

Determination of cut front position in laser cutting

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Abstract. Laser cutting has a huge importance to manufacturing industry. Laser cutting machines operate with fixed technological parameters and this does not guarantee the best productivity. The adjustment of the cutting parameters during operation can improve the machine performance. Based on a coaxial measuring device it is possible to identify the cut front position during the cutting process. This paper describes the data analysis approach used to determine the cut front position for different feed rates. The cut front position was determined with good resolution, but improvements are needed to make the whole process more stable.

1. Introduction

The Laser cutting is used in processing of flat metal sheets for construction, cutting of pre-formed parts or trimming of hardened 3D parts in several areas of manufacturing. Today laser cutting is the most common industrial application of the laser. In Japan, around 80% of industrial lasers are used in this way [1].

To reach a reliable cutting performance associated with the best productivity, the cutting process should operate close to its technological limits, but with good quality in face roughness and with dross free processing results [2]. For fusion cutting, the feed rate can be limited by the insufficient ejection of the melt out of the cut kerf, or by a power demand not covered by the absorbed laser beam power [3]. This lead to the possibility of monitoring the cutting phenomena “in process” (at real time) to make possible the self-optimization for the next generations of laser cutting machines.

One way to realize this monitoring in by acquiring information about geometric properties of the cut kerf during the process through a coaxial process observation [2].

Figure 1 shows a sketch of the cutting process observed by a coaxial perspective. The point of interest for monitoring is the melting point, named cut front position. This cut front position changes with different operational parameters as feed rate, laser power or laser focus position.



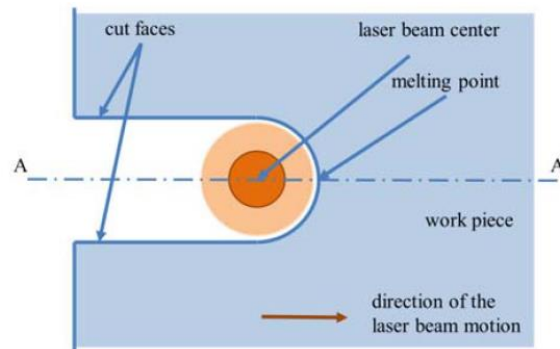


Figure 1. Sketch describing the cutting process [2].

2. Process Observation

The process observation with coaxial positioning is accomplished by combining and separating the optical path depending on the respective wavelength [4]. Figure 2 shows the coaxial setup. The processing radiation of the CO₂ laser is fully reflected by the beam splitter to the work piece, while the illumination laser beam with different wavelength crosses the beam splitter and reaches a high-speed camera mounted on the cutting head.

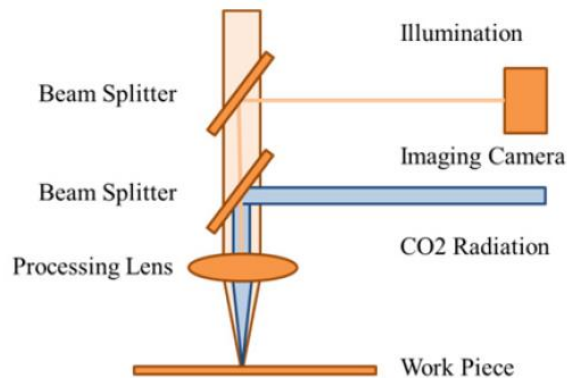


Figure 2. Coaxial setup for process observation [2].

The resulting image acquired by this system is shown in figure 3. This image has 280 x 300 pixels and represents only one frame of a set of 1000 frames acquired at a rate of 4 kHz for each test done. In the center of this image is easy to identify the cut kerf generated by the laser cutting process.

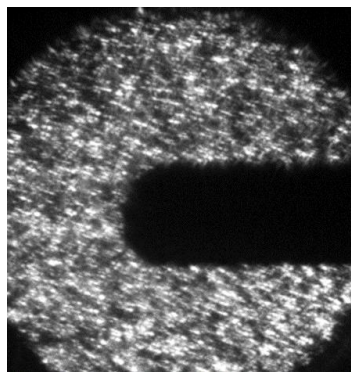


Figure 3. Image from the process observation.

3. Data Analysis

The experiments were conducted following pre-defined parameters, as shown in table 1.

Table 1. Setting parameters for the experiments.

Setting parameter	Value
Feed rate	900, 1200, 1500, 1800, 2100, 2400, 2700 mm/min
Laser Power	3.000 Watts
Focal length	250 mm
Focus positions	top surface level – 0 mm
Material	Stainless Steel 14301
Thickness	5 mm

For the focus position in 0 mm (position of the laser beam focus in relation to the metal sheet top surface), a test was done in each of the 7 feed rates and in each of the four cutting directions, resulting in a total of 28 cutting tests.

Figure 4 summarizes the investigations and the searched results to identify the cut front position for each test. Algorithms were created in Matlab® and Simulink® software to extract the geometric properties from the images.

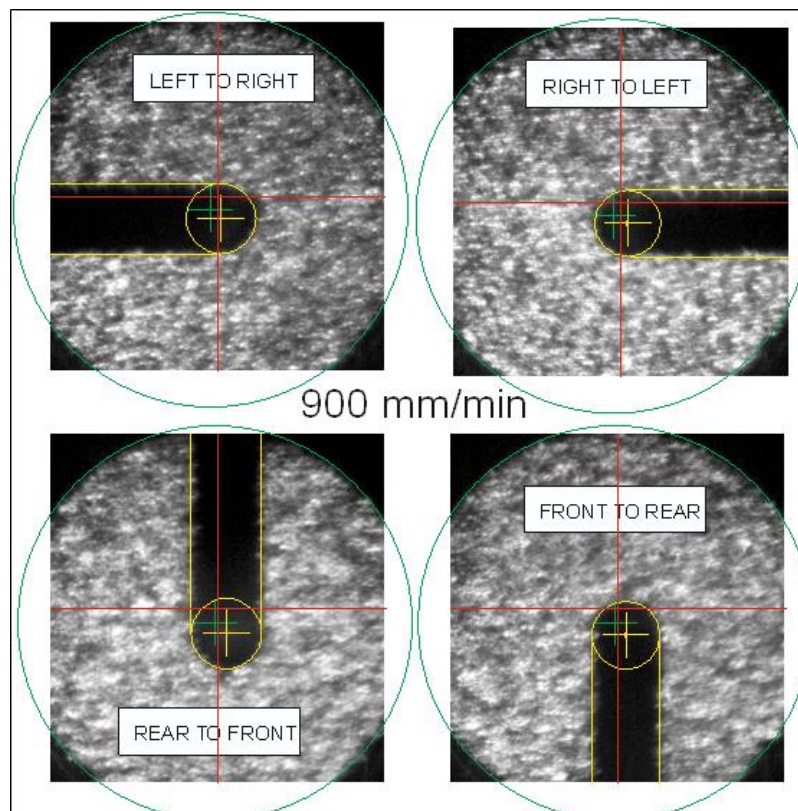


Figure 4. Analysis of results for cutting in four directions with the same process parameters.

In figure 4, the lines in red represent the centerlines for the image, identifying the camera center. The green circle represents the nozzle inner hole and the green cross represents the nozzle center. The lines in yellow represent the kerf geometry. Assuming that the laser beam has a circular profile, the yellow circle represents its position and the yellow cross represents the laser beam center.

Based on the behavior of the cut front position in relation to the nozzle center for each set of parameters used for the tests, it is possible to determine if the current set of parameters is near the critical condition or if the cutting process can be accelerated within a safe condition.

All the 1000 frames acquired for each test represents the same cutting phenomena with steady conditions.

The main task for the analysis consists in determining the cut kerf geometry to identify the cut width and the cut front position. As the use of only one frame can lead to an inaccurate determination of these properties, the analysis is based on a statistical superposition of the 1000 frames.

3.1. Analysis Algorithms for data extraction

The first step consists in converting the images in values that can be processed to enable the geometric analysis. Three processing algorithms were created for this purpose: one to process the kerf width, other for the cut front position, and the last one for determining the nozzle inner diameter.

The conversion is based on the determination of the intensity profile for each region of interest, as shown in Figure 5. In this case, the aim is to determine the kerf width, so the kerf was split in three regions (1, 2 and 3) and the intensity profile was determined for each half of these regions. The use of three regions is important to avoid errors caused by images aberrations and to verify if the kerf width keeps its uniformity. This algorithm automatically processes the 1000 frames and gives as result vectors with the pixel position and the related cumulative intensity of ten nearby lines, with each frame producing six vectors.

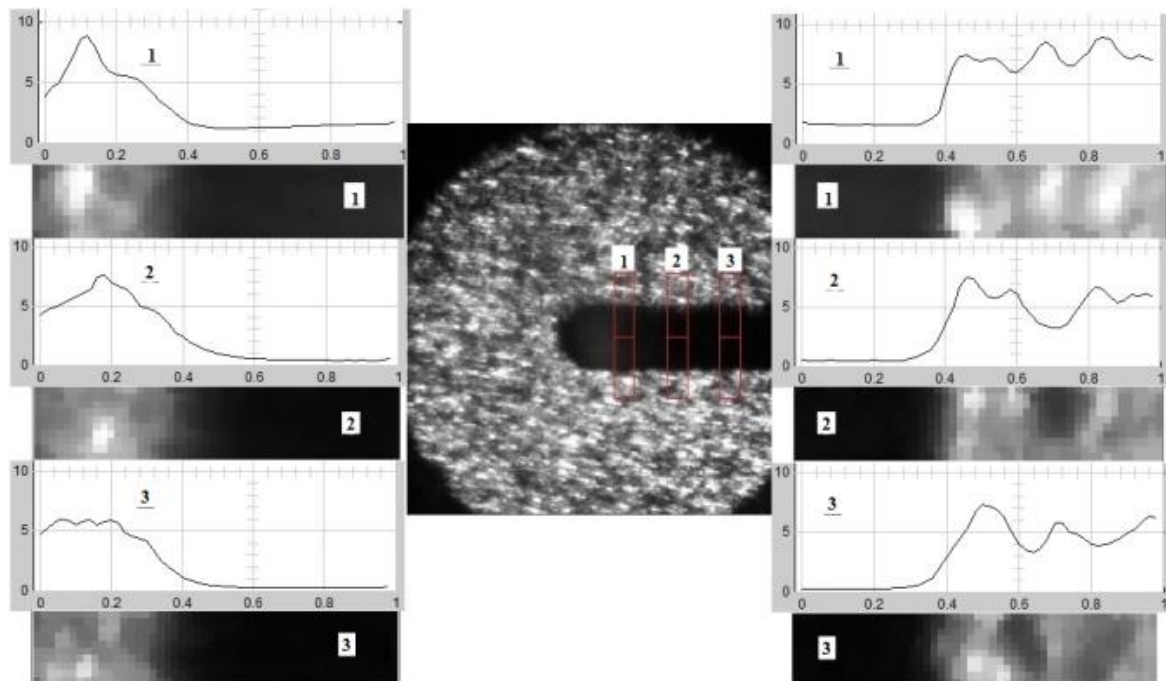


Figure 5. Intensity profile determination in kerf width analysis.

The same intensity profile extraction was also used to identify the cut front position.

To identify the nozzle inner diameter a contour filter was used and the resulting profile was converted in pixels positions, as shown in figure 6. This algorithm also automatically processes the 1000 frames and gives as result vectors with the pixel position of the contour profile for each frame.

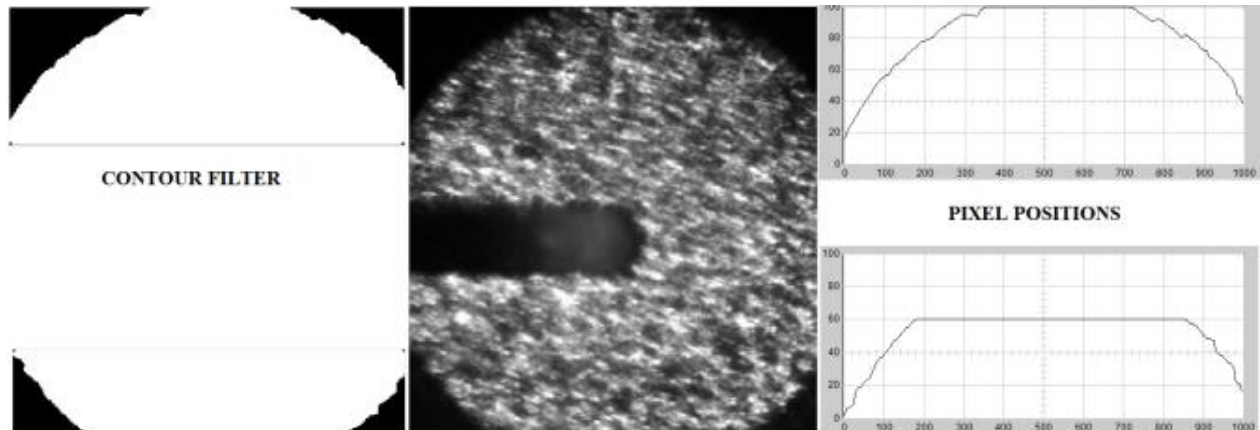


Figure 6. Nozzle inner hole determination.

3.2. Analysis Algorithms for geometric determination

The main concept for the analysis consists in making a statistical superposition of the 1000 vectors for each acquired attribute. This is done by fitting all individual intensity profile curves in one high degree polynomial curve using least squares method.

After finding the best curve that describes the nozzle inner diameter, the routine can calculate the circumference radius and its center coordinates (represented as the green cross in figure 4). This nozzle center is reference point to evaluate the cut front position displacement for different tests parameters. The nozzle center was checked for all tests to certify that the contrast parameters in the software were well adjusted resulting in the same nozzle center for all analysis. Mechanically, there was no change in the camera position in relation to the machine system.

From the best curve for each intensity profile during width and cut front position measurement, the criteria that was used to determine the geometrical point known as the edge between the region with material and without material was the determination of the minimum value of the polynomial derivate curve. This may not be the exact point in absolute terms, but it will be always the same point for all tests and can easily be used as reference to determinate the relative behavior of the width and the cut front position during all tested conditions.

As the laser beam is not perfectly centered in relation to the nozzle, the tests made in both sides for horizontal and vertical directions helped to determine the static laser beam incidence center. The cut front position can then be determined in relation to the laser beam center.

4. Results and Conclusion

Figure 7 shows the cut front position in μm for the tests made with the focus vertical position in zero (coincident with the sheet top surface) and showing the four directions of cut (horizontal, left to right and right to left and vertical, rear to front and front to rear) with different speeds.

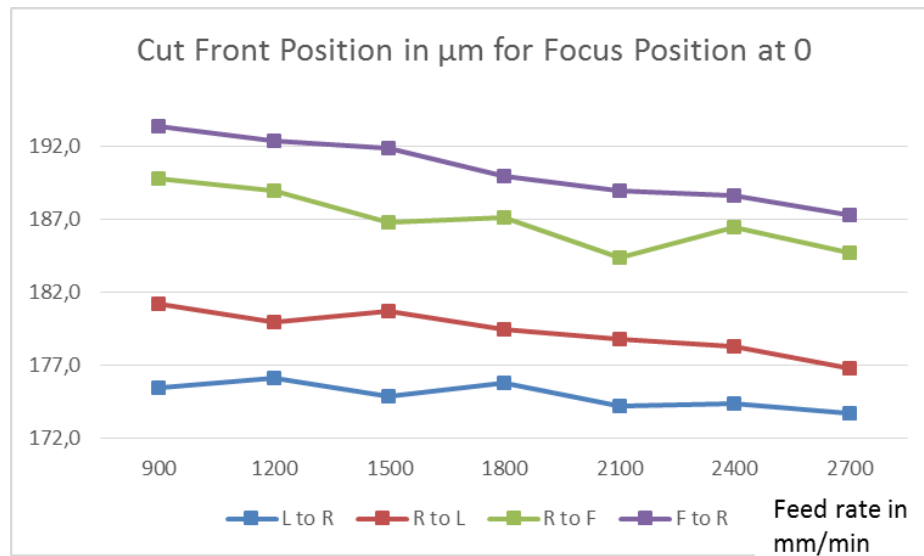


Figure 7. Cut front position for different feed rate.

The energy distribution of the laser is not uniform, which makes the cut front position different for different directions of cut. Also, the machine vibrations generated during the operation interferes significantly on the results. Despite this, it is clear that the cut front position changes with different feed rates and has potential to be used as monitored variable to adjust the feed rate during the machine operation to improve the process productivity.

5. References

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