Using ISO 10303-224 for 3D Visualization of Manufacturing Features

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Abstract. Globalization leads to increasing competition for companies. Next to this, customer seek for individual products, leading to a boost in costs for product development. We try to tackle both aspects in our current research. We are trying to develop a solution for the automatic extraction of routings from a three-dimensional product description. This leads to two advantages. First, costs for product development are decreasing because labour intensive planning will be eliminated. Second, the time between customer inquiry and offer can be reduced, which is an additional advantage to get ahead of competition. To develop such a solution, different aspects have to be considered. This paper deals with the product representation, which should allow us to automatically assign process steps to design-elements.

Feature-based design is a very promising concept for optimizing the entire product development by enhancing the product model with significant information. An approach for its implementation is the ISO-standard 10303 "Standard for the Exchange of Product model data". ISO-10303 provides a formal reference model for a consistent, standardized and complete product description which is fundamentally required for automated process planning.

This paper summarizes the reasons for choosing the formally specified feature objects of the ISO-10303 application protocol 224 for 3D-visualization and how we implemented the concept "geometry from feature". Therefore we have developed a modular "viewer-concept" for connecting suitable geometric modeling cores like ACIS with our AP 224 feature library which will be presented in the paper. Additionally, a short overview of automated process planning will be given.

Keywords: Feature-based design, 3D visualization, ISO 10303, Product model data exchange, STEP.

1 Introduction

International companies have to face extreme pressure caused by globalization. Accompanied by this, customers seek individual solutions to a competitive price. To obtain potential orders, corporations have to react fast and exact to customer inquiries [1]. However, innovative and individual customer demands

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require cost- and time-intensive feasibility analysis and cost estimates in the preliminary stages of the product lifecycle, especially in the design and process development phase. To stay competitive in the future, a completely automated solution is required, which links design and calculation. This is already possible for similar orders, which were already executed and are well documented in an ERP- or PLM-System like SAP or PARTSolutions.

An efficient product development is prevented by heterogeneous system landscapes, their different kinds of data exchange formats and incomplete product models. Additionally we have recognized that *product data management* is extremely difficult to handle, because *product lifecycle management* is frequently confused with implementing product data management as an ordinary IT-system.

To solve this problem, it is fundamental to exchange a complete product model that includes functional, geometrical and technological aspects of the product. In fact, the digital product model is primarily created by using CAD-systems. These systems are not able to represent extended product model data. For example, complete high level objects for the description of forms, dimensions, materials, tolerances or development rules and associations between them cannot be provided. From our point of view, these are crucial prerequisites for automated process planning which leads to automated cost estimation derived from the product model. Incomplete product models require manual extraction and integration of necessary parameters during the later stages of product development which can be a very error-prone process.

Feature-based modeling is an approach for enhancing the virtual product model with extended and context-depended product data. This enables direct information exchange between particular stages of the product lifecycle. The ISO-standard 10303 focuses on the exchange between different application systems and software implementations within different stages of the product life cycle. Today's market-dominating CAD-systems are supporting feature-based design, but are only able to use geometric form-features. These low-level objects are neither standardized nor do the systems support a neutral product data exchange of those feature objects. Therefore the data exchange and the transformation of different product data models between different application systems are tremendous hampered and in many cases impossible. However, both aspects are mandatory for an efficient and automated interpretation of the digital product model.

The ISO-standard 10303 is titled "Standard for the Exchange of Product model data". This standard provides a solution for creating a complete, consistent, standardized and platform-independent product definition across the entire product lifecycle. The scope of STEP lies on an unambiguous digital data exchange format. It consists of different application protocols (AP's) to cover a wide range of application areas like shipbuilding industry, electrical engineering or the automobile industry. Surprisingly, there is a lack of implementation of STEP in existing CAD-Systems. CATIA for example only supports the storage of AP 203 and 214 Files. Next to this, the exported files only include a boundary representation of the designed product.

This paper focuses on AP 224 of the ISO-standard 10303 with the title "Mechanical product definition for process planning using machining features". It orientates on milling and turning operations and is a building block for automated information exchange between process planning and manufacturing. Each manufacturing feature can be associated with a corresponding manufacturing process. Using this AP as the basis of a CAD-system, the designer is able to develop a part corresponding to its manufacturing. The designer has to describe a minimum required volume as a base shape. Afterwards he applies volumes that should be removed or shapes that result from machining operations.

During our researches we have realized that there is a surprising lack of implementations of the specialized context-depended application protocol 224. That is why we have implemented manufacturing features of AP 224 as an object-oriented application programming interface within a C++ feature-library. A modular viewer-concept connects this feature-library with the geometric ACIS 3D modeling core and can be used for the stepwise simulation of manufacturing processes and design. This results in the visualization of the part-model with corresponding three-dimensional objects based on the AP 224 manufacturing features. This model can be used to simulate the manufacturing of the part stepwise. Therefore we derive significant geometric parameters from feature instances and construct the corresponding geometry by destructive solid geometry. This process is also called "geometry from feature" [2].

2 Geometric Product Models

Retrieving required product information the right time and at the correct place is essential for the success and efficiency of each product lifecycle stage. Digital product models like two-dimensional technical drawings or three-dimensional CAD-models represent the product shape informative and geometric exact. These methods of information exchange and representation also replace expensive physical prototypes or design studies [3]. Furthermore, virtual product models are combined with modern simulation technologies like digital fabrics or virtual reality. This way, production and assembly faults can be recognized and avoided in the forefront. Digital product models increase the efficiency of the product lifecycle significantly [4].

Geometric product shape information is very important in most stages of the product lifecycle, especially for product design, process planning and manufacturing. This was the reason why CAD-systems were invented for modeling, detailing, visualizing and analyzing digital product models [3]. The data structures of CAD-models primarily consist of geometric primitives like points, lines, faces and solids. Especially the export to neutral data exchange formats like STEP is limited to pure boundary representation. This is not satisfying our preconditions of detailed high level objects.

In fact, incompatible data exchange formats of different computer-aided systems (CAx-systems) complicate the information flow and create delays. Every type of a CAx-system supports a corresponding stage of the product lifecycle [5].

E.g., product design is supported by CAD-systems (computer aided design), process planning by CAPP-systems (computer-aided process planning) and manufacturing by CAM-systems (computer-aided manufacturing). Accordingly, most developed product lifecycle environments possess a heterogenious system landscape with different requirements and digital product data representations.

The product data exchange and model transformations are not standardized and cause information losses or disastrous misinterpretations. In worst case's, the collaboration can also be hampered within one stage of the product lifecycle. An example is the usage of different software versions of one vendor which can lead to incompatibility.

Digital product models represent the product shape with geometric information and the model topology. Extended product information like design intentions, functional requirements or controlling and resource management information are not represented. They must be documented additionally.

Figure 1 illustrates a further problem for adapting models that is caused by the model topology and the used CAD-system. There are non-parametric and parametric CAD-systems. In a non-parametric CAD-system, every new geometric element is a single instance. Parametric CAD-system refer to the entire CAD-model. Assume that diameter D of the entire groove in figure 1 has to be reduced to $D' < D$. In a non-parametric CAD-model, every geometric element has to be changed. The parametric CAD-model can solve this problem but allows no change of a single geometric element. This is only possible by destructing the entire model [6].

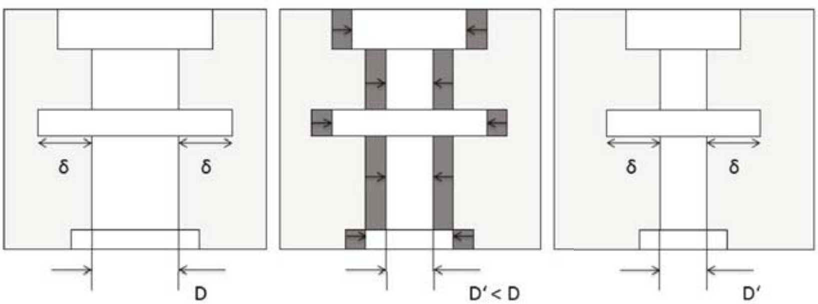

Fig. 1. CAD-model adaptation [6]

3 Feature-Based Modeling

An easier model adaptation and also product data exchange can be achieved with *feature-based modeling*. This approach enhances the digital product model with functional, geometric and technological product descriptions. Additionally, products can be designed faster because the designer only has to depose significant parameters instead of constructing difficult geometric product aspects like threads or gears. The concept of feature-based design is also used in the ISO-standard 10303 [7], especially in the application protocol 224 with a destructive design approach [8]. This application protocol offers a mechanical product definition and a standardized data exchange structure for process planning by using machining features. *Features* are an opportunity for creating interpretable product models, consisting of high-level objects.

3.1 Definition and Classification of Features

A *feature* defines physical and geometrical aspects of a part or assembly and contains context-depended information like shape, dimensions, material attributes, production time or tolerances. Additionally, a feature is an obvious entity with semantic significance in one or more engineering points of view. In conclusion Shah and Mantyla defined a feature as following [2]:

"A feature is a physical part of a building component or an assembly. It can be represented in a general way and owns engineering specific and predictable attributes. Each feature is an identifiable entity in a *feature model* and has some explicit representations."

The different engineering points of view require several specialized *feature-types* such as design-, manufacturing-, deburring- or inspection-features. In our work we focused on *manufacturing features*. The reason for this is the need for representation of important design- and manufacturing-information for process planning in high-level objects. Each manufacturing feature can be associated with a real milling or turning operation and with manufacturing operations in the resulting process plan.

3.2 Creating Features

There are two different concepts for the creation of features: *feature-based design* (FBD) and *feature-recognition* (FR). Both techniques are counterparts to each other. Feature-based design initializes feature-objects to derive the geometry. Feature-recognition requires geometric primitives to derive corresponding feature-objects, which are afterwards enriched by additional information. In general, feature-based design is also known as *geometry from feature* (GFF) while feature-recognition refers to *feature from geometry* (FFG) [2]. Figure 2 illustrates the contrary methods.

In both concepts the feature model is in relationship with the geometric model. The feature model is a functional and technical description of the building component or assembly. Derived from (or generated by) the design approach, the geometric model represents the corresponding geometry. Geometrical information can be used to visualize the building component or assembly as a two-dimensional graphic or a three-dimensional solid. We preferred the feature-based design approach cause of easier implementation and independence of proprietary data formats. In addition, feature recognition requires enrichment of derived objects which is an additional step.

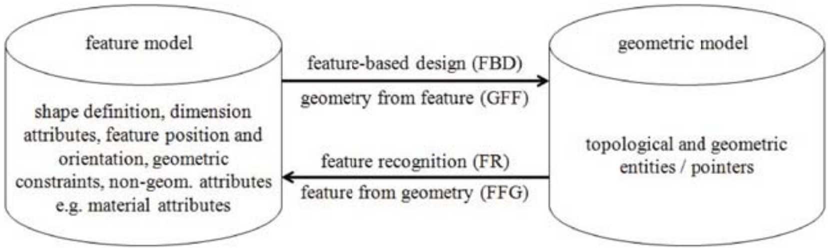

Fig. 2. Relationship between features and geometry [2]

3.3 Feature-Based Design

Feature-based design describes the part or assembly by initializing high-level feature-objects. The resulting semantics, associated parameters and relationships include information about form, position, dimension and geometric constraints. Feature-attributes can be used for derivation of the entire topology and geometry of the part and its visualization. Feature-based design can be divided into two different approaches for creating a feature: *destruction by machining-features* and *synthesis by design-features* [6], [9].

Destruction by machining-features orientates on destructive machining operations like turning, milling, drilling, planing and thread cutting. The part model of a building component or assembly is created by subtracting volume from its initial stock. This way the attributes of the subtracted volumes correspond to features.

Synthesis by design-features doesn't require an initial base shape volume. The building component or assembly can be built by adding and subtracting features. Each feature implies semantics about corresponding manufacturing operations like joining, welding and soldering or the operations named above.

Deriving the geometric model from the feature model requires a *feature library* for interpreting the feature-attributes like feature-position, -dimension or -orientation [2]. In our approach the destruction by machining-feature approach is used. The focus lies on feature descriptions of the application reference model in application protocol 224.

4 ISO-Standard 10303

The ISO-standard 10303 (mostly informally called STEP - "Standard for the Exchange of Product model data") pursues the superior goal to offer a mechanism for describing complete, obvious and platform-independent product definitions within the entire product lifecycle and the reuse or extension of existing product model data within each stage. The title of this standard implies that the data exchange is in the center of attention. This is not the only intention of the standard. It supports a continuous standardized product data representation and therefore also contributes computer integrated manufacturing. STEP connects the heterogenous computer aided systems by creating consistent data exchange standards for efficient and economical product development. As mentioned before, implementations are poor or missing in existing systems.

4.1 Architecture

STEP is an international standard for the product data exchange and was founded by worldwide experts under the patronage of the *International Organization for Standardization* (ISO). It includes a series of sub-standards. They are divided into several *application protocols* (AP's) which are listed for example in [10] and published separately.

Each application protocol is a standardized reference model for a specific application domain like machining industry, shipbuilding, electrical engineering or automobile industry. Different description-, implementation- and testing methods can be used for accessing common resources and creating a complex product data structure (see figure 3).

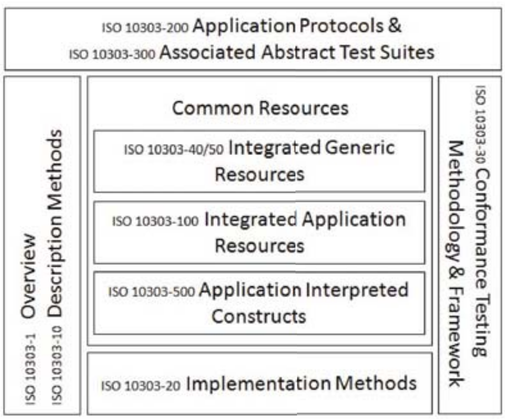

Fig. 3. STEP-Architecture [11]

Every application protocol includes three description models for its documentation and implementation. The *application activity model* considers the user's point of view by describing the scope of the AP with a special kind of activity diagrams (defined in IDEF-0 notation). Second, the *application reference model* presents possible objects (in AP 224 for example features) from an engineer's point of view by defining application specific product data. Third, there is an *application interpreted model* which supports the mapping of context-depend information in a neutral data exchange structure for the exchange between different application systems.

4.2 Application Protocol 224

Application protocol 224 (AP 224) supports feature-based design by using manufacturing features for the digital representation of product model data. It was standardized in 1999 [8], almost 30 years after the feature concept was invented. Recently, the 3rd edition was published by the ISO. AP 224 orientates on destructive machining operations and is suited for a feature-based design approach *"destruction by machining features"*.

Therefore it supports the application of manufacturing features and the digital representation of product data. AP 224 consists of thirteen different *units of functionality* and includes 262 object definitions for managing geometrical information, product- and production data.

Overall, AP 224 describes textually 48 manufacturing features with their specific attributes (see figure 4) which we have implemented object-oriented within a feature-library. For a visual representation some chosen manufacturing features are illustrated in addition.

The relationships between the manufacturing features are defined in the *application reference model* of AP 224. In the ISO-document it is represented textually with illustrations. Relations are mapped and visualized in several EXPRESS-G diagrams. Additionally, the relationships between feature attributes are documented in the *application interpreted model* which is provided by different EXPRESS reference paths. EXPRESS is a specific data model description language defined in ISO 10303-11 [12]. Its graphical pan don is EXPRESS-G which is useful for the interpretation of those complex data models [13]. The following figure 4 illustrates the example of an open slot, defined by the application reference- and the application interpreted model.

4.3 Automated Process Planning with AP 224

Process planning is a fundamental step in the creation of a new product or its optimization. The *process plan* (or routing) is a concrete guideline how to manufacture a part. To stay competitive it is important to generate a *process plan* under respect of the manufacturing environment and the requirements of the product in an economic way and a timely manner. Therefore the entire manufacturing environment with its available machines, their capacities and other resources should be considered. This information can be provided by today's enterprise resource planning systems (like SAP or Microsoft Dynamics).

Additionally, process planning requires knowledge about the product, especially its geometry, dimensions, material properties, tolerances and many other extended information. With a product model based on AP 224 manufacturing features, this information can be extracted automatically by an AP 224-based process planning system. Our primary approach of automated process planning can be described as a *generative planning* [14]. To give small and medium enterprises (SME's) a possibility to be ahead over competitors, we want to generate process plans for new components automatically.

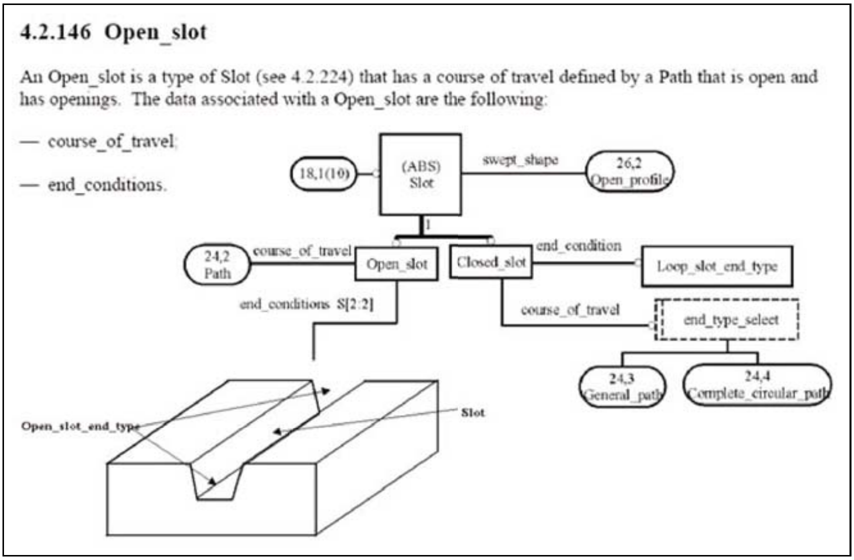

Fig. 4. Description of an Open_slot [8]

Another great advantage of AP 224 is that we can conclude corresponding manufacturing operations to each manufacturing feature used in the product model because of their semantics. First, based on the derived manufacturing operations it is possible to check the manufacturing environment if the required resources are available. Second, we can generate a dependency graph based on the features of this application protocol. Because of their semantics, significant attributes, relationships and rules, we can determine dependencies between single manufacturing features. Afterwards we divide these features into *dependent* and *independent* ones. Independent features can be employed directly. Dependent features require others to be employed in the forefront. Taking these two rules, we are able to build up an *dependency graph*. Finally we are going to find an optimized sequence of employing AP 224 features automatically by using genetic algorithms to produce the final part. The genetic algorithm is used to assess a process variant by scheduling it within a given factory environment. Further description of our approach of automated process planning and cost-evaluation can be found in [15] and [16].

5 Implementing STEP

In our work we have modeled the manufacturing feature-objects of AP 224's *application reference model* in UML-class diagrams. Afterwards we generated the relating source code with a model driven software architecture framework *GeneSEZ* in a C++ feature-library. This library is able to generate e.g. the building component in figure 5 and enables the definition of shapes, dimensions attributes, feature positions and orientations.

For three-dimensional visualization of complex building components we have developed a modular viewer-concept. It connects the geometric modeler ACIS with the generated AP 224 feature-library. The geometric ACIS modeler visualizes the geometric model in figure 5. Therefore the modeler obtains the necessary geometric information for the three-dimensional visualization from the AP 224 feature-library (feature model) from the viewer component.

With this solution we can visualize and create a product defined by AP 224 manufacturing features. During our researches we have used a roll axis-demonstrator (figure 5) which can be designed by using our implemented *destruction by machining-features* approach at runtime.

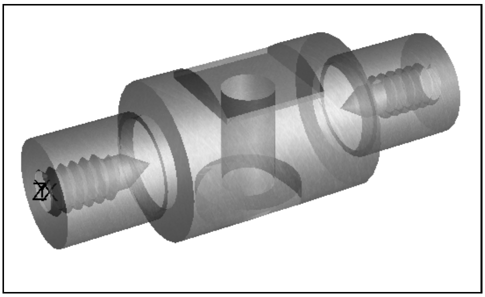

Fig. 5. Roll Axis-Demonstrator

First, the attributes of the roll axis-demonstrator are retrieved from the instantiated feature objects of the product model. This instantiation is done by the designer in the product design phase. The initialization starts with the cylindrical base shape (the initial stock) and subtracts all instantiated manufacturing features to create the final shape of the roll axis-demonstrator. The order of destruction is given by the derived routing.

We define the minimal geometric information for three-dimensional visualization of the cylindrical base shape with additional attributes like *base_shape_length* and *diameter*. Each manufacturing feature includes different shape attributes for retrieving its geometry. A *round_hole* for example can own a *taper* or a special *bottom_condition*.

After the initialization of an AP 224 library-object it will be transferred to its special viewer. This viewer extracts the required object attributes and constructs the geometric representation with combined ACIS method calls. The ACIS method `api_solid_cylinder_cone` can be used for drawing the cylindrical base shape. Because of the complexity of several manufacturing features we have created flexible geometric auxiliary constructions for their three-dimensional visualization.

Future work will lead to a graphical user interface for designing the building component or assembly. Afterwards, our own, FBD-based CAD-system will be used to design example parts more easier and will be fed by our automated process planning CAPP/CAM system.

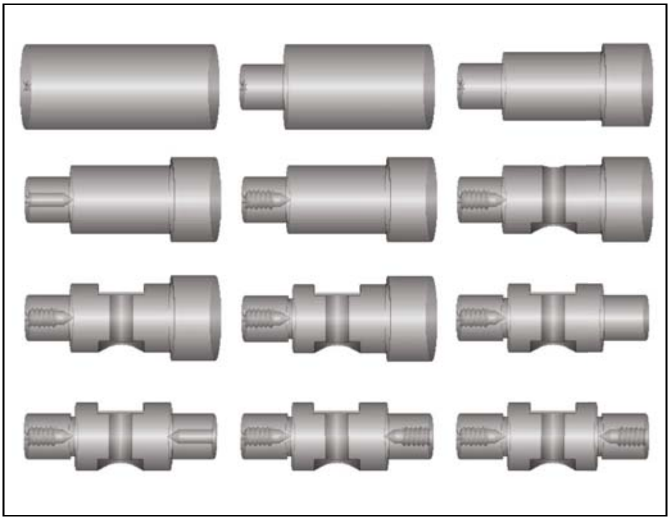

Fig. 6. Intermediate Variations

6 Conclusion

During our researches we have realized that there is a huge potential of STEP to optimize the product data exchange of the whole product lifecycle. An implementation is essential for fast and effective product development. There is still a surprising lack of implementations of the specialized context-depended application protocol. Although AP 224 and other protocols have great potential for implementing feature-based solutions and developing integrated CAx-systems for continuous product data integration.

Our presented viewer-concept realizes the approach "destruction by machining features" by subtracting different features from a base shape at runtime. The modular structure of our viewer concept separates the feature model from the geometric model clearly and practically demonstrates the approach of "geometry from feature". Every component of the viewer-concept can be exchanged, reused and extended.

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