Graduate School of Excellence
GSaME
advanced Manufacturing Engineering in Stuttgart

Doctoral thesis in Cluster C “Materials and Process Engineering”:

In-Prozess Qualitätssicherung für das Laserstrahlschneiden von Metallen

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Extended Abstract

In the last few decades laser material processing has evolved into a well-established and important manufacturing technology. Among processing technologies, laser cutting plays the most important role. The outstanding advantages of the laser cutting process compared to other thermal cutting technologies are the higher cutting feed rate, greater dimensional accuracy for both size and contour, smaller heat affected zones as well as higher flexibility in terms of contour and machinable materials. Continuous improvements of the laser beam source and system technology have resulted in a robust process. One of the main challenges in the future will be the increasing automation which will lead to more and more autonomous laser cutting machines with only little human supervision. Therefore, monitoring and control tasks will pass from the machine operator on to the machine itself. The main objective of this thesis is to develop a control system for a laser cutting machine, to diagnose the laser cutting process and to determine process attributes in order to distinguish quality cuts from failure cuts. The focus is placed on the “lost cut” and “self-burning” cutting defects during CO2-laser flame cutting of mild steel (S235) and fusion cutting of stainless steel (1.4301).

For that purpose, all relevant laser cutting process emissions were analyzed systematically and were correlated with the respective cutting status. Optical, electrical and fluid mechanical parameters served as possible information sources about the actual process status. As optical parameters, both the back reflected laser power (primary radiation) as well as the emitted thermal radiation (secondary radiation) in different spectral wavelength ranges and with and without additional illumination were analyzed. All optical parameters were measured coaxially to the laser beam axis in order to achieve direction independent results. In addition, an ohmmeter detected the occurrence of plasma between the metallic laser nozzle and the workpiece surface. Furthermore, measurements of the cutting gas pressure and flow rate during quality cuts and lost cuts of mild steel flame cutting were performed.

A fundamental spectroscopic investigation of the optical process emissions revealed that the thermal radiation (secondary radiation) of quality cuts could be described in good approximation by Planck’s law. Therefore, it was possible to calculate the cutting front temperature by using the method of quotient-pyrometry. As a result, the average cutting front temperature of quality cuts was found to be between the melting and evaporating temperature of the metal. Moreover, the temperature of mild steel (S235) flame cutting was about 300-500 K higher than during fusion cutting of stainless steel (1.4301). In addition, the average cutting front temperature decreased with increasing sheet thickness.

A spatial analysis of the laser power which is coaxially reflected back from the interaction zone of the laser beam with the workpiece showed that only 10% is reflected from the cutting front in the kerf. The main part (>90%) was reflected from the overlap zone of the laser beam with the workpiece surface outside the cutting kerf. Therefore, the signal strongly depended on the surface roughness of the treated material. It was shown that, as expected, reflective surfaces with little roughness showed higher CO2- laser reflections than surfaces with a higher level of roughness. Furthermore, the fraction of back reflected laser light increased with higher cutting feed rate which can be explained with a larger overlapping zone of the CO2-laser beam with the workpiece surface in front of the cutting kerf.

Results concerning lost cut of mild steel (S235)

During lost cut of mild steel flame cutting, the cutting front was inclined to such an extent that the lower end of the cutting front edge could not be detected anymore by means of the camera coaxially arranged to the laser beam axis. Slag drops, which in the case of a lost cut fly into the nozzle edge and serve as a clear indication for a lost cut, could be detected with the camera. With the photodiode, a significant increase in the variation of the optical secondary emissions could be detected in all studied thicknesses from 3 mm to 25 mm.

A detection of lost cut by measuring the oxygen gas pressure and flow rate was only possible when the distance between the workpiece surface and the cutting nozzle did not exceed one fourth of the nozzle diameter (nozzle blocking state). However, this special condition does not occur with the laser cutting nozzles and the respective nozzle distances currently used in practice. The feature is thus not relevant when using the current process parameters.

Results concerning lost cut of stainless steel (1.4301)

In the sensor-based detection of lost cut of stainless steel, the concentration was placed on the detection of plasma which typically occurs during this cutting defect. It was shown that the plasma formation can be reliably diagnosed using both optical camera and photodiode as well as electrically with ohmmeters. The high spectral radiance of the emitting plasma resulted in saturation of the optical detectors in all investigated wavelengths (□ = 658 nm/ 920 nm/ 960 nm/ 1600 nm). The large number of free charge carriers in the plasma also provides a significant reduction of the electrical resistance between the cutting nozzle and the workpiece by two to three orders of magnitude which could be measured by an ohmmeter.

Besides, measurements of the back reflected laser power revealed a significant increase of the signal oscillation which is due to the more inhomogeneous and more irregular surface during lost cut.

Results concerning self-burning of mild steel (S235)

Both camera and photodiode were capable of detecting the frequency of the grooves which are formed in the upper part of the cutting edges. It was found that a decreasing frequency of scoring correlated with an increasing self-burning tendency. If selfburning occurs, the emitted thermal radiation exhibited an increase in oscillation which was caused by irregular burning process and an increase of the emitting area. However, this mentioned attribute has to be regarded as a feature which also occurs during other cutting defects, such as lost cut of mild steel. Therefore, further attributes have to be taken into account to reliably detect self-burning: widening of the kerf sidewalls (the cutting kerfs are not aligned parallel anymore), increase of the radius of the cutting front, the cutting front edge leaves the spatial operating area of the laser beam and is positioned in front of the laser beam zone. All of these attributes could be reliably monitored by means of a camera.

The laser power meter detected a significant decrease in the back reflected signal due to the widening of the cutting kerfs during Self-Burning.

Conclusion

Overall, the use of a spatially resolved, optical measuring device (camera) provides the greatest potential in terms of assessing the current process status. An error detection of lost cut in stainless steel as well as of self-burning in mild steel could be achieved by using this sensor. An additional illumination improved the detection of geometrical features such as cutting kerf or workpiece edges on the upper surface.