A Quality-Oriented Approach to Product-Driven Production

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Summary: This paper presents a novel manufacturing quality-oriented control strategy for a product-driven production. The product-driven production offers a high degree of flexibility for production, which is provided by the application of Gentelligent Components, which inherently store their fabrication data and can autonomously initiate and influence their production. Analogously to a car´s navigation system, the optimum route through production is validated by the production control system out of a quantity of alternatives, considering “traffic jams” like bottlenecks or disturbances in order to avoid production interruptions. By considering only the avoidance of interruptions, the manufacturing quality is an often underestimated aspect of production control. Therefore, this paper deals with a novel quality-oriented production control strategy for a product-driven production of Gentelligent Components. In order to ensure manufacturing quality, especially for highly dynamic low batch productions, the existing product-driven production control was advanced by a novel quality-oriented control strategy. This paper presents the product-driven process control and the autonomous selection of alternative routes as well as the novel quality-oriented production control.

Keywords: Adaptive Process Planning, Product-Driven Production, Autonomous Production Control, Gentelligent Components.

1. Introduction

Within the last years’ production planning and control research, decentralised and self-driven production systems have become a considerable factor. A significant progress in information and communication technologies enables a higher degree in cooperation and responsiveness [1]. For example, Gentelligent (GI) components provide a novel framework for responsive production systems. Gentelligent components are able to sense, process and communicate information, due to their intelligence and genetic properties [2]. This technology was developed within the Collaborative Research Centre 653 ‘Gentelligent Components in their Lifecycle - Utilisation of Inheritable Component Information in Production Engineering’ (CRC 653) at the Leibniz Universität Hannover. One goal of the CRC 653 is the realization of a product-driven production of Gentelligent components. In a first step, the “genetic blueprint” – displayed by the component´s process plan – is stored within the raw part inherently (Figure 1). During production, the component searches its optimal route through production autonomously, by communicating with the production system. After production, the manufacturing history is inherently stored on the component, providing this information over the whole component’s lifecycle.

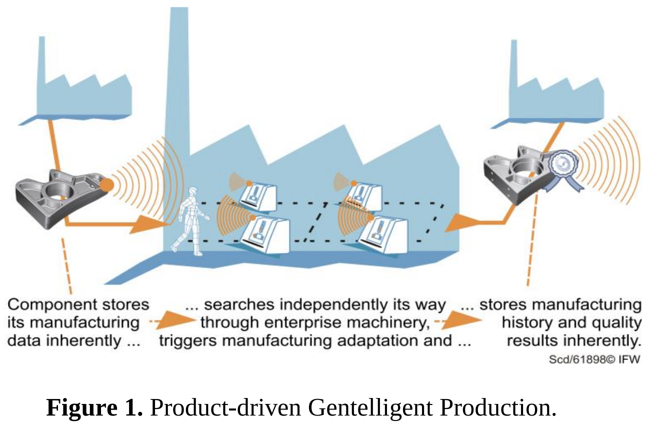

Figure 1. Product-driven Gentelligent Production.

Since there are several possible process plans for the component´s manufacturing, the role of the production control can be compared to a car´s navigation system. In case of production disturbances, the component is able to choose another process plan in order to continue production. Therefore, non-linear process plans are generated which will guide the Gentelligent component through the factory. They contain all possible routes through production so that the component can autonomously initiate its production and can adapt production plans in case of manufacturing interruptions [3]. Existing approaches are often merely aiming at the improvement of logistics performance [4], the implementation of agent-based systems [5] or the development of algorithms to reduce computing times [6]. In a fast moving and sensitive production environment flexibility is often more prioritized, than efficient quality management strategies. In order to provide a high degree of flexibility and an ensured manufacturing quality for production, existing reaction strategies have to be advanced, considering the influence of production interruptions on the product quality. Therefore, this contribution presents a quality-oriented approach to a product-driven production. The required control and planning strategies, enabling a product-driven production, are described in detail in the following chapters.

2. Adaptive Process Planning

The route of a part through its production is usually determined within the process planning. The process planning includes all planning activities before the start of production, aiming at a flexible and efficient production. These activities include determination of a raw part, selection of an appropriate manufacturing procedure, identification of the operation sequence, selection of machine tools, selection of tools and devices, and the calculation of the expected manufacturing times. To provide a basis for a high flexibility in production routes, the approach of Adaptive Process Planning has been developed at the Institute of Production Engineering and Machine Tools (IFW) [7]. The idea of Adaptive Process Planning is to increase the flexibility of job shop productions by creating and selecting alternative process plans.

In conventional process planning, all planning activities are carried out directly after the product design [8]. In case of disturbances before the start of production or during manufacturing, a replanning of remaining production steps is necessary. Thereto, production has to be interrupted and process plans have to be designed completely new (

Figure **2**, a). This means a high effort in time and costs caused by additional planning activities. Existing approaches for process planning are not satisfactory regarding flexibility and practicability in this field [7]. For that purpose, an integration of process planning and production control based on the management method of rolling horizons planning has been realised [9] (

Figure **2**, b). Therefore, rough planning for all feasible production alternatives is carried out automatically, directly after the receipt of an order. Contrary to conventional process planning strategies, detailed planning is divided into smaller terms which take place within production control.

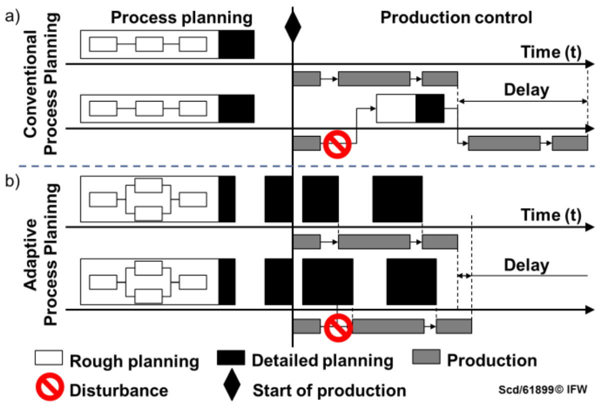

Figure 2. Sequence of Conventional (a) and of Adaptive Process Planning (b).

Gentelligent process planning in the preliminary rough planning phase enables the automatic creation and evaluation of non-linear process chains [10]. Thereto, possible sequences of given product features are listed considering technical and sequential dependencies. In the next step all feasible and economically reasonable combinations of resources (e.g. machine groups, tools, clamping devices) are allocated to the feature sequences. The result is a quantity of possible process chains to manufacture a component which are evaluated against manufacturing time and costs. From the product point of view, those process chains depict a variety of different routes through production.

3. Responsive production control

To ensure an efficient production of low-batch sizes in a turbulent production environment, the most efficient route through production has to be figured out for each individual component at response time. Therefore, alternative process chains have to be evaluated dynamically considering current data from production, logistics and quality control. This is arranged by an evaluation method based on real-time key performance indicators. These key figures (e.g. scrap rate, capacity utilisation) are aggregated for every alternative process chain. This multi-criteria evaluation reverts on current data which is generated in existing systems in the manufacturing environment like signal based process control, tool management systems or production data acquisition (PDA). With the help of the analytical hierarchy process (AHP) by Saaty a priority index can be calculated for every alternative process chain [11]. This serves as a decision support for the selection of the most efficient route through production. For a detailed description of the criteria see [7].

In real production environment sudden changes and disturbances lead to the necessity to adapt process chains and routes through production. In case of disturbances some process steps are no longer feasible or have to be modified, depending on the kind of disturbance. Therefore, current manufacturing data has to be interpreted to recognise different kinds of disturbances and to deduce activities in order to select an optimum route through production. This is realised by a rule-based classification system for manufacturing disturbances, proposing an appropriate alternative route through production out of the number of previously planned alternative process chains. Figure 3 shows an example of alternative process chains.

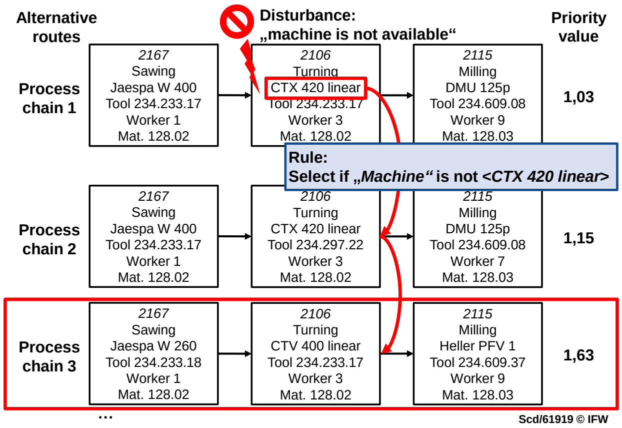

Figure 3. Rule-based reaction on disturbances.

As the priority process chain is no longer available due to a machine breakdown, an alternative process chain is chosen, avoiding the disturbed machine tool. But frequent changes of the process plan generate a considerable danger of quality faults. Thus, the manufacturing quality has to be considered by the reaction strategies, as a major evaluation parameter. The following chapter presents the advance production control for a quality-oriented production control.

4. Quality-oriented production control

In order to control manufacturing processes with regard to the resulting manufacturing quality, an in-process quality monitoring is necessary. Conventional process monitoring systems are able to identify a couple of process faults during the process [12]. Furthermore, advanced monitoring strategies are able to interpret and validate process faults against impacts on manufacturing quality of the machined workpiece. Therefore, a model-based quality monitoring system for the observation of surface accuracy in milling operations was developed, which is able to interpret cutting forces and process vibrations on quality impacts [13]. Thereby, occurring shape deviations of the workpiece can be observed during the manufacturing process and reactions can be performed in order to ensure manufacturing quality. In case of quality impacts, a detailed report can be communicated to the production control instance in order to adapt process plans and to ensure a high quality production. This novel methodology offers new possibilities for production, like a responsive quality-oriented production control.

A quality-oriented production control requires efficient reaction strategies, in order to ensure a high manufacturing quality. These reaction strategies are deduced from an experience database of manufacturing results obtained from the running production. This process knowledge is gathered automatically by linking practiced process parameters to resulting manufacturing qualities. This knowledge can be provided in parallel to the day-to-day business, by quality monitoring systems, with low effort. An example for the process knowledge database is given by observed surface roughness results over practiced cutting velocity (v_c = 40–220 m/min), as shown in Figure **4**.

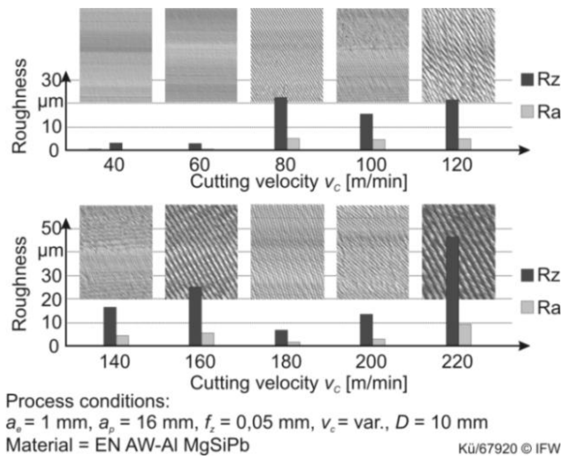

Figure 4. Extract from the process knowledge database for the systematic of cutting velocity on surface roughness.

It can be seen, that surface roughness mainly increases over cutting velocity, due to occurring process vibrations of the machine tool. Some local minima can be identified, which offer adequate roughness at high cutting velocity (e.g. v_c= 180m/min). Such technological process knowledge provides valid systematic relations from the manufacturing process, which are necessary to adapt the process parameters appropriately. The presented process experience (Figure **4**), e.g. can be used in case of occurring vibrations during the manufacturing process, in order to find appropriate process parameters, which will satisfy manufacturing time and quality demands in parallel.

In order to ensure the progress of production, even in case of quality problems, the adaption of process parameters based on the process knowledge database provides a flexible reaction. In case of a systematic quality damage, improved process parameters can be evaluated. Based on existing reaction strategies (c.f. Figure 3), an autonomous reaction can be provided by a closed loop process control strategy, which identifies quality problems and finds alternative process parameters based on the process knowledge database. Such closed loop reaction strategy for a quality-oriented production control, based on alternative manufacturing operations, is demonstrated in Figure 5.

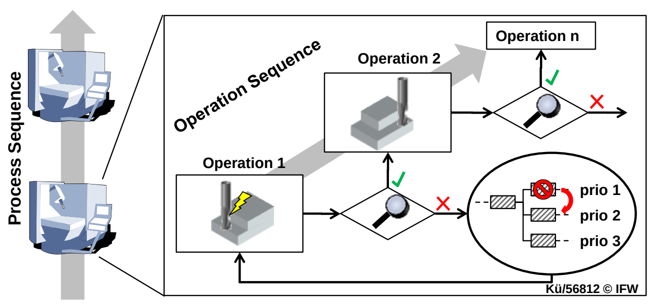

Figure 5. Procedure of quality-oriented production control.

The quality-oriented production control is able to identify manufacturing quality damage, based on the novel quality monitoring strategies. During the production, quality errors are identified and the process is adapted autonomously based on alternative manufacturing operations (c.f. Caption 3) or alternative process parameters (c.f. process knowledge database Figure 4). The decision process is based on gathered information about occurring process interruptions and their systematic reason. Thereby, manufacturing alternatives are prioritized dynamically, based on the analytical hierarchy process (AHP), concerning manufacturing time, costs and quality criteria. After the adaption of the manufacturing process, production can continue, till the next interruption occurs (c.f. Figure 5).

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