Methods for Implementing Compensation Strategies in Micro Production Systems Supported by a Simulation Approach

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Abstract. Customers demands for highest product quality and lowest product costs and the use of rapidly changing technologies are the challenges for industrial companies. To cope with these challenges production processes need to be more effective. This also applies to the production of innovative micro products. However, the micro production has so far not adopted the advantages of established organization and quality strategies in production systems. Therefore, this article proposes three compensations methods which integrate quality strategies into a micro production system (MPS) with respect to the special needs of producing micro products. The aim is to balance quality errors against each other throughout the production process. This is illustrated by the example of micro assembly. This example uses a simulation approach to show the integration of the afore mentioned compensation methods in combination with a quality strategy. It allows a dynamic view of the effect of balancing errors during the whole production process.

Keywords: Quality Strategies, Compensation of Errors, Micro Production System (MPS), Simulation Approach

1 Introduction

Customers demand highest product quality while at the same time demanding a low product price. Therefore, industrial companies have to fulfill these demands in order to compete in the global competition. Innovative products with customer specific variants considering high quality and low prices are the future. Deciding on the design of a responsive and flexible production system and the implementation of an appropriate method mix is the right choice [18, 17]. In today's production of conventional products there are different approaches to design a production system that meets all the mentioned requirements. The possibilities arise from all aspects of a Lean-Production-System including Just-in-Time-, Kaizen- or Quality-Strategies [19, 15, 14, 11]. Best results could already be achieved, like mass production of high quality goods in companies as Toyota or Volkswagen show.

On the other hand there are industry branches that so far could not adopt such production systems. Especially today's micro production processes are mostly considered detached from each other and their environment. There are no interconnected production chains represented and considered, e.g. from the product design through manufacturing processes and logistics to a final quality control. No micro production systems are existing that include the aspects of a Lean-Production-System as described above. There are only attempts to organize technological interfaces or logistical aspects that allow a combination of different processes [2, 9, 4]. However, these do not allow a continuous assessment of the process capability of the production process nor do they offer the chance to increase the production performance over the whole production process. The potential effects of balancing quality errors across multiple processes and across their environment as it is possible in established production systems cannot be used. This raises the following questions: How can a lean MPS be organized and planned? How to model and simulate an according production chain? Which quality strategies can be integrated and are useful in a MPS?

Trying to answer some of these questions the following chapters describe a concept for organizing a micro specific production system. Experiences of completed projects support the development of this concept. Three methods are introduced to establish a quality strategy in a MPS.

2 Production System Design in the Micro World

The challenge of producing micro parts is on the one hand to become capable of the production processes and on the other hand to produce economically. High quality products from preceding processes, a detailed process know-how and capable production technologies are needed to produce micro parts [8, 7]. But also the design of the production system itself can have a high impact on its performance – in macro production as well as in micro production [3]. Production system design involves defining the problems, goals and outlining the alternative course of action by solving the problem to coping with the market pressure under constrained conditions. Many production companies organize the manufacturing facilities and processes according to a general framework and philosophy. The aim is to provide best quality at lowest cost and shortest time through the elimination of waste under involvement of all employees [14, 1].

The Toyota-Production-System (TPS) is the origin of today's integrated production systems in which the reduction of waste is the focus. This is also interesting for today's micro production. A key feature of this production system is the continuous improvement process, called Kaizen, which forms the basis for all methods and tools of the system [14, 15].

Lean-Production-Systems (LPS), as they are considered today, are derived from TPS. LPS constitutes a comprehensive regulatory framework for all finished processes in the company, where not only the direct production processes but also all support processes are taken into account. The most important production related goal of LPS is to work in both ways: customer-oriented and economically. The targets for the assessment of LPS considered are quality, time and cost [6].

One of the key elements of LPS is quality management. It is achieved through implementing an appropriate quality strategy into a specific production system. There are several quality strategies such as Economic Conformation Level (ECL), Zero Defect Production, Selective and Adaptive Production Systems (SAPS) and Total Quality Control. The goal of these quality strategies is to get a maximum rate of good products at a minimum of costs [5, 12].

The previous considerations are also interesting for the micro production [10] and should be considered and implemented in a *micro production system* (MPS). Figure 1 introduces a concept for such a MPS.

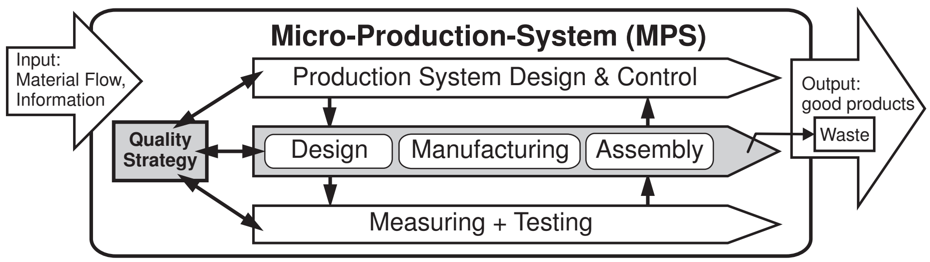

Fig. 1. Concept of a micro production system with integrated quality strategies.

The proposed MPS consists mainly of three parts: 1. The organizing and planning level that can be called *Production System Design and Control*. Here also the information flow is realised. 2. The level of the *actual production processes*, e.g. design of parts/products, manufacturing and assembly 3. *Helping processes*, such as measuring and testing, that help the organizing processes to control the production.

At all times, these parts are in interaction with a central quality strategy. The quality strategy has to be integrated into the MPS in such a way that it is able to cope with the special challenges of the micro world as discussed in [10]. For implementing one of the mentioned quality strategies, methods on a technological level will be discussed in the next chapter.

3 Methods for Implementing a Compensation Strategy into a Micro Production System

This article focuses on methods that compensate quality errors throughout the whole production system. These methods use the infrastructure of the MPS, as shown in fig. 1 and can be implemented at any stage of the production process. They propose a technological way to realise a SAPS quality strategy in a MPS.

This unlocks the potential to react accordingly to possible influences on component quality, geometries etc. which were detected during the entire process chain by taking appropriate measures.

The following describes the suggested compensation methods in general using these categories: *production control, pre-process control and process control*. Afterwards the description of an example shows their application in the production process. The example describes the implementation in the micro assembly. Figure 2 supports the description. The material and information flow symbolize the interaction of different production steps.

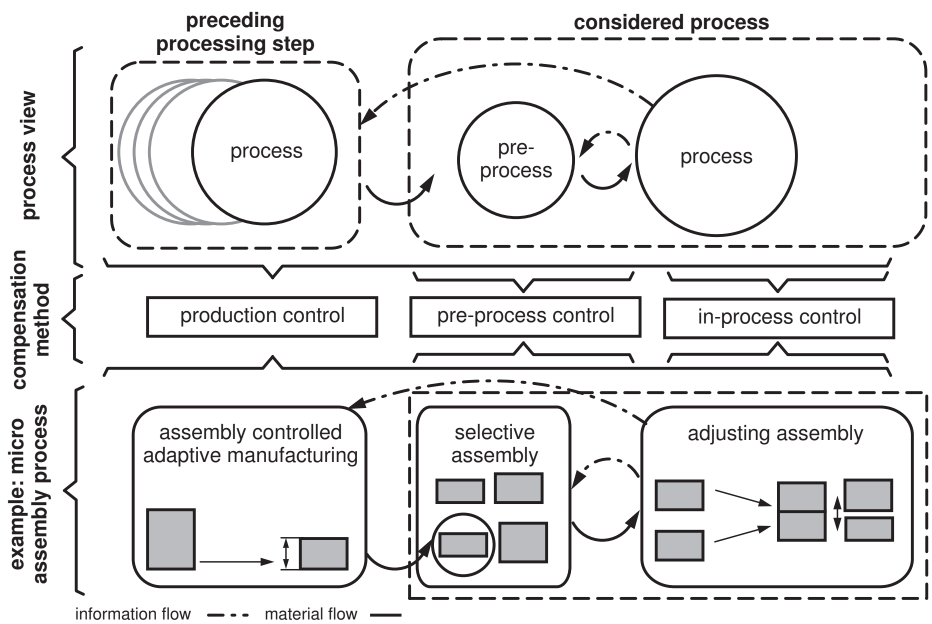

Fig. 2. Concept of different compensation methods in a MPS.

Production Control means a return of information on components from the observed process to preceding processes and allows an individual adjustment of the components that will be produced in the future. The main goal of this compensation method is to reduce stocks. The information exchange takes place across the process boundaries. Ideally all processes in the system communicate with each other and allow a mutual support. In the example of the assembly process a geometrical deviation of the first Part "A" can be determined before joining. Then, the information which geometrical dimensions for the second joining partner, Part "B", are needed, can be passed on to the (possibly better controlled) production step of the other part. This allows balancing the error already in the production of the second part. It is called an *assembly-controlled adaptive manufacturing*. Only a MPS provides the information flow that allows this way of a final assembly.

Pre-Process Control tackles the problem of occurring errors within the system boundary of the considered process step. The focus lies on balancing quality errors by reacting in the considered process step. Before the actual process step starts, a helping process adjusts the production parameters for the following step. A communication between the pre-process and the process itself is needed and can be established by the MPS. For example a *selective assembly* improves the quality rate of a production system in a cost effective manner. It is a method of measuring and sorting parts before they are assembled. The parts populations are partitioned into groups that have a certain distribution. Then they are purposefully selected: a Part "A" and a Part "B" so that they fit together and will produce an Assembly "C" that correlates with the requested quality. The number of groups, into which the parts are distributed, the tolerances of the components and the stock availability of the parts are some of the factors influencing the assembly [13].

Process Control can take place directly in the process under the consideration of further process information. No communication with other processes is necessary. The online adjustment of process parameters effects directly the outcome of the production step. Looking at the micro assembly it is called an *adjusting assembly*. For example: when assembling two parts with adhesives, variations of the thickness of the parts can be eliminated by a variable adhesive volume. An adjusting assembly is made possible by in-situ measurements such as In-Process-Laser-Scanning (IPLS) [16].

4 A Simulation Approach for Verification

The goal of the simulation approach is to evaluate the performance of a MPS dynamically by the variation of different parameters in the production process. It will offer the user the opportunity to evaluate alternative implementations of different compensation methods. In addition, many dynamic interdependencies between the various elements of the production system are considered. The used software tool to perform this simulation is *AnyLogic* by XJ Technologies. The following section describes the simulation model in general. It has to be configured for a specific case to get the corresponding results.

4.1 Description of the Model

The model consists of different layouts, which cover the different parts of the proposed MPS, see fig. 1. The manufacturing department, the production control and the main level that includes the transport system and the final assembly build the structure of the simulation model. These layouts consist inherently of production system elements such as manufacturing, measurement, storage and transport, material flow, control, etc. Each element consists of embedded objects like queues, delays, combine stations, etc. and activities such as parameters, dynamic variables, events and functions. Beyond that, these layouts are modeled with their logical and temporal interlinking to achieve the goal from the modelling. The embedded objects and activities are modeled so that their properties can be individually configured as input data.

Output data as criteria for the assessment of the effect and performance of the MPS are: The *Assembly Quality Rate* in % (AQR) that indicates the number of good assembled products or the failure rate. The *Combine Rate* in % (CR) that indicates the waiting time and work in process (WIP). The *Throughput Time* in sec. (TT) that indicates the required period of time for parts to pass through the production process.

By the systematic variation of input parameters, the change on the output data and the behaviour of the production system can be seen. Several input parameters are possible: *Dimension Target, Manufacturing Tolerance, Measurement Capability, Altered Dimension Target, Number of Classes, Tolerance Class Width, Classification Rules, Target Quality, Assembly Measurement Uncertainty and Assembly Range.* It is possible to derive an optimal set of design parameters depending on the considered production processes.

4.2 Simulation Results

Different production scenarios are used in order to evaluate the simulation model of the MPS. This specific case implements the SAPS quality strategy with two compensation methods (Production Control and pre-process Control). In each scenario the number of assembled components is 5000, the accepted assembly range is 18 μm and the measurement uncertainty is set to 3 μm. The classification of tolerances corresponds to user and customer demand and can be changed dynamically. A randomized production system is the reference production system. In this scenario there is no quality strategy nor a production control implemented. The diagrams in fig. 3 compare the reference scenario with a MPS that includes a selective assembly and another one with an assembly-controlled adaptive manufacturing. By the systematic variation of the manufacturing tolerance, following effects and findings can be derived:

Increasing the manufacturing tolerances decreases the AQR by an amount of 77 % in the case of a randomized production, see fig. 3.1. The AQR decreases gradually by only 25 % in the case of a selective assembly and an assembly-controlled adaptive manufacturing until a manufacturing tolerance of 25 μm and stays on this level. A decreasing AQR causes a low quality of assembled parts which means a big amount of waste. The results show that an implementation of both compensation methods is capable of avoiding the increase of waste by keeping the AQR high. The CR is in the case of the reference scenario always maximal because all produced parts are assembled without considering their quality, see fig. 3.2. This means no WIP exists because no extra time for measuring parts before assembly is necessary. In the other cases an effect on the CR can be seen. It is due to the fact that a high manufacturing tolerance causes a bigger amount of bad parts that cannot be combined. This effect is comparable in both scenarios and shows a reduction of the CR of 20 % in the worst case of a manufacturing tolerance of only 100 μm. The implementation of both compensation methods raises the WIP following the growth of the manufacturing tolerance. In the range of low manufacturing tolerances the adaptive manufacturing allows a 6 % lower WIP than selective assembly. The throughput time (TT) in the reference scenario is minimal compared to the MPS with compensation methods, see fig. 3.3. This is due to the fact that there are no stocks or extra processes of measuring in the reference scenario. When implementing the discussed methods, a negative impact on TT of the production system can be expected. However, the production times in micro production are very high, so that this negative impact is overwhelmed by the benefit of the described MPS.

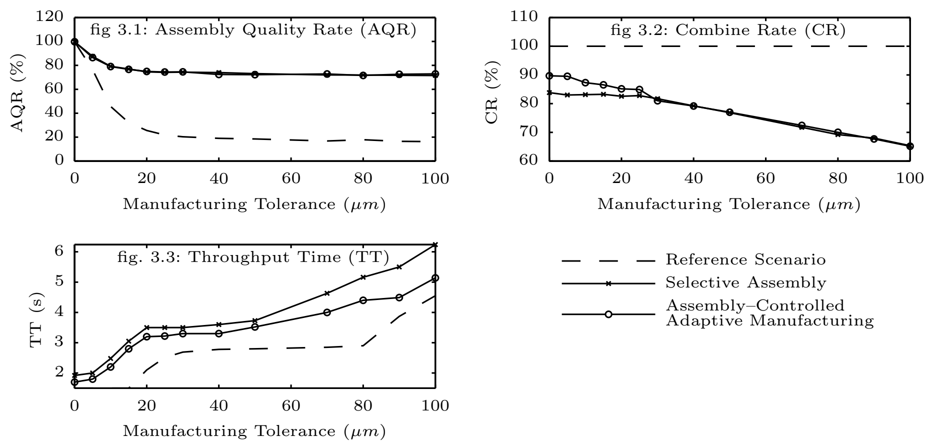

Fig. 3. Benchmark of a MPS with selective assembly and a MPS with assembly-controlled adaptive manufacturing compared to a reference scenario.

5 Conclusion

This article discusses Lean-Production-Systems and their impact on the production of conventional products. It points out that there is a need to use the benefits of these production systems also in the micro production. Therefore, a concept for a micro production system (MPS) is introduced. Furthermore, the implementation of a quality strategy with two different compensation methods on technological basis is analysed. Finally a benchmark of the proposed MPS is carried out by a simulation approach that is estimated for a specific case. In future work a further investigation on ways for organizing a MPS and the integration of other quality strategies will be carried out. The challenges of a lower number of items in micro production and the control of measurement processes still have to be solved. Process parameters, taken from the analysis of actual production processes, will support further simulation runs.

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