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# On the Method of Multi-Layer Laser Micro Machining

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**Abstract.** The presented method was developed for laser micromachining of material surfaces. The method allows to the creation of a spatial structure (2.5D) with the usage of a laser beam. The method presented in the article should be classified as removal techniques using the phenomenon of cold ablation. The method can be successfully used for pico- and femtosecond lasers equipped with a galvo scanning head. The advantage of the method is that it generates trajectories and modulates beam power based on the spatial geometry of the structure contained in the 3D data exchange file. The method uses proprietary solutions allowing for proper modulation of the laser beam power depending on the required geometry. The control application for the laser device and galvo head was developed based on the National Instruments LabView environment.

## Introduction

Developing spatial micro textures with a controlled geometry is a technologically difficult task. This is mainly due to the texture dimension not exceeding one millimeter. At present, there is a narrow set of technologies capable of carrying out such a task, for example, classic milling, EDM machining, or laser processing [1]. Another issue during micro texturing is the need to maintain a proper surface condition near the machining area. The occurrence of cracks, melting or degradation of material near the micro-texture is unacceptable for almost all applications [2]. It is also necessary to control the occurrence of a heat-affected zone when using methods in which thermal exposure can occur. One of the supreme methods for manufacturing micro textures is laser processing. Laser forming a microstructure that is a vertical projection of a given shape onto a surface is a simple and well-known process. The task of creating spatial structures is definitely more difficult and complex.

Laser machining involves exposing the material to a concentrated, coherent, and focused beam of light [3]. The effects of the exposure depend on the length of the emitted light wave, the method of laser work, the pulse duration, and the frequency of pulses. The positioning accuracy of the laser beam is around 1-1.5 [µm] when using a galvanometric head. Depending on the beam mode and the length of the emitted beam, the trace of the beam can be circular with a diameter of 10 [µm]. For galvanometric heads, the beam feed rate can be close to 10 [m/s]. A significant difference between laser removal of material and the conventional methods used so far is the much better repeatability and speed of the process. As a result of the phenomenon of cold ablation in the process of laser machining of the surface, the influence of thermal exposures is reduced [4]. There is also no influence of mechanical forces in the process in question. Furthermore, it is possible to make a precise surface structure on thin-walled elements, as opposed to the precision milling process. Laser technology is also applicable in machining susceptible materials, including soft plastics. The so-far known and developed methods of making microstructures, with the use of laser technology, allow only perform cavities of the assumed flat geometry. There are only a few commercial full 3D laser machining methods.

**Outline of the Method**

Despite the numerous advantages mentioned above, laser processing technology also has its limitations. According to the author, the most important limitation of the method is the possibility of making micro textures with a fixed outline in the cross-section. This is mainly due to the method of programming the laser equipment derived from the welding and cutting technology. Most commercial systems provide the possibility of programming the laser beam trajectory on a certain plane. The spatial effect of the structure is achieved through repeated execution of the indicated contours of the prepared program. It is an inefficient and tedious method. Laser beam guidance is usually provided by specialized galvanometric heads or, less frequently, by Cartesian robots [4]. The geometry of structures is the result of extruded cutting of certain flat shapes along the third dimension. A graphical interpretation of the limitations of the methods used is shown in Fig. 1.

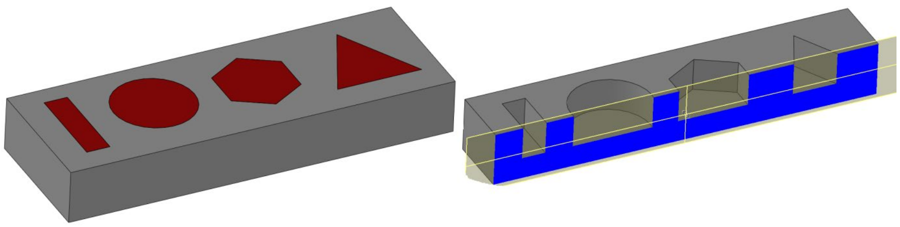

***Fig. 1.*** *An example of spatial textures that can be obtained using the classic laser micromachining method.*

The presented method allows obtaining spatial micro textures using a laser device emitting a concentrated beam of optical radiation with a wavelength of 343 [nm] and a pulse duration of 6.2 [ps]. The use of such a laser allows for ablative material removal, significantly eliminating the area of the heat-affected zone. The main property of the described technology is a new way of planning the laser beam trajectory that is different from that used so far. The planned micro texture was assumed to be processed in layers from top to bottom. The 3D geometry of the planned micro-texture is transferred in the form of a three-dimensional data exchange file, e.g. STL. The input 3D file containing the spatial geometry was divided into layers of thickness corresponding to the depth of the cavity after a single laser scanning process. The concept of dividing into layers is shown in Fig. 2.

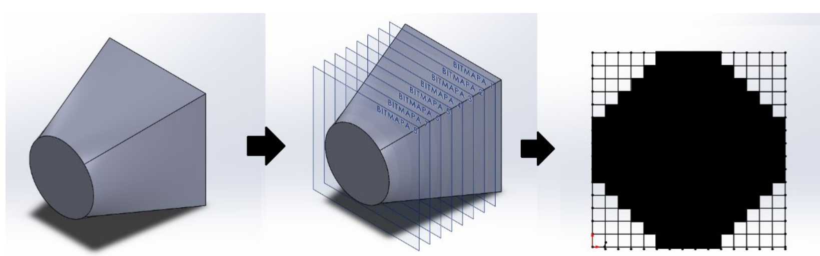

***Fig. 2.*** *Stages of geometry conversion for the developed technology.*

The division of the STL file into layers was developed with the use of the LabView environment. The final quality of laser machining will depend on the number of intermediate layers created. Each of obtained layers was transformed into a raster image containing a set of pixels with coordinates in a flat arrangement. The size of a single pixel corresponds to the size of the laser dot

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and is controlled depending on the laser device and optics used. Each pixel created will become the point of exposure of the beam on the workpiece. Pixel coordinates in the created raster were transformed into a three-dimensional matrix containing also the layer number. It can be stated that the final result of the procedure is the development of a set of “voxels”, i.e. the smallest indivisible three-dimensional elements corresponding to pixels in raster graphics. A single "voxel" has a volume equal to the volume of the cavity after a single exposure to the laser beam. Based on the developed matrix, flat trajectories were generated each for the layer.

## Method Implementation – Test Stand

For the development of the control application responsible for geometry division, the NI LabView environment was used. Laboratory Virtual Instrument Engineering Workbench LabView is a system-design platform and development environment for a visual programming language from National Instruments [5]. LabView is commonly used for data acquisition, instrument control, and industrial automation in a variety of operating systems. The programming language used in LabView, sometimes called G, is based on data availability. The structure code and front panel of the developed application are shown in Fig. 3 and Fig. 4 respectively.

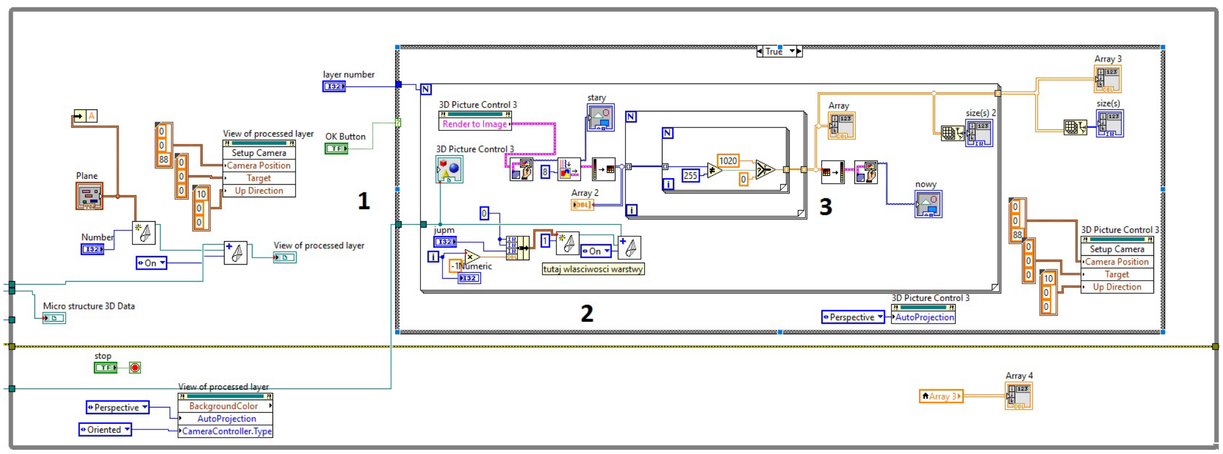


***Fig.3.*** *LabView application source code.*

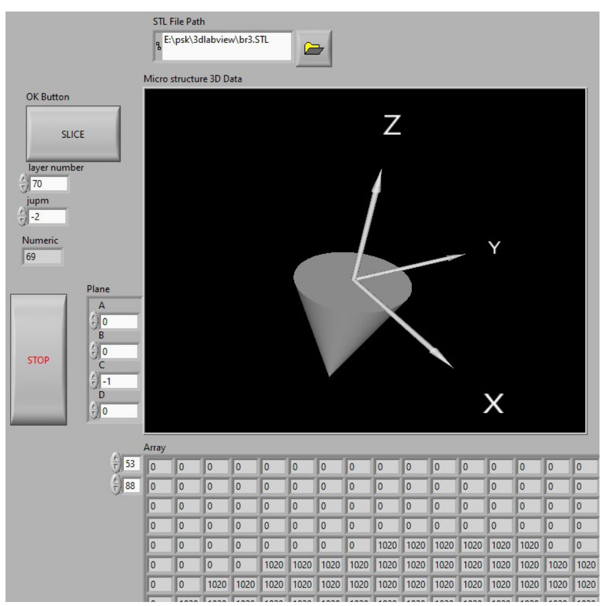


***Fig.4.*** *The front panel of the application.*

The presented code has been synthetically divided into three logical sections (Fig. 3). The first section (1) is responsible for uploading the proper STL file into the system. This section presents geometry in space also. The second section (2) is responsible for geometry slicing according to the input parameters such as the number and thickness of layers. The third section (3) contains procedures that create raster temporary layers and builds a three-dimensional power table for laser processing. In case the average RGB index of some pixel in the raster is not equal to 0 (not black), then at corresponding coordinates in power table system inputs max power of the laser. In other cases, the system enters the value 0. The obtained power matrix is transmitted successively to the laser device.

The presented laser station (Fig. 5) is part of the equipment of the Department of Terotechnology and Industrial Laser Systems of Kielce University of Technology. Experimental laser TruMicro series 5000 is a solid-state laser, based on mono crystal disk Nd:Yb pumped by the laser diodes, with the basic wavelength of 1060 [nm]. The laser generates a third harmonic with a wavelength of 343 [nm]. It is an ultrashort pulse laser with a pulse duration of about 6.2 [ps] and a nominal frequency of 400 kHz. The frequency can be divided by a natural number in the range of 1-10000. The single pulse energy is in the range of 0.5 - 12.6 μJ and the maximum pulse power is 2.032 MW. The average continuous power is 5 W.

***Fig.5.*** *Experimental Trumpf TruMicro laser station.*

The presented laser stand is used for drilling micro holes, surface texturing, and other laser micromachining technologies. The stand is equipped with a two-axis Scanlab galvo head enabling scanning at a speed of 3 [m/s]. The working area of the head is a square with a side length of 90 mm. The software provided with the laser has limited capabilities and is difficult to use, because of the experimental laser destination. The laser is fully integrated with the head using the control RTC4 PC interface board, with implemented real-time system.

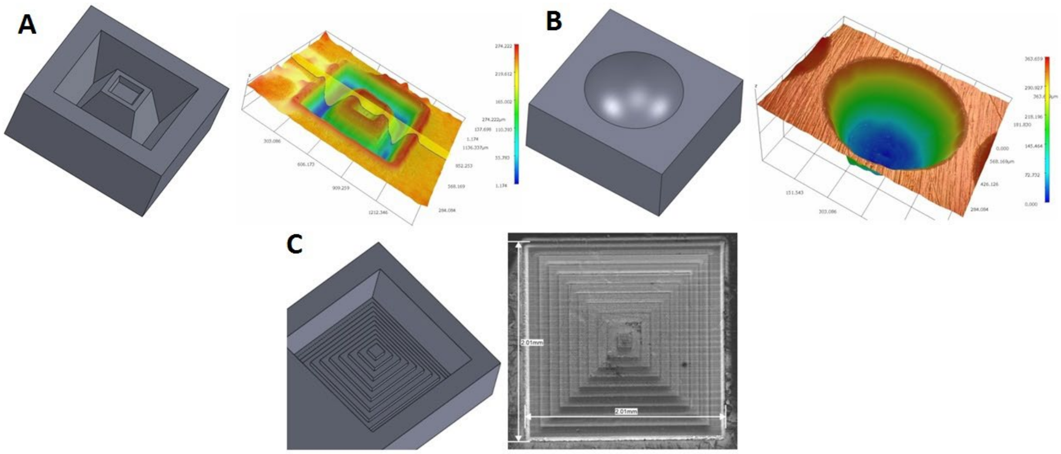


***Fig.6.*** *Reference and microscopic image of obtained microstructure (A - truncated cone, B-sphere, C- step pyramid).*

Three preliminary experiments were conducted to verify the developed multi-layer laser machining method [6-8]. The samples of PMMA material were used in the research process. Machining parameters are listed in Table 1.

***Table 1.*** *Laser machining parameters*

| Pulse Energy [μJ] | Beam Velocity [mm/s] | Repetitions per layer | Pulse Duration [ps] |
|---|---|---|---|
| 6 | 200 | 300 | 6.2 |

A CAD SolidWorks graphic program was used to create spatial geometries in STL files. The geometries in the form of a step pyramid, a sphere, and a truncated cone were made. The goal of the experiment was to obtain structures compatible with assumed and uploaded geometries. No specific depth of texture was assumed. Preliminary observations and microscopic photographs were made with the usage of a confocal microscope Hirox KH-8700. The comparison of the geometries and created structures uploaded is presented in Fig. 6 (A, B, and C respectively).

**Summary**

The results of the experiments confirm the effectiveness of the presented method for making micro textures with strictly assumed shapes and geometrical dimensions. With quite simple algebra manipulations it is possible to perform very complex micro textures (2.5D). The method can be easily used for most commercial, and industrial laser devices and their control systems. A hardware limitation of the presented method is the maximum depth of microstructure. It is caused by the length of the laser beam focus waist, which is different from the wavelength and focal length of the lens used. This problem can be easily solved by synchronization the head movement along the Z-axis during the machining process. A certain disadvantage of the solution is the inability to process the surface remaining in the shade. For this reason, this kind of machining is classified as 2.5D, not full 3D. The dimensional accuracy of the method requires proper resolution adjusting of the generated power and trajectory maps with the knowledge of the spot size of the beam. The obtained depth of microstructures depends on the number of programmed scan repetitions for each layer. The exact solution to these problems requires further development work.

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