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CONSIDERATIONS ON THE PRECISION OF NC MACHINE-TOOLS USED FOR NON-CONVENTIONAL CUTTING OPERATIONS

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Abstract: *The paper analyses various non-conventional possibilities of cutting complex-shaped parts made of steel sheets in conditions of high part precision and short production time: abrasive jet cutting, laser cutting, plasma cutting. It focuses especially on the precision offered by the numerical-controlled machine-tools used for the cutting of metal sheets with the help of a laser, function of several influence factors and comparing it also with the results obtained with other cutting methods. Based on this, recommendations are made for the correct choice of the processing parameters and of the NC equipment to be employed.*

Key words: *machine-tools, numerical control, laser cutting, plasma cutting, precision*

1. INTRODUCTION

Nowadays, the means and techniques employed for cutting various materials, and especially metallic materials, are very diversified, so both producers and users of cut parts are often faced with a difficult choice with regard to the right technique and machine to use for a certain application, the more so when the part has a complex shape.

The precision of parts realized by cutting can be improved significantly by using equipments for numerical control (NC) on the machine-tools used for this purpose. However, there are a variety of factors that can negatively affect precision even under these conditions [1], so special precautions have to be taken when programming a machine-tool for an operation that demands a high accuracy.

The paper presents several modern options for metal cutting: laser cutting, plasma cutting and abrasive jet cutting, focusing especially on the factors influencing the precision of parts obtained by laser cutting on NC machine tools.

2. MODERN NON-CONVENTIONAL CUTTING TECHNOLOGIES

2.1 Laser Cutting

Laser cutting is a technology that uses a focused beam of high energy laser light to cut material by selectively burning, vaporizing and/or melting a highly localized area, while an assist gas is used to remove the molten material from the resulting cut. It is one of the fastest and most accurate methods for cutting a variety of metals and non-metals.

Nowadays, both gaseous (CO_2) and solid-state (Nd:YAG) lasers are employed for cutting various materials. Since, in the case of CO_2 lasers, the type of gas flow can affect the cutting performance, several laser subvariants can be identified, such as fast axial flow, slow axial flow, transverse flow, and slab lasers for. As an example, transverse flow lasers circulate the gas mix at a lower velocity, requiring a simpler blower, while slab or diffusion cooled resonators have a static gas field that requires no pressurization or glassware for protection [2].

The work principle of a laser cutting system is presented in Fig. 1 [3].

The main advantages of laser cutting over other cutting methods can be summarised as follows [5]:

- it can cut a variety of metals and non-metals;
- it can produce part accuracies better than 0.08 mm;
- it can cut thinner metals at over 170 mm/s;
- it produces a narrower heat affected zone than plasma;

However, there are also several disadvantages to be considered:

- high cost of the equipment;
- the thickness of materials that can be cut is very limited (10-20 mm at best);
- the cutting of metals with highly reflective surfaces (such as aluminium, but also titanium, to some extent) can cause problems for the equipment (especially for the focusing lens);

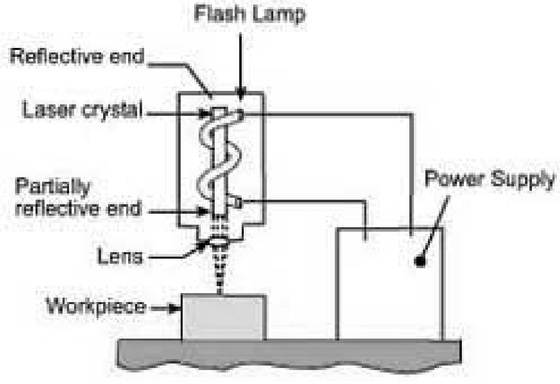


Fig. 1. The principle of laser cutting [3].

- it can cause micro-fracturing in some materials;
- variations in the material's quality can affect the cutting results;
- the maintenance of the cutting equipment requires advanced knowledge;
- depending on the material being cut, noxious fumes can be produced during the cutting process.

2.2. Plasma Cutting

The plasma cutting process is based on the action of a superheated gas plasma jet created via a controlled electrical arc between the work head and the part to be processed [3]. This electrically conductive, ionized gas plasma is hot enough to easily cut through a variety of metals, with part accuracies better than 0.25 mm attainable with the high density torch designs [4, 5].

The main advantages of plasma cutting over other cutting methods can be summarised as follows [5]:

- it can cut a variety of metals and non metals;
- the cutting speed is higher than for abrasive jet cutters;
- the plasma cutting equipment's price is only about a third that of a laser cutting system;
- the handling of the plasma cutting equipment can be learned relatively quickly;
- the equipment's maintenance is simple.

However, there are also several disadvantages to be considered:

- plasma cutting is generally not as accurate as laser cutting;
- the thickness of parts that can be cut is limited (up to 120-160 mm);
- the consumables in the cutting head deteriorate with use, affecting the quality of the cut;
- the heat induced in the cut part can lead to undesired side-effects, such as microfractures in some materials;
- depending on the material being cut, noxious fumes can be produced during the cutting process;
- the heat-affected zone may be rather large.

2.3. Abrasive Jet Cutting

The waterjet cutting process uses a thin stream of water brought to very high pressures by passing it through a narrow nozzle. When mixing a small amount of abrasive into the water, the process is called abrasive jet cutting. While water jet cutting systems can be employed only for the cutting of soft materials at efficient speeds, abrasive jet cutters can handle virtually any material.

The main advantages of abrasive jet cutting over other cutting methods can be summarised as follows [5]:

- it can cut a variety of metals and non metals;
- it produces part accuracies better than 0.12 mm;
- it can cut even through relatively thick parts;
- it doesn't lead to a heating of the part or cause microfracturing;
- it produces minimal kerf widths (0.65 to 1.3 mm);
- the abrasive jet cutting equipment's price is only about half that of a laser cutting system;
- the handling of the abrasive jet cutting equipment can be learned relatively quickly;
- the equipment's maintenance is simple;
- no noxious fumes are produced during the cutting process.

However, there are also several disadvantages to be considered:

- it is very slow compared to other processing types;
- it is very noisy;
- the consumables in the cutting head (jewel, mixing tube) deteriorate with use, affecting the quality of the cut;
- the heat induced in the cut part can lead to undesired side-effects, such as microfractures in some materials.

The major problem encountered here is that, due to the relative novelty of the method and the investment costs implied by the acquiring of the adequate equipment, in Romania there are still relatively few abrasive jet cutting systems in use.

Given the advantages of laser cutting in terms of precision, and the availability of a laser cutting machine for the authors, the researches presented in this paper have focused on this type of non-conventional cutting.

3. THE PRECISION OF CNC LASER CUTTING MACHINES

At the CNC machine-tools, the feed movements are realized in an automated regulation regime. The information on displacement and speed, needed for the part's processing, is generated by the machine's control unit and then transmitted to the numerical axes.

The controls materialize the movement instructions, which are converted into displacements, with controlled speeds. of the machine-tool's slides on such trajectories that the part's contour can be obtained. The instant position and speed of the mobile elements is transmitted to the control unit by means of position and speed transducers, in feedback loops.

The precision of parts processed by laser cutting, on CNC machine tools, is significantly influenced by following two main factor categories:

- the configuration parameters of the position control system on each movement axis;
- the feed rate on each movement axis.

Previous researches presented in the speciality literature [3, 6, 7, 8, 9] indicate that errors introduced by the functioning of the numerical axes represent the main part of errors in the processing on CNC machine-tools.

The errors that appear in the functioning of the movement control systems are directly translated into contour generating errors. This is especially true for trajectories which require variable feed rates on the various axes, such as circles or curved lines.

Numerical axes are complex systems, in which the position and feed rate are controlled in closed-loop technology. The speed loop is typically placed within the axis drive system, while the position loop is external to the axis drive system.

Within the position loop, the actual position is collected as a feedback signal and compared to the required position. This position feedback signal can be taken from the engine shaft or from the leading screw (indirect measuring), for this being employed a rotation transducer. Furthermore, the position feedback signal can be also taken from the mobile element of the kinematic feed chain (the machine's slide), for this using a linear transducer.

Actually, the problem of position control has to be treated differently in the case of fast movements and in the case of machining movement (feed). In the case of fast feeds, only the precise reaching of the designated final point is important, whereas the actual trajectory is not important. To the contrary, in the case of machining feeds, the fidelity with which the desired trajectory is followed by the laser cutting head, is crucial.

The main factors influencing the precision of the CNC cutting machine-tool's machining feed can be grouped into dynamic constraints, uncertainty factors and non-linearity.

Among the dynamic constraints, we have the dynamic disturbance of the system, which manifests itself either through the existence of different speed amplification factors on the axes, leading to contouring errors in stationary regime, or through different time constants on each axis, which negatively influences the transitory regime. In the case of cutting a circular contour, for example, this contour will become rather an ellipse, with a "thinning" along the axis with a smaller amplification factor. Errors may appear especially during changes of direction or stops, which influences negatively the cutting of corners.

An uncertainty factor is for example the changing of the part type processed on the machine. As this leads to a change in its mass, the system's inertia is modified abruptly. The feed system's mechanical transmission components' wear is another example of uncertainty factor, leading to a slow but continuous change of working parameters. Finally, among the non-linearity we can count friction, saturation and the allowance at the reversal of the movement direction.

This shows that by precisely controlling the elements of the feed kinematic chain, and especially the parameters of the control system of the numerical axes, we can significantly improve the CNC laser cutting machine-tool's performance.

However, even when using an optimal feed rate, recommended by the speciality literature for given material characteristics and process conditions, there can still appear contouring errors due to a dynamically imbalanced control system. This underlines the importance of using mathematical models and experimental researches for an optimal tuning of the working parameters of laser cutting machine-tools.

4. EXPERIMENTAL RESEARCHES

The experimental researches regarding the cutting precision were carried out on a NTX-48 Champion laser cutting machine manufactured by Mazak (Japan) using a CO_2 laser with a laser wave length of 10.6 μm and having following characteristic working parameters:

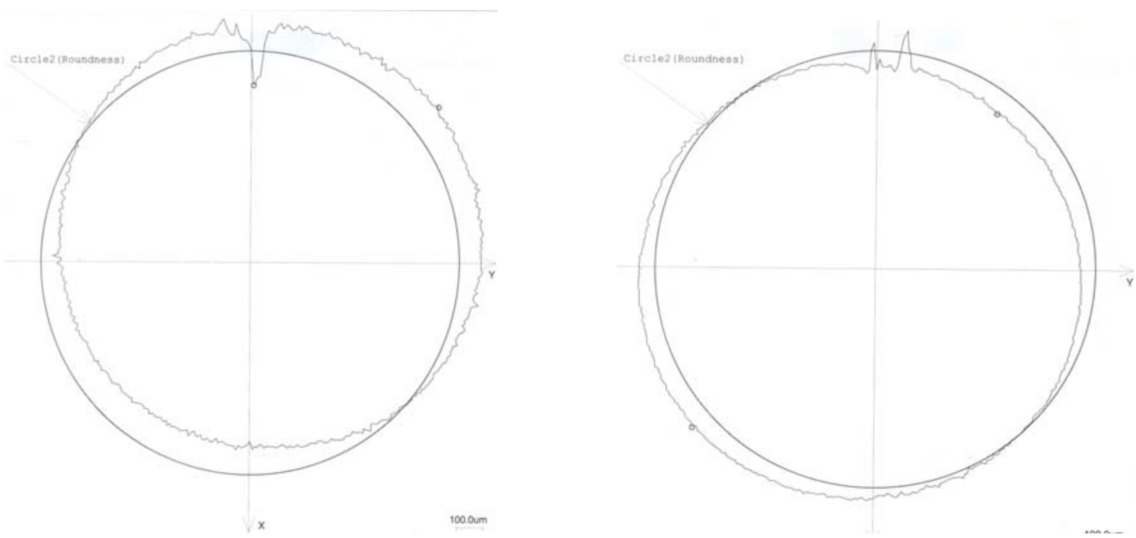
- maximal power output: 1.5 kW;
- impulse frequency: from 0 to 2000 Hz;
- maximal machining feed rate: 10 m/min;
- maximal fast feed rate on X and Y axes: 24 m/min;
- maximal fast feed rate on *Z* axis: 20 m/min;
- positioning precision on *X* and *Y* axes: ±0.01/100 mm;
- positioning precision on *Z* axis: ±0.01/500 mm;
- NC control unit: Mazak L-32B.

The blanks used for these researches were sheets of OL 52 2k steel, STAS 500/2-88, with thicknesses of 6 mm and 8 mm, respectively.

The aim was to obtain, by laser cutting, discs with a diameter of 60 mm and to assess the dimensional errors and thus the machine's precision, for different working regimes and NC setups.

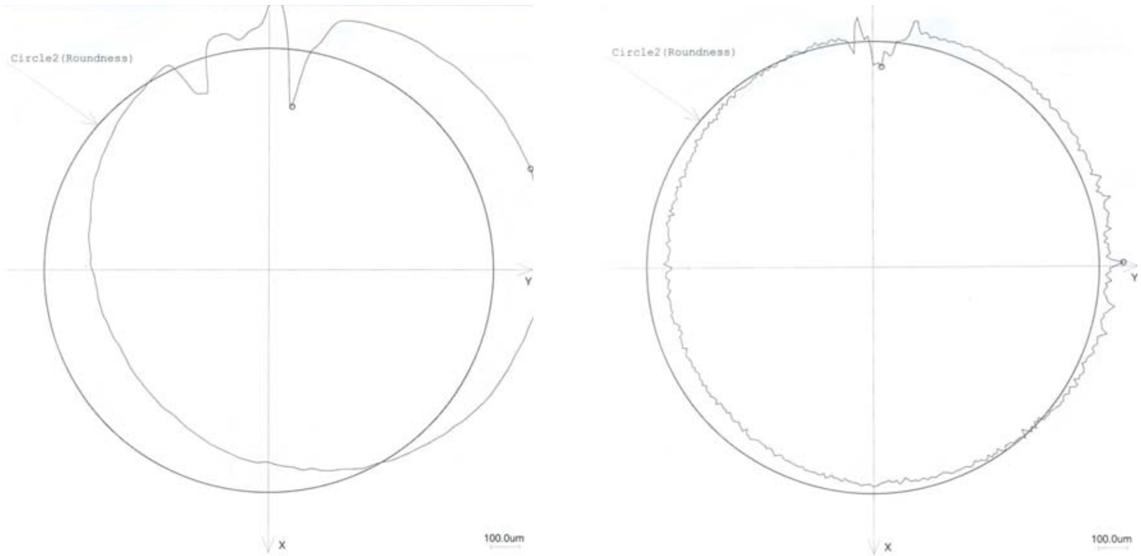
Fig. 2a shows the result of cutting a disc from a 6 mm thick steel sheet, with a feed rate v = 400 mm/min and a cutting power P = 1600 W.

In comparison, Fig. 2b presents the contouring errors in the case of cutting a disc from the same type and thickness of steel sheet, but with a feed rate v = 800 mm/min and a cutting power P = 2000 W.



a) b)

Fig. 2. Contouring errors at the cutting of a circular shape from a OL 52 2k steel sheet of 6 mm thickness with:
a) v = 400 mm/min; b) v = 800 mm/min.



a) b)

Fig. 3. Contouring errors at the cutting of a circular shape from a OL 52 2k steel sheet of 8 mm thickness with: a) v = 400 mm/min; b) v = 1000 mm/min

Fig. 3a presents the contouring errors in the case of cutting a disc from a metal sheet of 8 mm thickness with a feed rate v = 400 mm/min and a cutting power P = 1600 W, while Fig. 3b shows the result of cutting a disc from a 6 mm thick steel sheet, with a feed rate v = 1000 mm/min and a cutting power P = 1400 W. It can be seen that for lower feed rates, the contouring errors are relatively large compared to the case of higher feed rates, a phenomenon that aggravates with increasing sheet metal thickness. This indicates that the optimal setting for this laser cutting machine is achieved when cutting mild steel types or softer materials in general, whereas for harder and/or thicker materials, which require a lower feed rate, a modifying of the machine's dynamics is needed for ensuring an acceptable precision.

5. CONCLUSIONS

The researches presented in this paper have shown, on the one hand, the superiority of laser cutting systems over other non-conventional cutting methods with regard to precision, even if the high costs of the laser cutting equipment may pose some startup problems.

On the other hand, the importance of a precise control of the feed rate with the help of rotation transducers has been proven and an optimal feed rate has been found for the studied case.

In future, it is sought to use the outcome of the experimental researches presented here for generating and optimising mathematical models that could take into account the above-mentioned error-inducing factors and thus lead to a more precise cutting technology.

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