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Programming of adaptive repair process chains using repair features and function blocks

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Abstract

The current trends of product customization and repair of high value parts with individual defects demand automation and a high degree of flexibility of the involved manufacturing process chains. To determine the corresponding requirements this paper gives an overview of manufacturing process chains by distinguishing between horizontal and vertical process chains. The established way of modeling and programming processes with CAx systems and existing approaches is shown. Furthermore, the different types of possible adaptions of a manufacturing process chain are shown and considered as a cascaded control loop. Following this it is discussed which key requirements of repair process chains are unresolved by existing approaches. To overcome the deficits this paper introduces repair features which comprise the idea of geometric features and defines analytical auxiliary geometries based on the measurement input data. This meets challenges normally caused by working directly on reconstructed geometries in the form of triangulated surfaces which are prone to artifacts. Embedded into function blocks, this allows the use of traditional approaches for manufacturing process chains to be applied to adaptive repair process chains.

Keywords: CAx; Flexible process chain; Adaptive; Function blocks; Manufacturing; Turbomachinery; Repair

1. Introduction

Flexibility in manufacturing processes is becoming a key objective in today's economic environment with current trends like mass-customization and cyber-physical systems. These trends and the rise of novel near-net-shape production technologies lead to new requirements on manufacturing process chains. Introducing flexibility into manufacturing process chains results in higher complexity as production steps will typically depend on dynamic decisions based on influences such as measurement data or process parameters. Therefore, tools for complexity management will have to be put in place to support the user in modeling and executing process chains.

A prominent example are repair process chains in the maintenance, repair and overhaul sector in the aerospace and energy industries. Due to the use of expensive super alloys repair processes are a cost-efficient alternative to the production of new parts and are put in place whenever possible. The need for maintenance results from the superposition of the three factors mechanical and thermal load as well as erosion. Furthermore, individual damage patterns and deformations will occur at the rotating turbine components [1–3]. The repair process chains in use consist of several steps like milling, laser cladding or grinding. Each process has to be adapted individually to the repair case, the result defines the input for the next step. Complex dependencies are a consequence of this approach and have to be mastered.

In the past several companies have developed different strategies to satisfy the need for this kind of repair process chains. A common practice is to manually identify the damages and adjust the computer-aided design (CAD) accordingly. These adjustments may include (i) transformations to equalize a part distortion, (ii) adding of auxiliary geometries such as planes to allow planning of the computer-aided

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manufacturing (CAM). Another commonly used approach to implement an adaptive repair process chain is to develop custom-tailored software systems for each kind of part and type of damage.

Obviously, both approaches need a substantial amount of manual preparation and are thus far from optimal in terms of cost. To overcome this situation an approach is required which can capture the required repair process knowledge and is able to support automated execution of the repair processes. This results in new challenges for process planning and manufacturing. Today's CAx systems and approaches are not able to fulfill these demands. Therefore, this paper introduces *repair features* which can be used as a basis for planning and programming of repair process chains. Furthermore, this paper shows how the benefit of repair features can be leveraged by the use of function blocks to program adaptive repair process chains, as well as how they can be set up with function blocks.

Having introduced repair features this approach can combine the commonly used way of process planning and programming with the new requirements for handling of adaptive repair process chains. Furthermore, it has the potential to be easily adopted by the industry as the established way of programming manufacturing process chains through CAD/CAM can still be integrated into the presented approach.

2. Fundamentals and state of the art

Flexibility in manufacturing has long been a subject of research. In the last 90 years it has been treated from economic, organizational and technical viewpoints. Although it is not possible to make a clear-cut distinction between these concepts, this paper places emphasis on the technical aspect and focuses on the role of CAx software systems in this context.

2.1. Flexibility in manufacturing process chains

In an attempt to sum up previous works and to create a common terminology, Browne et al. [4] introduced a classification which defines eight types of manufacturing flexibility: (i) *Machine flexibility*, the ease of making the changes required to produce a given set of part types. (ii) *Process flexibility*, the ability to produce a given set of part types, each possibly using different materials, in several ways. (iii) *Product flexibility*, the ability to changeover to produce a new set of products very economically and quickly. (iv) *Routing flexibility*, the ability to handle breakdowns and to continue producing the given set of part types. (v) *Volume flexibility*, the ability to operate a flexible manufacturing system profitably at different production volumes. (vi) *Expansion flexibility*, the ability of expanding a system as needed in a modular way. (vii) *Operation flexibility*, the ability to interchange the ordering of several operations for each part type. (viii) *Production flexibility*, the universe of part types that the flexible manufacturing system can produce.

As Sethi [5] pointed out, CAx technologies in conjunction with CNC machining centers are a prerequisite for achieving any of these flexibilities but especially for machine, operation and product flexibility. Sethi rejected the idea of computer flexibility as an own category, arguing that computer technology underlies all the categories defined by Browne. With the advance of computer and communication technologies and their widespread distribution within the manufacturing industry branches, it has become increasingly clear that these technologies have a significant influence on manufacturing flexibility. The classification of Kusiak [6] takes this development into account and considered computer flexibility as an own category. In this paper methods to describe and model flexibility in the CAD/CAM domain along repair process chains are discussed. In order to do this a distinction between horizontal and vertical process chains is made [7], see Fig. 1.

A horizontal process chain is a series of manufacturing processes needed to produce a work piece. A typical horizontal process chain in the processing of formed sheet parts contains cutting, forming and joining [7]. Another example is the repair manufacturing process chain of worn turbine blades through additive laser cladding and re-contouring [8,2,9].

A vertical process chain describes, in contrast to horizontal one, the way from the idea to the product and contains other types of processes [7]. Typically, a series of steps is needed to plan and execute a single manufacturing process which involves personnel, machine tools, tools, fixtures. Often vertical process chains deal with geometric modeling (CAD), tool path planning (CAM), post processing and the manufacturing process itself (e.g. milling, grinding) [10].

Flexibility in the vertical process chain can take several forms which all have to be supported by the different software systems in use. The geometry of the workpiece might change, making every produced part unique (product flexibility). Examples are repair processes on parts which have acquired their current geometry through wear, parts being produced by a casting or forging process and thus have varying stock or unique tools and dies. The manufacturing process can be replaced by another technology, for example punching by laser cutting or milling by grinding (process flexibility). Process flexibility also means changes in process strategy which may be necessary after a change of workpiece material or the machine tool. Finally, the machine tool may be a subject to change, for example by changing the fixture, tool holder or axes setup (machine flexibility). Product flexibility will make demands on the CAD system, process flexibility on the CAM system and machine flexibility on the CAM system, post processor and CNC machine tool controller.

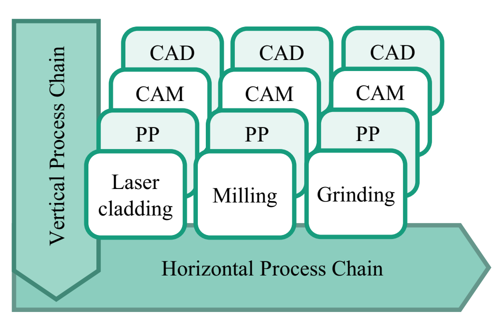

Fig. 1. Horizontal and vertical repair process chains.