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On the tracking of individual workpieces in hot forging plants

Mathias Liewald(3)*, Celalettin Karadogan, Benjamin Lindemann, Nasser Jazdi, Michael Weyrich

University of Stuttgart, Germany

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ABSTRACT

Tracking each workpiece provides two major advantages in forging technology. First, the matching of physical workpiece with the monitored process information facilitates root-cause analysis for product quality. Second, the following process steps can be adapted according to the incoming workpiece properties to improve the robustness of hot forging process chain. The paper presents a general tracking methodology and tagging experiments on aluminium and steel forgings for harsh drop-forging technology. Furthermore, a framework for streaming and processing large amounts of real-time data as well as a multidimensional approach to model and analyse the workpiece information for individual and batch-tracking are presented.

Introduction

The real-time networking of technical systems over digitalisation of products and processes is the revolutionary step in Industry 4.0. The fusion of virtual and real world with real-time data opens the way for real-time optimization of complex value-added systems based on the processing of measurement data and the forecast of future developments [1]. Analysis of big-measurement-data allows the determination of anomalies, correlations, patterns and constitutes the base for machine learning and adaptive-robust systems.

Hot forging is one of the technologies having a great potential of improvements in the spirit of Industry 4.0 [2]. The product quality and process stability are evaluated usually after forming or even after the heat treatment, based on properties of randomly selected products. The state-of-the-art application is the isolated digitalisation of individual processes and disassociated digitalisation of finished products. As a result, the cause of the scatter in the product properties cannot be linked with the individual process variables and parameter fluctuations. Efficient data communication within a forging system can only be achieved by backtracking and linking online labelled measurements with physical workpiece, otherwise, correlations and patterns cannot be extracted. Furthermore, the reduction of the scrap rate by adaptive process parameters based on incoming material or part properties cannot be achieved.

Cannolly [3] has reviewed in 2005 the use of bar and matrix codes in assembly operations and for part tracking. Types of codes, marking methods and machine vision equipment are compared and the superiority of matrix code labelling is emphasized. Song et al. [4] developed a robust and accurate material tracking and locating solution for materials stored in large laydown yards. Proposed solution features barcoding and GPS-technologies for material tracking and fast retrieval in a cost effective manner. Dai et al. [5] investigated the tracking capability from the perspective of supply chain considering the tracking and recall costs in a supply chain with endogenous pricing. Denkena et al. [6] introduced a vibration assisted face milling technology enabling the machining of a matrix code or similar shapes into the component surface eliminating an additional marking step. Vedel-Smith and Lenau [7] developed a matrix code marking strategy for green sand castings where a flexible insert tool is used to emboss the mould itself before the melt is poured in. Montanini et al. [8] explored the possibilities of active infrared thermography in restoring covered and abraded marks obtained by laser, dot peen, impact, press and scribe marking on a steel surface. They reported on tested thermography techniques proved to be helpful in reducing local optical reflections and obtained enhanced readability with proper image processing of the raw images. The optical tracking of objects

* Corresponding author.
E-mail address: liewald@ifu.uni-stuttgart.de (M. Liewald).

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is an active research topic until now and can be applied too for tracking workpieces in the forging plants. Stolkin et al. [9] addressed the visual object tracking problem in extremely poor visibility conditions which could be transferred to forging environments. Akin et al. [10] introduced an effective DIC-based tracker with an improved deformable part-based model which tackles also scale changes in successive pictures. Kanagamalliga and Vasuki [11] recently showed how background subtraction and feature extraction could be used to improve the visual tracking. He et al. [12] introduced an approach for spatio-tracking of moving objects using multiple cameras simultaneously. When applicable these DIC-based tools can be used to track workpieces eliminating the necessity of physical tags.

The common application of part marking in forging companies today depends usually on the size of workpiece and the production rate. Large workpieces with small production numbers are tracked by using labels, needling or marking. Small workpieces being manufactured in high production volumes do allow batch tracking. The ability to sample accurate process data and to correctly assign them to corresponding workpieces is a major challenge regarding the heterogeneity of data sources concerning data formats, protocols and sampling rates. Hence, software modules are needed that uniformly transfers the collected data from the machine level to a factory-cloud level storage. Modules should have an individual interface for each data source and a standardized interface to further the recorded data. Fundamentals of this concept are paved by Faul et al. [13].

The aim of this paper is on the one hand to formalise the know-how necessary for the workpiece tracking in forging plants using the state-of-the-art hardware and software techniques. On the other hand, a deep focus is put on further investigation of physical tags and data driven modelling of traceability. A successful workpiece tracking system needs robust tags *and* components wired with tracking software running at both machine and factory-cloud level. In this context, at first a general workpiece tracking methodology is developed and supported with multidimensional modelling of data-driven-traceability built on PLC-based data acquisition and processing. This methodology can be used to build a tailor-made tracking system. Second, practical tags appropriate for forging environment are investigated thoroughly and laser-engraving of QR and DM-codes are performed onto the hot surface of forged aluminium and steel workpieces. Finally, an assistance system for a single/batch tracking is introduced.

Workpiece tracking methodology

A production line in a forging plant may consist of various processes depending on product itself and available infrastructure. This section introduces elements of a generalized methodology that can be tailored to a variety of production systems. Workpieces can be tracked on a batch level or individually. Harshness of the process, tag durability, process and tagging speed determines tracking intensity. A complete production line may contain processes such as casting, extrusion, sawing, turning, transfer, storage, heating, forging, blasting and heat treatment. Process information can be stored in the factory-cloud and can be associated to a specific workpiece by means of a master-identity. It is not necessary to store the complete master-identity on a tag fixed to the workpiece. Local or temporary identities can be assigned and reused at the machine level provided that the corresponding master-identities are distinct. In case economic and physical conditions desire for the next process relabelling can be performed. Tracking of a workpiece over a master-identity using various local-identities throughout the production line requires networking of the technical tracking systems in real time. Manual identification, transfer and registration of identities can be a part of this network. With such manual networking practise the tracking problem reduces to localized tracking of workpieces throughout individual processes.

Process formalisation

Process in a forging production line may be clustered into the following process categories (PC):

- (PC1) Tag endures throughout the process.
- Tag does not endure throughout the process and
  - (PC2) workpieces are processed in sequence
  - (PC3) batch processing is performed.

Processes belonging to PC1 do not damage the tag applied onto the workpiece, so the tag can be identified flawlessly after processing. Examples are storage, transfer or heat treatment. Workpieces qualified as scrap can be identified and registered easily. *Processes belonging to PC2* do damage the tag, but the sequential processing allows the tracking of the identity within and after processing according to the identity scanned before the process. Parts can be qualified as scrap during or right after the process. Especially scrap determined and separated during process has to be registered in real time, which can be automated or performed by manual triggering. State-of-the-art applications such as force measurements and part proximity sensors located at grippers can be used for recognition of missing parts. *Processes belonging to PC3* damage the tag, the individual identity of produced part is lost since many workpieces are processed together. In this case individual relabelling is not practical due to high production rate or constraints given by logistics. Such processes (e.g., heat-treatment, blast cleaning) consequently permit only batches to be tracked. Individual information of workpieces processed together can be merged in a “statistical representation” stored in the factory-cloud and only can be associated to batches.

Tagging time being longer than the process time in case of PC2 hinders the tracking of all the workpieces individually unless multiple tagging stations are employed. Valuable linked information on processes and workpieces however can be created for some of the workpieces with a single tagging station.

Batch tracking can be enriched by inline measurements to improve on-site the information content of the tracking. Henceforth tracking with additional individual information can be performed during the rest of the process chain. For example, the workpiece size, usually having a high scatter frequency, is an important issue for process control and for posterior big-data analysis on parameter dependency. On-site measurements can be extended with fast geometry measurements (such as shear face of a billet) or with eddy-current measurements, if applicable.

The operative tracking actions are tagging with the (part or batch) identity and tag scanning to recall the (part or batch) identity and the corresponding information in the factory-cloud. The computational tracking actions are locating the identity in the factory network, providing the required information from the factory-cloud to the process machine and storing the generated production information to the factory-cloud. Locating the identity in the factory network is either achieved by onsite tag scanning or “virtually” without the aid of a physical tag on the workpiece and can be named as a *virtual tag*. If a strict transfer protocol with sequential processing is implemented for a range of processes, a virtual location tracking can be performed using onsite busy/free location switches. These location switches can be realised either by part sensors or digital monitoring with image processing. In the absence of a strict transfer protocol, location switches have to be supported by motion tracking to perform the virtual tracking.