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Model-driven Process Planning and Quality Assurance

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Abstract

Systematic process planning is a key enabler for robust product realization from design through manufacturing. Every process and operation must be designed in the best possible way to ensure that the overall process chain leads to the right product quality. During the last two decades a shift from inspection of manufactured products to a more holistic approach with quality assurance as an integrated activity throughout the product realization process has emerged in manufacturing industry. The importance of the principles addressed in the methods and tools used in automotive industry for quality management is indisputable. However, the tasks of creating and managing documents for Process Failure Mode and Effect Analysis (PFMEA), Control plans, Initial process studies and Measurement System Analysis (MSA) results in high workload. Also, lack of interoperability between different computer applications used in process planning and quality assurance results in information fragmentation, data duplication and potential data inconsistency. This paper proposes a novel, model driven approach for process planning integrating quality assurance which emphasizes the application of digital models to create, represent and use information of products, processes and resources. By reducing the amount of data and document duplication, the presented model driven approach has potential to radically increase the direct value adding part of manufacturing engineer's daily work also contributing to achieve a more holistic view in interdisciplinary work between different experts in product realization.

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Keywords: Computer Aided Process Planning (CAPP); Quality assurance; Model driven

1. Introduction

Systematic process planning is a key enabler for robust product realization from design through manufacturing. Quality does not only depend on downstream control activities. In manufacturing, every process and operation must be designed in the best possible way. Each step shall contribute and ensure that the overall process chain leads to the right product quality.

Toyota is known for applying a front-loading approach in work projects, i.e. they allocate the main work effort on careful planning in the early stages of product realization. Thereby they are able to address potential problems in advance, and to put in countermeasures before the problems even has occurred.

The same is true for skilled process planners who anticipate problems early in process plan design and put in place countermeasures to avoid that problems occur in manufacturing, thereby designing a robust manufacturing process.

Hence, a frontloaded approach applied in process planning can imply that early decisions made by skilled process planners set the manufacturing conditions for product quality, a pre-requisite to create customer value.

Careful process planning in an early phase is emphasized in the Advanced Product Quality Planning and Control Plan (APQP) reference manual. The importance of the principles in the APQP reference manual is indisputable. However, the tasks of creating and managing its required documents for Process Failure Mode and Effect Analysis (PFMEA), Control

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plans, Initial process studies and Measurement System Analysis (MSA) results in high workload.

A major shortcoming with today´s work methods for process planning and quality assurance is that the creation of APQP required documents is done separated from the process planning. As the documentation in many cases is done by process planner, their competence is used in an inefficient way. Instead of doing the documentation the focus should be on improving production contributing to create customer value. In that sense, today's quality assurance work methods fail to capitalize on the valuable approved information already created in process planning.

Besides the work effort of creating the required documentation, the lack of interoperability between different computer applications used in product realization results in information fragmentation, data duplication and risk of inconsistent data. Representation mismatch increase information ambiguity and causes interpretation difficulties (Fig. 1).

When today's engineers spend time on work caused by information fragmentation – valuable time is spent on non-value adding work. Therefore, currently available APQP tools and work methods must be improved. To increase overall efficiency, it´s very important to base the detailing work within product realization on already created and approved results.

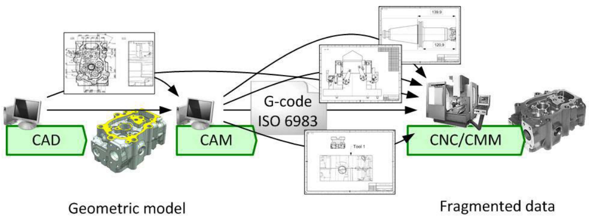

Fig.1. Today´s work methods results in data fragmentation, data duplication and risk for inconsistent data.

1.1. Research premises

This research is based on following fundamental premises:

- A process plan is a detailed manufacturing solution from the process design intent.
- Process planning is performed based on a process design rationale.
- Decisions made in process planning determine the conditions for manufacturing the right quality.

1.2. Process design and process design rationale

Price M. A. et al. defines design intent for a general system as: ''*The set of functions which the system was designed to deliver in the anticipated operating environment*'' [1]. In a process planning context this can be reformulated as: "*Process design intent is the expected manufacturing capability which the planned process was designed to deliver in the anticipated manufacturing environment*". Process planning is performed based on a process design rationale, i.e. a logical reasoning as a basis for a process planner in making decisions. A process design rationale can be formalized as an explicit listing of decisions made during process design and the reasoning behind the decisions, i.e. why those decisions were made. Ability to communicate process design intent in an efficient way is valuable in process plan analysis activities such as PFMEA.

2. State of the art

2.1. Process planning

Process planning is a central and important activity in the product realization process. Process planning is a key area for manufacturing which has been studied within the international academy for production engineering, CIRP since its formation in 1951. According to CIRP dictionary [2], Process Planning is defined as an activity which;

"*Includes all planning measures to be taken once to ensure the production of a part, an assembly or a final product at the lowest cost and best quality, which are mainly interpretation of the part design data, selection of the manufacturing processes and process optimization, determination of the routing plans as well as planning of the means of production and manpower assignment*.".

During process planning a myriad of decisions are made. Decisions which have different impact, determine the level of manufacturing robustness, i.e. the capability of the resulting process plan to enable efficient manufacturing of products.

Usually a process planner evaluates several alternative solutions. For the same manufacturing requirements there can be different process alternatives. In addition, there are interfaces to other important work within an organization interacting with process planning, e.g. product development, production equipment acquisition and factory design.

Altogether, this means that process planning is more or less iteratively performed, rather than being a straight forward process, and a holistic view is required to achieve the most appropriate manufacturing solution.

The iterations and the process design rationale is however "lost" in the final process plan and its representation as work instructions, NC-programs, Control plans, etc. These resulting artifacts of process design contain no hints of the process design rationale behind their creation.

Operation sequencing and setup planning can be considered as two important activities in process planning, and particularly operation sequencing has been a main topic for many years in CAPP research. For both activities, decisions can be motivated from a process design rationale.

In setup planning, manufacturing feature information and Product Manufacturing Information (PMI) including Geometric Dimensioning and Tolerance (GD&T) of a workpiece model, can be used to determine appropriate setup sequence and perform feature clustering for each setup. Process design rationale can for instance be described here in terms of loosely and strictly related tolerances [3, 4].

In operation sequencing, manufacturing interactions, as described by Faheem W. et al. [5] is a way of managing operation precedence constraints in a rational way. The authors divide the interactions in two categories, hard and soft constraints. While the latter are constraints which affect the quality, cost or efficiency of a plan, the former are constraints which affect plan feasibility. Here, manufacturing features, and manufacturing interaction, divided into hard and soft constraints, is a way of represent and communicate process design rationale.

Process design rationale can in a rudimentary way be partly expressed in different kinds of rules implemented in a CAM system, e.g. as in Siemens NX and their application called Machining Knowledge Library.

The Machining Knowledge Library contains operations rules to determine machining processes and machining process sequence for different features (Fig. 2). A hole feature might for instance, depending on design requirements, be machined in different ways, e.g. a sequence starting with spot drilling, followed by drilling and a final reaming.

There are also other CAM systems which have a similar approach to process planning automation, e.g. EdgeCAM, Esprit, Delcam and many more. However, regardless of CAM system the approach has limitations as rules, processes and feature parameters, object properties, etc., are all based on a particular CAM system´s own data model. Thus, the "machining knowledge" is not system neutral. The knowledge is instead system dependent and cannot easily be transferred to, or implemented in another CAM system.

```
REM Application Criteria
mwf.THREAD_TYPE = "Metric_Cut"
$$ Expecting Thread_Type = Metric_Cut

REM Cutter attributes
tool.CutterDiameter = mwf.DIAMETER_1
tool.Cutter_LENGTH_D1 > CEIL(mwf.THREAD_LENGTH)
tool.CutterPitch = mvf.PITCH
```

Fig. 2. Example of rule expressions in Siemens NX Machining Knowledge Library.

2.2. Quality assurance

The purpose with quality assurance is to ensure that processes and products comply with defined requirements. Quality assurance in production is as equally important for robust product realization as effective process planning.

Historically, quality assurance used to focus very much on inspection of manufactured products. The impact of Juran and Deming's ideas in Japanese industry made western companies change their view of quality assurance, from part inspection in manufacturing to process control and a more holistic approach of quality assurance as an integrated activity throughout the product realization process.

In automotive industry, methods and tools used for quality assurance have been harmonized in ISO/TS 16949:2009. To ensure that a manufacturing system is capable to consistently meet engineering design requirements and specifications, the Automotive Industry Action Group (AIAG) has defined the Production Part Approval Process (PPAP) as a standard required to be implemented in companies that are suppliers in automotive industry.

For this research, a literature study regarding publications in the field of quality planning and quality assurance, indicates that the majority of studied publications are either related to quality aspects from a supply chain and operations management perspective [6, 7], or application of Quality Function Deployment for quality planning during design stages [8], and in Total Quality Management [9].

In a CIRP keynote publication, Maropoulus P. G. and Ceglarek D. [10] reviews the definitions of verification and validation in the context of engineering design from preliminary design, to design in the digital domain and the physical verification and validation of products and processes. The keynote particularly emphasizes the important role that international standards such as ISO 10303 STEP plays in preserving design intent and seamlessly utilizing the associated information and manufacturing practices in a heterogeneous manufacturing environment.

Lindqvist R. presents in his licentiate thesis [11] a holistic work methodology for Geometrical Control and Inspection Planning, (GCIP), supporting APQP interdisciplinary work between different experts in product realization.

Available software applications to support process planning in performing PFMEA, MSA, and creating Control plans etc. can be categorized as PLM software as solutions from PTC, Dassault Systémes, Siemens PLM and ARAS, or CAQ software as from Q-DAS, Babtec, Boehme-weihs and IQS. In addition, a common solution is to build on desktop applications as MS Office (Word, Excel etc.).

Regardless of software category, they all share the same shortcoming, lack of effective integration between process planning and quality assurance.

2.3. ISO 10303 STEP in manufacturing

Increased usage of various kinds of software for process planning and virtual manufacturing in industry, and the need for being able to collaborate in supply chains, is a strong motivation for system neutral data representation.

The international standard, ISO 10303 STEP (STandard for the Exchange of Product data), is an important system neutral solution for industrial data representation. ISO 10303-214 (STEP AP214) is implemented in most major CAx systems for the data exchange of 3D geometry data.

Through the common information modeling language ISO 10303-11 EXPRESS, several other international standards in manufacturing engineering, e.g. ISO 13399 for cutting tool representation, ISO 13584 PLib, and ISO 10303-238 STEP-NC, are enabled to share the same implementation method as STEP AP214, facilitating a complete and seamless product data exchange cycle through the product realization process.

Recently developed ISO 10303-242 Managed model-based 3D engineering (STEP AP242) and ISO 10303-238 Application interpreted model for computerized numerical controllers (STEP-NC) with needed extensions for supporting quality assurance have the potential to be the main information representation for model driven process planning and quality control. However, further data schema development is required.

The 3rd edition of ISO 10303-21 enables new possibilities for partitioning a coherent data set in separate files [12].

3. Research approach

3.1. Research theses

- New and radically improved work methodologies can be realized through utilization of coherent digital models, enabling holistic process planning.
- Coherent digital models can be developed which carries the information generated in process planning through product realization.

3.2. Model driven process planning and quality assurance

Today, digital models are used to various degrees in manufacturing engineering to support synthesis, analysis and communication.

Model driven process planning is a methodology that emphasizes the application of digital models to create, represent and use information of products, processes and resources (Fig. 3).

The objective with model driven process planning is to support skilled process planners by using computer software for information utilization through modeling in communication, creation, visualization and interaction.

This type of approach requires effective information modeling, and information models capable to represent product, process and resource data, as well as process design rationale, which is particularly important with the human capabilities; intelligence, creativity and adaptability, combined with manufacturing experience make human expertise a vital asset of a company.

Product and process model based digital information will be a key asset in future product realization. The demand on management and exchange of digital information in product realization has steadily increased during the recent decades, and is expected to further increase.

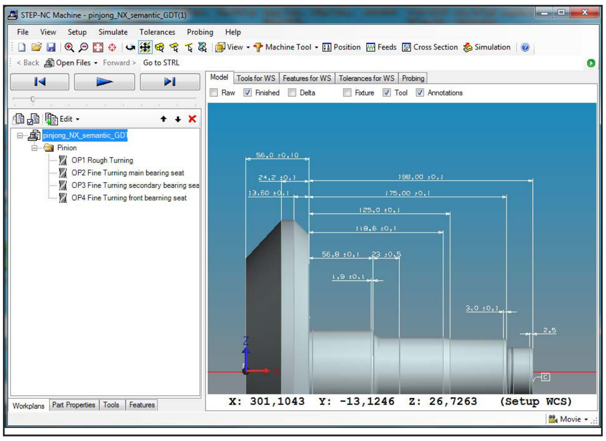

Fig. 3. A STEP model of a Pinion with presentation and representation of Geometric Dimensions and Tolerances (GD&T).

ISO 10303 STEP enables coherent models capable of integrating engineering concepts with elements of shape and motion, enabling new functionalities and more efficient support to production engineering processes, e.g. using CAD/CAM based machining simulation in order to be in control of geometric distortions after machining of forged components, as demonstrated in Swedish national research project FFI – Feature Based Operation Planning (Fig. 4) [13].

Coherent information is a cornerstone in model driven process planning where the resulting process plan is a digital and computer interpretable model defining what is to be machined and how to machine the product by representation of operations, operation sequence, machining features, initial stock, in-process parts, manufacturing resources, etc.

Providing the process planners with well designed software that conforms to above described principles of model driven process planning and efficiently supports process planners in their daily work enables them to spend more time on value adding activities instead of data re-entering.

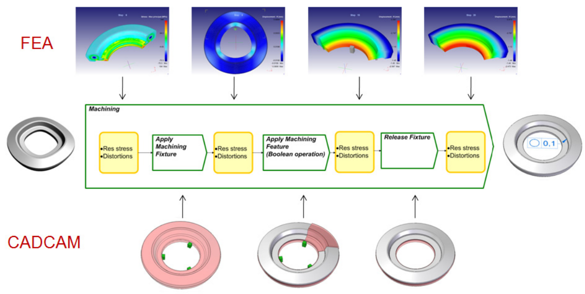

Fig. 4. Simulation of process chain for machining of a crown wheel.

3.3. Method

The presented research is based on several years of work with information modeling for process planning, performed in national Swedish research programs and in international collaboration within ISO TC184 SC4 WG3 T24 STEP-manufacturing. To analyze and define the user requirements, Process planning and quality assurance in Swedish manufacturing companies have been studied. Based on industry needs, test implementations demonstrating the possibility to relate quality assurance information to operations and in-process models (IPMs) have been developed, and validated by industry research partners.

3.4. Thesis verification

The feasibility of the novel, model driven approach for process planning integrating quality assurance presented in this paper have been validated through several demonstrations in national Swedish research projects during almost a decade.

Model based presentation of work instruction information for machining was demonstrated in March 12, 2008 at an open STEP-NC seminar during a ISO TC184 SC4 WG3 T24 STEP-Manufacturing meeting hosted by Scania in Södertälje, Sweden. For the demonstration a STEP-NC software was integrated in a Siemens Sinumerik 810D CNC controller for a Hardinge VMC 600II 3-axis machining center.

A STEP-NC process plan, for a simple workpiece with features representative for a typical powertrain component, was developed in MasterCAM X2. The toolpaths were translated to ISO 6984 G&M code, which then was used to execute the STEP-NC process plan in the machining center.

The integrated STEP-NC software was used to demonstrate a novel kind of man-machine interface capable of using the powerful STEP-NC information (Fig. 5). Based on studies of user need of information, three different tabs were implemented in the STEP-NC software, each one presenting a particular view of work instruction relevant information for the machine operator through the CNC-controller interface [14].

Based on the modeling approach for the digital factory developed by Kjellberg T. et al. [15], research contributions made in the area of manufacturing resource modeling supporting process planning has been presented by Hedlind M. et al. [16] and Li Y. et al. [17].

Results from national Swedish research projects [13, 18] on utilization of digital models integrating GD&T and engineering semantics has been presented by Hedlind M. et al. [14] and Li Y. et al. [19].

As a result of the research performed in above mentioned national research program, contributions in product- and manufacturing resource modeling were compiled into a large and internationally recognized demonstration, hosted by KTH – Production engineering, during the ISO/TC 184/SC 4 meeting in Stockholm in June 2012. The demonstration that covered machine tool kinematic modeling, kinematic error modeling, cutting tool data representation and software implementations based on STEP AP242, STEP-NC machining and other research contributions, definitely proved the capability of model driven process planning and the validity of so far achieved research results.

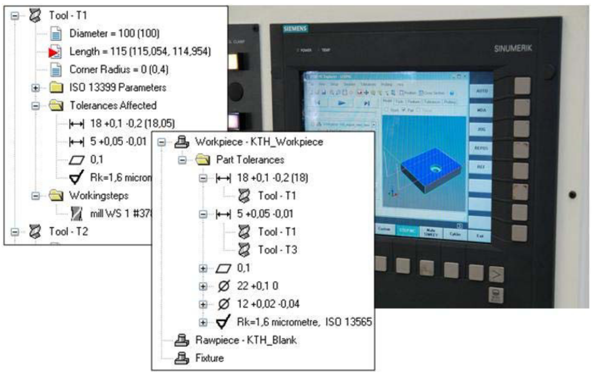

Fig. 5. STEP-NC implementation of work instruction views in Siemens Sinumerik 810 D CNC controller.

4. Results

The research results are; modeling principles, methods and tools for process planning integrated quality assurance.

The approach of model driven process planning and quality assurance requires data schema development. The schemas, based on ISO 10303 STEP and expressed in the EXPRESS language, will be extensions of current schemas for process plan information including quality aspects. This will make it possible to develop new software applications for process planning and quality assurance, conceptually illustrated in Fig. 6 with STEP-NC process plan integrated PFMEA.

Through coherent representation of process design rationale, as a part of the process plan, applications for holistic model driven process planning radically improves product realization. Industry partners in this research has estimated that elimination of the problems related to information fragmentation, through the application of a common information model in process planning, can reduce today´s non-value adding time on documentation with 50%, and potentially increase quality in production.

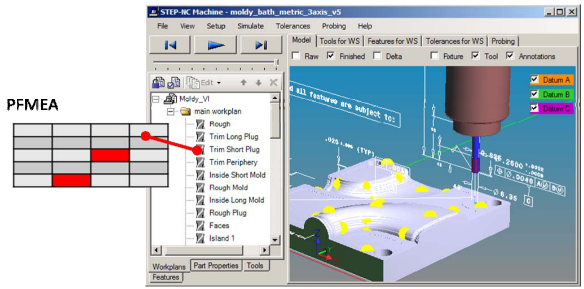

Fig. 6. STEP-NC process plan integrated PFMEA.

5. Conclusion

The novel approach of model driven process planning integrating quality assurance as presented in this paper is that a well performed model based process plan also will encompass and represent all its important quality aspects.

Ability to relate and communicate product requirements, manufacturing process and measurement information will result in higher control of the quality in manufacturing.

Coherent digital models can be developed which carries the information generated in process planning through product realization. Common implementation methods in STEP makes it possible to represent and exchange vital APQP elements, such as process plan, PFMEA, Control plan etc., in and between different STEP application protocols such as STEP AP214 and STEP-NC, facilitating a complete and seamless product data exchange cycle through the product realization process.

New and radically improved work methodologies can be realized through utilization of coherent digital models, enabling holistic process planning. New software applications that utilize consolidated models will contribute to increased transparence of achieved results in the product realization for all involved in the cooperation or in an extended enterprise type of business.

Replacing today´s documents in process planning with digital models representing process plan as well as quality related information, the amount of data and document duplication in product realization is considerable reduced – enabling process planners to allocate more work on creating and improving process plans, and to use new process planning functionalities.

In competence and technology dissemination the presented model driven approach has potential to radically increase our ability to learn and develop competence in production engineering. Model driven implementations of process plan integrating PFMEA and Control plan demonstrating new functionality in a user oriented way, is a good way to pedagogically convey the possibilities and the importance of this new technology for future competitiveness, contributing to levering future productivity in an efficient way.

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