A USER-FRIENDLY SIMULATION TOOL TO FACILITATE WRITING OF COMPLEX PART PROGRAMS FOR LASER MICROMACHINING

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Abstract

Excimer micromachining tools used to produce micromachined parts are often controlled by manually written numerical control (NC) part programs in RS-274 “G” and “M” codes, or NC-code.

The manual creation of the part programs in NC-code is a time-consuming process for users and relies on their expertise. This often results in a trial-and-error approach to producing a part program for the desired shape because a user rarely gets it ‘right the first time’. Furthermore, writing programs to machine complex microstructures is difficult. As few CAD/CAM tools are available to assist programming for laser micromachining, the aim of the research was to develop a user-friendly CAM tool to assist programmers.

A simulator tool has been written to interpret a part program and to display the intended part. With this simulation tool, the part programmer works more effectively by being able to view the machined surface and check the program using the simulation tool before trialling it on an expensive laser machine. The simulator allows the user to easily modify and retry a program during its development. The simulator provides a number of debugging features to enable the user to step through the program and determine what is happening at each instruction.

The capability of the simulator tools is demonstrated through several part programs.

Keywords: excimer laser micromachining, simulation, NC part programming, CAM, CAD/CAM.

Introduction

Laser micromachining tools are used to fabricate microstructure fluidic structures using polymer materials. The system used in this research was an Excimer Series 8000 Series Laser Micro Machining System (Exitech Ltd) controlled by a Unidex 500 Controller (Aerotech Inc.). The controller reads numerical control (NC) part programs in RS-274 “G” and “M” codes to direct the ablation process.

A simulator tool has been written in Visual Basic to model the micromachining produced by the part program operation before committing the program to machine the part with the laser system.

Part programmers rarely get the programming ‘right the first time’ as the NC programming language used is a relatively low-level language and prone to errors. With this simulation tool, the part programmer works more effectively by being able to view and check the program using the simulation tool before part production. The simulator also error checks the program and enables step-by-step interpretation of the code.

The simulator further allows a user to investigate various paths and other parameters used in the development of novel microstructures for texturing or patterning.

The simulator is one of several research projects undertaken by the authors to provide tools to assist with the development of microstructures [2], [3], [4], [5] & [6]. Other complementary work includes software to automatically generate the NC part program for a part drafted in a solid modelling package. (A CAD/CAM tool has been developed elsewhere for this type of laser micromachining system to produce the NC commands to machine the part [1].)

Excimer laser operation

For the Excimer 8000 Series system, each laser pulse ablates a relatively uniform thickness (usually in the range of a few hundred nanometres to around 1µm) of material from the surface of the workpiece within the projected pattern outline. The cut edge slopes at approximately 7° due to the optical interactions at the workpiece. This slope may vary with depth when repeated cuts are made in the one position.

An optical system focuses the laser onto the workpiece through a mask and typically reduces the mask pattern image at the workpiece by 10 times.

The NC commands cause the controller to move the workpiece and mask relative to the laser and to set laser firing parameters.
The controller interprets the commands through two separate boards. A motion command for Board 1 enables planar translation of both the workpiece and mask in x and y directions. The same motion command for Board 2 enables workpiece rotation, elevation to focus the laser, beam attenuation and a spare function, which currently is mask rotation. Consequently, the board required must be selected through a board switch command prior to the motion command.

The rate of travel can be set for each axis. This rate can also be flagged as ‘linear’ so that either x or y motions are automatically adjusted to complete at the same time.

The laser trigger pulses are controlled through the Position Synchronised Output (PSO) card and are interpreted through Board 1. The PSO commands set parameters, which include the pulse trigger rate, number of pulses, and the fixed distance increment depending on x, y or xy movement.

The controller stores the commands in Board 1, Board 2 and PSO buffers which are not switch settings and these are executed in parallel. NC commands can pause the interpretation of the part program until Board 1, Board 2 or PSO commands are complete.

**Simulator Tool**

For the simulation, the laser is assumed to have a uniform ablation rate over the area of the beam and shot to shot, which is a reasonable approximation to the micromachining process. The edges of the cut are assumed to be vertical to simplify the modelling.

The workpiece is represented as a grid or raster. At each laser firing a uniform thickness is subtracted from those grid points that lie within the projected pattern outline.

The NC part program defines the path of the pattern movement relative to the workpiece and the position and relative orientation of the pattern at laser firing.

The simulation tool was designed to read the NC part programs and display the 3D machined surface. The tool will handle large programs for complex parts. During a simulation run, the status of each command is adjusted at each laser-firing event.

**Graphical user interface**

The graphical user interface (GUI) for the simulation tool is shown in Figure 1.

During a simulation, a part program is first read in. The laser path defined by the NC-code is then plotted in the path window shown in the left-hand side of the interface and the bounds of the part are calculated. The required mask patterns are read directly from Microsoft Excel worksheets. The spreadsheet format was chosen as it allows for parametric definition of patterns to enable families of patterns to be easily specified and graphed separately within the spreadsheet. A selected pattern outline (ie the toolpath) is shown in the pattern window and the patterns for each mask can be scrolled in the window. Multiple patterns can be used in the one simulation.

![Figure 1 Simulation tool graphical interface.](image)

The example shown in Figure 1, is of a particle transportation device which was designed and fabricated to demonstrate the performance of the IRIS CAD/CAM tools. This microfluidic device incorporates a network of microchannels and obstacles. Barriers in the main channel are used to direct the flow of particles, while allowing a relatively unimpeded flow of the carrier fluid. The polycarbonate chip with the microchannel network forms one part of the complete device. (A cover is bonded to the top of the device to seal the open channel network.)

The particle transportation device is shown modelled in plan view as a grid of depth in the main window of the GUI. The machined surface is plotted in 2D in this main window at the end of each simulation run.

The depth is indicated as a grey or colour scale (as selected) and the intensities can be varied to promote features of the image. The scale is shown in the bottom left corner. For this example, Red = 0 μm, Blue = 17 μm and the majority of the machined depth is at Green = 12 μm.

The grid can be windowed and the resolution increased for higher accuracy modelling. The simulated time and number of laser cuts is summed during the simulation and posted in Figure 1. The depth information can be exported as a .stl file for display as a 3D model.

Horizontal and vertical depth sections of the grid can be made on the fly. These are displayed in graphs in the right and bottom windows in Figure 1. The section lines are through the movable cross-hairs in the main window.

The simulator assumes that the cut depth will be the same at each firing and is set as a simulation parameter. For
In this simulation the cut depth for each laser pulse (1.21 m ablated per pulse) was scaled to give the actual measured channel depth.

**Excimer laser parametrics**

Parameters specific to the laser micromachining system are read in from a configuration file. These include parameters such as maximum and default feed-rates and defaults for machine settings.

Parameters specific to a user’s operation can be saved to a profile and automatically retrieved on simulation start-up. These include parameters such as working file directory, scaling defaults, cut depth on each cut, pattern demagnification factor, laser beam width, and grid default settings.

**NC part program debugging**

To assist in part program debugging, the program can be stepped through and the grid re-plotted when required. The part program monitor interface shows various parameters and the buffered NC-commands for each step.

The simulation tool checks the code on each pass for likely programming errors such as coding errors (for example, incorrect commands) and logic errors (for example, attempting to fire the laser faster than the repetition rate set).

The part program path plot is also valuable in detecting programming errors. The path can be plotted to a separate window for better viewing.

Co-ordinates can be displayed for select locations in each window.

**Simulation output for further processing**

The grid and sections can be exported in various formats for further evaluation and reporting. These include:

- images for simulation and sections as bitmap files (.bmp) files.
- sections as text (comma separated variable .csv) files for further analysis/graphing using, say, a spreadsheet.
- grid to a location (stereo lithographic .stl) file for import to a viewer for 3D interactive viewing. Depth re-scaling and re-setting zero can be done on export to assist in viewing small depth machining. A large number of applications are available to provide 3D viewing of these files.

The example grid was constructed by simulation of a suitable NC tool path in combination with a set of circular and square mask patterns. The result was then exported from the simulation tool as an .stl file and viewed in three-dimensions in a CAD system or .stl editing tool (e.g. STL Editor from Floating Point Solutions), and is shown in Figure 3.

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**Figure 2** Part program operation monitor.

**Figure 3** A 3D view of a microfluidic particle transportation device as modelled by the simulator.

The following example, Figure 4, uses a single triangular mask/image that has been dragged across the sample surface in 2 orthogonal directions to create a relatively complex surface relief. Prediction of such surface structures by means other than a simulation tool is difficult.
Summary
A simulator has been developed to read NC part programs for an excimer laser micro machining system controlled by a Unidex 500 Controller. The capability of this tool has been demonstrated by simulation of both microfluidic, microtexturing and microoptical structures.

This simulator assists programmers in manually developing their part programs through viewing the simulated models without operating the laser at all. As well as part visualisation, the software also provides error checking and error debugging facilities. This updates the toolbox available to excimer laser micromachining to bring it into alignment with other fabrication process tools.

The simulator currently uses a subset of the available commands but specifically those that are commonly used. The library can easily be extended as required.

Multiple patterns are currently selected through comment statements in the part program rather than through the mask position relative to the laser.

The ablation rate is set as a constant for each simulation. This could be extended to include a database of material properties versus laser fluence rates to predict machining rates as is currently available in other IRIS CAD/CAM tools.

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References


