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Sustainable process planning of manufacturing variants for high-precision parts

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Abstract

The fast industrial development causes progressive rising demands for energy and materials, which are in opposition to a shortage of basic materials. The consequence consists in rising costs for energy as well as materials, which leads to challenges in competitive capability especially for small and medium-sized enterprises. The technological comparison of variants within the process planning as innovative approach for the reduction of a company's resource demand as well as the design of the technological planning algorithms has to be extended with appropriate energetical evaluation methods. Modeling, screening and application of manufacturing variants are specified within the technological planning and might contribute to realize a required and necessary reduction of resources. The production of high-precision components for the aviation industry causes machining effort up to 97% of raw material. The resultant considerable resource demands ought to be reduced by the selection of the manufacturing variant and/ or a new consideration of used raw materials. Based on those experiences, a systematic approach for the sustainable process planning is evolved.

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Keywords: Sustainable Machining, Computer Aided Process Planning (CAPP), Algorithm, resource efficiency, high-precision components

1. Introduction

The reduction of process related usage of energy and material is an essential influencing factor for the structure of a company's overall costs [1]. Especially for manufacturing companies which produce high precision parts, this is substantial when considering the worldwide growing energy and material demand. Joint research of the authors with companies of the aviation and machine industry validate that, since the production of those components show a machining effort up to 97% and often include working with materials which are difficult to machine. Additionally, those parts cause a cost intensive sourcing of required raw materials, long machining periods of 1,5 hours or more as well as the usage of precision tools with internal cooling, energy intensive and high-performance tooling machines and appropriate auxiliary units like high pressure coolant pumps. The reduction of high energy and material usage per part leads to the positive effect of a sustainable reduction of carbon dioxide (CO_2) emissions and can be influenced by the work planning. Basic investigation in [2],[3],[4],[5],[6],[7],[8] clarify that the work planning can contribute to a sustainable and efficient manufacturing of high precision parts.

2. Resource-oriented technological comparison of variants

2.1. Basics

The term resource efficiency characterizes the efficient usage of company internal resources like energy, material, staff, machines, capital and so on with the main aim to create a sustainable handling with limited resources even beyond the company's boundaries. Within this article, the term resource refers to required energy as electric current and neccessary raw material. Additional information about the definition of energy and material efficiency in the manufacturing sector can be found in [3],[9],[10],[11],[12].

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2.2. Methodical resource-oriented technological comparison of variants

The technological planning, in a broader context also indicated as work planning, is the technology-oriented subtask of the work preparation. The work planning includes every singularly occuring planning measures which ensure the fabrication of a product (single parts, assemblies, etc.) suitable regarding manufacturing and resources under a continuous consideration of the economic efficiency. [13]

When implementing a specific, resource-oriented reconsideration of alternative manufacturing processes within the work planning, more sustainable sequences of production can already be specified during the planning phase with a minor cost expenditure. As a result, the reduction of material usage as well as material costs as well as the reduction of energy usage can be achieved. The differentiation of production variants is methodically roughly possible by means of alternative work plans (cf. Figure 1) as well as by variation, application and selection of separate working processes and by division of working processes.

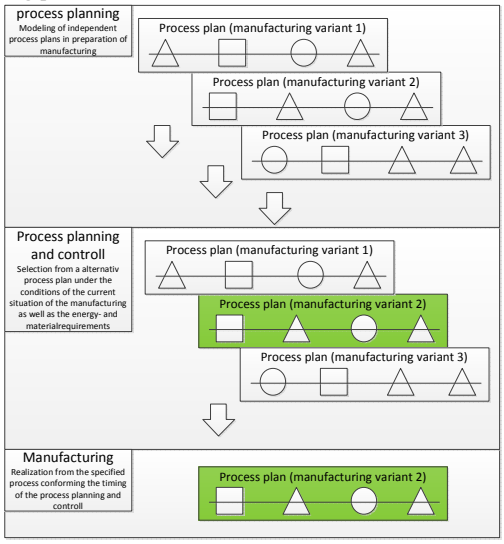

Fig. 1. General scheme of utilization from alternative process plans in the production process

The information which are essential for a resource-oriented selection of manufacturing variants have to be specified with energetical and material related parameters (e.g. type and dimension of the raw part as well as thereby defined resource usage in the primary material or the part-specific energy demand on a machine).

For this purpose, seven component-specific and eight machine-oriented categories with associated technological and resource relevant parameters in the context of a preliminary classification where defined.

Furthermore it was necessary to expand the previous target quantities of the technological planning (e.g. the construction adequate manufacturing or the development of the most cost-efficient manufacturing variant) and to include the target quantities for energy and material efficiency. The influence of the components or types of components on fundamental restrictions regarding listed main categories like material, quality or dimension of the component can be identified by means of the four steps for the creation of the work plan (part of the consequent development of manufacturing processes). Those steps are parent part determination, process sequence allocation, production resources selection and time allocation also consider interdependencies between the individual planning results which are assessable concerning costs, time, energy and material efficiency [14].

The planning algorithm which is shown in figure 3 represents the material oriented expansion of the first step of the work plan creation and is used for the specification of the raw material. Based upon this algorithm, the assessment of the energy which is contained in the waste material fraction is possible initially without considering the energy costs for the processing.

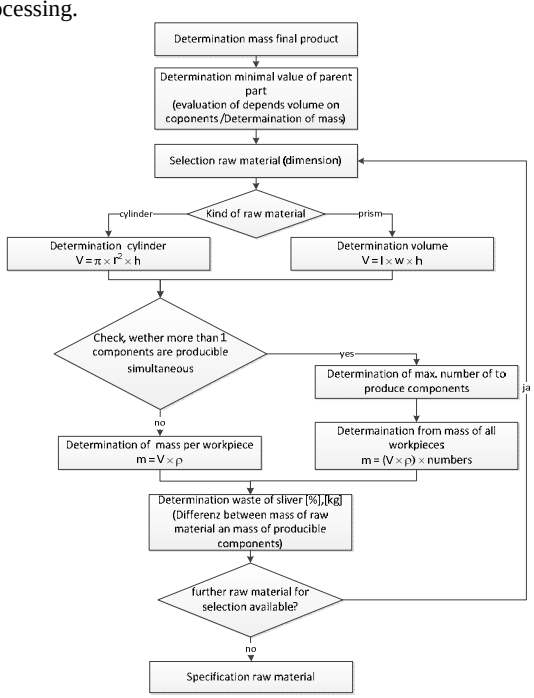

Fig. 3. algorithm of planning for ressource orientated appointment of a parent part

Alternatives in the raw parts require their own work plans due to major differences in the process sequence and processing characteristics. In this case, the network analysis would still allow a complete illustration of the variant.

The implementation of the shown planning algorithm is described in the following section. A calculation algorithm for the energy consumption of machining manufacturing processes was established, based on material specific cutting forces and the calculation of the main time. This algorithm has to be enlarged to include machine specific parameters and the energy consumtion planning for auxiliary process times, downtimes and distribution times.

2.3. Systematic approach for the sustainable process design

On basis of the systematic of the work planning and the