# Technological Parameters and PMMA Surface Structure

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**The paper focuses on the issue of microprocessing of polymer materials by laser. Specifically, the task is solved by changing the technological parameters, namely the cutting speed, the power and a change of DPI and their impact on the resulting surface quality and depth of cut. During machining, the input technological parameters were changed and followed by evaluation of their interaction with the concentrated radiant energy of the laser beam PMMA, as and representative of the amorphous polymers, was selected for experimental machining. It is one of the best machinable polymer materials regarding this unconventional technology, and it is also frequently applied in industrial practice.**

**Keywords:** Laser beam, Laser Mode, Technological Parameters. Amorphous Polymers

## 1 Introduction

Regarding the practice, laser micromachining is performed mostly by UV lasers, excimer lasers and some types of solid - state lasers, such as Nd: YAG. These machines emit radiation of very short wavelength (100-351nm for UV and excimer lasers and 1064 nm for Nd: YAG laser) and thus reach higher efficiency. It is generally known that the shorter the wavelength of radiation λ and the smaller thermal conductivity of the laser are, the higher its efficiency is. The process of material ablation is a complicated combination of photochemical and photothermal processes. When the radiation reaches the ground, there happens a break of chemical bonding by absorption of energy quantum and by raising the temperature. UV and excimer lasers cause mainly photochemical ablation. A $CO_2$ laser that emits heat radiation at a wavelength of 10600 nm brings about mostly photothermal ablation resulting in a different quality of the machined material. Dimensions and shape of any laser machined structure are dependent on optics and mechanism of laser machine and also on characteristics of the machined polymer. For factual applications the important parameters are laser power, feed and the number of the beam passes in the same groove [1].

UV lasers usually work in pulse regime with the pulse duration of few nanoseconds. They are distinguished by prevailing photochemical ablation, and thus the smaller dimensions and more precise shapes of the machined parts are obtained. In case of photothermic ablation, it has an impact on the only a small volume of the material due to nanosecond pulses. However, these pulses cause uneven material removal. Their other disadvantage is higher purchase cost. [1].

$CO_2$ lasers work mainly in the continual regime. During the laser beam focus on the part surface, there happen quick raise of temperature, melting of the material and its subsequent decomposition and vaporisation of blow off by added gas. The specific mechanism of polymer decay is dependent on the strength of monomer chemical bonds and polymer composition. In the case of PMMA. There is a transformation into monomer and vaporisation, resulting in clean and smooth machined surface not stained by any residues from polymer degradation. [1].

Regarding $CO_2$ laser-micromachining, it is necessary to find a balance between the technological parameters of the laser system – power and feed. As mentioned above. The $CO_2$ laser causes photothermal ablation while excimer and UV lasers are characterised by photochemical ablation. Resulting surfaces are thus different as you can see in Fig. 1. Nevertheless, in cases of their specific applications, this difference can be neglected, and then cheaper alternation of using the $CO_2$ laser applied. [2].

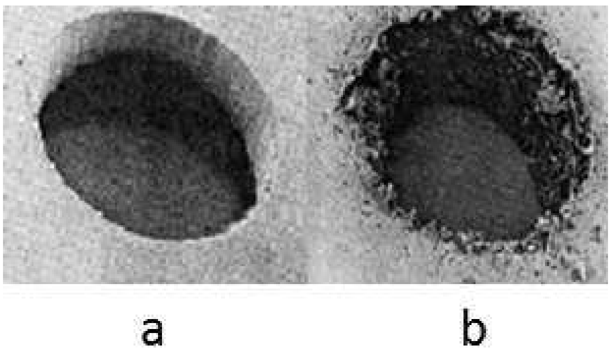


***Fig. 1*** *Illustration of the influence of laser wavelength on the quality of the machined hole in the polyamide*

*a) UV laser. b) $CO_2$ laser*

## 2 Methodology

One possibility of correcting the resulting surface quality and also of the machined surface depth is the change in the DPI resolution.

Laser machining produces grooves on the machined surface formed by a laser beam in the direction of the beam movement. The shape of the grooves is determined by the division of the power throughout the laser beam cross-section - the laser structure mode. The used ILS 3NM laser is operated in the TEM00 mode. This mode has a power divided along the beam cross-section according to the Gaussian frequency curve, with the maximum power being in the middle of the beam and decreasing to the edge (see in Fig. 2). The transverse roughness profile shown in Fig. 2 has an opposite shape to the Gaussian curve [3].

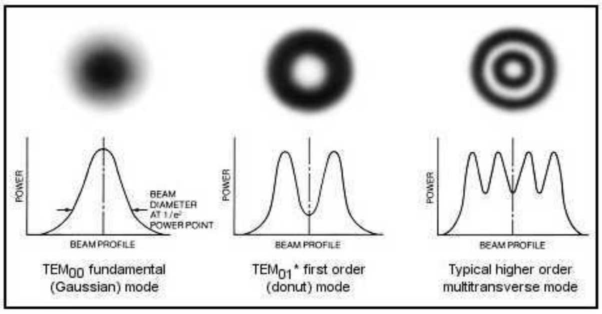


***Fig.** 2 Laser beam in TEM00 mode and others*

As mentioned above, the transverse roughness is determined by the displacement of the laser beam, which gradually forms the grooves in the material. Several factors influence the resulting surface roughness. [4].

The main factors are:

- Laser beam diameter
- DPI (dots per inch. i. e. laser beam path density)
- Laser power
- Laser mode
- Focal point position

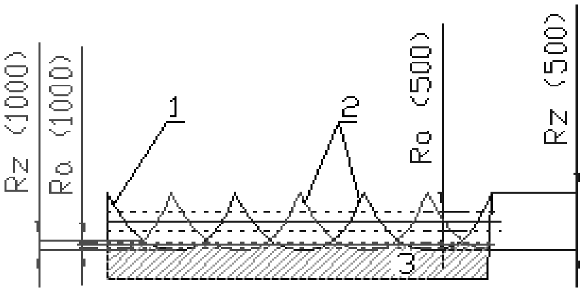


***Fig. 3** Transverse roughness profile*

1 – profile for resolution 500 DPI
2 – profile for resolution 1000 DPI
3 – the resulting profile of the machined surface

The DPI usually expresses the density of the dots in the area. It can also be used to indicate the path density, such as in this case when it indicates the number of grooves that the laser beam forms on the one inch long (25.4mm) path. The precondition is the different surface roughness at different DPI settings, as demonstrated in Fig. 3.

Therefore, let´s assume that when changing the resolution, for example from 500 DPI to 1000 DPI, the individual paths partially overlap and thus the peaks between them are removed, as depicted by the hatched area in Fig. 3. The resulting surface quality would be lower, and the depth of cut increased.

## 3 Obtained and Evaluated Data for 500 DPI and 1000 DPI Resolution

Tab. 1 lists the technological parameters of power and cutting speed as a percentage of the maximum power P =100W and the cutting speed v = 1066 mm/s and the corresponding value.

***Tab. 1** Conversion table of power and cutting speed*

| | [%] | [W] | | [%] | [mm/s] |
|---|---|---|---|---|---|
| power P | 10 | 3 | cutting speed v | 10 | 106.6 |
| | 20 | 6 | | 20 | 213.2 |
| | 30 | 9 | | 30 | 319.8 |
| | 40 | 12 | | 40 | 426.4 |
| | 50 | 15 | | 50 | 533.0 |
| | 60 | 18 | | 60 | 639.6 |
| | 70 | 21 | | 70 | 746.2 |
| | 80 | 24 | | 80 | 852.8 |

Tab, 2 and 3 show the measured Ra values and the cutting depth for 500 DPI and 1000 DPI resolution when changing the technological parameters.
The 3D graph allows you to view all the monitored quantities at the same time (see Fig. 4 – 7).

***Tab. 2** Dependence of roughness Ra [mm] on power P [%] and f cutting speed in [%] for 500 DPI and 1000 DPI*

| DPI 500 | | | | | | | DPI 1000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **v/P** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **v/P** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** |
| **30%** | 19.18 | 21.21 | 22.96 | 24.11 | 24.21 | 23.19 | **30%** | 9.325 | 12.58 | 13.05 | 13.63 | 13.74 | 16.24 |
| **40%** | 19.21 | 20.41 | 21.09 | 21.53 | 22.07 | 22.26 | **40%** | 9.809 | 10.72 | 11.54 | 11.49 | 10.84 | 14.78 |
| **50%** | 18.11 | 20.39 | 20.30 | 23.45 | 22.23 | 23.95 | **50%** | 7.327 | 8.187 | 8.986 | 10.33 | 10.07 | 9.301 |
| **60%** | 14.35 | 14.72 | 17.08 | 17.11 | 19.73 | 19.41 | **60%** | 7.017 | 8.724 | 9.486 | 9.139 | 9.977 | 9.498 |
| **70%** | 14.29 | 14.39 | 16.89 | 18.19 | 18.48 | 19.75 | **70%** | 6.694 | 8.163 | 9.674 | 10.13 | 8.797 | 9.267 |
| **80%** | 12.12 | 13.62 | 16.83 | 16.32 | 17.33 | 18.58 | **80%** | 6.439 | 8.013 | 9.280 | 8.838 | 8.077 | 7.362 |

***Tab. 3** Dependence of groove depth h [μm] on power P [%] and cutting speed f [%]. for 500 DPI and 1000 DPI*

| DPI 500 | | | | | | | DPI 1000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **v/P** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **v/P** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** |
| **30%** | 121.4 | 161.8 | 203.4 | 237.2 | 268.6 | 276.8 | **30%** | 210.3 | 360.9 | 444.0 | 720.3 | 591.7 | 685.0 |
| **40%** | 85.59 | 117.8 | 141.3 | 182.3 | 215.6 | 227.7 | **40%** | 186.7 | 292.3 | 451.0 | 541.4 | 601.2 | 667.1 |
| **50%** | 63.56 | 85.27 | 101.5 | 129.7 | 165.1 | 167.2 | **50%** | 244.8 | 337.6 | 410.8 | 486.7 | 546.5 | 598.3 |
| **60%** | 54.77 | 76.59 | 90.58 | 106.3 | 127.8 | 137.0 | **60%** | 332.1 | 111.8 | 188.4 | 305.1 | 257.7 | 369.3 |
| **70%** | 22.65 | 34.83 | 66.80 | 68.26 | 82.72 | 108.4 | **70%** | 70.80 | 72.50 | 124.8 | 202.2 | 257.8 | 317.2 |
| **80%** | 16.89 | 30.26 | 46.80 | 60.80 | 69.46 | 109.5 | **80%** | 29.30 | 36.80 | 95.6 | 158.4 | 225.8 | 274.8 |

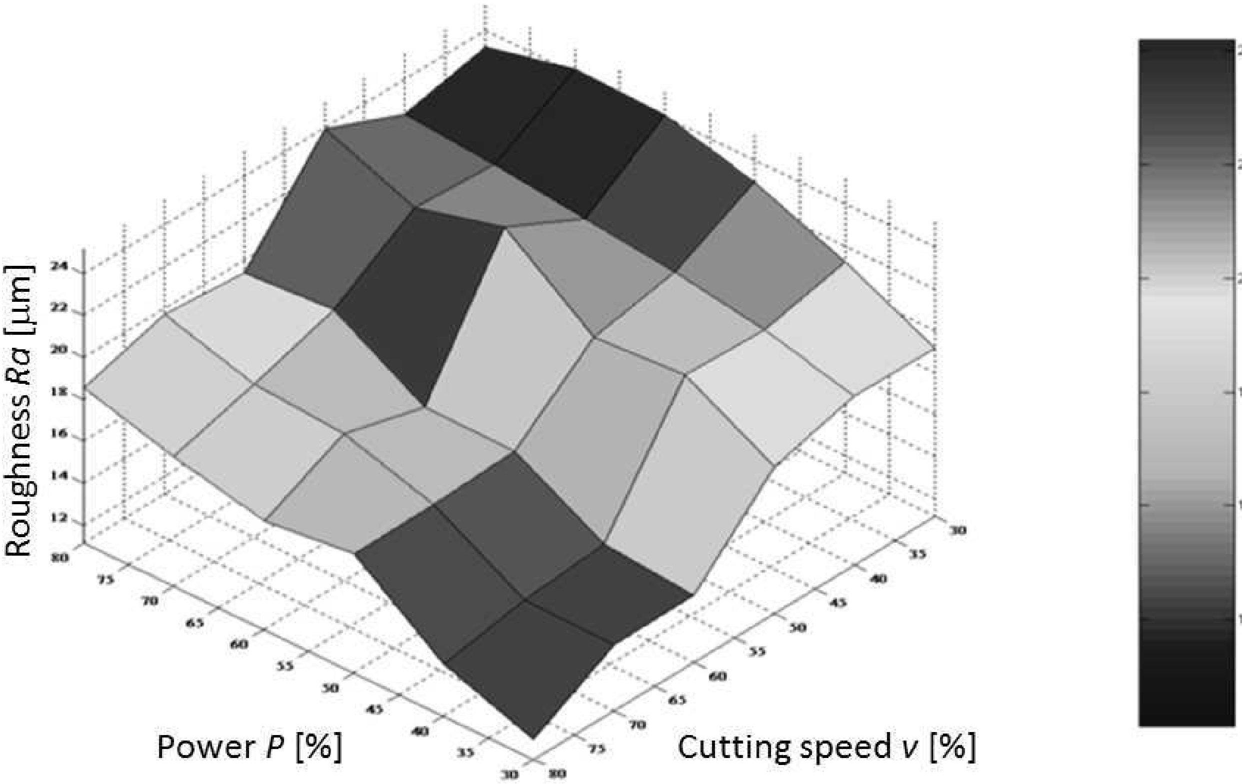


***Fig. 4*** *3D graph for the dependence of roughness Ra [µm] on power P [%] and cutting speed v in [%], 500 DPI*

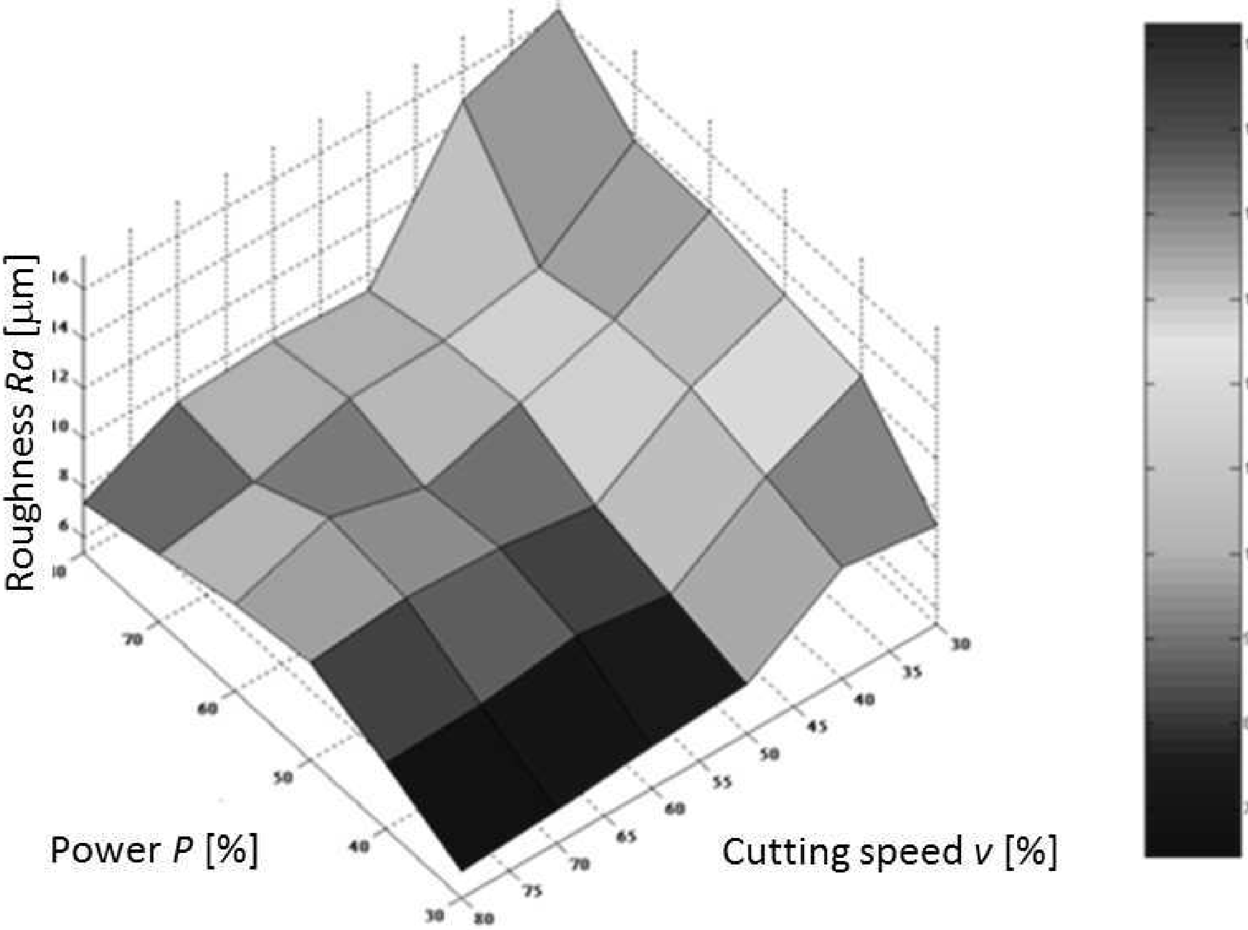


***Fig. 5*** *3D graph for dependence of roughness Ra [µm] on power P [%] and cutting speed v in [%], 1000 DPI*

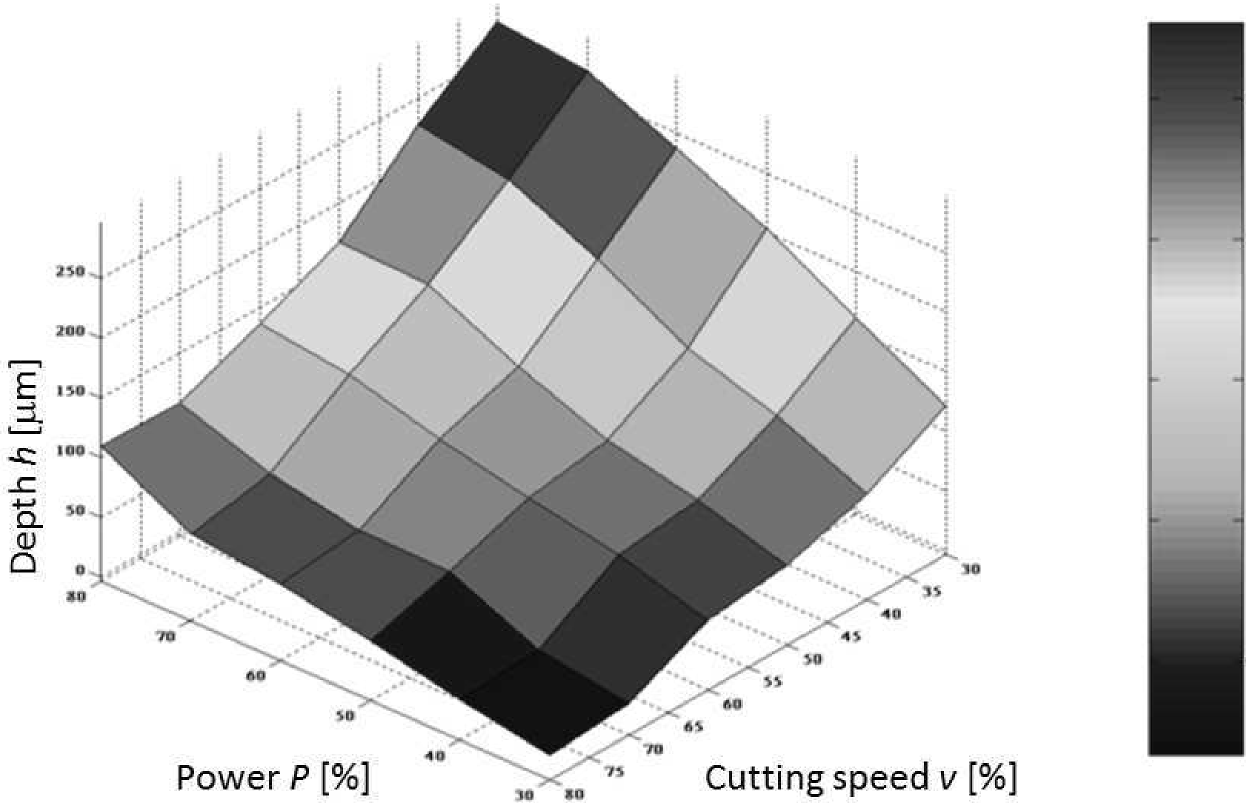


***Fig. 6*** *3D graph for dependence of groove depth h [μm] on power P [%] and cutting speed v in [%], 500 DPI*

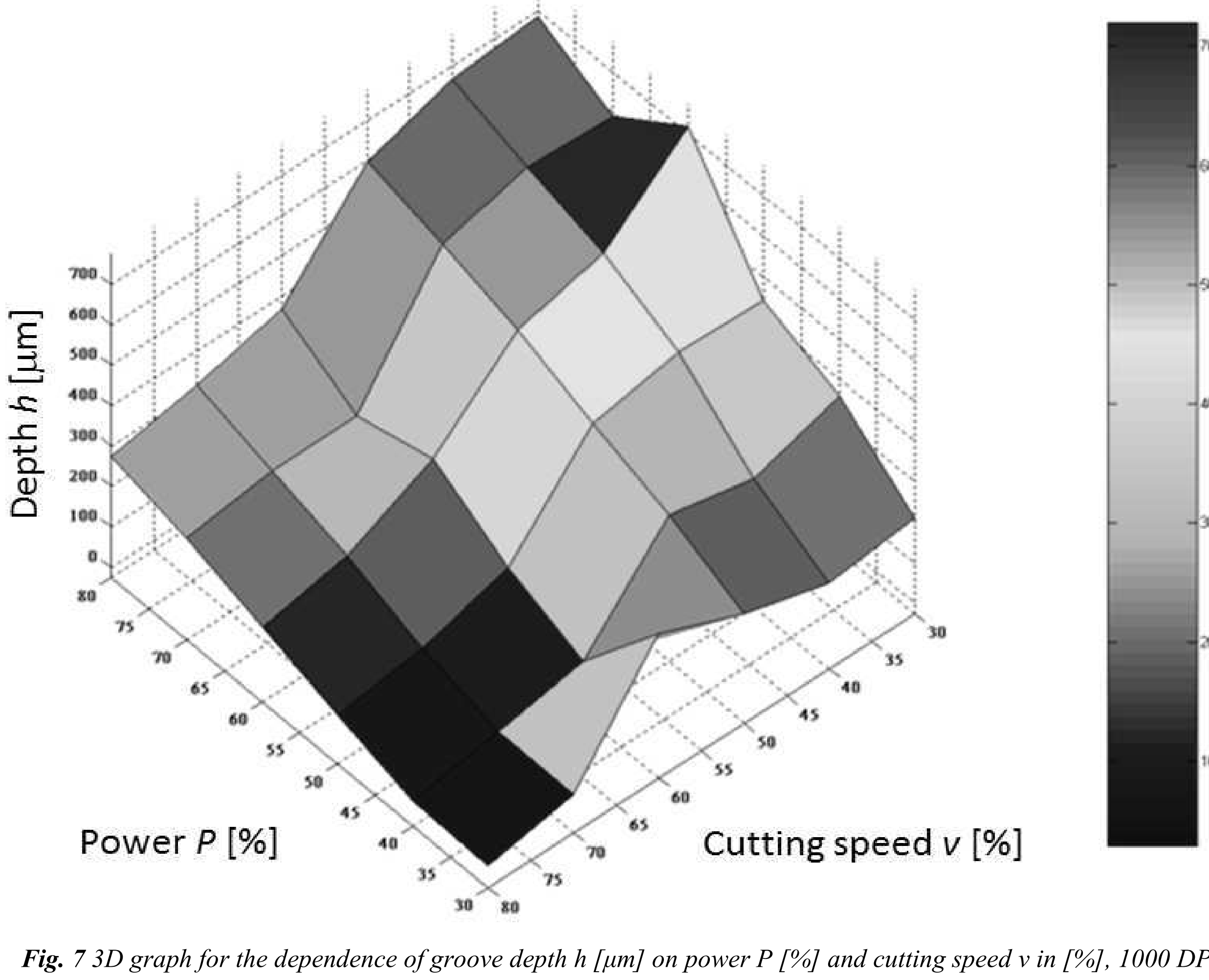


***Fig. 7*** *3D graph for the dependence of groove depth h [μm] on power P [%] and cutting speed v in [%], 1000 DPI*

It is clear from the Table II and Table III that there is an almost constant difference of the mean arithmetic variance Ra in dependence on the power setting P and the feed rate f at the 500 DPI and 1000 DPI. The mean arithmetic deviation Ra decreases with increasing laser beam feed rate setting value.

The dependence of the increasing depth of the groove h with the increasing power P is obvious. It means that the required depth of the machined groove can be controlled by increasing the power. There is also interesting dependence of the feed rate setting. The groove *h* is always deeper when machined by a feed rate of 1000 DPI for all feed settings.

## 4 Conclusion

The performed experiments proved that it is necessary to include also the step parameter of laser feed – DPI in technological parameters having an impact on resulting surface quality and depth of the machined surface. The results confirmed the assumption of an increase in the quality of the Ra surface when changing the DPI from 500 to 1000 DPI by up to 50%. Based on that, can be stated that by defining a suitable combination of the feed rate parameters f, the power P and the fineness of the laser beam feed rate (DPI), the desired quality of the machined surface can be achieved for a particular practical application.

Laser machining is influenced by a variety of factors. The result of the optimisation process is to evaluate the impact of the individual factors, highlight main influence, neglect less important one and, generally speaking, to be able to set parameters of laser machine in the way to maximise properties of the product. However, the main role in the introduction of the technology into practice plays also the issue of the capital expenditure that confronts us with the need for the maximal use of laser energy. Unfortunately, without the in-depth study and knowledge of the issue, it is not possible to reach the real economic use of the machine. [5, 6].

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