Gentelligent Production – A New Era of Production Technology

B. Denkena¹, A.T. Lenz¹, M. Krüger¹

¹ Institute of Production Engineering and Machine Tools (IFW), Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

Abstract
Process planning represents an important link between product design and product manufacturing. The quality and reliability of generated process plans, carried out in this early stage of production, affects the productivity of the whole production chain. The paper presents a novel concept for simulation based process planning for metal cutting processes supporting the planning quality and flexibility by using gentelligent technologies in terms of production. The ambition of the simulation based process planning is the verification of alternative process sequences using a technological manufacturing simulation, predicting technological quantities as well as geometrical quality indicators.

Keywords:
production engineering, detailed planning, ontology based planning, process simulation, geometrical quality simulation

1. Introduction

Visions in the production engineering are characterized by innovative concepts and technologies eliminating current deficits of today's production at the same time. They deliver new aspects and chances for the production of tomorrow. One aspect of the Collaborative Research Centre (CRC) 653 "Gentelligent Components in their Lifecycle" is the "simulation based planning and monitoring of manufacturing processes" which aims to improve flexibility of the process planning and to decrease complexity of planning. Especially for a job-shop manufacturing scenario, improved flexibility and planning quality is important for reaching a high workload and low fault liability. Another ambition is the integration of manufacturing information into the planning and monitoring of manufacturing processes. Nowadays information systems in production engineering are often based on personal communication or paper cards. The information chain is often only unidirectional from process planning to the manufacturing process. Results within process planning are often dependent on the individual experiences of the involved persons [1]. The absence of information feedback avoids a deeper process understanding of process interruptions in terms of process planning. An automatical generation of process information by an intelligent process monitoring system and its integration into a superior information cycle can improve the flexibility and efficiency of the whole production chain.

The concept of the gentelligent production represents a first step towards this vision. First work was done for a linkage between process planning and production control and further work enables a virtual ramp-up process in terms of process planning. In the following chapter, a brief overview about the vision of gentelligent productions and its applications is given.

2. Gentelligent Production

2.1 The idea of gentelligent production

The availability of manufacturing information stored or transmitted by gentelligent components, enables the integration of relevant manufacturing information into the planning and monitoring of manufacturing processes. Thereby, the integration of gentelligent technology into shopfloor environment enables new possibilities for tomorrow's production. Within the CRC 653 “Gentelligent Components in their Lifecycle”, a new concept in production engineering is pursued – the gentelligent production.

![Figure 1. Information flow of the gentelligent production](image-url)
2.2 The idea of Virtual Planner

In order to meet the production demands of gentile components, a reliable and stable manufacturing process has to be ensured for the production of the first component. For this purpose, the Virtual Planner was developed, enabling a technological validation of detailed process sequences in terms of process planning. Based on evaluated process chains from the Adaptive Process Planning (APP), detailed process plans have to be carried out. The detailed process planning instance requires a technological validation of process parameters to achieve an optimum between contrary process goals, like e.g. quality and execution time. Therefore, a range of applicable process parameters was proposed by a technological knowledge base. In order to validate the chosen manufacturing process, the process simulation is carried out under consideration of the adjusted process parameters. Thereby, a number of valid process parameters can be achieved, delivering alternative process parameters for a further validation in terms of APP. By this proceeding, the Virtual Planner aims to achieve a maximum of planning quality and flexibility for the production. Figure 2 shows the information flow inside the Virtual Planner.

3. Simulation based process planning

The application of simulation based process planning is presented in the subsequent chapters.

3.1 Adaptive Process Planning

APP enables a reactive process control, by using information returned from the shop floor. Since alternative processes are integrated into the rough planning already, the current manufacturing process can be modified quickly in case of interruptions of the manufacturing processes. Furthermore, purely hypothetic assumptions can be avoided by a decentralized detailed planning [3]. The invention of APP is a combination of different concepts for an integrated process planning and production control. The advantages of a conventional hierarchic, nonlinear and dynamic planning have been combined for the development of the novel planning concept. APP uses nonlinear process plans which result in a number of valid process parameters. Therefore, the generation of valid process parameters to achieve an optimum between contrary process goals, like e.g. quality and execution time.

The Virtual Planner aims to achieve a maximum in planning quality, ensure production quality and reduce failure costs. The application of APP evaluates alternative process chains by specific priority rules supporting the agility of production, but the validation of detailed process plans requires technological experience for the validation of detailed process plans. Therefore, the generation of detailed process sequences is supported by a technological knowledge base, including technological relations and restrictions related to geometrical features of the manufactured workpiece. Geometrical features are functional elements of a geometry, which can be fully characterized by their attributes [6, 7]. Features represent a natural link between the design and production planning.
phase [8]. The feature object is used in process planning for the representation of manufacturing relevant attributes of a feature, like dimensions, tolerances or specific quality demands. For the representation of the technological knowledge base an existing ontology for the ontology based rough planning was used, consisting of: geometrical features, material properties, manufacturing strategy, tools, machine tools and quality demands and quality results based on the feature [9].

The amount of stored information is oriented on the requirements and circumstances of the process planning inside the gentelligent production (Figure 1). A detailed process plan for a milling operation consists of sequential sub process steps like e.g. rough milling, finishing and deburring operations. Such objects are included into manufacturing process class including conducted information, like cutting velocities, feed rates, cooling lubricant and recommended milling tools or machining strategies. Additional information, like current workpiece geometries during the machining process, is achieved from the manufacturing information cycle and is available for the decentralized detailed planning of subsequent manufacturing operations. Remaining information from the executed manufacturing process delivers information of resulting workpiece quality, which was afterwards stored in the knowledge base. With increasing expertise of executed processes, a larger knowledge of verified manufacturing alternatives for APP can be achieved. The availability of such manufacturing experience knowledge supports the detailed planning by proposing an applicable process parameter range (compare Figure 2). Thereby, required planning times could be shortened and planning quality could be improved, using verified machining parameters from executed machining processes.

3.3 Simulation based validation of manufacturing processes

The detailed planning of manufacturing processes is supported by technological relations, provided by a virtual process simulation inside the Virtual Planner (Figure 2). The prediction of technological process quantities like cutting forces provides a key enabler for the calculation of systematic influences on the workpiece quality [10]. Such technological information feedback enables the validation of proposed process parameters and the adaption of operation sequences in terms of detailed process planning. In order to predict technological objectives for the validation of manufacturing processes, a process simulation was developed which predicts resulting process forces and workpiece geometries. The process simulation uses a semi-empirical process force model [11], which is based on the work of Altintas [12]. By means of the NC-code driven cutting path the workpiece geometry is intersected with the geometry of the workpiece in parameterizable discrete steps. Resulting from this calculation, the intersection geometry arises as discrete time distances from which the cutting force is deduced. To consider influences of force-induced deflections resulting in static form errors on the machined surface, the simulation includes mechanical resiliencies of tool and workpiece. Conducted experiments have shown that the amount of modelling effort depends on the complexity of the workpiece. Deflections of simple workpieces e.g. can be represented by a model for superposed stresses, which highly shortens computing time [13]. Anyway, to predict the deflection even in processing of complex workpieces, the finite element method is required to model the complex interaction of tool and workpiece. Depending on the amount of resiliencies, the amount of tool deviation is not neglectable, when using slim endmill geometries. For this case, the prediction of static form errors due to the force induced deviation of the endmill, delivers an important criterion for the validation of milling operations. The process force induced deviation of the endmill is calculated using an analytical beam model [14]. The model is based on bending theory, processing specific moments of inertia along the tool axis. The moments of inertia were calculated, using the cross-section of the endmill, which receives from an axial discretization of the endmill. A parametrical geometry model was created which generates the cross-section geometry of an endmill using three parameters, the nominal tool diameter, the number of cutting edges, and the percentile chipping space dimension. For the prediction of the static form error generated by the process-induced deviation of the endmill, a material removal model was developed, which calculates the resulting surface topography for helical milling operations. The resulting workpiece topography was generated by the deviation data along the tool movement. Figure 5 shows the resulting wall geometry from a helical milling process, with the given parameters. The model delivers the resulting wall geometry in vertical direction (on the right) as well as the prediction of the kinematic surface roughness resulting from the feed (on the bottom). The off-colour plot in the middle gives a qualitative overview of the shape deviation along the machined surface.

The information, generated by the process simulation delivers helpful criteria for the selection of process parameters in terms of detailed process planning. Therefore, quality related information is stored in the knowledge to support further validation processes. By means of the process simulation technological parameters like feed rates and engagement conditions can be verified against their influence on the workpiece quality, including geometrical quality demands, delivered by the workpiece's product data. Thereby, the decision between contrary process goals like time and quality in a virtual pilot production supports the process planning to achieve a maximum of efficiency for the upcoming manufacturing processes.
4. Summary

The approach of simulation based process planning, presented in this paper, includes manufacturing information from gentelligent components for the simulation based process planning. The itemization of conventional process plans provides a knowledge based configuration of feature based manufacturing operations in terms of detailed process planning. For this approach, a technological knowledge base was designed, which includes technological relations and restrictions of machining operations. The availability of process information along the gentelligent production chain provides the generation and storage of executed manufacturing data, which could be returned into the knowledge base, delivering manufacturing experience for an automated propose of applicable process parameter. Such proceeding provides a range of process parameter for the technological simulation of manufacturing operations. The simulation of the geometrical machining process predicts cutting forces and workpiece geometries, including geometrical shape deviations of the machined surface. Therefore, a material removal model was developed which includes the process force induced deflection of the endmill and resulting shape deviations on the workpiece geometry. The prediction of workpiece geometries and cutting forces deliver important objectives for the validation of detailed process plans. Thereby, the decision between contrary process goals like execution time and quality by means of a virtual pilot production supports the process planning to achieve a maximum of efficiency for the upcoming manufacturing processes.

Further work will be done for the monitoring of geometrical quality indicators out of the manufacturing process and the feed-back of this information, to get detailed manufacturing information in terms of detailed process planning.

Acknowledgments

The results presented in this paper were obtained within the Collaborative Research Center 653 "Gentelligent Components in their Lifecycle" subproject K2. The authors would like to thank the German Research Foundation (DFG) for its financial and organizational support.

References