STATISTICAL APPROACH TO THE ANALYSIS OF THE CUT QUALITY IN LASER CUTTING PROCESS

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Abstract: *The laser cutting process is a popular technology for cutting different types of materials economically. Kerf width and surface roughness are affected by laser power, cutting speed and type of assist gas. In this paper CO₂ laser cutting of tungsten alloy is investigated. Statistical approach is used to analysis the impact of the process parameters on the quality characteristics. The analysis shows that the quality of the cut depends on all considered process parameters and that it is affected differently at different assist gases. Cutting speed has a stronger effect on the kerf width when used air as assist gas, while for oxygen and nitrogen the laser power has a stronger effect. Laser power has a stronger effect on surface roughness when used air and oxygen as assist gasses, while cutting speed has a stronger effect if nitrogen is used.*

Key words: *CO₂ laser cutting, tungsten alloy, cut quality, statistical approach*

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1. Introduction

Laser beam machining is an advanced non-traditional thermal process, and it has a wide range of applications in different machining processes in industry due to its advantages. The laser beam cutting process has several advantages in comparison with other cutting process such as: process can be carried out under atmospheric conditions, there is no mechanical contact between work piece and laser device, a small heat-affected zone and narrow kerf, various type of materials can be cut, it has high degree of flexibility (Eltawahni et al., 2016). The focus of manufacturers using laser cutting process is the optimization of the productivity and the required quality of the products made by laser cutting. Both aspects are dependent on the appropriate choice of the process parameters, and these parameters are different for each type of material and thickness. These parameters are usually laser power, cutting speed, focus position, and assist gas pressure and type. The effect of process parameters in CO₂ laser cutting of stainless steel of medical grade AISI316L using nitrogen as an assist gas are analysed (Eltawahni et al., 2012). Authors shown that the upper kerf width increases as the laser power, pressure of nitrogen and diameter of nozzle increase, but it decreases by increasing of cutting speed and focus position. Assist gas type is essential to minimize the production cost by increasing the cutting speed. Changing the assist gas type and its effect on the pulsed and CW Nd:YAG laser cutting of 1.2 mm austenitic stainless steel sheets is studied by (Ghany & Newishy, 2005). It is shown that in comparison nitrogen with oxygen, nitrogen caused brighter and smoother cut surface with smaller kerf, although it did not prove to be economical. A grey based response surface methodology is used to predict the optimal level of cutting parameters in CO₂ laser cutting of Al6061/SiC/Al₂O₃ composite sheets with 4 mm thickness (Adalarasan et al., 2015). Laser power, pulsing frequency, cutting speed and assist gas pressure are considered as cutting parameters.

For modelling and optimizing of any machining processes, the numerical methods (Begic-Hajdarevic & Bijelonja, 2014; Kadri et al., 2015), artificial neural network (Klancnik et al., 2015; Saric et al., 2016; Mohamed et at., 2016), fuzzy logical method (Rodic et at., 2014; Saenz et al., 2015) and other intelligent techniques (Ficko & Placic, 2013; Klancnik et al., 2016; Rao et al., 2016) are common used. Further analyses of interest are especially laser cut uncommon materials. Experimental study on the laser cutting of difficult to laser cut Duralumin sheet by using a hybrid approach which is obtained by the integration of robust parameter design with fuzzy logic theory is performed (Pandey & Dubey, 2012). The aim was to improve geometrical accuracy by simultaneously minimizing the kerf width and kerf deviations at top and bottom sides. In order to evaluate the surface roughness of the laser cutting of tungsten alloy by using oxygen as assist gas, statistical process control method based on control charts is applied (Begic-Hajdarevic et al., 2015). Key objective was to find cutting speed and laser power achieving stable process and best cutting quality.

In this research paper a statistical approach is used to analysis the impact of the process parameters on the quality characteristics. The experiments are performed on 1 mm thick tungsten alloy sheet using CO₂ laser system. Three input process

parameters such as laser power, cutting speed and assist gas type are taken into account. Kerf width and surface roughness are considered as output characteristics.

2. Experimental procedure

The experiments are conducted on a CW 2000 W Rofin laser with focal length of 127 mm. Tungsten alloy in sheet is used as work piece material. Specimens are cut on dimensions 100 mm x 100 mm with 1 mm thickness. Three different assist gasses such as nitrogen, air and oxygen are used in experiments. Assist gas is supplied coaxially with the laser beam through a 2 mm nozzle diameter. Nozzle distance, focus position and assist gas pressure are kept constant, and their values are given in Table 1.

Process Parameters	Assist Gas Type		
	Air	Oxygen	Nitrogen
Nozzle distance [mm]	1	1	0.75
Focus position [mm]	-1	-0.5	-0.5
Assist gas pressure [bar]	15	12.5	15

Tab. 1. Process parameters and their values.

The upper kerf width is measured using an optical microscope fitted with a video camera and a zoom lens. The average of five measurements of kerf width is recorded for all specimens. The arithmetic average roughness parameter Ra , values are measured using a Taylor-Hobson stylus instrument. Five consistent surface roughness values of each specimen are measured and an average value is calculated for each specimen. Roughness is measured along the length of a cut surface approximately in the middle of the thickness.

3. Measurement data analysis

A statistical analysis is performed to evaluate the measurement data. Measurement data are given in Table 2. The analysis contains a summary of measurement data, histogram plots for each result parameter, normal plots for each result parameter, overall box plots for each result parameter and box plots for each result parameter by each process parameter. Each assist gas is considered separately.

The summary of measurement data shows experimental values for both process parameters, number of measurements available for each parameter and minimum, maximum, mean, median, first and third quartile values for both result parameters.

Histogram plot intervals include the higher value end point, but not the lower value end point, with exception of the first cell which also includes the lower value end point. In the normal Q-Q plots sample quartiles are representing measurement results and are plotted versus theoretical quartiles in a sorted order. Theoretical quartiles represent a standard normal distribution. A normal line passing through first and third quartile is added. Outliers in box plots are calculated as values below the first quartile minus 1.5 times interquartile range or values over the third quartile plus 1.5 times interquartile range.

Assist Gas Type	Power [W]	Speed [mm/min]	Kerf [mm]	Ra [μ m]	Assist Gas Type	Power [W]	Speed [mm/min]	Kerf [mm]	Ra [μ m]
Air	1500	2000	0.24	5.24	O ₂	1750	4500	0.32	6.25
Air	1500	3000	0.22	4.04	O ₂	1750	5000	0.27	7.13
Air	1500	3500	0.23	2.76	O ₂	1750	5500	0.31	5.97
Air	1500	2500	0.23	3.30	O ₂	1750	4000	0.32	6.80
Air	1750	2000	0.24	5.46	O ₂	2000	3000	0.35	7.73
Air	1750	2500	0.23	3.95	O ₂	2000	3500	0.34	7.22
Air	1750	3000	0.23	3.80	O ₂	2000	4000	0.34	7.18
Air	1750	4000	0.23	3.77	O ₂	2000	5000	0.29	6.01
Air	1750	3500	0.22	3.33	O ₂	2000	6000	0.27	3.73
Air	2000	2000	0.24	7.17	O ₂	2000	4500	0.31	6.14
Air	2000	3000	0.23	4.66	O ₂	2000	5500	0.27	4.49
Air	2000	3500	0.23	4.50	N ₂	1500	1000	0.17	5.82
Air	2000	4000	0.23	3.52	N ₂	1500	2000	0.19	4.97
Air	2000	4500	0.23	2.77	N ₂	1500	1500	0.18	5.41
Air	2000	2500	0.24	4.92	N ₂	1750	1000	0.20	5.33
O ₂	1500	3000	0.35	7.75	N ₂	1750	1500	0.19	5.57
O ₂	1500	3500	0.32	7.58	N ₂	1750	2000	0.18	6.56
O ₂	1500	4000	0.29	6.79	N ₂	2000	1000	0.20	5.41
O ₂	1500	4500	0.28	6.02	N ₂	2000	1500	0.19	5.92
O ₂	1750	3000	0.34	7.78	N ₂	2000	2250	0.19	7.14
O ₂	1750	3500	0.33	8.22	N ₂	2000	2000	0.18	6.23

Tab. 2. Measurement data used in statistical analysis.

3.1 Air as assist gas

For air as assist gas is available 15 experiments. Range of cutting speed is 2000 mm/min to 4500 mm/min and range of laser power is 1500 W to 2000 W. Number of available result points for each cutting speed and laser power is visible in Table 3. Minimum and maximum measured values for kerf width and surface roughness as well as median, mean and first and third quartile values are also visible in Table 3.

Cutting Speed		Power		Kerf Width		Surface Roughness	
[mm/min]	Result points	[W]	Result points	Value	[mm]	Value	[μ m]
2000	3	1500	4	Min.	0.2200	Min.	2.760
2500	3	1750	5	1st Quartile	0.2300	1st Quartile	3.425
3000	3	2000	6	Median	0.2300	Median	3.950
3500	3			Mean	0.2313	Mean	4.213
4000	2			3rd Quartile	0.2350	3rd Quartile	4.790
4500	1			Max.	0.2400	Max.	7.170

Tab. 3. Summary of measurement data analysis for air.

The measurement result frequency of kerf width (Fig. 1) is highest in range from 0.225 mm to 0.23 mm with nine available result points, four result points are available in range from 0.235 mm to 0.24 mm and two in range from 0.22 mm to 0.225 mm. Zero result points are available in range from 0.23 mm to 0.235 mm. The measurement result frequency of surface roughness (Fig. 1) is highest in range from 3 μm to 4 μm with six available result points, four result points are available in range from 4 μm to 5 μm , two in range from 2 μm to 3 μm and one result point is available in range from 7 μm to 8 μm . Zero result points are available in range from 6 μm to 7 μm .

Fig. 1. Histogram for kerf width (left) and surface roughness (right) – air.

A weak match between kerf width measurement results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 2). Kerf width results are distributed on three levels. Deviations from normal line are found on all levels. A close match between surface roughness measurement results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 2). Some deviations are found at the low and the high end of the graph.

Fig. 2. Normal Q-Q plot for kerf width (left) and surface roughness (right) - air.

Box plot of all measured kerf width results, with a mean value of 0.23 mm, reveals a normal result point distribution towards higher than median values and an outlier result point in lower than median direction (Fig. 3). Box plot of all measured surface roughness results, with a mean value of 4.21 μm , reveals a close to normal result point distribution with a wider result point distribution range towards higher than median values (Fig. 3). One outlier point is found with a measured surface roughness value of 7.17 μm .

Fig. 3. Box plots of overall kerf width (left) and surface roughness (right) – air.

Fig. 4. Box plots for kerf width (left) and surface roughness (right) by speed - air.

Box plots of kerf width result points (Fig. 4) reveal no result point dispersion at cutting speed 2000 mm/min with a mean at 0.24 mm and at 4000 mm/min and 4500 mm/min with a mean of 0.23 mm. At cutting speeds 2500, 3000 and 3500 mm/min the mean kerf width value is 0.23 mm. A one sided result point distribution with median being an edge value is revealed for those cutting speeds. At cutting speed 2500 mm/min result points are dispersed only in the direction towards higher than median, while at

cutting speeds 3000 mm/min and 3500 mm/min result points are dispersed only in the direction towards lower than median. Box plots for surface roughness (Fig. 4) reveal a close to normal result point distribution at cutting speeds 2500 mm/min and 3500 mm/min. At cutting speed 2000 mm/min the highest result point variation is found with a wider result point distribution range towards higher than median values. A similar situation occurs at cutting speed 3000 mm/min, but with a narrower result point distribution range. At cutting speed 4000 mm/min all result points are completely inside the first and third quartile range with a balanced distribution. At cutting speed 4500 mm/min only one result point is available.

Fig. 5. Box plots for kerf width (left) and surface roughness (right) by power - air.

Box plot for kerf width (Fig. 5) at laser power 1500 W shows a balanced result point distribution throughout the entire kerf width range. At laser power 1750 W most results are measured at kerf width 0.23 mm with one outlier over and one below median. At power 2000 W most result points are measured at kerf width 0.23 mm with a couple of points at third quartile and none below median value. Box plot for surface roughness (Fig. 5) at laser power 1500 W shows a balanced result point distribution with a mean value of 3.84 μm , at 1750 W most result points are concentrated around median, with no whiskers and two outliers and a mean of 4.06 μm . At laser power 2000 W most results are concentrated around median, with a mean of 4.59 μm . In the direction of lower than median values result points are distributed in a wider range than in the direction of higher than median, where result points are in the median to third quartile range, with no whiskers and one outlier point.

3.2 Oxygen as assist gas

In statistical analysis 17 experiments are available for oxygen as assist gas. Cutting speed measurement range is 3000 mm/min to 6000 mm/min and laser power measurement range is 1500 W to 2000 W. Number of available result points for each cutting speed and each laser power is visible in Table 4. Minimum and maximum measured values for kerf width and surface roughness as well as median, mean and first and third quartile values are also visible in Table 4.

Cutting Speed		Power		Kerf Width		Surface Roughness	
[mm/min]	Result points	[W]	Result points	Value	[mm]	Value	[μm]
3000	3	1500	4	Min.	0.2700	Min.	3.730
3500	3	1750	6	1st Quartile	0.2900	1st Quartile	6.020
4000	3	2000	7	Median	0.3200	Median	6.800
4500	3			Mean	0.3118	Mean	6.635
5000	2			3rd Quartile	0.3400	3rd Quartile	7.580
5500	2			Max.	0.3500	Max.	8.220
6000	1						

Tab. 4. Summary of measurement data analysis for oxygen.

Measurement result frequency of kerf width (Fig. 6) is highest in range from 0.27 mm to 0.28 mm with four available result points. Three results points are available in range from 0.31 mm to 0.32 mm and in range from 0.33 mm to 0.34 mm. Two result points are available in range from 0.28 mm to 0.29 mm, from 0.3 mm to 0.31 mm and from 0.34 mm to 0.35 mm. One result point is available in range from 0.32 mm to 0.33 mm and zero result points in range from 0.29 mm to 0.3 mm. Measurement result frequency of surface roughness (Fig. 6) is highest in range from 7 μm to 8 μm with seven result available points, followed by range from 6 μm to 7 μm with six result points. One result point is available in each of the remaining range intervals.

Fig. 6. Histogram for kerf width (left) and surface roughness (right) – oxygen.

A weak match between kerf width results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 7). Some major deviations from the normal line are found at the low and the high end of the graph. A weak match between surface roughness results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 7). Some major deviations are found at the low and the high end of the graph.

Fig. 7. Normal Q-Q plot for kerf width (left) and surface roughness (right) - oxygen.

Box plot of all measured kerf width results (Fig. 8), with a mean value of 0.31 mm, reveals a close to normal result point distribution with a denser distribution range in the direction towards higher than median values. Box plot of all measured surface roughness results reveals a close to normal result point distribution between the first and third quartile, (Fig. 8). A wider variation range of result points is found in the smaller than first quartile whiskers interval compared to the opposite, higher than third quartile interval. The mean value of surface roughness results is 6.63 μm .

Fig. 8. Box plots of overall kerf width (left) and surface roughness (right) – oxygen.

Box plots of kerf width by cutting speed (Fig. 9) reveal a close to normal result point distribution at cutting speeds 3500 mm/min, 4000 mm/min and 4500 mm/min with a denser result point distribution towards higher kerf width values for all three cases. At cutting speed 3000 mm/min result points are available only in the lower than median direction, at 5000 mm/min and 5500 mm/min only two result points are available and at 6000 mm/min only one result point is available. Kerf width mean value

at cutting speed 3000 mm/min is 0.35 mm, at 3500 mm/min it is 0.33 mm, at 4000 mm/min it is 0.32 mm at 4500 mm/min it is 0.317 mm, at 5000 mm/min it is 0.28 mm, at 5500 mm/min it is 0.29 mm and at 6000 mm/min it is 0.27 mm. Result variation is the highest for 4000 mm/min and 5500 mm/min cases. Box plots of surface roughness by cutting speed (Fig. 9) reveal a normal result point distribution for the 3000 mm/min and the 4500 mm/min case and a close to normal result point distribution for the 3500 mm/min case with a denser result point distribution towards lower than median. At cutting speed 4000 mm/min result points are distributed only in the direction towards higher than median. At cutting speed 5000 mm/min and at 5500 mm/min only two result points are available and at cutting speed 6000 mm/min only one result point is available. Surface roughness mean value at cutting speed 3000 mm/min is 7.75 μm , at 3500 mm/min it is 7.67 μm , at 4000 mm/min it is 6.927 μm , at 4500 mm/min it is 6.14 μm , at 5000 mm/min it is 6.57 μm , at 5500 mm/min it is 5.23 μm and at cutting speed 6000 mm/min it is 3.73 μm . Result variation is the highest for 5500 mm/min case.

Fig. 9. Box plots for kerf width (left) and surface roughness (right) by speed - oxygen.

Box plot of kerf width (Fig. 10) at laser power 1500 W reveals a close to normal result point distribution with a wider range in the direction towards higher kerf width values. At laser power 1750 W the distribution is close to normal with one outlier point below the first quartile line. At laser power 2000 W the measured kerf width result distribution is completely symmetrical. At 1750 W laser power the mean value is the highest at 0.32 mm. For 1500 W and 2000 W the mean value is 0.31 mm. Result point variation is highest for 2000 W case. Box plot of surface roughness by laser power reveals a close to normal result point distribution for each individual power level, (Fig. 10). At laser power 1500 W and 2000 W a wider result point distribution range in the direction of smaller than median is revealed and at 1750 W a wider result point distribution range in the direction of higher than median is revealed. Surface roughness mean values are 7.04 μm at 1500 W, 7.03 μm at 1750 W and 6.07 μm at 2000 W. Result point variation is highest for 2000 W case.

Fig. 10. Box plots for kerf width (left) and surface roughness (right) by power-oxygen.

3.3 Nitrogen as assist gas

In statistical analysis 10 experiments are available for nitrogen as assist gas. Cutting speed measurement range is 1000 mm/min to 2250 mm/min and laser power measurement range is 1500 W to 2000 W. Number of available result points for each cutting speed and each laser power is visible in Table 5. Minimum and maximum measured values for kerf width and surface roughness as well as median, mean and first and third quartile values are also visible in Table 5.

Cutting Speed		Power		Kerf Width		Surface Roughness	
[mm/min]	Result points	[W]	Result points	Value	[mm]	Value	[μm]
1000	3	1500	3	Min.	0.170	Min.	4.970
1500	3	1750	3	1st Quartile	0.180	1st Quartile	5.410
2000	3	2000	4	Median	0.190	Median	5.695
2250	1			Mean	0.187	Mean	5.836
				3rd Quartile	0.190	3rd Quartile	6.152
				Max.	0.200	Max.	7.140

Tab. 5. Summary of measurement data analysis for nitrogen.

Measurement result frequency of kerf width (Fig. 11) is highest in range from 0.185 mm to 0.19 mm with four available result points, followed by range interval from 0.175 mm to 0.18 mm with three result points, 0.195 mm to 0.2 mm with two results points and 0.17 mm to 0.175 mm with one result point. In range from 0.18 mm to 0.185 mm and 0.19 mm to 0.195 mm no result points are available. Measurement result frequency of surface roughness (Fig. 11) is highest in range from 5 μm to 5.5 μm and from 5.5 μm to 6 μm with three available result points. One result point is available in each of the remaining range intervals.

Fig. 11. Histogram for kerf width (left) and surface roughness (right) – nitrogen.

A weak match between kerf width measurement results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 12). Kerf width results are distributed on four levels. Deviations from normal line are found on all levels. A weak match between surface roughness measurement results and a normal distribution is revealed in the Q-Q normal plot graph (Fig. 12). Bigger deviations are found at the high end of the graph.

Fig. 12. Normal Q-Q plot for kerf width (left) and surface roughness (right) - nitrogen.

Box plot of all measured kerf width results reveals a wider result point variation range towards smaller than median kerf width values (Fig. 13). In the direction higher than median only whiskers points exist. A mean value of 0.19 mm is found. Box plot of all measured surface roughness results reveals a wider result point variation range towards higher than median values (Fig. 13). A mean surface roughness value of 5.84 μm is found.

Fig. 13. Box plots of overall kerf width (left) and surface roughness (right) – nitrogen.

Fig. 14. Box plots for kerf width (left) and surface roughness (right) by speed-nitrogen.

Box plots of kerf width by cutting speed (Fig. 14) reveal an unbalanced result point distribution for all cases. For 1000 mm/min result variation is the highest and oriented only towards lower than median values. Mean kerf width at 1000 mm/min is 0.19 mm. At 1500 mm/min result point distribution is found only towards lower than median kerf width values. Mean kerf width value at 1500 mm/min is 0.19 mm. At 2000 mm/min result point variation range is similar to 1500 mm/min, while result point distribution is found only in direction towards higher than median values. Mean kerf width value at 2000 mm/min is 0.18 mm. At cutting speed 2250 mm/min only one result point is available with mean kerf width value 0.19 mm. Box plots of surface roughness by cutting speed (Fig. 14) for 1000 mm/min and 1500 mm/min cases reveal a wider result point distribution towards higher than median values. At 2000 mm/min the result point distribution range is wider towards lower than median values. Result

point variation at 2000 mm/min is the highest among all cases. At 2250 mm/min one point is measured. Mean surface roughness values are 5.52 μm at 1000 mm/min, 5.63 μm at 1500 mm/min, 5.92 μm at 2000 mm/min and 7.14 at 2250 mm/min.

Kerf width by power box plots reveal a normal result point distribution at all laser power levels (Fig. 15). Mean values are 0.18 mm at 1500 W and 0.19 mm at 1750 W and 2000 W. Surface roughness by power box plots (Fig. 15) reveal a normal result point distribution for 1500 W and 2000 W cases and a more dense result point distribution in the direction towards lower than median for the 1750 W case.

Fig. 15. Box plots for kerf width (left) and surface roughness (right) by power-nitrogen.

3.4 Summary results

When using air as assist gas a weak reduction of kerf width with rising cutting speed is observed. With oxygen assist gas a kerf width reduction with rising cutting speed is found, with an exception point at 5000 mm/min. As only a few result points are available at 5000 mm/min and at higher cutting speeds and if considering the extreme values for those cases, the observed trend can be generalized over the complete cutting speed range. With nitrogen as assist gas, kerf width mean values are falling with rising cutting speed in range from 1000 mm/min to 2000 mm/min. As only one result point is available at 2250 mm/min, the trend can be extrapolated over the complete cutting speed range. Generally, by rising cutting speed a reduction of kerf width can be expected regardless of assist gas type.

When using air as assist gas no clear trend is observed between 2500 mm/min and 4000 mm/min. In this interval, surface roughness result points range from 3 μm to 4 μm . At 2000 mm/min, surface roughness mean value is 50 % higher than mean values in range from 2500 mm/min to 4000 mm/min and at cutting speed 6000 mm/min it is 25 % lower, resulting in a general trend of lower surface roughness towards higher cutting speeds. With oxygen as assist gas a trend of surface roughness reduction by rising cutting speed is observed. Similar to kerf width an exception point is detected at

cutting speed 5000 mm/min. When nitrogen is used as assist gas, a trend of rising surface roughness by rising cutting speed is detected, but also result point variation is rising with rising cutting speed. The first is different to air and oxygen cases. It is found that, surface roughness by cutting speed trend is dependent on assist gas type.

Almost no effect of laser power on kerf width is detected when using air as assist gas. When oxygen is used, maximum mean kerf width value is found at 1750 W. A weak kerf width rise by rising laser power over the complete range is detected. If nitrogen is used as assist gas, minimum mean kerf width value is found at 1500 W. At higher laser power kerf width is constant. Overall, small differences in kerf width are detected and a minor effect of laser power on kerf width is concluded. Generally, with rising laser power a rising kerf width is to be expected.

When using air as assist gas, with rising laser power a rising surface roughness is detected. When using oxygen, a falling surface roughness by rising power is detected. When using nitrogen, a rising surface roughness by rising laser power is detected, but also result point variation is rising with rising power. It is found, that surface roughness by power trend is dependent on assist gas type.

4. Contour plots

To present trends over complete measurement range for both process parameters, contour plots are generated. One plot is generated for each result parameter and each assist gas. A fitting model considering main effects and factor interactions is selected and applied on the complete air, oxygen and nitrogen data sets. Fig. 16 relates to the contour plots for kerf width on the left hand side and for surface roughness on the right hand side.

For air, cutting speed has a stronger effect on kerf width than power, while for oxygen or nitrogen power has a stronger effect. For air and oxygen, lowest kerf width values are found at highest cutting speeds and at lowest laser powers. For nitrogen, lowest kerf width values are found at lowest cutting speeds and at lowest powers. In case of nitrogen, if both parameters are rising, kerf width passes a maximum in the middle of the measurement range. At lower cutting speeds for nitrogen, power has a stronger effect on kerf width, while at higher powers, cutting speed has a stronger effect on kerf width.

In case of air or oxygen, power has a stronger effect on surface roughness than cutting speed, while cutting speed has a stronger effect if nitrogen is used. The lowest surface roughness values for air are found at highest cutting speeds and at lowest powers, for oxygen at highest cutting speeds and at highest powers and for nitrogen at highest cutting speeds and lowest powers and at lowest cutting speeds and highest powers. In case of nitrogen, if both parameters are rising, surface roughness passes a local minimum.

Fig. 16. Contour plots for kerf width (left) and surface roughness (right).

5. Conclusion

The analysis shows that the quality of the cut region is dependent on all considered parameters and that it is affected differently if the same process parameter trends, but different assist gases are used. Surface roughness by cutting speed and surface roughness by power trends are found to be dependent on assist gas choice. For the kerf width quality criteria no similar behavior was observed. A general conclusion can be made that regardless of assist gas, kerf width is rising with rising cutting speed or with rising laser power. By rising both parameters, kerf width is rising, with a minor exception detected for nitrogen at the highest measured parameter values.

Due to the use of different measurement intervals for each assist gas type and the low amount of data in some regions, the results are not the most suitable for comparison. As a consequence, the analysis does not try to result in a general conclusion, but rather offers individual interpretations of process behavior for a better understanding of the laser cutting technology.

In the future work, more detailed discussions should be considered on the impact of different process parameters and type material on the quality characteristics in some non-conventional cutting processes such as abrasive water jet cutting, plasma arc cutting and so on.

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