Zpět

Micromachining with usage of LASER

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This article combines basic information of laser problems and options of laser process controlling during micromachining. Possibilities of process controlling from view of laser source are characterized. The interaction of laser beam with workpiece (absorption and laser pulse length) is briefly defined. Next chapters deal with laser setting, which is divided into movement controlling of laser beam and laser beam setting from view of process parameters. Other part of the article compares advantages and disadvantages of micromilling and laser micromachining, where the similar attributes are confronted. The end of this article is dedicated to summarization of problems, which occur during laser micromachining, conclusion and possible recommendations eliminating mentioned problems.

Key words: laser micromachining, processing, laser setting, HAZ

1 Introduction

Laser technologies, especially DMLS (Direct Metal Laser Sintering) and micromachining are dynamically developing sector in industry. DMLS, or so-called 3D print for rapid prototype principle is now being applied in many research fields. The laser micromachining provides the processing of all materials under certain conditions.

Problems of laser micromachining offer countless amount of choises. Laser technology can be integrated into the CNC machines, where the multi-axes kinematic can be used and wide extend of applications with high accuracy can be supported. In case of laser macromachining we are talking about non-contact processing, because there is no mechanical interaction between laser beam and machined workpiece.

Assuming that laser source and its path were chosen and designed correctly, it is possible to micromachine a wide extend of materials with laser spot size of units of tens micrometers. That means the new options of micromachining in micro scale are on a topic of these days.

2 The Possibilities of Process Controlling from View of Laser Source

In order to choose a correct laser source for micromachining, the basic properties must be understood, because they are important for interaction of laser radiation with machined workpiece. Micromachining by laser beam is heat process. Efficiency of this process depends on thermal and optical properties instead of mechanical attributes of machined material. Materials showing considerable brittleness or hardness have favorable heat properties. E.g. low thermal diffusivity (α) and conductivity (λ) are especially very suitable for laser micromachining. An absorption is next important variable of machined material [2,3].

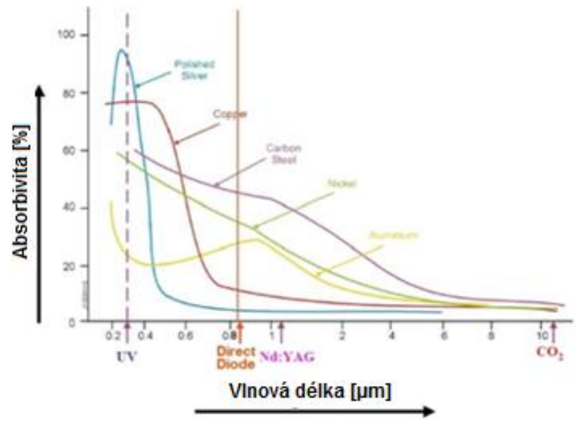
2.1 Absorption

Absorption of material is an important condition for the actual machining process. This can be defined as the fraction of incident radiation that is absorbed at perpendicular incidence. Every material has certain value of absorption which is called absorption coefficient μ. It can be expressed by Beer-Lambert law [3].

$$\boldsymbol{I(z) = I_0 \cdot e^{-\mu z}} \tag{1}$$

where:

I_o input intensity of radiation
I_z intensity of radiation in depth z
μ absorption coefficient

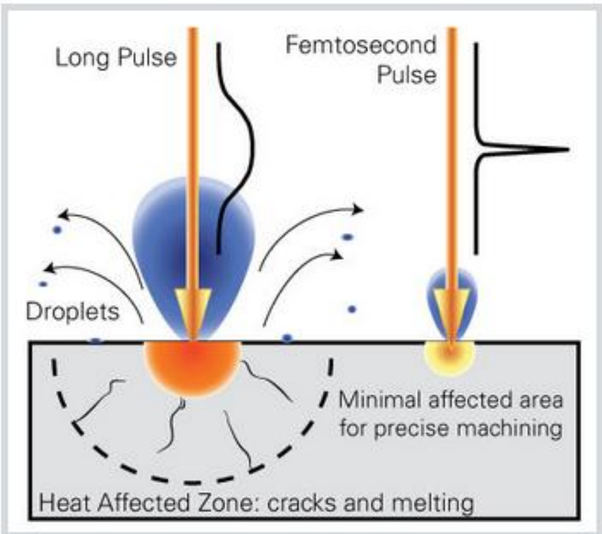


Graf 1 A=f(λ)[1]
Graph 1 A=f(λ) [1]

2.2 Laser Pulse Length

Pulse length is another powerful variable of interaction laser-workpiece in field of micromachining. There are two major considerations: laser pulse energy and heat diffusion time. Generally, for a given amount of energy, the shorter the pulse is, the higher the peak power delivered to the target will be. It means, that only a few units of watts are needed for micromachining of the most materials.

Once applied, the heat energy does not stay localized at the point where it was initially deposited. The heat diffusion time is the time required for a given amount of energy to dissipate into the surrounding material and is specific for that material. Depending on the heat diffusion time of the material, the laser pulse duration is divided into two time regimes: long (µs and ns pulse durations) and ultrafast (ps and fs pulse durations) [2].



Obr. 1 Rozdíl mezi krátkými a dlouhými pulsy [9]
Fig. 1 Difference between short and long pulses [9]

3 The Possibilities of Laser Setting

The overall setting of these laser centres is a very complex matter because of large number of variable parameters. These laser parameters can be devided into 2 areas. The strategy of the movement of the laser beam is concerned in first of them and second one solves an experimental investigation that directly affect the characteristics of laser beam output [4].

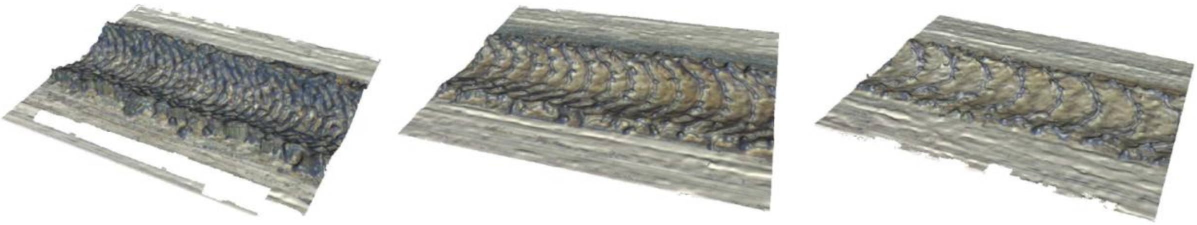
3.1 Movement Controlling of Laser Beam

Laser processing works on the principle of dividing of an imported model into layers where distance among layers is set by operator. Dividing of the models is made by slice generator, which in the most causes works with model height in Z direction. These slices are subsequently hatched. This hatching serves as a path of the laser beam. The principle of laser micromachining can be characterized as a marking of the material layer by layer. Since the size of layers significantly affects machining time and final depth of created shape, it is therefore necessary that this parameter was set optimally.

Another possibility how to control the process is from the view of beam leading where the hatching is important to set correctly. Here a pulse overlap factor S_p and scan overlap factor H must be set properly, where pulse overlap factor S_p is expressed as [5]:

$$S_p = 1 - \frac{v_f}{d * f_p} \tag{2}$$

where:
v_f scanning speed
d spot diameter
f_p pulse frequency



Obr. 2 Různé možnosti nastavení parametru S_p - od největší hodnoty (vlevo) po nejmenší (vpravo)
Fig. 2 Diferent options of S_p setting - from the highest value (on the left) to the lowest value (on the right)

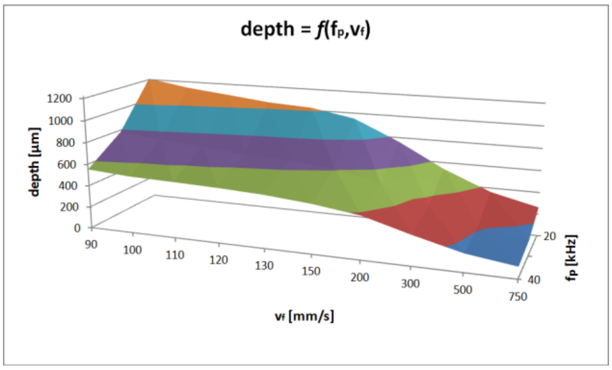
Laser beam defocusing, where the energy is being concentrated under or above the surface of the workpiece and final properties of functional surfaces are modified, is another considered setting. Movement strategies of laser beam have many other options where it is possible to use e.g. axes synchronization with combination of sky-writting command[8], but characterictics of this advanced setting is not the aim of this article.

3.2 Laser Beam Setting from View of Process Parameters

This category includes all parameters, which affects the quality of the laser beam at the output. The beam can be influenced by: scanning speed v_f, pulse frequency f_p and power P. Macrogeomatrical and microgeometrical requirements can be achieved by combining of all mentioned process parameters. The dependence of depth on v_f and f_p parameter were experimentally investigated in graph No.2.

There are shown two dependencies in graph No.2:

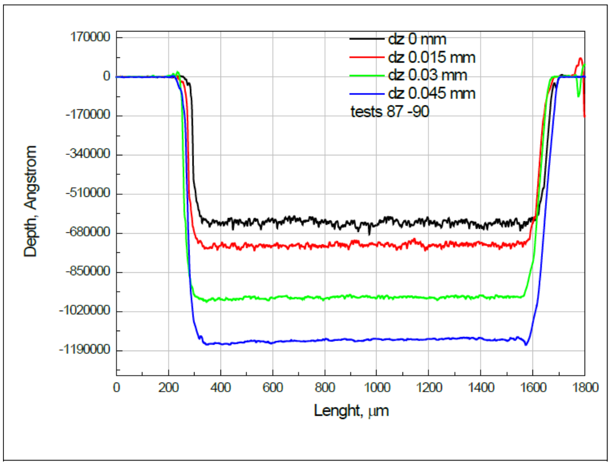
- When the scanning speed is increased, the final depth decreases ($\uparrow v_f \Rightarrow \downarrow$depth)
- When the pulse frequency is increased, the final depth decreases ($\uparrow f_p \Rightarrow \downarrow$ depth)



Graf 2 Závislost parametrů v_f a f_p na hloubce
Graph 2 The dependence of v_f a f_p parameters on depth

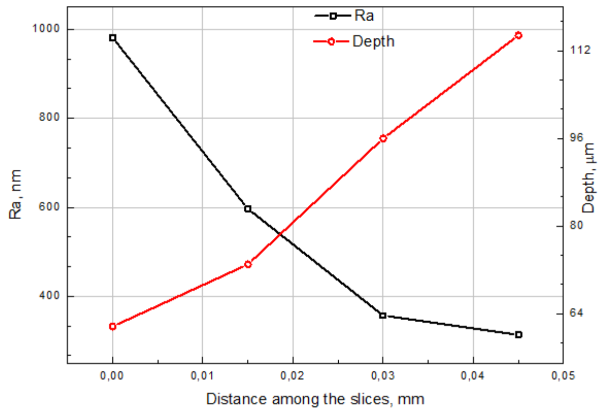
Mentioned statement about decreasing depth during higher pulse frequency value is associated with laser ablation threshold I_{ea}. During the process of ablation the intensity of the laser beam I [GW/cm^2] (laser power per unit area) must exceed the threshold for laser sublimation I_{ea}. The intensity of the laser beam I is influenced mainly by the pulse frequency which determines the pulse peak power.[5] Therefore the ablation threshold I_{ea} limiting the usage of higher pulse frequency values for material ablation is influenced by material properties and type of laser source. Absorption coefficient, thermal conductivity, thermal diffusivity, material temperature, melting temperature and temperature of evaporation (ablation) are the properties of machined material. From the side of the laser source, we are talking about laser spot diameter, laser pulse energy, wavelength, polarization and whole character of laser beam pulse length (ns, ps,…).

After investigating and understanding of all dependencies on interaction workpiece it is possible to combine both groups laser parameter setting in the way so that the resulting relationships provide the most meaningful values. E.g. graph No.3 characterizes different distance among slices and final depth of dimple, where constant count of slices was kept.



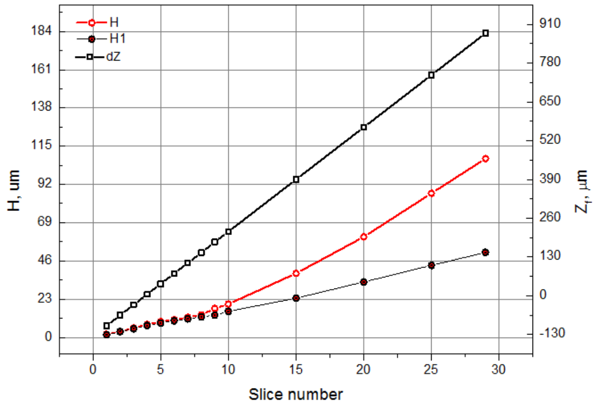
Graf 3 Závislost hloubky kapsy na vzdálenosti mezi vrstvami během procesu
Graph 3 Dimple depth dependence on the distance among layers during processing

The distance among slices strongly influences the depth of final dimple. It can be found that distance among the slices also influences the final surface roughness at the bottom of the dimple. The graph No. 4 illustrates this dependence. By optimizing the distance among the slices and count of slices the required surface roughness can be achieved.



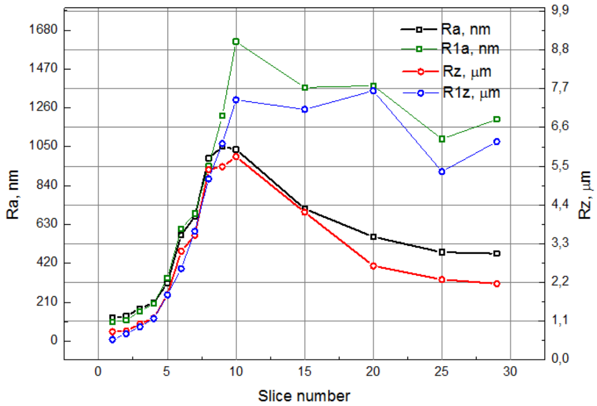
Graf 4 Hloubka kapsy a drsnost povrchu v závislosti na vzdálenosti mezi vrstvami při konstantním počtu vrstev
Graph 4 Dimple depth and surface roughness dependence on the distance among layers. The total count of layers is constant.

The influence of slices count for the final dimple depth and surface roughness also can be found from the experimental results. When the dimensions of the dimple are much higher than laser beam diameter, the depth dependence on the slices count is almost linear. The graphs 5 and 6 illustrate the dimple depth and surface roughness dependence on the slices count.



Graf 5 Závislost hloubky podle počtu vrstev. Pravá stupnice ukazuje aktuální zaostřenou pozici laserového paprsku vypočtenou z porvchu vzorku. H-hloubka (když je vzdálenost mezi vrstvami rovna 0); H1 - hloubka (když je vzdálenost mezi vrstvami rovna 35µm)

Graph 5 Depth dependence on the slice number. Right scale bar indicates the actual laser beam focus position calculated from sample surface. H – depth, when distance among slices is 0, H1 –depth, when distance among slices is 35 um



Graf 6 Závislost parametrů R_a a R_z na počet vrstev. R_a aR_z - vzdálenost mezi vrstvami je 0µm; R_{1a} a R_{1z} - vzdálenost mezi vrstvami je 35µm

Graph 6 Surface roughness R_a and R_z dependence on the slice number. R_a and R_z – distance among slices is 0; R_{1a} and R_{1z} – distance among slices 35um.

4 Advantages and Disadvantages of Convencional and Unconventional Micromachining

The high potencial and advantages of laser micromachining were defined in the opening paragraph of this article, however it is appropriate to confront unconventional micromachining technology with conventional micromilling. Laser micromachining offers many advantages: the life of the laser source (as a cutting tool), minimal cutting forces and camera system. However, this technology compared with micromilling has following disadvantages: non-standard control system, different understanding of cutting conditions, constant focal length is needed and higher purchase price of the techlogy. Comparison of various micromachining methods is in following table, where the advantages are colored by green and disadvantages by red.

Tab. 1 Porovnání jednotlivých metod mikroobrábění [6]
Tab. 1 Comparison of various micromachining methods [6]

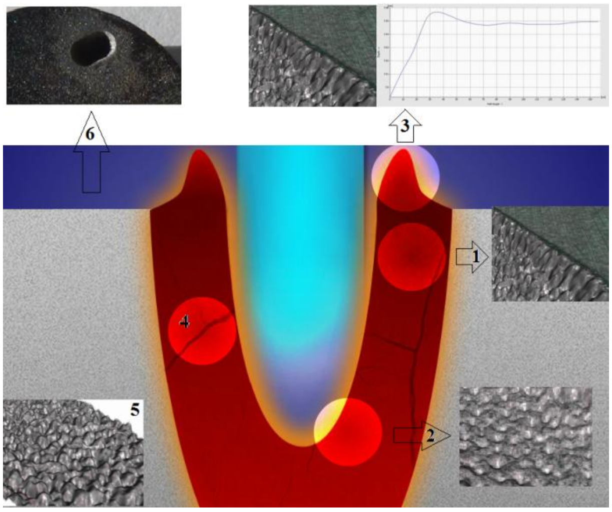
Micromilling	**Laser Micromachining**
Tool life	Reliability of laser source
Cutting forces	Almost zero cutting forces
5 axes kinematic machining required	In many causes 3 axes kinematic is sufficient
Contact probe	Contact probe + camera system
Standard control system	non-standard control system
Cutting conditions (v_c, a_p, a_e, f_z)	Cutting conditions (v_f, f_p, slice, hatching, P)
Lower purchase price of technology	Higher purchase price of technology

5 Summarization of Laser Micromachining Problems

Laser micromachining problems lie in a complex process setting where it brings many difficulties. A heat affected zone (HAZ) is especially main problem among others. It is important to make a minimal or almost none HAZ when machining the functional surfaces of workpiece, which have to be loaded by various mechanical forces.

Impacts of HAZ can be in forms such as are shown in Fig. 3 and characterized in the following points.

1. *Different surface colloring*
2. *Recast layer*
3. *Damaged adjacent structure*
4. *Microcracks,residual stresses*
5. *Characteristic surface topography*
6. *Others - surface debris*



Obr. 3 Formy HAZ a její následky [1]
Fig. 3 Types of HAZ a its effects [1]

This inappropriate phenomenon can be restricted by right choise of laser source and suitable setting of micromachining. Shape inaccuracies, insufficient surface roughness and other problems must be optimized by correct laser parameter setting or some model modifications.

6 Conclusion

In order to ensure the full extent of potential, it is necessary to design a compact construction. It means that a complex solution of laser micromachining center will provide maximum reachable workspace in laser cabinet. The multiaxes kinematic is important due to shape micromachining, this feature can universalize a portfolio of modifiable products. For this purposes the movement of laser beam and kinematic of stages have to be synchronized. Precise clamping of workpieces and high variability of fixtures including a possibility of non-contact measurement with sufficient resolution in workspace are required when positioning entities on the workpieces. Programming flexibility which enables to correct some problematic elements of process leads to elimination or reduction of problems mentioned in chapter 5.

By combining of these requirements with the appropriate laser source it is possible to achieve the laser multidisciplinary micromachining center, which can be used in medicine, engineering and electrical industries.

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Abstrakt

Článek: Mikroobrábění s využitím LASERu

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Klíčová slova: laserové mikroobrábění, zpracování, nastavení laseru, TOO

Tento článek kombinuje základní informace laserové problematiky a možnosti kontroly laserového procesu mikroobrábění. Charakterizovány jsou zde možnosti kontroly z pohledu laserového zdroje, kde je stručně definována interakce laserového paprsku s obrobkem v podobě aspektů, jako je absorpce a délka pulzu. Dále článek pojednává o nastavení laseru, které je rozděleno do kontroly pohybu laserového paprsku a nastavení z pohledu procesních parametrů. Následující část porovnává výhody a nevýhody mikrofrézování a mikroobrábění laserem, kde jsou konfrontovány stejné atributy. Závěr článku je věnován sumarizaci problému, které nastávají během tohoto mikroobrábění a shrnutí či případná doporučení, které eliminují výše zmíněné problémy.

Zpět