

An in-process quality control concept for laser chemical machining

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Abstract

This contribution reports on an in-process quality control concept for precise material removal on micro parts caused by laser-induced chemical reactions. This control concept consists of a state observer, a quality controller based on neural nets, real-time control loops for process parameters and an in-process measurement via interferometer.

1. Introduction

Based on a laser-induced thermal activation, the laser-chemical machining (LCM) combines advantages of both laser machining and electro-chemical machining (ECM) [1]. It realizes a localized material removal at low laser power in specified areas without causing micro-cracks and debris [2]. This method is suitable to produce micro forming tools with high strength and hardness. But, due to multifarious influences, the conventionally controlled LCM process shows a high scattering of the quality features. A quality control system can provide a reduced reject rate and enables flexible finishing of individual geometries.

2. Experimental setup

In the LCM process, the etching liquid, which is injected coaxially to the focussed laser beam, is guided to the surface of the workpiece. The workpiece is fixed in an etchant pool above an xyz-linear stage. During the finishing, the workpiece is positioned by the stage (Figure 1). For controlling the process parameters, a real-time control system was developed and implemented in Matlab/Simulink. This system contains a closed-loop laser power control via an AD-converter, a flow rate control

and three position as well as velocity controls for the linear stage in x -, y -, z -directions via a serial interface (RS232). In addition, the motor operated telescope for the focus diameter adjustment is open-loop controlled with digital voltage signals via RS232. All control loops are integrated into a graphical user interface (GUI) to operate the machine and to visualize the process. The GUI runs on a Host-PC in Matlab environment, and the control model for all process parameters is implemented on an industrial PC with a real-time operation system, named xPC (Figure 1). In this case, the settling times of the laser power and the workpiece feed rate are below one second and suitable to real-time variation during the processing [3]. The laser focus radius and the etchant flow rate can be varied after one removal process.

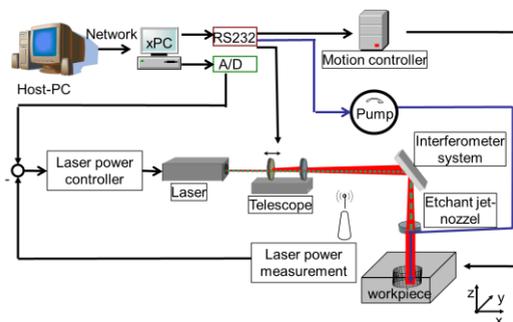


Figure 1: Experimental setup and automation concept of laser-chemical machining

3. Quality control concept

Due to the dynamics of laser energy absorption, heat accumulating, chemical reactions, hydrodynamics, and transport phenomena, various disturbances could be caused during the material removal by using LCM [4]. In order to produce a desired geometry already for the first product and to achieve a smooth removal surface, a quality control system is designed to compensate random deviations in the material removal (Figure 2).

The cross section of the removal path is approximated by a Gaussian curve with two quality variables of the cavity form [5]. The amplitude represents the removal depth a_1 and the standard deviation the removal width a_2 , respectively. The removal rate is resulting from four process parameters, feed rate of the workpiece v , laser power p , focus radius D of the laser and flow rate of the etchant Q .

A process prediction block calculates the required process parameters v_0, p_0, D_0, Q_0 to achieve the desired form variables $a_{1,0}$ and $a_{2,0}$. The process parameters are individually real-time controlled by conventional control methods (see section 2). The produced removal depth $a_{1,m}$ is planned to be observed during processing by using an interferometer [5], and a state observer estimates the removal width $a_{2,e}$, which cannot be measured in-process, according to the actual removal depth and the actual set values of the process parameters. The analysis of the post-process measurements by a 3D-laser scanning microscope shows that the removal width linearly depends on the depth in one path along the feed direction. The coefficients of this linear relation were determined by the process parameters.

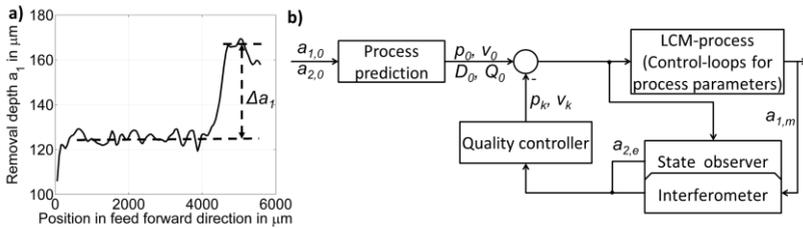


Figure 2: In-process quality control for laser-chemical machining: a) A random deviation of removal depth Δa_1 along the feed forward direction; b) The control concept with state observer and quality controller

A quality controller calculates the effective laser power p_k and workpiece feed rate v_k according to the produced geometry described by the measured depth $a_{1,m}$ and the estimated width $a_{2,e}$. The deviations of the laser power and the workpiece feed rate from the set values are used to adjust the finishing process.

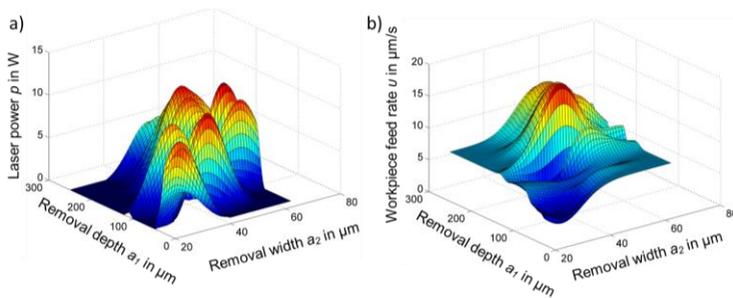


Figure 3: Inverse process model depending on the removal depth and width: a) Dependency of the laser power; b) Dependency of the workpiece feed rate

Because of the nonlinear relations among the process parameters and the quality features, conventional methods of controller design are not suitable to the LCM-process. According to the analysis, the causation among the real-time varied process parameters (p , v), and the resulted form variables (a_1 , a_2), a quality controller is designed by an inverse process model based on radial basis functions (RBF). The dependency of the laser power and the workpiece feed rate on both the removal depth and width are illustrated in Figure 3.

4. Summary

An in-process quality control concept with a state observer for a laser chemical machining was presented in this paper. By using a radial basis functions process model, a quality controller is designed to compensate the random removal deviations. Thereby, the form deviations can be reduced to achieve an efficient micro finishing. The implementation of the control concept with the in-process measurement is future development.

Acknowledgment

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