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THE OPTIMIZATION OF THE PROCESS PARAMETERS FOR THE LASER CUTTING OF THE COGGED WHEELS MADE OF PLASTIC MATERIAL, USING THE TAGUCHI ROBUST DESIGN

OPTIMIZAREA PARAMETRILOR DE PROCES PENTRU TĂIEREA CU LASER A ROȚILOR DINȚATE DIN MATERIAL PLASTIC, UTILIZÂND PROIECTAREA ROBUSTĂ TAGUCHI

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Abstract: *The utilization of the robust design Taguchi realizes the optimization of the laser beam reshaping of the cogged wheels made of plastic material. The experiments realized so far, have followed to relate the laser beam parameters and to establish the nominal optimum values of these ones, so that, to be able to control the shape, the dimensions and the state indicators of the wheels surface, and the processing efficiency to be the highest possible. The plastic material cogged wheels obtained through unconventional technologies (processing with CO2 laser) are used especially for prototypes due to their high productivity and low producing costs compared to the ones obtained through conventional technologies.*

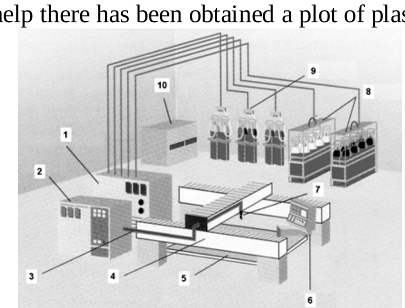
Rezumat: *Utilizarea proiectării robuste Taguchi realizează optimizarea prelucrării cu fascicul laser a roților dințate din material plastic, experimentele efectuate urmărind corelarea parametrilor fasciculului laser şi stabilirea valorilor nominale optime ale acestora, astfel încât să poată fi controlate forma, dimensiunile şi indicatorii de stare a suprafeței roților, iar eficiența economică a prelucrării să fie maximă. Roțile dințate din material plastic obținute prin tehnologii neconvenționale (prelucrare cu laser CO_2) sunt utilizate în special pentru prototipaje datorită productivității ridicate si costurilor scăzute de realizare în comparație cu cele obținute prin tehnologii convenționale.*

Key words: *gears, laser processing, Taguchi's Robust Design*
Cuvinte cheie: *roți dințate, prelucrare cu laser, proiectare robustă Taguchi*

INTRODUCTION

The laser is a device which allows the producing and amplifying of an electro magnetic radiation contained in the longings range of the wave in ultraviolet and ultra red, through the controlled phenomena of stimulated emission.

The cutting equipment, computer assisted, utilizes a CO2 laser source (picture 1), of 2 kW. With this equipment help there has been obtained a plot of plastic material cogged wheels.



Picture 1 The laser installation with CO2

1. – module for electrical feeder according to the adequate parameters of the equipment
2. – laser source with CO2
3. – the optic route of the working beam
4. – the mechanic structure of the cutting machine
5. – material for processing
6. – module for numerical control
7. – controlled cutting head
8. – units for ensuring the assisting gas (He, Ar, N_2, O_2)
9. – gas feeding unit for active environment (CO_2)
10. – cooling group

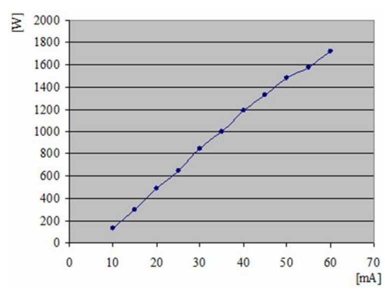
PROCESSING PARAMETERS

a. the wavelength [λ = 10,6 μm] – depends on the nature of the emitter environment – imposes certain characteristics to the optic system and determines the concrete parameters of the interaction with the material

b. the beam spread [deg], which inferior restricts the beam focalisation and it is determined by the configuration of the laser resonator

c. the emitted powered [W], whose size must be regulated depending on the nature and the thickness of the material

The power depends, practically, linear on the electric power (picture 2)



Picture 2 The dependency of the power on the electric power

d. the cutting speed (the relative movement of the beam – part) [mm/s]; this adjusts according to the nature and the thickness of the material, the laser power, the focusing conditions, the geometry of the part, the nature and the characteristics of the gas

e. the vertical position of the focusing spot, established according to the processed material and thickness of the part

f. impulse and break times [ms]; these influence the dynamic of the thermic processes

g. the nature, pressure and debit of the gas (the gas may have chemical effect; the pressure is adjusted according to the nature of the used gas and the followed objective – the processing speed or quality; the debit is determined dependent on the pressure and the diameter of the nozzle)

h. the distance nozzle/part [mm], constant size, in order to preserve the gas flow parameters

i. the nozzle (the internal geometry and the exit diameter), having an important role in establishing characteristics of the gas injection

The used laser equipment contains the Laser DX3 programme that is conceived as an extension AutoCAD, completing its facilities regarding the constructive designing assisted by the computer and ensuring a strong engineering module of the tools machines with numerical control. It allows the control of the producing process of the component from the basic drawing to the finished part.

THE OPTIMIZATION OF THE TECHNOLOGICAL PARAMETERS WHEN PROCESSING THE COGGED WHEELS WITH LASER EQUIPMENT

Normally, when there is noticed a dispersion or a instability of a product's characteristics when it is produced or used, there are searched the causes to reduce or even eliminate them. The Taguchi strategy is the total opposite; instead of seeking to eliminate these parasites factors (named noise factors), it seeks to minimize their impact, auctioning determined upon the factors controlled through the finding of their values combinations, so that the process or the products to follow the functional performances and in the same time to be noise – factors proof.

The state of the parts' surface was declared to be the target criteria taking into consideration the fact that the real state of the technical surfaces represents a factor of direct influence on the behaviour of the elements constructive from all point of views. The influence of the surface state actions upon the bearer capacity, the friction factor, the resistance of wearing by abrasion, adherence, respectively, corrosion and reliability of the layers superficially deposited and even upon the aspect.

Regardless of the material and obtaining technological method, the mechanical parts are affected by shape errors and by the presence of the roughness. The discrete character of the material and the imperfections generated by any technical method in real conditions, conduct to the impossibility of obtaining ideal surfaces, perfect flatness, cylindrical, spherical, etc.

The roughness of the surface processed with laser is influenced, mainly, by 6 factors, presented in table 1. There have been studied the possible combinations for the case when these factors have two levels.

Table 1

The levels of the control factors

	Factors	**Level 1**	**Level 2**
A	speed	3000 mm/s	4500 mm/s
B	Power	170 W	180 W
C	Impulse time	5 ms	3 ms
D	Break time	3 ms	5 ms
E	Nozzle/defocusing	d 4 mm/5 mm	d 4 mm/2,5 mm
F	Gas debit	20 l/min	10 l/min

The Taguchi robust design uses a cross matrix of experiences $\mathbf{L_8}$, allowing the reducing of the experiments number from 128 to 8 and the research of an interaction (pic.2).

In a cross matrix each level of each factor is being combined with each level of the other factors in an equal multiplying number. When the effect of one factor depends on the level of another factor it is considered that between these two there is an interaction.

The interaction I_{A1B1} between the speed and power (when the A factor - the speed – is at the level 1 and B factor – the power – also at the level 1) is equal to the response of the system in the configuration A_1B_1, minus the general average $\overline{T}$ respectively, minus the sum of E effects of each of the two factors:

$$I_{A1B1} = \overline{A}1\overline{B}1 - \overline{T} - E_{A1} - E_{B1} \quad (1)$$

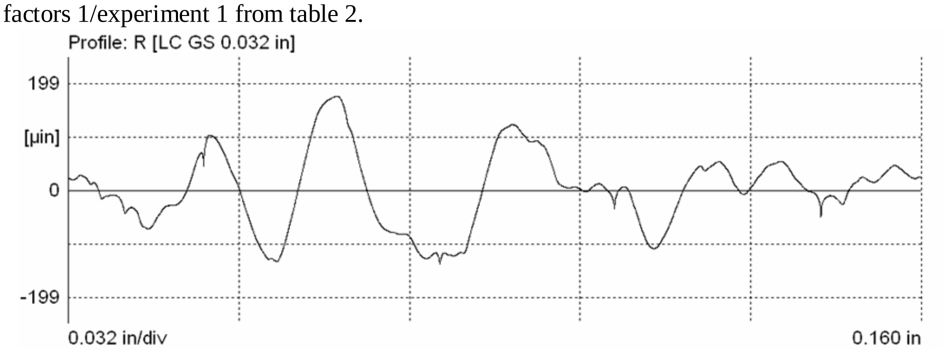
Determining the good values which are to be given to the controlled factors is being done experimentally, with the goal to optimize the product or the process, so that it:

- fulfils the wanted functional performances ($R_a \approx 0,8$ μm)
- is robust, which means, insensitive to the noise factors

The measuring regarding the quality of the processed surface has been made with an electronic roughness meter typed Mahr, obtaining profiles with roughness R_a for the trials realized according to the 8 factors combinations (table 2).

In order to appreciate the average and variation of the results relatively to an experiment, that is for a determined configuration of the different factors levels there have been made 5 experiments for each combination of factors.

In picture 3 there is presented as an example, the profile R_a for the combination of factors 1/experiment 1 from table 2.



Picture 3 The profile R_a for the combination of factors no. 1/experiment no.1

Each trial is realized with a different combination of the factors' levels and each level of each factor is combined with each level of other factors, of an equal number of times (table 2)

Table 2

The combinations of factors and the experimental results

Trial No.	Controlled factors							Values					
								Measured					Calculated
	A	B	AB	C	D	E	F	nr.1	nr.2	nr.3	nr.4	nr.5	S/N
1	1	1	1	1	1	1	1	1,027	0,895	0,977	0,944	0,867	16,303
2	1	1	1	2	2	2	2	1,498	1,32	1,242	1,52	1,591	3,773
3	1	2	2	1	1	2	2	0,496	0,712	0,525	0,725	0,714	14,229
4	1	2	2	2	2	1	1	1,415	1,189	1,145	1,337	1,379	5,944
5	2	1	2	1	2	1	2	1,275	1,282	1,354	1,175	1,305	6,343
6	2	1	2	2	1	2	1	1,092	0,982	0,969	1,092	0,928	13,034
7	2	2	1	1	2	2	1	1,104	0,987	0,978	1,054	1,058	12,363
8	2	2	1	2	1	1	2	1,175	1,179	1,165	1,164	1,151	8,708

The Taguchi experiments plans are concomitantly using the average and the variability of the measured characteristics' values and are using as performance indicators, the report Signal/Noise, which simultaneously take count of: the wanted value (the signal) to be reached and the unwanted value (the noise) to be eliminated.

The use of this performance indicator allows finding the combination of the controlled factors' levels that have proved to be the least sensitive to the noise factors.

The shape of the Signal/Noise reports allows the direct evaluation of the quality related costs (the concept function of quality loss, conceived by Taguchi).

If the reports S/N (table 2) are calculated based on MSD, according to the equation (2), results o combination of the factors and interactions which offer the optimum performance conditions (presented in table 3).

$$\frac{S}{N} = -10\log(MSD) = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - y_N)^2\right]$$

where: n – the number of measurements

y_i – the measured values

y_n – target (nominal) value

Table 3

Optimum and performance conditions

No. of column/Factor	The description of the level	Level	The contribution
1. speed	4500 mm/min	2	0,024
2. power	180 W	2	0,223
3. the interaction 1x2	int 1x2	1	0,199
4. impulse time	5 ms	1	2,222
5. break time	3 ms	1	2,981
6. nozzle/distance	4 mm / 2,5 mm	2	0,762
7. gas debit	20l/min	1	1,823
The total contribution of all factors			8,233
The current general average of the performance			10,087
The expected result on optimum conditions			18,321

The optimizing characteristics with symmetric variation represent the case defined by Taguchi “Nominal The Best – NTB”, which means “the nominal value is the best”. It is noticed that, if the value of the characteristic is equal to the target value, the quality level is maximum, and the value of the function loss is minimum, respectively zero.

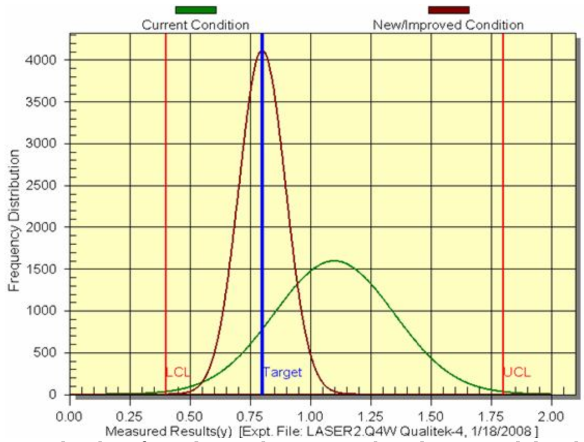
Any deviation from the target value determines a quality loss. So, if a characteristic takes an effective value which is different of the target value, results an deviation, (which is a quality loss) and the quality level has a lower value than the expected maximum value, even if this effective value is within the tolerance range.

As a result of the laser processing parameters optimization and the use of the Qualitek-4 programme, there has been obtained the combination of the factors’ levels that make the reducing of the variation around the target value possible. In picture 4, there is presented by comparison the distribution of the results before and after the optimization.

The confirmation experiment was realized using the optimum combination of the factors’ levels and of the interaction between the speed and power according to the programme Qualitek 4, there have been obtained 5 cogged wheels with a measured roughness for each of them: 0,8; 0,788; 0,837; 0,893; 0,712.

After making the experiments, there has been taken a conclusion that using the optimum combination of the factors’ levels and of the interaction, by taking into account their effects upon the report Signal/Noise and by including the target value when expressing the report S/N, brings an improve of the roughness value dispersion around the target value.

A comparison between the current, forecasted and realized conditions is presented in table 4, where it is noticed a significant increase of the report S/N and of the realized capacity indicators Cp and Cpk, respectively a reduction of the realized standard deviation, compared to their current values.



Picture 4 The chart for reducing the variation based on normal distribution

Table 4

Comparison between the current and forecasted conditions

Initial experiments	Current conditions	Forecasted conditions	Realized conditions
The Report S/N	10.087	18.321	24.459
The average	1.098	0.8	0.806
The standard deviation	0.25	0.096	0.047
Cp	1	2.58	5.231
Cpk	0.601	2.58	5.231

CONCLUSIONS

- The technological process of processing the mechanical parts with conducted laser beam cutting depends on a series of factors, whose influence and interdependency cannot be quantified and ordered in a intuitive mode.

- The rationalizing of the process in finding an optimum combination of the influence factors, with direct consequences on the quality statistic parameters of the parts, is possible based on some mathematic fundament methods, of which The Taguchi Robust Design is proved to be a great success.

- Applying the method requires minimum resources, consisting of a reduced plot of parts and an algorithms operating soft instrument

- Practically, the process optimization allows that by processing on a given machine to be obtained high quality parts, in conditions of efficiency and precision, that other way, through random combinations of the process factors, is very little possible to be realized.

- Increasing the quality in Taguchi way, represents a significant improvement of the quality statistic parameters (reducing and balancing the dispersion, giving the average a value close to the nominal value), having as consequence the increasing of the conformity level of the parts from a given plot.

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