Study on Laser Micro-Drilling Process

MIHAIELA ILIESCU¹, TEODOR NECȘOIU², MARIAN LAZĂR²
¹Manufacturing Department, ²Research and Production Department
¹POLITEHNICA University of Bucharest, ²SC OPTOELECTRONICA 2001 SA
¹Splaiul Independentei 313, Bucharest, ²Atomistilor 409, Magurele
ROMANIA
¹iomi@clicknet.ro, http://www.imst.pub.ro; ²tnecsoiu@optoel.com, http://www.optoel.ro

Abstract: There are many situations when a classic drilling process is not worth to be used – even the material to be machined is too hard, or the geometrical precision conditions for the required whole are too high. As laser technology has known an impressive development, the laser does represent the solution for the mentioned situations. This paper presents some experimental research done in order to determine optimum process parameters for obtaining micro-holes by using the laser beam.

Key-Words: - laser beam, pulse, energy, micro-drilling, process, parameters.

1 Introduction

When conventional (mechanical) machining procedures (turning, milling, drilling, etc.) can no longer be used because of severe conditions related to geometrical complexity, accuracy and / or material required by new application areas of the parts involved, there are the new machining technologies to be applied.

One of the most efficient is laser micro-machining, where the laser beam does represent an universal tool that “machines” with no need of special force to fix the part and without wearing when impacting the surface to be transformed. In laser micro-machining there is no absolute request for void equipment, thermal influenced zones can be neglected and thermal deformations are very small, while the machined materials can be tough, extra-tough or, fragile ones.

Some of the most important factors that do “ask” for laser micro-machining can be mentioned as:
- part material ⇒ glass, polymers, silicon, hard stainless steel, thin films, etc;
- shape and geometrical precision of the surfaces to be obtained ⇒ holes, slots, channels, complex 2D / 3D shapes;
- high accuracy and small dimensions ⇒ from hundreds of microns up to microns.

There are also, expectations from laser micro-machining processes, referring to:
- obtaining the required features with high precision;
- good price, fast turnaround, one off to larger numbers of parts;
- new, inovative design and product ideas, customized products.

Laser micro-machining „covers” a large spectrum of machining procedures, one of the most important being: laser micro-drilling

Because of the aspects mentioned below:
- the complexity of factors that influence the process;
- the variety of micro-machined materials;
- the different types of laser generated radiation;
- the relatively short period of time they have been developed since;

there are very few, if any, ‘standard’ procedures available for laser micro-maching. This means that the result is determined as much by who is doing the work and how it is undertaken it.

So, prediction of the „outcome” is of rather high uncertainty.

Application of laser micro-machined parts is wide, fitted to new modern industrial sectors, like:
- microelectronics – patterning of high resolution electronic circuits; printing and transfer masks;
- biotechnology – obtaining high quality micro-channels in polymers; fabrication of optical structures as micro-lenses;
- photonics – high quality machining of optical materials and semiconductors; precision machined placement structures as grooves and wells for optical devices;
- precision engineering – high speed drilling of meshes in metal foils with hole size as small as 2 microns; in situ trimming of machined and pre-assembled devices without damage to adjacent parts; production of high tolerance slits and holes.
2. Laser Micro-Drilling Theoretical Aspects

Laser micro-drilling is used, specially when very small dimension diameter hole must be obtained.

The materials can be of various types like: hard or extra-hard, very thin foils, glass, composites, etc.

Values obtained for hole dimensions can be [1]:
- 5 μm to 5 mm in diameter;
- 15 to 18 mm in depth

A schematic representation of the micro-drilling process is shown in figure 1, while the various types it can be done are evidenced by figure 2.

![Fig. 1 Scheme of the micro-drilling process [3]](image)

There are specific aspects involved by the laser micro-drilling, some of them mentioned next [1]

⇒ hole diameter, \( d \)

\[
d = 2\sqrt{d_0^3 + \frac{3Eig\theta}{\pi L_v}} \quad [\text{mm}] \quad (1)
\]

⇒ hole depth, \( h \)

\[
h = \frac{1}{tg\theta} \left[ \sqrt[3]{d_0^3 + \frac{3E}{\pi L_v}} - d_0 \right] \quad [\text{mm}] \quad (2)
\]

where:
\( \theta \) is the angle of focusing cone;
\( d_0 \) – initial diameter of laser beam;
\( E \) – pulse energy;
\( L_v \) – material’s vaporizing specific energy

⇒ hole shape – characterized by length / diameter ratio, usually less than 20:1 – see figure 3

⇒ angle between hole axis and the (upper) surface – usually of 15° ÷ 90°.

![Fig. 2 Types of the micro-drilling process [3]](image)

![Fig. 3 Laser micro-drilled hole shape [1]](image)
3. Laser Micro-Drilling Experiments

Experiments were made at OPTOELECTRONICA 2001 Company and the experimental stand consisted in the following components [3], [4].

1. Laser central unit TruePulse 62 (TRUMF) – see figure 4. This is a Nd: YAG laser type, that generates intense invisible radiations, with wavelength „close to” infrared radiations. Some of its technical characteristics, as mentioned by the producer, are presented in table 1.

2. Isel-automation machining systems - systems made of three main components:
   - isy CAM software – for designing the part and setting machining instructions
   - ProNC software - interface for the basic unit
   - Flatbed or Euromod basic units.

An image of the whole experimental stand is shown in figure 5.

![optical unit](image)

![central unit](image)

Fig. 4   True Pulse 62 laser unit [3]

Fig. 5 Experimental stand

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Rradiation wave length</td>
<td>1064 nm</td>
</tr>
<tr>
<td>- Medium power</td>
<td>65 W</td>
</tr>
<tr>
<td>- Pulse minimum power</td>
<td>250 W</td>
</tr>
<tr>
<td>- Pulse maximum power</td>
<td>5000 W</td>
</tr>
<tr>
<td>- Pulse minimum duration</td>
<td>0,2 ms</td>
</tr>
<tr>
<td>- Pulse maximum duration</td>
<td>50 ms</td>
</tr>
<tr>
<td>- Pulse maximum energy</td>
<td>50 J</td>
</tr>
<tr>
<td>- Maximum frequency of pulse repetition</td>
<td>900 Hz</td>
</tr>
<tr>
<td>- Laser beam quality</td>
<td>8 mm mrad</td>
</tr>
</tbody>
</table>

Table 1 [3]

The laser system producer, TRUMF does offer some guiding information on laser micro-machining process parameters [3], [5].

But, when experimenting on the studied materials (hard steel, copper-zinc alloy and aluminium alloy) and following the instructions, the results were not good at all. First, for the steel samples, it did not result a penetrated hole and, after that, for the copper sample, the material was burned out.

This is why, many experiments had to be done, for various values and combination of the micro-drilling process parameters, till good results were noticed. This is because, the real materials did not have the physical and chemical real properties as the one considered by TRUMF Laser Technology producer.

So, there were considered different values for pulse energy, pulse time and even, pulse shape.
There were several combinations of them and, finally it was okay.

An image of the computer screen, as well as of the obtained micro-hole, for the hard steel material sample is shown in figure 6.

Further step was done, meaning that of microscope measuring the hole diameter. Results for the hard steel sample, as well as for a copper alloy sample are presented in figure 7.

Fig. 6 Experimental results

4. Conclusion
Laser micro-drilling is used, specially when very small dimension diameter hole must be obtained. The materials can be of various types like: hard or extra-hard, very thin foils, glass, composites, etc.

The laser system producers offer some guiding information on laser micro-machining process parameters, but when experimenting, the results were not good at all.

It was necessary to make experiments with specific materials (hard-steel, copper-zinc alloy, aluminium alloy) and existing equipment. So, optimum values for laser micro-drilling process could be determined.

The results should be further used in industrial application.

Further research must be developed – based on design of experiments and specific software so that, if possible, regression models of process parameters to be determined.

References:

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