IMPROVING THE MANUFACTURING ACCURACY OF CNC LASER MACHINES

Cristina BIRIȘ[1]

ABSTRACT: This paper presents some experimental researches regarding the manufacturing accuracy of a profiling machine together with an approach to eliminate the positioning and contouring errors. In order to reduce the errors, a tuning process of the feed drives of the machine was realised. The accuracy of the profiling machine was tested before and after the tuning process, in order to validate the proposed approach. There are unfolded both positioning tests along one axis and contouring tests on two axes.
KEY WORDS: laser cutting, tuning, contouring error, cutting speed.

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.

One of the most critical components for achieving a high precision are the feed systems, assimilated with electromechanical motion control structures that can be realised in a modular, reconfigurable structure. The possibility of using modular cutting systems also allows a significant cut of the costs of such an equipment, without implying a loss of performances [2].

Today's industrial production is characterised by great variations in the number and quality of the products that need to be realized and by design-production cycles of steadily decreasing time spans.

In order to meet these demands and to remain competitive, industrial companies need to make sure that their processing machines can provide both the best possible levels of accuracy and the highest possible processing speeds. Of course, in most cases, these two requirements cannot be fulfilled at the same time, so a compromise has to be found, with the part accuracy being usually the dominant characteristic.

The accuracy of the processed parts and therefore the accuracy of the resulting part can be significantly improved by using advanced control systems, such as in the case of numerical control (NC) machines. The impact of these systems has come to be felt especially strong in the area of materials cutting, where it allowed the shifting of interest from mechanical cutting technologies towards thermal and unconventional cutting technologies, a good example for this being laser cutting. Even so, there are a variety of factors that can negatively affect precision even under these conditions, so special precautions have to be taken when configuring and programming a machine-tool for an operation that demands a high accuracy.

One of the machine components of special importance for achieving a high cutting accuracy are the feed control systems, also called numerical axes, assimilated with electromechanical motion control structures that can be realized in a modular, reconfigurable structure. The possibility of using modular processing systems also allows a significant reduction of the costs of such equipment, without implying a loss of performances [3].

The performances of such modular reconfigurable cutting systems can be assessed by analysing the dynamic behavior of the numerical axes on each motion axis, but also the kinematic accuracy (which can be described function of the motion type as positioning precision for the movement on each individual axis or as contouring precision in the case of multiaxial movement), this also allowing to determine the main causes for

[1] Universitatea “Lucian Blaga din Sibiu”, Emil Cioran,4, Sibiu, România
E-mail: cristina.biris@ulbsibiu.ro

errors and the possibilities of compensating them [4].

The numerical axes materialise the movement instructions, which are converted into displacements on trajectories that allow the realising of the part's contour. 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 servo systems of the machine tools are defined as closed loops systems. There are three basic servo control loops (the velocity loop, the current loop and the position loop). To move an axis a command is generated and to ensure that the axis is properly responding to the command a feedback is provided by the controled axis. To ensure that the axis is following the desired path the command is constantly corrected based on the feedback and command.

By tuning a system in order to obtain a better performance the loop gain for each control loop is adjusted. The loop gain means the ability of the servo system to follow the desired or program path. All the systems have a certain lag regarding the commanded position wich is related to how well tuned are the servos. Therefore by tuning the system can be reached a smaller lag, a higher loop gain resulting in a better path accuracy and a more precise part.

Speciality literature indicate that errors introduced by the functioning of the numerical axes represent the main part of errors when using CNC machine-tools.

This paper focuses on improving the contouring accuracy of the profiling equipment by experimental process and system tuning.

2 EXPERIMENTAL RESEARCHES

The experimental researches regarding the cutting precision were carried out on a NTX-48 Champion laser cutting machine manufactured by Mazak using a CO2 laser 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;
- 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 reference parts that were processed on the Mazak machine were made of S355JR steel sheets, with thicknesses of 3 mm, 6 mm and 8 mm respectively.

Table 1. Input parameters of the experimental system

Parameter	Unit	Value
Motor rated power P	[W]	300
Motor rated armature voltage U_b	[V]	75
Motor rated torque M	[Nm]	1.18
Motor rated rotating speed n	[min^{-1}]	2500
Motor instantaneous maximum armature current i	[A]	40
Motor armature winding resistance R	[Ω]	1.1
Motor torque constant K_t	[Nm/A]	0.273
Motor velocity constant K_v	[Vs/rad]	0.273
Motor instantaneous maximum angular acceleration ε	[rad/s^2]	38400
Motor rotor inertia J_m	[kgm^2]	$0.270 \cdot 10^{-3}$
Load inertia J_l	[kgm^2]	$2.583 \cdot 10^{-3}$
Motor viscous braking constant B_m	[Nms/rad]	$3.7242 \cdot 10^{-4}$
Load viscous braking constant B_l	[Nms/rad]	$82 \cdot 10^{-4}$
Tachometer gain K_{th}	[Vs/rad]	0.00668
Lead screw step	[mm]	5
Gear ratio K_g	-	1
Incremental encoder gain K_e	[imp/rad]	2500/2π
Mass of the slide	[kg]	30
Cutting force	[N]	1000
Sampling period T	[s]	0.01

The aim was to obtain rectangular shapes with sides measuring 40 and 60 mm, respectively, to assess the dimensional errors and thus the machine's precision, for different working regimes and NC setups.

The input parameters of the experimental system (for one axis) are shown in table 1.

Cutting corners at 90^0, without stopping in the corner, is one of the situations in which the system behaviour has a decisive influence on the machine accuracy.

When cutting a corner two kinds of errors can occur: over cutting, which adversely affect the profile obtained, and under cutting (less important in practice, because the corners are provided with corner radius).

The occurrence of one or other of the two types of errors is determined by the input of signal level of the automatic position adjustment on the axis of the servosystems.

The study focused on speed influence on the error size occured at the corner point. For this purpose, on MAZAK NT-X48 laser cutting machine, rectangular parts were cut from sheet metal with different thicknesses, using speeds between 2000 and 500 mm/min (from 0,033 to 0,008 m/s). The parts were then measured on ZEISS CONTOURECORD 1600 D measuring device.

In figures 1 and 2 contouring errors are shown when cutting a rectangle from a sheet metal of 3 mm thickness with a speed of 2000 mm/min (Figure 1) and 1500 mm/min (Figure 2).

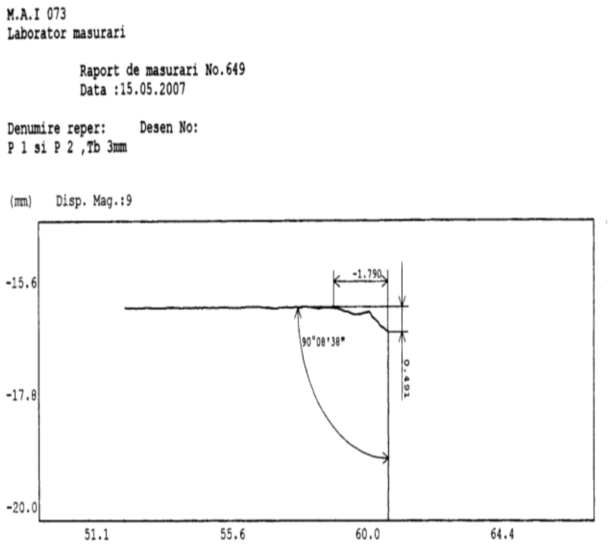

Figure 1. Contouring errors when cutting a rectangle from a steel sheet of 3 mm thickness with a speed of 2000 mm/min

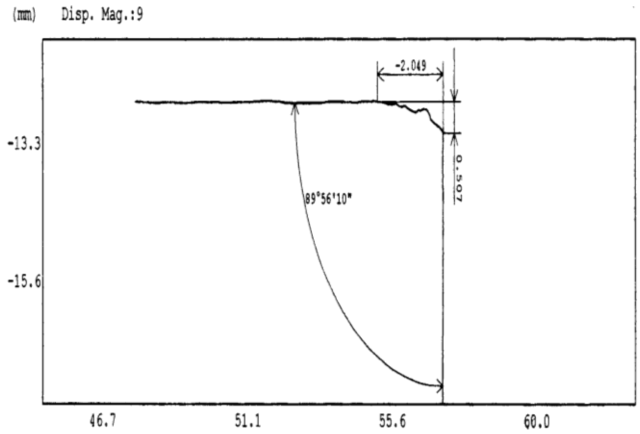

Figure 2. Contouring errors at the cutting of a rectangle from a steel sheet of 3 mm thickness with a speed of 1500 mm/min

Figures 3 and 4 show two examples of corners cut from a 6 mm sheet metal thickness, with a speed of 2000 mm/min (Figure 3) and 1000 mm/min respectively (Figure 4)

In Figures 5 and 6 are also shown two examples of generated corners from a 8 mm sheet metal thickness at a speed of 1500 mm/min (Figure 5) and 500 mm/min (Figure 6).

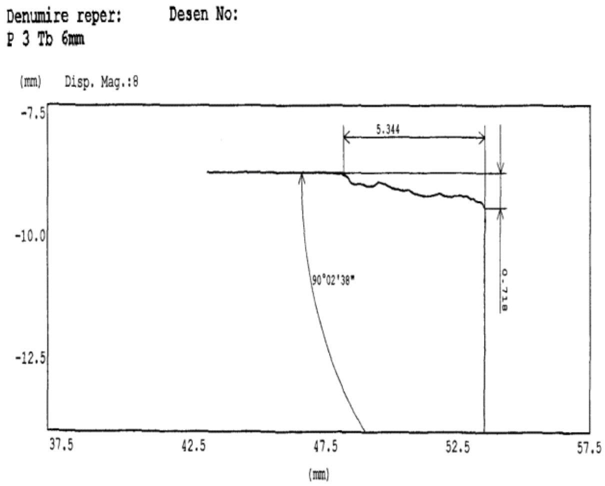

Figure 3. Contouring errors when cutting a rectangle from a steel sheet of 6 mm thickness with a speed of 2000 mm/min

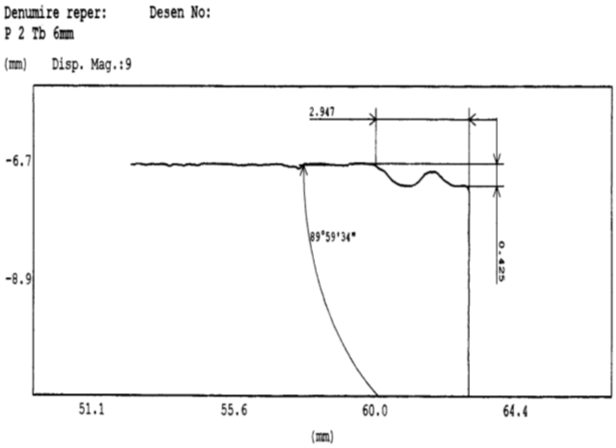

Figure 4. Contouring errors when cutting a rectangle from a steel sheet of 6 mm thickness with a speed of 1000 mm/min

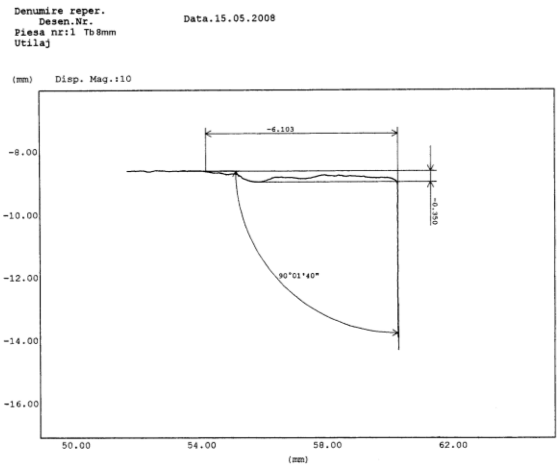

Figure 5. Contouring errors when cutting a rectangle from a steel sheet of 8 mm thickness with a speed of 1500 mm/min

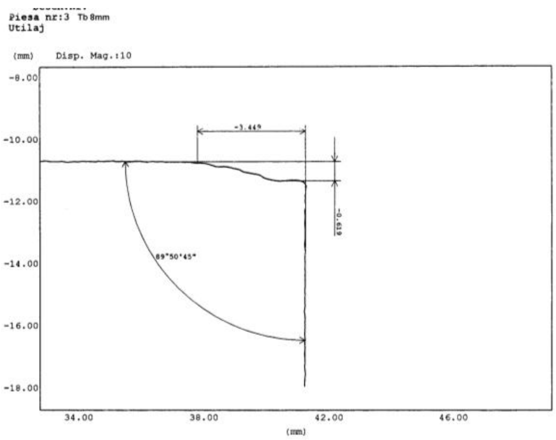

Figure 6. Contouring errors when cutting a rectangle from a steel sheet of 8 mm thickness with a speed of 500 mm/min

The experimental researches were aimed at reducing errors.

Thus, tuning the system was attempted by modifying the damping factor ξ, and hence amplifying factor K_{pd}.

Under these conditions, a corner cut from a 3 mm thickness sheet metal is shown in Figure 7 and 8 mm respectively in Figure 8. In this case it can be seen that the contouring errors are reduced.

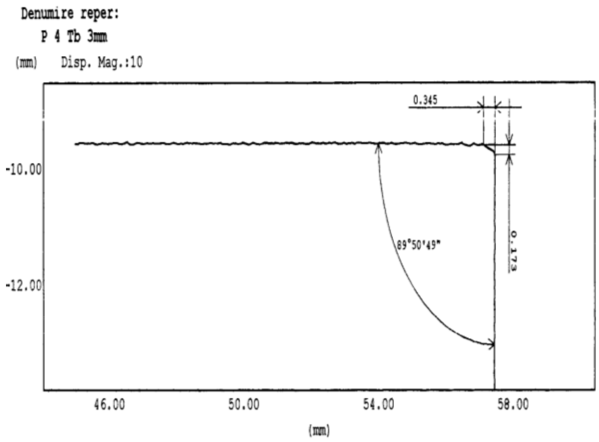

Figure 7. Contouring errors after tuning when cutting a rectangle from a steel sheet of 3 mm thickness

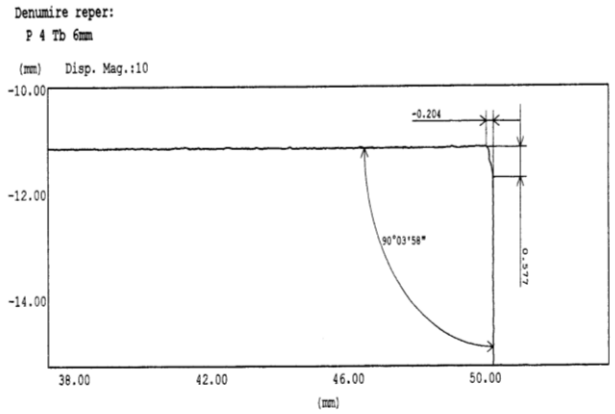

Figure 8. Contouring errors after tuning when cutting a rectangle from a steel sheet of 6 mm thickness

To further reduce the errors, it was chosen tuning the system by working with different amplifying on the two axes.

According to the tolerances imposed and the actual shape of the workpiece, in practice the system can be tuned by choosing on which of the two axis amplifying factor will be smaller, depending on the axis on which it is desired to reduce the error.In Figures 9 and 10 respectively are the results obtained from the generation 90 degrees corners from sheets metal with different thicknesses and different amplifying factors on the two axis. In the first case (Figure 9) we can observe a decrease of contouring error on the x-axis while in the second case (Fig. 10) on y-axis.

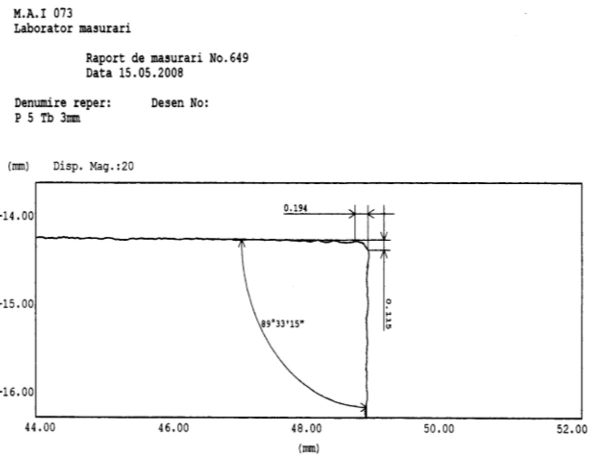

Figure 9. Contouring errors when cutting a rectangle from a steel sheet of 3 mm thickness with different amplifying factors on the two axis

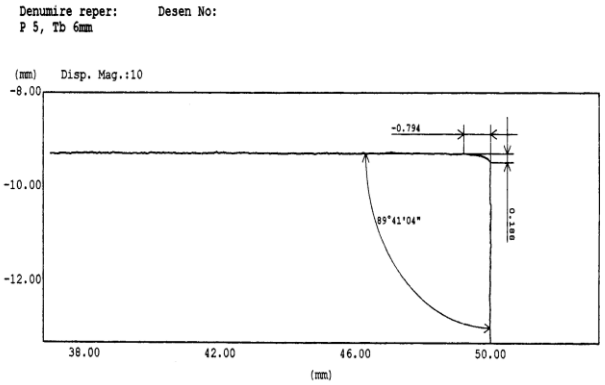

Figure 10. Contouring errors when cutting a rectangle from a steel sheet of 6 mm thickness with different amplifying factors on the two axis

3 CONCLUSIONS

This paper presented an experimental approach for studying the behaviour of the feed drives of profiling equipment, seen as mechatronic motion control system.

The controllers within the system were tuned by a combined method using both analytic relations for the position controller and also a trial-and-error simulation process for the other ones. The main goal of the tuning process was to achieve a good dynamic behaviour of the system.

The researches presented were aimed at improving the accuracy of profiling machines, more precisely of laser cutting machines by tuning the components of the numerical control equipment attached to these machines.

The researches outlined here have shown that the best solution is to have amplification factors with smaller, but different values on the two plane movement axes. This was confirmed by the results of the actual cutting of parts during the experimental researches.

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

4 REFERENCES

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