A quality control system for laser chemical finishing of micro forming tools

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Abstract

This contribution reports on a controlled material removal method caused by laser-induced chemical reactions at low laser powers for finishing micro forming tools. In order to realise a precise and stable machining, a quality control system based on three feedback levels is implemented. In this paper, the control system will be introduced on the example of finishing edge rounding.

1 Introductions

Machining of micro forming tools with high surface quality and shape fidelity is limited to a small number of applicable technologies due to the mechanical properties of the tool material on micro scale. In order to manufacture such micro tools, micro machining methods like micro milling and conventional laser ablation can be used. However, micro-cracks can result when using these techniques. Laser-induced Jet-Chemical Machining (LJCM) offers a suitable solution for the finishing of micro forming tools. It is based on a laser-induced thermal activation of heterogeneous chemical etching reactions between an ambient medium and a solid.

2 LJCM setup

The main components of the LJCM setup are fibre-laser, xyz-linear stage and a liquid-phase etching cell as shown in Figure 1. The continuous wave (cw) fibre-laser source is operating at a wavelength of 1080 nm at a maximum power of 300 W. The focus diameter of the Gaussian machining laser beam can be varied combining a Galilei telescope and a focusing lens system. The liquid-phase etching cell consists of two parts, a basin and a co-axial nozzle assembly. An adjustable pump enables flow rates of the etchant jet-stream between 2 and 20 m/s. The focused laser beam is guided coaxially to the etchant jet-stream through the nozzle onto the work piece surface. The work piece is fixed in the basin, which is mounted on the computer controlled xyz-linear stage allowing feed rate control of the work piece.

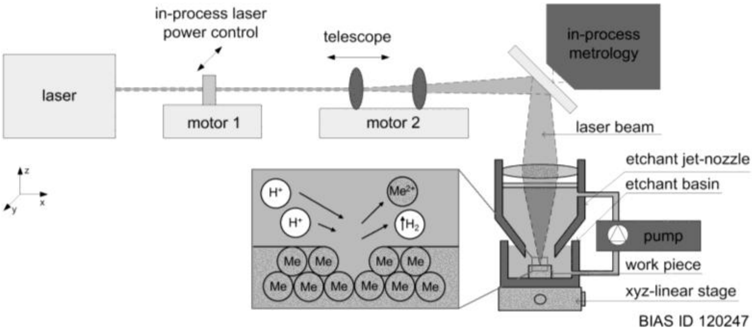

Figure1: Setup and functional scheme of Laser-induced Jet-Chemical Machining

Selective material removal is possible for all metals with a material specific passivation layer. The passivation layer is locally reduced under formation of hydrogen and water soluble metallic salts caused by the thermal influence of the laser beam [1]. In contrast to laser ablation, material removal can be already achieved at low laser powers [2]. Therefore, melting of work piece material is avoided which leads to high quality tools without burrs, debris and micro cracks. For precise material processing of e.g. micro rotary swaging tools [3], a quality control system is required.

3 Quality control concept

The quality control system optimises the process stability and the manufacturing accuracy of machined contour. The contour accuracy is affected by four main process variables: laser power, laser focus diameter, feed rate of the work piece and flow rate of the etchant. The desired contour of the work piece is achieved by a sequence of overlapping removal paths. Each removal path acts as a sub-process and its cross section can be considered as the quality features of the sub-process. According to the feedback levels, the quality control system can be evaluated on three levels, cross-process for the process chain, near-process and in-process for each sub-process [5]. The cross-process controller (the path planning) links the sub-processes (individual removal paths) and designs their positions as well as cross sections to achieve a smooth desired contour. The cross section of an individual removal path is oriented parallel to the edge of the work piece and can be approximated by a Gaussian curve with a position variable $\underline{x}$ and two form variables: removal depth a_1 and removal width a_2 (Figure 2a). The final contour of the work piece is the superposition of the appropriate single Gaussian cross sections. An optimal combination of several removal cross sections is calculated by minimising the deviation between desired contour and the superposition of individual removal paths. Figure 2b shows a path planning for edge rounding with three removal paths. By using more removal paths, the superposition could be better adapted to the desired contour. But, this results in increasing machining time. The deviations between the predicted and the measured machined profile are recorded and saved in a data base. The interaction of the individual removal path is analysed and fed back to the path planning algorithm as a correction factor.

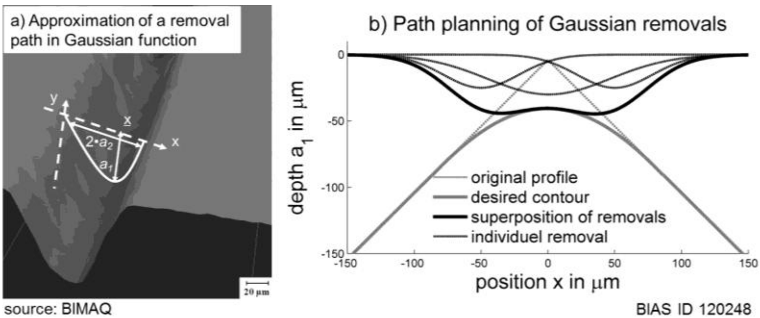

Figure 2: a) Approximation of a removal path in Gaussian function; b) Path planning of Gaussian removals [4]

On the near-process level, the four process variables are determined according to the required removal cross section including two form variables. Such a near-process controller can be realised by a forward process model and an iterative optimisation algorithm by using the simplex method [5]. The process model is based on analysis of cause-effect relations between inputs (the process variables) and the outputs (form variables of the removal cross section). Due to the complex physical relations, the LJCM process is modelled by an artificial neural network, which is presented in [6]. A data pool of measured removal paths from previous investigations is used for building the process model. To determinate the process variables an open loop control is implemented for the near-process level. The calculated process variables are led to the in-process control loop. They are individually observed and controlled. The classical control theory for the linear time-invariant system has been applied to adjust the process variables. For this purpose, a graphical user interface is designed in MATLAB to monitor the process in real-time and to operate the machine.

4 Summary

LJCM has been designed for a precise finishing of metallic work pieces in micro range. Both the automation and the quality inspection of this process require a quality control system in three levels. The cross-process controller predicts form accuracy of the work piece and assigns quality requirements for each sub-process. The near-process controller determines the process variables of the sub-process and the in-process control loop enables operating the machine with respect to the required process variables.

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