Fuzzy set decision-making system for determining the technological parameters of the laser cutting process

F S Blaga[1], A Cristea[1], G Nastor[1], A Pop[1], T Buidos[1] and I Lucaciu[1]

[1]University of Oradea, Faculty of Management and Technological Engineering, str. Universității nr.1, Oradea 410087, Romania

E-mail: fblaga@uoradea.ro

Abstract. The technology of laser cutting of metallic and non-metallic materials is more and more frequently used in the industrial environment. Under these conditions there is a permanent concern to improve the quality of the parts obtained, more precisely the quality of the surfaces resulting from cutting. Cutting process parameters: power, cutting speed significantly influences the quality of cut parts. The paper presents how a decision-making system based on fuzzy sets was developed to determine the technological parameters of the laser cutting process. Input parameters were defined: material thickness and roughness. Output parameters have been defined: cutting power and speed. Next, the specific steps of elaborating a decision system based on fuzzy sets were completed. A user interface has also been created. Validation of the decision system based on fuzzy sets was achieved through experimental research.

1. Introduction

Laser cutting is a technological process common in the industry. The dependence of the quality of the parts, of the cut surfaces, on the process parameters is the object of the concerns of a significant number of researchers.

The paper [1] presents the result of research conducted to improve the quality of aluminium copper alloy parts obtained by laser cutting. Thus, it was found that the use of off-axial supersonic nozzles allows obtaining high quality cut surfaces.

A study on the effect of laser cutting parameters on the area affected by heat in CO_2 laser cutting of AISI 304 stainless steel is presented in [2]. The mathematical model of the thermally influenced area was expressed according to laser cutting parameters, such as laser power, cutting speed, assist gas pressure and focusing position using an artificial neural network.

The research presented in papers [3] and [4] highlights those parameters such as laser power, cutting speed, distance between nozzle and workpiece have a major impact on surface roughness and cutting width. It was also found that the effect of the assist gas pressure on the surface roughness and cut width is less significant.

In the paper [5] is developed an expert system based on fuzzy sets to predict the quality of the surface resulting from laser cutting. The system input parameters are: power, assist gas pressure and cutting speed. Outputs are surface roughness and slag inclusion. The results of the study show that the proposed fuzzy model can be used to predict surface roughness and slag inclusions in the case of the carbon dioxide (CO_2) laser cutting process for the Incoloy 800 alloy.

The paper [6] presents the process of defining new parameters for cutting fireproof steel parts (AISI 314 steel) for which the recommended cutting parameters have not been provided by the laser manufacturer.

There is research on the use of fuzzy systems to determine technological parameters and other processing processes. In [7] a fuzzy system is developed for determining the technological parameters specific to turning processing. Article [8] presents a fuzzy system for determining the parameters specific to the welding process

This paper presents how a decision system based on fuzzy sets was developed to determine the technological parameters of the laser cutting process. Also, the results obtained by using the fuzzy system are compared with the experimental results.

2. Defining the decision-making system based on fuzzy sets to determine the technological parameters of the laser cutting process

The steps to be followed for the development of the decision-making process based on fuzzy sets for determining the technological parameters specific to the laser cutting process will be developed in the following

2.1. Establishing the input values with which the technological parameters will be determined.

The method of determining the technological parameters based on fuzzy sets is that several evaluation criteria can be considered at a time. These criteria will be defined as the inputs to the decision-making system

The input values in relation to which the technological parameters are determined are: *Thickness* (mm) and *Roughness* (μm).

2.2. Defining the range of values for each input parameter

Each input quantity is associated with a variation range, within which its specific values can be found. These value areas will be:

$$D_{Thikness}=[1;\ 20]\ (mm) \tag{1}$$

$$D_{Roughness}=[3,2;\ 25]\ (\mu m) \tag{2}$$

2.3. Defining the linguistic variable associated with each input parameters

Each input parameter is associated with a linguistic variable. Thus, the input variable Thickness is associated with the linguistic variable Thickness and the input size Roughness is associated with the linguistic variable Roughness

2.4. Establishing the linguistic degrees associated with each input language variable

Linguistic degrees are defined for each linguistic variable. These will be useful to characterize to "fuzzy" the certain information.

The linguistic degrees associated with the input language variable *Thickness* are:

$$TL_{Thnickness}=\{Vs,\ s,\ Md,\ L,\ VL\} \tag{3}$$

The linguistic degrees associated with the input language variable *Roughness* are*:*

$$TL_{Roughnes}=\{Vs,\ s,\ Md,\ L,\ VL\} \tag{4}$$

The two linguistic variables, corresponding to the input sizes, were associated with the same linguistic terms: Vs: very small; s: small; Md: average; L: large; VL: very large.

2.5. Establishing the membership functions associated with each linguistic term. Input variables

In the case of both variables associated with the input variables, the linguistic degrees associated with the membership functions are triangular.

Figure 1 shows the membership functions corresponding to the associated linguistic degrees input language variables *Thickness.*

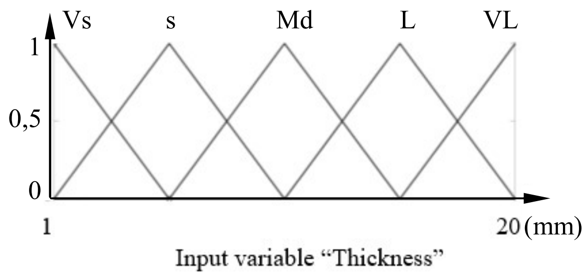

Figure 1. Membership functions corresponding to the linguistic degrees associated input language variables *Thickness.*

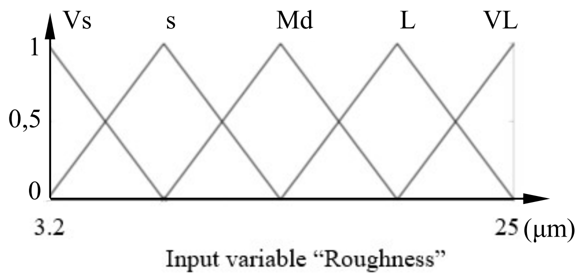

Figure 2. Belonging functions corresponding to the linguistic degrees associated input language variables *Roughness*.

Figure 2 shows the membership functions corresponding to the linguistic terms associated with the input language variables *Roughness*.

2.6. Defining the outputs of the decision-making process

The outputs from the decision process are the following technological parameters: *Power* (W) and *Speed* (mm/ min).

2.7. Defining the range of values for the outputs

Each output size is associated with a range of variation. These value areas will be:

$$D_{Power} = [10;\ 3000]\ (W) \tag{5}$$

$$D_{Speed} = [0;\ 10000]\ (mm/min) \tag{6}$$

2.8. Defining the linguistic variable associated with each output

Each output is associated with a linguistic variable. Thus, the output variable Power is associated with the linguistic variable Power and the output variable Speed is associated with the linguistic variable Speed.

2.9. Establishing the linguistic degrees associated with each output language variable

Linguistic degrees are defined for each output language variable. The linguistic degrees associated with the linguistic variable Power are:

$$TL_{Thnickness} = \{Vs,\ S,\ Md,\ L,\ VL\} \tag{7}$$

The linguistic degrees associated with the linguistic variable of exit Speed are:

$$TL_{Speed} = \{Vs,\ s,\ Md,\ L,\ VL\} \tag{8}$$

2.10. Establishing the membership functions associated with each linguistic degree. The Outputs.

In the case of both variables associated with the outputs, the linguistic degrees associated with the membership functions are triangular.

Figure 3 shows the membership functions corresponding to the linguistic degrees associated with the output language variables *Power*.

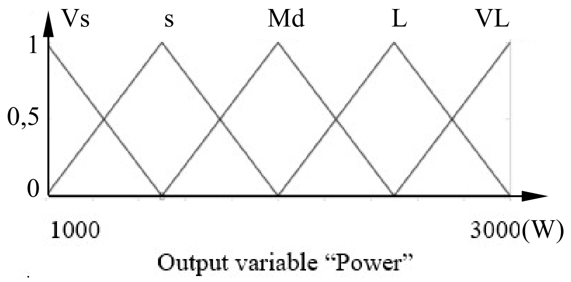

Figure 3. Belonging functions corresponding to the linguistic degrees associated linguistic variables output *Power*.

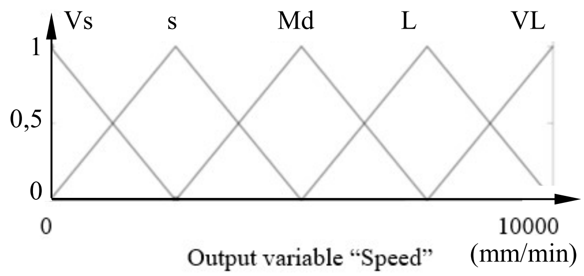

Figure 4. The membership functions corresponding to the linguistic degrees associated linguistic variables output *Speed*.

Figure 4 shows the membership functions corresponding to the linguistic degrees associated with the output language variables *Speed*.

2.11. Establishing the method of connecting the various values of the membership functions

The set of input and output linguistic variables, the linguistic degrees, to which membership functions have been associated, characterize “fuzzy” the firm values of the input and output quantities, respectively. The dependence between the output variables and the input variables is achieved by the MIN-MAX method, resulting in 25 shape inference rules:

1. If (Thickness is Vs) and (Roughness is Vs) then (Power is L)(Speed is VL)
2. If (Thickness is Vs) and (Roughness is S) then (Power is VL)(Speed is VL)
3. If (Thickness is Vs) and (Roughness is Md) then (Power is L)(Speed is Md)

………………………………………………………………………………………

9. If (Thickness is s) and (Roughness is L) then (Power is Md)(Speed is s)
10. If (Thickness is s) and (Roughness is VL) then (Power is s)(Speed is Vs)
11. If (Thickness is Md) and (Roughness is Vs) then (Power is VL)(Speed is Md)

………………………………………………………………………………………

23. If (Thickness is VL) and (Roughness is Md) then (Power is L)(Speed is Md)
24. If (Thickness is VL) and (Roughness is L) then (Power is L)(Speed is L)
25. If (Thickness is VL) and (Roughness is VL) then (Power is Md)(Speed is L)

The dependence of the output variables on the input variables can also be highlighted by representing the area of variation of an output as a function of two inputs. Figure 5 highlights the dependence of the *Power* on the two inputs: *Thickness* and *Roughness*.

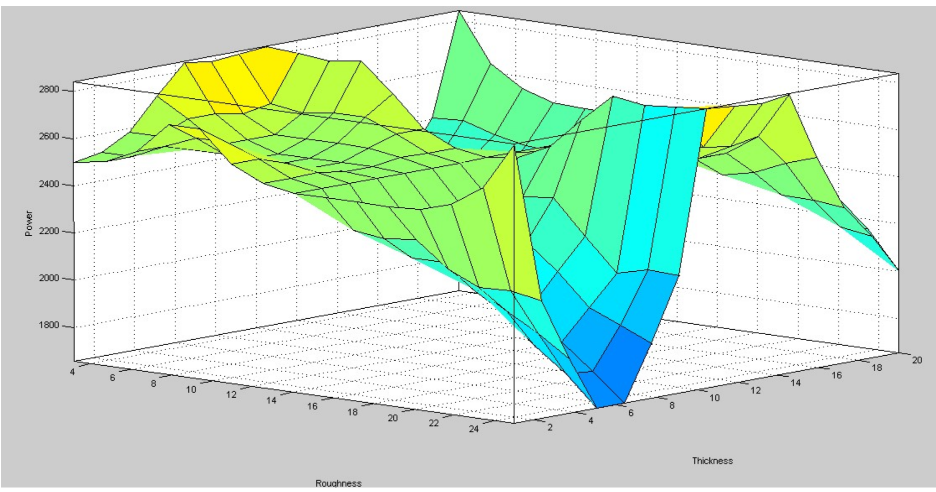

Figure 5. The variation surface of the *Power* according to *Thickness* and *Roughness*.

The *Laser decision* system implemented in the Fuzzy Logic Toolbox from Matlab® is shown in figure 6.

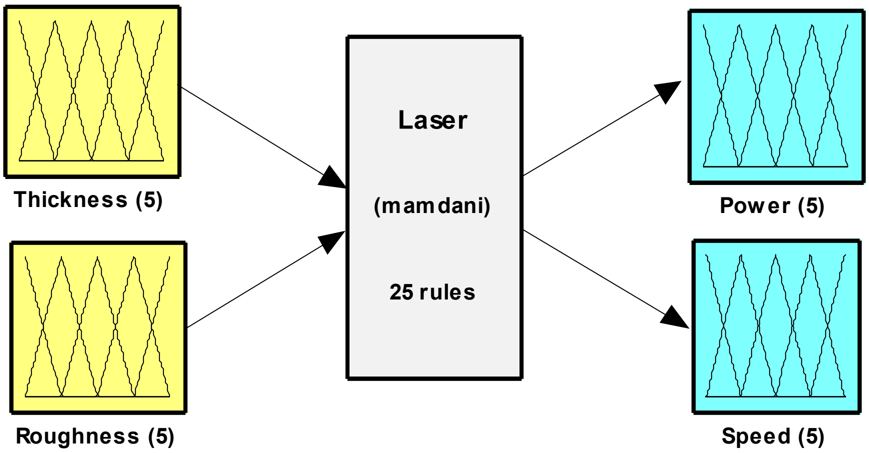

Figure 6. Laser decision making fuzzy system.

To determine the technological parameters of the laser cutting process, a package of programs was developed in the Matlab® environment. These programs allow:

1. Entering the firm values of the input quantities:
   - Thickness (mm);
   - Roughness (μm).
2. Determining the values of the technological parameters of the laser cutting process by using the Laser.fis decision system.

The graphical interface generated by the main program *INTERFACE.m* is presented in figure 6.

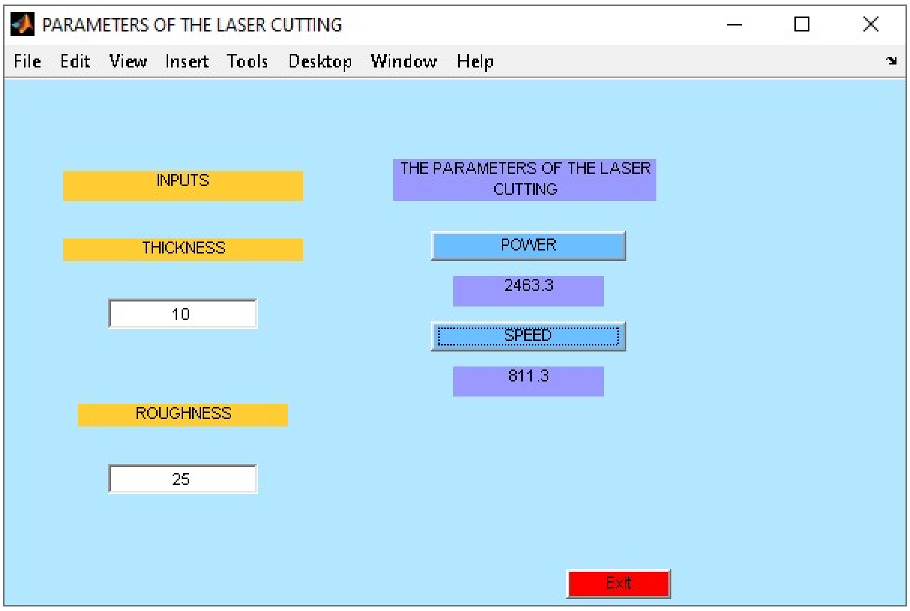

Figure 7. The graphical interface.

3. Experimental research

The validation of the fuzzy system for determining the technological parameters of laser cutting was done by performing some tests using the laser cutting machine model SFG3015G (Figure 8). Figure 9 shows the control equipment of the machine

Figure 8. SFG3015G machine.

Figure 9. Machine control equipment.

The technical parameters of the laser cutting machine model SFG3015G are as follows:

- Working surface: 1500 * 3000 mm
- Laser power: 3KW
- Maximum cutting thickness: 20 mm
- Maximum movement speed: 80 m / min
- Maximum acceleration: 0.8 g
- X / Y axis positioning accuracy: ± 0.05 mm
- Repeated positioning accuracy of the X / Y axis: ± 0.02 mm

The material of the samples was carbon steel S235JR. Semi-finished pieces of different thicknesses were cut: 1 mm; 3 mm; 10 mm. Table 1 presents a summary of the experiments performed.

Next we will exemplify, in detail, two cases of using the fuzzy system and the way in which the obtained results were found in the experiments performed.

Figure 10 shows the user interface in which the values of the inputs were entered: Thickness = 1 mm and Roughness = 12.5 µm. Activate the fuzzy system, the values of the outputs result: Power = 2523.3 W and Cutting speed + 5864.9 mm / min. Figure 11 shows the parameters adjusted using the control equipment of the laser cutting machine: Power 2700 W and speed 5500 mm / min. The resulting piece is the one in figure 12.

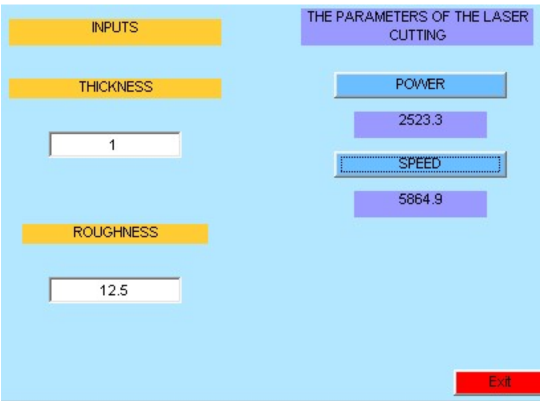

Figure 10. Interface: sample Thickness = 1 mm; Roughness = 12.5 µm.

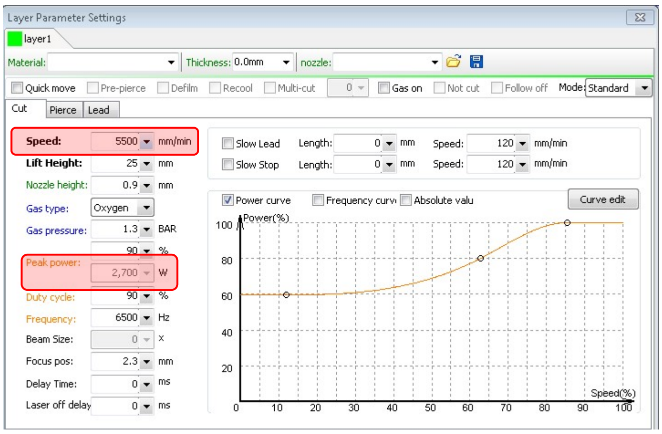

Figure 11. Equipment: sample Thickness = 1 mm; Roughness = 12.5 µm.

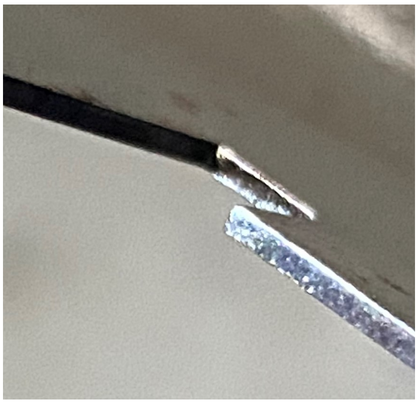

Figure 12. Sample Thickness = 1 mm; Roughness = 12.5 µm.

Figure 13 shows the user interface in which the values of the inputs were entered: Thickness = 10 mm and Roughness = 3.2 µm. Activating the fuzzy system results in the values of the output quantities: Power = 2837.7 W and Cutting speed 5000 mm / min. Figure 14 shows the parameters adjusted using the control equipment of the laser cutting machine: Power 2880 W and Speed 5500 mm / min.

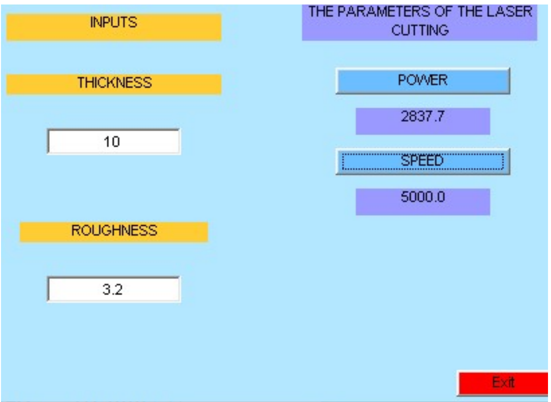

Figure 13. Interface: sample Thickness = 10 mm; Roughness = 3.2 µm.

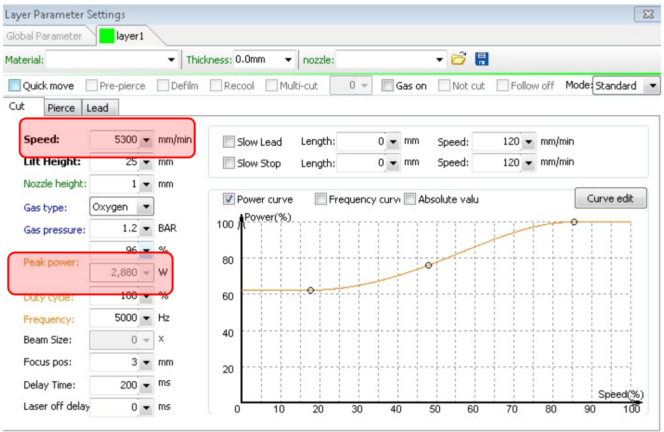

Figure 14. Equipment: sample Thickness = 10 mm; Roughness = 3.2 µm.

The resulting sample, under the conditions described, is that in Figure 15.

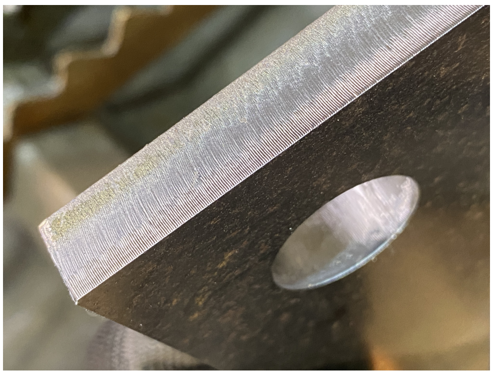

Figure 15. Sample Thickness = 10 mm; Roughness = 3.2 µm.

As mentioned before, Table 1 summarizes the results of the experiments. It is found that the values of the cutting parameters determined with the help of the fuzzy system and those adjusted on the machine have, in general, the same tendency of variation. This is also highlighted in the graphs in Figures 16 and 17.

Table 1. Fuzzy system parameters and equipment parameters

Nr. crt.	Sample features		Fuzzy system parameters		Equipment parameters	
	Thickness (mm)	Ra (μm)	Speed (mm/min)	Power (W)	Speed (mm/min)	Power (W)
1	1	12.5	5864	2523	5500	2700
2	1	25	800	2840	1000	2850
3	3	3.2	6590	2546	6600	2700
4	3	12.5	4907	2525	5000	2400
5	3	25	910	2012	900	2100
6	10	3.2	5000	2837	5300	2880
7	10	12.5	5460	2523	6000	3000
8	10	25	811	2463	1100	2280

Figure 16 shows the speed variation graphs.

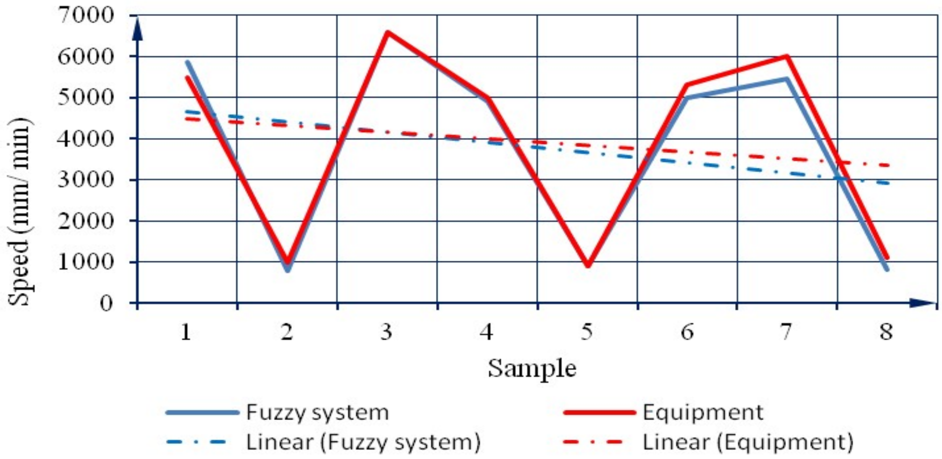

Figure 16. Speed variation graphs.

Figure 17 shows the power variation graphs.

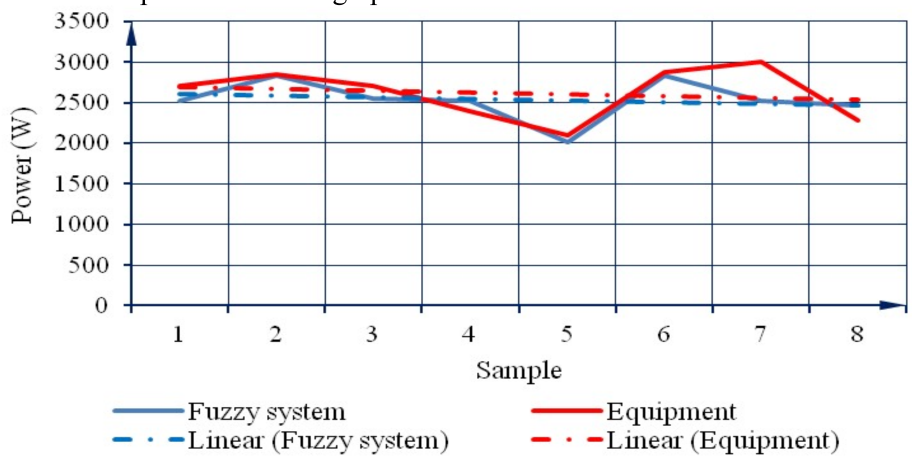

Figure 17. Power variation graphs

If the variation trend is the same, there are differences in the case of the absolute values of the two parameters, for the situation in which they result from the fuzzy system or they are set on the equipment. These differences are significant in the case of the 10 mm thick blank.

4. Conclusions

The presented system is an interactive, modern and efficient software tool, structured on functional components, having an interface with the user in order to design the technologies.

The use of fuzzy systems in determining the technological parameters specific to the laser cutting process, offers the possibility to develop a multicriteria decision-making system. In the concrete case analysed, the criteria were: material thickness and roughness.

The results obtained after using the fuzzy system depend on the way in which the inference rules were defined, these establishing the dependence of the outputs in relation to the inputs. For the analysed case, the outputs were the cutting power and speed parameters.

Comparing the experimental results with the values resulting from the use of the fuzzy system, it was found that in the case of small material thicknesses the differences are insignificant. In the case of samples made of thicker material, the differences increase.

Consequently, future research needs to improve the decision-making system based on fuzzy maths by increasing the number of language degrees associated with input and outputs and by adjusting the ranges of values associated with membership functions.

5. References

[1] Riveiro A, Quintero F, Lusquinos F, Comesana R and Pou J. 2011 Appl. Sur. Sci. **257** 5393–5397

[2] Madić M J, Radovanovi R M, 2012, *Ther. Science*, **16 Suppl. 2** S363

[3] Wadekar S and Deokar S U 2016 *IJIR* **2 Issue-7** 434

[4] Nguyen V, Altarazi F and Tran T 2022 *Math. Probl. Eng*. **2022** 14

[5] Chong Z S, Mohzani M, Chin J F, Yupiter H.P. 2011 *Exp. Syst. Applic*. **38** 7558

[6] Radonjić S, Mitrović A and Kovač P 2012 *16th International Research/Expert Conference"Trends in the Development of Machinery and Associated Technology"* TMT 2012, Dubai, UAE, pp 47- 50

[7] Stanasel I, Blaga F and Hule V 2010 *Proceedings of 14th ModTech International Conference-New face of TMCR Modern Technologies, Quality and Innovation - New face of TMCR*, Nedelcu D, Slatineanu L, Mazuru S and Milosevic O Nedelcu D, Slatineanu L, Mazuru S and Milosevic O Slanic Moldova Romania pp 559-562

[8] Blaga F, Lucaciu I and Ţarcă I, 2010 *Proceedings of 14th ModTech International Conference-New face of TMCR Modern Technologies, Quality and Innovation - New face of TMCR*, Nedelcu D, Slatineanu L, Mazuru S and Milosevic O Nedelcu D, Slatineanu L, Mazuru S and Milosevic O Slanic Moldova Romania 131- 134