Optimal situationally adapted production systems based on an active state machine-process-model

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Abstract

The aim to adjust production systems to the current situation is a key incitement to develop Optimal situationally adapted production systems. They comprise additional sensory and adaptive coupled models of process and machine. The paper presents auspicious components, being developed in current research projects.

Keywords:

situationally adapted, production systems, tool integrated sensors, machine-process-model, digital twin

1. Introduction

In order to increase productivity and process stability for production systems as well as to reduce tool wear and rejects, one key enabler is to adjust production systems to the current situation, which comprises the prior status as well as the manufacturing task and environmental conditions. With the aim to act autonomously under changing conditions, an optimal situationally adapted production system can be realized utilizing additional interconnected sensors, actuators and model representations on the machine level. Process-following state images must comprise the interaction of machine and process. In addition, they must be close-to-reality and fast to compute. In the following sections, the paper presents data acquisition and modelling strategies for cutting and sheet metal forming processes to enable optimal situationally adapted production systems.

2. Cutting: Adaptive models for chatter prediction and tool integrated monitoring

The autonomous adjustment of technological parameters and a robust chatter prediction under changing process and environmental conditions should be a key feature of production systems of the future. This requires suitable model representations and a precise determination of current process parameters.

In order to predict chatter vibrations, stability criteria have to be applied to a coupled model of the cutting process and the machine tool. The accuracy of the predicted stability boundaries as well as the computation time is affected by the stability analysis algorithm, the complexity of the models and the model parameters. Uncertainties of model parameters may lead to significant differences between predicted and measured stability boundaries. Simulations with varying parameters are one possible approach to take these uncertainties into account. However, this is time consuming even when time efficient algorithms in frequency domain or discrete time domain, e.g. [1], [2] are applied. To increase simulation speed, a new method to provide confidence levels of stability boundaries has been developed [3].

This approach is based on stability analysis in the frequency domain. It avoids the time consuming explicit computation of directed open loop transfer functions of the process-machine-interaction. Instead, the transfer functions are approximated by a first order Taylor polynomial. The coefficients of this polynomial are determined by a discrete estimation in the neighborhood of a reference parameter set. To consider uncertainties, a normal distribution is assumed for each parameter, where the expected value represents the reference parameter for the Taylor series expansion. Possible applications of the approach are:

- Taking into account uncertainties, caused by errors in measurements and parameter identification and therewith enabling a robust chatter prediction in advance of a machining operation.
- Adjusting model parameters during machining operations after tool wear, thermal influences and other effects, replacing costly measures with necessary standstill of the machine.

For suitable results, the model should comprise a set of initial model parameters, provided by conducting measurements and additional process-following sensor signals to constantly adjust the model representation to the real process. However, today´s process monitoring systems in practical use are mostly indirect [4]. Data is not yet commonly acquired in direct proximity of the tool´s

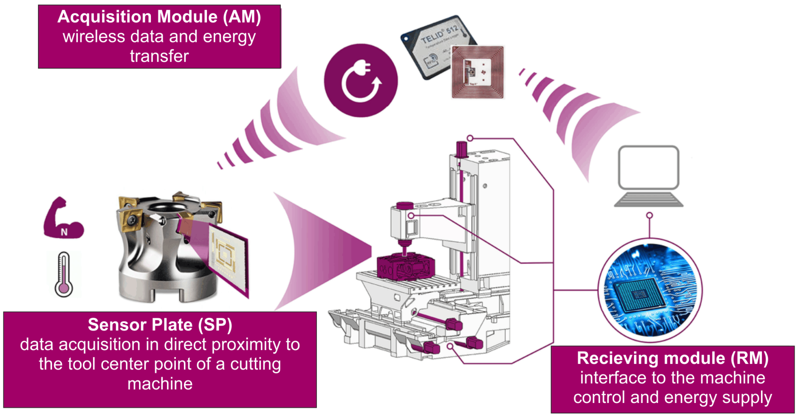

Figure 1: Working principle of the tool integrated monitoring

cutting edge. Hence, the necessity for re-calculation and measurement uncertainties occur.

A new approach, aims on enabling a tool integrated measurement principle. Piezo ceramic sensor layers are capable of high frequency force measurement and can be applied on surfaces with complex geometries. They offer a high potential for data acquisition in proximity of the tool center point. The presented approach, carried out in a collaborative research project “SensoTool”, is pursuing the objective of developing a cutting tool with integrated force and temperature measurement (Figure 1).

Therefore a sensor plate (SP) is added between tool holder and indexable insert and serves as substrate for the piezo ceramic sensor layer for temperature and force measurement. A data acquisition module (AM) is integrated into the tool carrier and transmits the measured data via near field communication to a receiving module (RM). Signal preprocessing (filtering, calculation of mean and maximum values) on the AM is necessary to achieve real-time conditions due to limited data transmission rates. Subsequently, the data is fed back to a machine-process model in order to provoke parameter adjustments through the machine control.

New sensory principles, the evaluation of controller/machine data and a constantly updated machine-process model can provide a full image of machine and process by means of a digital twin. Therefore, fast algorithms can be applied to identify parameter changes and re-assess chatter stability and technological parameters. The gathered data can be used to autonomously adapt machine parameters, e.g. feed rate and cutting speed. This offers the opportunity to constantly remain in a stable process window, reduce wear and maximize productivity.

3. Forming: Model-based cylinder force adaptation

Advanced forming process models have the potential to enable machine presses to automatically fine-tune die cushion forces in case of alternating coil properties. FE process simulations with coupled tool and machine properties allow the prediction of cylinder forces before the try-out on the machine press [5]. The presented models account for elastic bolster deformation as well as slide tilting. Additionally, they comprise efficient die cushion models which allow applying actual cylinder forces to the blankholder.

Incoming sheet coils typically show a fluctuation of their formability properties, affecting the part quality. Most of modern deep drawing presses possess multi-point die cushions which enable the user to locally adapt cylinder forces. In-line material tests allow simulations with the exact properties of the sheet material currently in the production line. The part quality can be assigned to the flange outline, assessed by visual measurement [6]. Figure 2 demonstrates the utilization of a simulation model by means of a digital twin. From coil A, the production press produces parts of suitable quality with the initial set of cylinder forces. The quality criterion is based upon comparing the actual flange outline with the desired one. When coil B comes into production, the digital twin is fed with new material properties and assesses the part quality

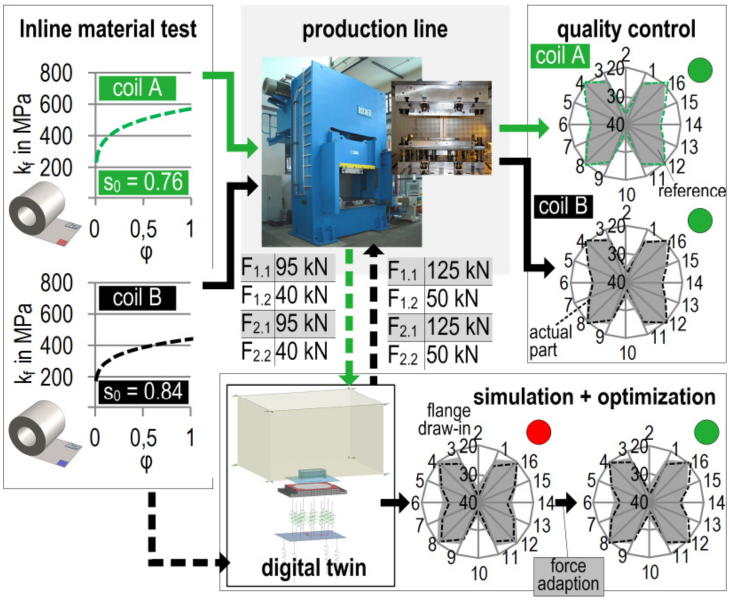

Figure 2: Press line adapts to changing material properties

based upon flange deviations. If poor quality is detected, the cylinder forces are adapted by linear programming using the flange deviation as the objective function to be minimized. Ultimately, the computed set of cylinder forces is transferred to the press control, assuring adequate part quality. Together with actuators, tests and quality control, the process model forms a cyber physical system which can act autonomously on material property alternations.

4. Summary

The shown examples present measures towards autonomously acting production systems. Key enablers for those are new, additional sensory principles as well as model representations, serving as digital twins. Well assembled, they have the ability to perform as Optimal situationally adapted production system.

5. Acknowledgments

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