of acquiring comprehensive information on a specific test matrix, enhancing the overall search and analysis process.

3.2 Simulation

Due to the malfunctioning of the laboratory's CNC laser machine and the lack of CAM platforms that simulate specific Aerotech^{TM} equipment, it was not possible to perform experiments with the software or test it using the Aerobasic syntax. Therefore, for the online simulations, the website NC Viewer and the software CIMCO were employed. These platforms enabled the G-Code to be imported and interpreted. The platforms could then simulate the tool's movement, allowing the observation of the trajectory of the tool and the variation of the parameters.

The reliability and effectiveness of the software is initially assessed by comparing the test matrix pattern defined by the user with the test matrix geometry graph generated by the software. This graph is then compared with the results obtained in simulations carried out on more than one CAM platform, using the G-code generated by the software. The consistency between these results proves the accurate interpretation of the information by the software and validates the accuracy of the G-code generated.

For this article, the simulation generated comprises a 5x4 test matrix, with elements 8 mm wide, 4 mm high and spaced 1 mm apart. The trajectory pattern is of the Raster type, with a line spacing of 0.5 mm. The speed varies vertically and the number of passes horizontally, with initial values of 100 mm/s and 1 and a step of 50 mm/s and 1, respectively. The G-code syntax tested was the basic three-axis syntax. Figure 7 shows the results generated by the software.

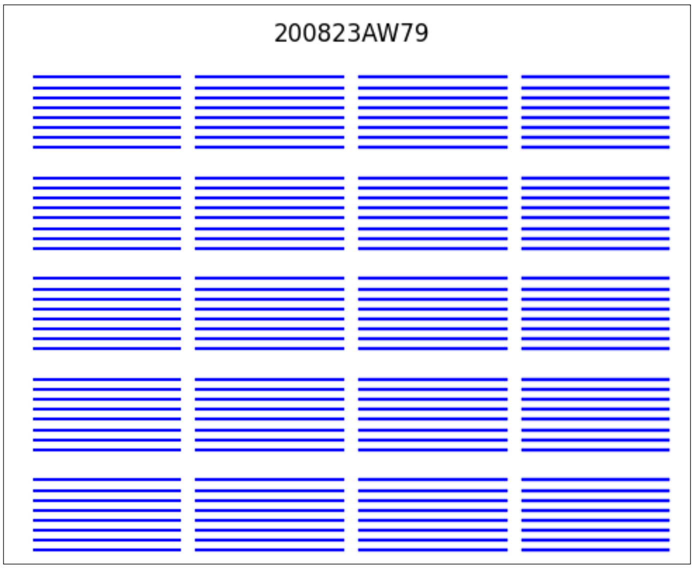

Figure 7. Parameter test matrix simulated by the software

Figure 8 shows the simulation stage conducted on NC Viewer and CIMCO software.

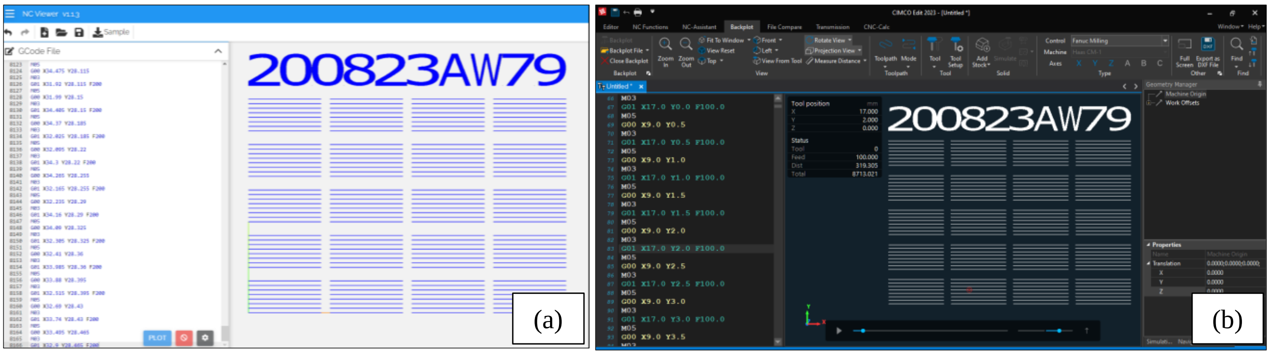

Figure 8. Parameter test matrix simulated by (a) NC Viewer and (b) CIMCO software.

In all the simulations conducted, the information given by the user and the tool's trajectory predicted by the software perfectly aligned with the trajectory generated in both CAM platforms. The complete operation of the software and the testing of the results can be accessed via the QR-code depicted at Figure 9. A short demonstration video was produced to help visualization of the software use and simulation.

Figure 9. Software testing video.

4. CONCLUSION

This paper describes the development of software for generating parametric test matrices for laser processing. The main functionalities and limitations of the software are listed as follows:

- Tests and simulations demonstrate that the system effectively generated accurate information consistently.
- The approach of using a machining report and a machining code led to improved information management.
- The software's backend was structured in a modular manner, allowing the addition of new post-processors, new laser path patterns, and the adjustment of machinery limits.
- The software has no integration with other platforms, making it necessary to transfer manually the generated G-code to the operational software of the CNC laser machine.
- It was not possible to evaluate the Aerobasic post-processor.

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6. REFERENCES

Aerotech, 2019, *Software A3200 Motion Composer Suite*, Aerotech Inc., Pittsburgh, https://www.aerotech.com/wp-content/uploads/2020/11/a3200-motion-composer-suite.pdf. Accessed 20 Septemeber 2021.

Aerotech, 2020, *AGV-HP(O) 2-Axis Galvo Scanner Hardware Manual*, Aerotech Inc., Pittsburgh, https://www.aerotech.com/wp-content/uploads/2020/09/AGV-HPO.pdf. Accessed 20 Septemeber 2021.

Aerotech, 2021, *PRO115SL and SLE Mechanical Bearing, Ball-Screw Stage Hardware Manual*, Aerotech Inc., Pittsburgh, https://www.aerotech.com/wp-content/uploads/2021/07/PRO115SL.pdf, Accessed 20 Septemeber 2021.

Baumgratz, F. M., 2022. *Three-dimensional laser beam micro-machining: methodology, development and implementation.* Master's thesis, Graduate Program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brasil.

CIMCO, https://www.cimco.com/download/public/. Accessed 21 July 2023.

IPG, 2014, *YLR-400-AC-Y14 Specification G22-29503*, IPG Photonics, Oxford, https://doceru.com/doc/cv158xe. Accessed 20 Septemeber 2021.

IPG, 2015, *YLR-Series User Guide*, IPG Photonics, Oxford, https://www.artisantg.com/info/IPG_Photonics_YLR_200_1030_Manual_202285163733.pdf. Accessed 20 Septemeber 2021.

IPG, 2020, *YLR-1070 Series Ytterbium Fiber Lasers*, IPG Photonics, Oxford, https://www.ipgphotonics.com/de/172/FileAttachment/YLR-1070+Series+Datasheet.pdf. Accessed 20 Septemeber 2021.

Jenoptik, 2019, *F-Theta JENar™ Lens Series*, Jenoptik, Jena, https://www.jenoptik.com/search?searchTerm=F-Theta+JENar™+Lens+Series+170-1030. Accessed 20 Septemeber 2021.

Oliveira, C. C., 2019. *Effect of the movement geometry superimposed on the linear displacement path of the laser beam on the surface of an AISI 316L stainless steel sample for micro-welding applications* (in Portuguese). Master's thesis, Graduate Program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brasil.

Prujanski, C. L., 2021. *Development of a cam software for tool path generation in micro milling applications*. Bachelor's thesis, Graduate Program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brasil.

Silveira, C. A., 2020. *Analysis of synchronous and simultaneous movement between galvanometer scanner and linear axes in laser applications* (in Portuguese). Doctoral thesis, Graduate Program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brasil.

Steen, W. M., 2003. *Laser material processing*. Springer-Verlag, London.

Mishra, S. and Yadava, V., 2015. "Laser beam micromachining (LBMM) – A review". *Optics and lasers in engineering*, Vol. 73, p. 89-122.

Nc Viewer, https://ncviewer.com. Accessed 21 July 2023.

7. RESPONSIBILITY NOTICE

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