Chapter 19
Modeling for Self-Optimization in Laser Cutting

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ABSTRACT

Laser based cutting processes comprise a significant part of industrial manufacturing. To ensure a high level of cutting quality the process parameters have to be kept at the right values and within defined tolerances. In this context, the position of the laser beam focus is one of the most important parameters. However, due to thermal heating of optical elements the focal position shows a transient behavior. The handling of this focus shift is aggravated by the fact that the focal position is not directly detectable during processing. In this chapter an introduction in the topic of laser cutting is given. Subsequently, a closed mathematical formulation of laser fusion cutting is presented before a reduced model is developed that allows the determination of a focus shift by an experimentally accessible surrogate criterion. The theoretical predictions are finally validated by experimental results.

INTRODUCTION

Laser based processes depict a significant part in today's industrial manufacturing. Caused by continuous enhancements of existing laser based processes as well as the new developments in the field of laser processing a future increase of the importance of laser based industrial manufacturing can already be foreseen. Currently laser cutting is the leading application in the field of laser processing from the processing of flat metal sheets for construction over cutting of pre-formed parts in white goods industry to trimming of hardened 3D-parts in automotive industry. All these variants require a reliable performance concerning the resulting product quality which is typically determined by the roughness of the cut faces – the ripples – and the occurrence of solidified melt adherent at the lower side of the work piece – the

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dross. However, several phenomena of the cutting process are yet not completely understood so that a satisfactory description of the correlation between the process adjustments and the resulting product quality is prevented. Thus, the common procedure to ensure the requested cut quality is to establish setting parameters for the cutting machine so that the requested quality is always reached and to collect the latter in so called technology tables. However, to find these setting parameters time consuming empirical experimental testing is required, where test series comprising several thousand experimental tests are not unusual. Furthermore, influences like unforeseeable changings of the machine status, typically caused by disturbances of the setting parameters, cannot be covered. These aspects show the necessity for further modeling of the cutting process. On the one hand a reliable description of the resulting quality in dependence of the setting parameters reduces the time-consuming and uneconomical experimental testing. On the other hand a comprehensive process model is the basis of the development of a process control in order to react on changes of the machine status during processing. In this context, the focal position of the laser beam, i.e. the position of the beam waist relative to the work piece, is one of the most critical setting parameters in a real world scenario. While the focal position is not directly detectable during processing caused by the inaccessibility of the process zone it has a major impact on the resulting cutting quality. In this context, a challenging problem is the occurrence of disturbances or degradations of the optical elements of the cutting machine and a subsequent shift of the focal position during processing. Thus, a focal shift during the cutting process leads to uncontrollable variations of the resulting cutting quality which cannot be compensated by conventional process control. The common approach to handle the focus shift is to cut a thin metal sheet with different adjustments for the focal position and to observe the resulting cut widths. As the energy distribution widens with increasing distance from the beam focus such a cut results in a sample with an increased kerf width. This so called comb-cut allows the correlation of the focal position to the resulting kerf width by manually testing with a gauge. However, the determined reference position based on the comb-cut approach only describes the condition of the machine at the moment when the comb-cut is being produced. Variations during the process cannot be covered so that the status of the machine is known only after each job by reproducing a further comb-cut. In this chapter a reduced process model for laser fusion cutting is presented which offers a possibility of tracking the focal position during processing. In detail, a surrogate criterion for the focal position is defined which is measurable during the process: The first molten point at the upper side of the work piece in feed direction – the melting point. Subsequent reduction of the underlying physical equations and comparison with experimental explorations lead to the result that the correlation between the melting point and the focal position can be described by a two-dimensional one-phase model, i.e. a model that only considers the solid state of the work piece (one-phase model) and neglects the heat conduction in the direction of the laser beam axis (two-dimensional).

BACKGROUND

In the field of laser processing, scientific research and development cover monitoring and quality assurance. Today the development of the technology of high-performance cutting machines, which is already well established, is moving towards a so-called autonomous machine which is tough to incorporate cognition of the underlying physical mechanisms. Related fundamental research activities are focused on the influence of fluctuations of parameters and the resulting dynamical behavior of the process as well

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