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A strategy for logistic quality control in micro bulk production

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Abstract

A continuous trend to function integration, miniaturization and densification opens new opportunities in industry and research. To manufacture micro products, tools, materials and technologies have to be scaled down from the macro to the micro domain. Thereby, a downscaling of classical processes leads to unexpected process behavior, so called size effects. Additionally, new challenges arise for in-process quality inspection based on the dimension of the micro products which requires microscopic solutions for reliable quality control. To handle these challenges in mass production, new strategies for the planning of logistic processes with a focus on logistic quality parameters are necessary. This contribution introduces a closed-loop quality control strategy for bulk production in micro cold forming. A discrete event simulation model incorporating characteristics of optical quality inspection and general process parameters allows the quantification of the system's performance.

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1. Introduction

During the last decade, the demand of micro components increased strongly. Thereby, single components became increasingly smaller while providing more functions and having more complex geometries [1]. As a consequence,

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manufacturing of micro components became a complex task, while economic requirements increased simultaneously. The driving force for the success of semiconductor based materials and micro-electro-mechanical systems (MEMS) has mainly been based on advances, which allow the production of mechanics-based systems using production systems based on electronics and semiconductors [2]. The development has further been pushed to metals and polymers, which are not based on semi-conductor materials. To manufacture metals and polymers in the micro domain, traditional manufacturing methods like forming have to be downscaled from the macro to the micro domain. Based on Hansen et al. [2] components based on metals are called micro mechanical systems and the term micro corresponds to objects smaller than 1mm in at least two geometrical dimensions [3].

One approach, to achieve high throughput rates at comparably low costs, is the application of cold forming techniques for the micro manufacturing of metallic micro components [4]. Different cold forming processes can be combined to achieve highly flexible manufacturing facilities with comparably low special requirements [5]. Such production systems face the challenge of producing vast amounts of high quality components while remaining cost efficient. Thereby, micro manufacturing is characterized by very low tolerances, the occurrence of so called size-effects [6] and a high degree of specialized manufacturing technologies.

As a result, the adjustment of a diversity of processes in micro manufacturing poses different challenges to the process designer. On the one hand, a careful selection and adjustment of available process technologies is required [7]. The suitability of certain process technologies strongly depends on the manufacturing context (e.g. materials, tools, preceding or succeeding processes). Due to the high specialization, it might even be possible that processes have to be adapted or developed for a certain task. On the other hand, as a result of inherently low tolerances in micro production, slight changes to a single process or material parameter can strongly impact the products quality and therefore the overall process chain. Consequently, suitable quality inspection techniques have to be developed and applied, in order to achieve robust and reliable manufacturing process chains. Based on quality inspection results, process control mechanisms are applied to optimize logistic quality criteria.

This paper introduces a strategy for logistic quality control in a micro bulk manufacturing process. Different metrologies with varying throughput and measurement uncertainty are applied in a simulation study to show their impact on the overall production time as well as on the number of scrap parts produced.

2. Quality Inspection in Micro Manufacturing

2.1. Micro-cold Forming and Size Effects

Micro cold forming processes provide a suitable approach to manufacture high quality micro components. Generally, such processes are characterized by high manufacturing accuracies and high throughput rates. Thereby, the work pieces usually become hardened during the cold forming processes, which results in more robust products. Compared to other manufacturing approaches, cold forming processes additionally lead to a reduction of waste materials and energy consumption [8].

Although in macro manufacturing cold forming processes are well known and widely used in mass production, they cannot be applied directly to micro manufacturing. The downscaling of those cold forming processes, and thus of the work pieces, tools and machines, is only possible to a certain degree. Thereafter, the impact of so called size effects impedes the further downscaling of the cold forming process [6].

Vollertsen defines size effects as “deviations from intensive or proportional extrapolated extensive values of a process which occur when scaling the geometrical dimensions” [6]. In this context he defines intensive values as parameters, which are not expected to change due to a change of an object’s mass (e.g. its temperature or its density). In contrast, extensive values are expected to vary with a different mass (e.g. the object’s inertia force or its heat content). Generally, size effects occur due to the inability to scale all relevant process parameters equally [6]. As an example, the downscaling of a metal sheet’s thickness can result in a changing density due to local defects, although the density is considered an intensive variable. In addition to these effects, technical limitations further facilitate the occurrence of size effects. For example, the downscaling of mechanical grippers is limited by technical factors. For very small work pieces, the gripper’s adhesive force will eventually overcome the gravitational force at a certain point. Consequently, the gripper will not be able to release the work piece without aid. Basically, Vollertsen defines three distinct categories of size effects (Fig. 1) [6]: