EXPLORING THE VARIOUS PARAMETERS OF CO_2 LASER IN THE CUTTING OF PAPER

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Abstract: *The revolution in the printing industry started by digital printing has resulted in the introduction of personalised production of small runs, fast job changes and short deadlines. By introducing digital printing into mainstream and production focus, even for the largest printing machine manufacturers, a new era of the graphic industry has just begun. After these significant changes in the printing process, the following process of graphic production – post-press needs to be digitalised. The initial goal is to back up the possibilities of digital printing and enable it to be applied as widely as possible to its full potential. Postpress has become a bottleneck in the digital world. One of the analogous processes, which is the focus of improvement, is the cutting of graphic materials in irregular shapes in the process of creating packaging. The use of lasers enables the digitisation of the die-cut or partial cutting post-press process. Cutting of different shapes is obtained when the laser touches the substrate and where it evaporates at that moment. A thermal process accompanies this evaporation, that to a greater or lesser extent affects the substrate to be cut. The parameters that govern laser are the subject of this paper. The development of laser cutting technology has opened various possibilities for innovations in the graphic and printing industry. Since this is still considered as new technology, extensive researches on its options are essential to reach the full potential of this technology. This paper is going to analyse the overall characteristics and use of laser technology in the graphic industry by focusing on the processing of paper materials. Indispensible to mention are the advantages and disadvantages of this technology. There are a lot of comparisons among existing technologies developed for cutting graphic materials and paper. The importance of this topic is concerning all production phases of the graphic product – from processing the raw material to cutting the final product such as packaging. Regarding that, the scope of the laser processing of the graphic materials is reviewed. The paper gives suggestions for further research and experiments regarding this topic.*

Keywords: post-press, die-cutting, CO_2 laser, packaging, paper

1. INTRODUCTION

Postpress remains one of the last stages in graphic production that still resists digitisation. The processes that take place in it are either manual or are done on specialised machines that are not so sophisticated and flexible. The handling of the post-press itself is of such a nature that it can be automated and even integrated into the in-line process of graphic production, but it isn't easy to fully digitise.

By analysing the trends in the printing industry, it can be seen that the sales of conventional solutions for finishing machines are in constant decline in the last decade. Only devices designed for digital printing resist the demand reduction, so it is not surprising that many large manufacturers of graphic finishing machines adapt their machines to the requirements of digital printing, smaller runs and ink-jet and toner prints. The growth of the production of packaging and labels must undoubtedly be in the focus of development of post-press machines because the packaging sector will take over 50% of the total printing in the coming period.

Getting the final shape of particular printed products, primarily when its merits compared with a standard, rectangular, was associated with mechanical cutting blades - mechanical dies. This process is time-consuming and expensive, noisy and can be dangerous for the operator. It enables minimal flexibility because the smallest changes in the shape of the final product require re-creation of the dies-cut form. To make the dies-cutting process more flexible, machines that perform cutting with the help of CO_2 lasers have come into use. Computer-guided CO_2 lasers are specially adapted to paper materials. Although these are high power lasers, so they are very safe because of the use of internal gas which prevents the paper materials ignition. Laser power is such that when the laser hits the surface of the substrate, the substrate evaporates, leaving behind a precise cut. The laser is guided to the material by optics that can be changed. When different optics is set, it influences the size and distance of the laser focus.

By adjusting the laser parameters, the paper can be completely cut but also kissed-cut. The adjustment also allows you to cut different types of papers and cardboards as well as film materials, without the need to change even one tool on the machine. The trajectory of the laser is determined digitally, which eliminates the need for a dies cut forme when cutting irregular shapes. Also, the precision of laser guidance, with an extremely small diameter of the laser beam, enables very fine and precise cutting of material. Small shapes and diameter were impossible to cut with the mechanic dies-cut. One of the most significant benefits concerning the dies-cut form is precise that each cut can be of a completely different shape, which completely fits into the possibilities of digital printing.
Laser cutting systems, paired with digital printing, are the focus of companies that manufacture the graphic equipment, so further growth, development and production of laser cutting machines can be expected.

Figure 1: Modern laser cutting machine (image taken from https://www.highcon.net/press-release/highcon-launches-euclid-iiic-corrugated/)

2. A FUNDAMENTAL PRINCIPLE OF CO_2 LASER PAPER CUTTING

The word laser comes from the acronym "light amplification by stimulated emission of radiation" (Gould, 1959). The laser emits monochromatic coherent light whose energy affects the surface it hits. CO_2 laser (carbon dioxide) is a gas laser that emits infrared light with a wavelength of 9.6 and 10.6 microns (μm). It is highly efficient and suitable for both industrial and medical use.
To use the techniques of laser cutting, optimally is necessary to know the principle of cutting material. The mechanism of paper cutting by laser is based on the evaporation of the substrate. Laser cutting mechanism involves heating the material to the temperature of evaporation, or the temperature at which chemical degradation of the material occurs. The physical change that a material undergoes is the conversion of the material directly from a solid to a gaseous state (Piili, 2013). The temperature that will be reached depends on the material that receives the laser beam and whose molecules are excited by it If the material evaporates at 150 ° C for the material to degrade, the laser should excite the molecules to move at a speed that will raise the temperature to the point of evaporation.
Consequently, the temperature of the laser depends on the substrate that receives the laser beam. The largest part of the laser power is used for breaking chemical bonds in the material. When paper materials are cut with a laser beam, chemical degradation involves breaking long chains of cellulose molecules to carbon and water vapour (Malmberg et al, 2006a). Products formed by chemical degradation of the material evaporate or are removed from the kerf by the action of a jet of auxiliary gas of the laser beam. With the development of laser technology, due to the use of various inert gases within the laser structure, the ignition of the material that evaporates is prevented. Therefore, laser cutting is safe and is used both in the paper industry for paper production and in graphic finishing processes. (Federle and Keller, 1992a; Malmberg and Kujanpää, 2006b).

3. THE USE OF LASERS FOR PAPER CUTTING

Laser cutting of fibrous materials has several possibilities of application. Laser cutting of uncoated as well as coated paper materials, does not affect the printing properties of the paper (Piili, 2013). Also, printed papers and cardboards can be cut using a laser beam, so the cutting quality is excellent (Malmberg and Kujanpää, 2006a; Malmberg and Kujanpää, 2006b).
Laser cutting of paper materials can be used in combination with digital printing. The advantage of digital printing is the ability to produce small runs with a rapid change of the image being printed. The advantage of laser cutting is the fact that there is no change in tools when changing jobs. The shape that needs to be cut is set digitally, like in digital printing (Boyle, 1999).
Further, using a laser beam offers the possibility of making perforations on paper or cardboard with great precision and speed. Perforations done with mechanical tools leads to the problem of weakening the material due to broken fibres and uneven sized hole cut, which occurs due to mechanical wear of tools with which to perform perforation (Piili, 2013). On the other hand, by using a laser to make a perforation, the holes that are created are open and of equal size (Mommsen and Stürmer, 1990; Brockmann, 1999).
The use of lasers is possible even for kiss cutting (partial cutting) of multilayer materials such as stickers and labels (Figure 2). Kiss cutting can also be used instead of the process of corrugated cardboard creasing on die-cutting machines.
Malmberg et al. (2006b) state the situations in which the use of lasers for cutting paper materials is recommended:

- when the cutting process is done by hand
- when working with small circulations below 1000 pieces
- always with products that are printed using a digital printing technique
- when it is necessary to achieve a high degree of cutting accuracy, as well as cutting complex geometric shapes
- when making samples or batches of samples
- if an expensive material is used for the processing of which a high degree of manufacturing accuracy is necessary
- in production where different types of products are made and when the high speed of delivery is required

One of the most critical questions that arise when analysing the quality of laser cutting is the appearance of the cut face. Cut face with carbonation due to the consequences of combustion changes the colour and reduces the overall quality of printed products. The cut face of the material cut mechanically contains fibres that protrude beyond the edge, which can also cause many problems in the production. (Piili, 2013). However, laser cutting is a non-contact technique, and no tool can damage the cut face. Also, when cutting with a laser, the loss of material is smaller. If the laser is optimally adjusted, there will be no change in the colour of the material around the cut face, and the cut will be clean, without free fibres, making it firmer and more compact.
In the case of Nd: YAG laser, the absorption of its wavelength by the paper is unsatisfactory. Cutting edge looks like a faint imprint on the surface of the paper material. Cutting paper materials with this laser is feasible, at very high laser power, low laser speed, resulting in a cutting edge that is mostly carbonised and the width of the cutting edge is over 300 microns.
Paper materials best absorb the wavelength of CO_2 lasers, which is why this type of laser is used to cut paper, cardboard and pulp. (Ainsworth, 1978; Federle and Keller, 1992b; Joore et al, 2003; Malmberg and Kujanpää, 2006a).

4. INFLUENTIAL LASER PARAMETERS

4.1 Laser power and speed

Laser power is defined as the total amount of energy emitted in one unit of time. The unit in which the laser power is expressed is Watt (W). The maximum laser power intensity is expressed in watts per unit area (usually W cm^{-2} or W mm^{-2}). When cutting non-metals, maximum intensity is required to achieve high temperatures when cutting the substrate, which results in good cutting quality combined with high cutting speeds (Steen, 1991).

Federle and Keller (1992) have conducted an experiment in which CO_2 laser was used to cut paper intended for offset printing grammage substance of 80 g/m^2. It is noticed that the laser power and the laser speed are in a linear relationship with each other. As the laser power increases, the cutting quality increases. However, if cutting is performed with a higher laser power than is required for a given material, the kerf increases, the cut face carbonisation increases, and the quantity of evaporation increases (Federle and Keller, 1992a; Federle and Keller, 1992b).

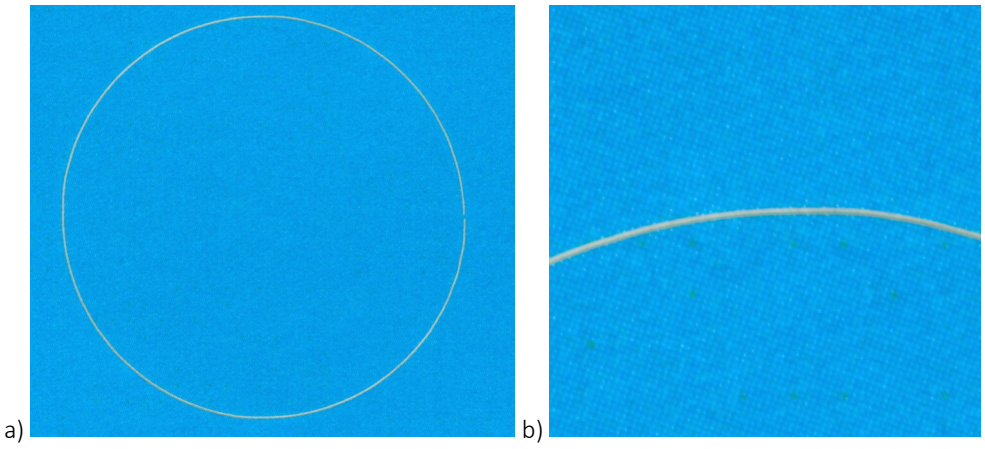

Figure 2: a) Optimal laser power for kiss-cut of printed self-adhesive paper b) detail

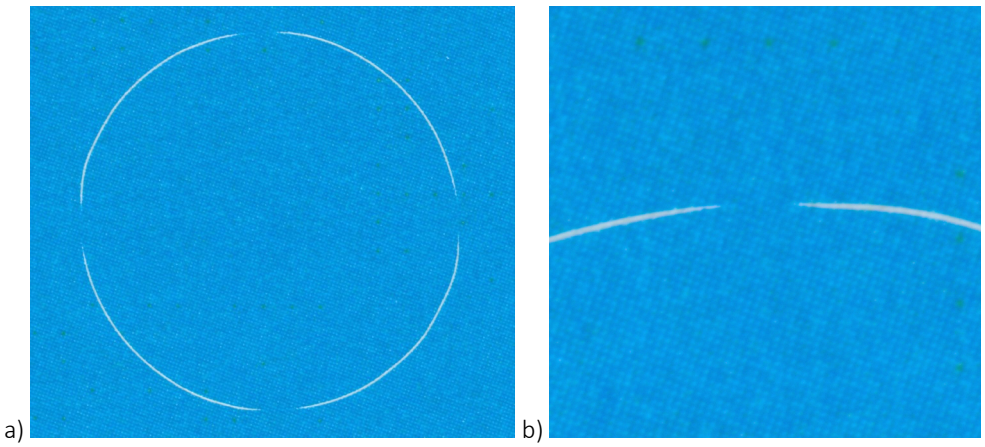

Figure 3: a) Low laser power for kiss-cut of printed self-adhesive paper b) detail

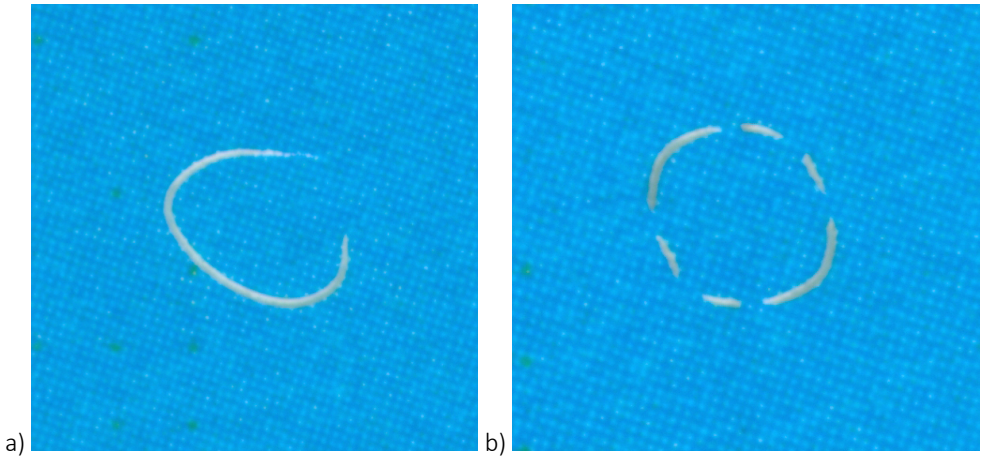

Figure 4: Influence of cutting speed and power on laser precision: a) high power and cutting speed b) lower power and cutting speed

4.2 Grammage substance

Some studies investigated how grammage affects the cutting speed when cutting with a CO_2 laser. Federle and Keller (1992a) experimented with paper materials for offset printing, grammage from 80 to 170 g/m^2, at a laser power of 600 W. It was concluded that grammage and cutting speed are not linearly dependent. They also concluded that the grammage has no effect on the quality of laser cutting, nor on the kerf.
Research by Ramsay and Richardson (1992) showed that more laser power is needed to cut thicker paper materials as opposed to thinner paper materials. They also concluded that with constant laser power, when cutting thicker materials, a lower laser speed is needed to perform a successful cut, where this is not the case for thin materials.
The cutting of paper materials with a grammage of 500 to 1700 g/m^2, with a laser power of 1700 W, was also tested. The experiment showed that there is a relationship between the grammage of paper materials, the laser cutting speed and laser power. Increasing the grammage causes the laser speed to decrease, so that cutting can occur (Joore et al, 2003).

4.3 Paper thickness

The influence of material thickness on successful laser cutting was investigated. The cutting of several different paper materials with a constant laser power of 550 W was examined. Maximum cutting speeds for different material thicknesses were found. It was concluded that cutting speed increases with decreasing material thickness. The less material needs to evaporate, the cutting is faster (Malmberg et al, 2006).

4.4 Bulk

Bulk is the thickness of a sheet of paper and is the opposite property of paper density. High bulk is a type of paper with a greater thickness than other papers with the same grammage. This property of the paper is essential if the paper is required to be stiff. Malmberg et al. (2006) examined the effect of bulk on laser cutting speed. CTMP and pine pulp cuts were performed at a constant laser power of 90 W and 550 W. It was concluded that as the bulk increases, the cutting speed increases. High bulk papers have lower density, so there is less material required to evaporate when cutting, resulting in faster laser cutting (Malmberg et al, 2006).

4.5 The amount of moisture in the paper

Natural fibres have a hollow cross-section. The amount of water in the paper has a significant effect on laser cutting. If the moisture content increases, then the following happens:

- The thermal conductivity of paper materials increases
- Paper reflection increases
- part of the laser power is spent on evaporating water from the material

It has been proven that water absorbs the wavelength of CO2 lasers very well (Ojala, 1993). The laser power required to cut the material increases with increasing paper moisture, as more heating is needed to convert larger amounts of water into water vapour (Malmberg et al, 2006). Stepanov et al. (2015), examined the possibilities of cutting dry and wet paper (with 30% - 40% dry matter content) using CO2 lasers and showed a significant difference in the laser power needed for cutting dry and wet paper. Laser energy of 16.4 J / m was calculated to cut dry paper, while laser energy of 94 J / m was required to cut wet paper.

4.6 Coating

Authors Federle and Keller, based on their studies, claim that there is no difference in cutting different paper materials when cutting with a laser (Federle and Keller, 1992a; Federle and Keller, 1992b). They noticed that there is a difference between coated and non-coated materials, where the coating edges are coloured, and smoke appears, depending on the quality of the coating. Increasing the amount of coating causes greater scattering and absorption of laser light due to the higher amount of coating material (Rämö, 2004).

In their paper, Malmberg et al. (2006) tested the following paper materials: LWC (*lightweight coated*), CWF (*coated wood-free*) and SC (*supercalendered*). The laser used for cutting was Triumpf TLF 2700 HQ carbon dioxide laser, which has a power range from 115 W to 2700 W. The results showed that uncoated LWC paper cuts faster than coated. The explanation given for this results is that the paper coating absorbs the laser light and thus less laser cutting power remains which are manifested by reduced cutting speed. It has also been proven that the amount of coating affects the laser power required for cutting – higher laser power is needed if the amount of paper coating increases. When it comes to the kerf, it was noticed that the paper coating caused the kerf to expand, which is a consequence of the laser light scattering due to the presence of coating pigment particles. Increasing the power of the laser also led to the widening of the kerf.

5. CONCLUSION

The need to find a solution in post-press that will match the advantages of digital printing is a very demanding task. Through the development of modern technologies, the graphic product kept its digital form further and further from one phase to next. Keeping the product in digital form for as long as possible meant speeding up the work process, reducing errors and increasing the possibility of correcting any shortcomings. First, digitalisation appeared in the process of prepress, layout, while the other phases remained analogous. Then slowly digitalisation moved step by step until it reached the printing process. In the printing process, the print finally turns into an analogue form, and its further processing also continues analogue. This is where the problems that plagued graphic artists for centuries arise. Although the automation of the finishing process is at a high level, the machines used still process the product with the help of mechanical tools. This is in no way conducive to the philosophy of today's business in the printing industry as we have seen the gradual progress of digital technology through the process of prepress to the printing itself, so it will undoubtedly continue in the process of post-press.
The use of laser cutting systems is no longer science fiction. The development of lasers has made it possible to cut even sensitive materials such as paper without any traces of cutting like burning or combustion. The ability to influence different parameters of the laser such as its speed, power, frequency and resolution allows it to adapt to a vast range of different materials from paper, cardboard to films and foils. Different materials react differently to the laser beam, so it is necessary to increase the number of experiments that will show the influence of the laser beam and its parameters on different substrates. In addition to cutting, the laser can be used for various surface treatment such as engraving, especially for cardboard, but also cover materials.
The negative aspects of the use of lasers must also be investigated experimentally, especially the part related to environmental protection and safety at work. Also, the downside of laser processing is its low speed. It can be increased if more laser heads are installed in the machines that will cut the material at the same time, but this significantly increases the cost of the process. Whether the laser cutting system will be able to fit into the dominant offset printing technique is jet to be seen, but for now, this system is not usable for conventional graphic production.

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