

STEP-Compliant CAD/CAM Integration

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Abstract -. *The objective of STEP is to provide a neutral data model capable of describing product data throughout the life cycle of a product that is independent from any particular software application or computer platform. AP203, AP214, AP224 promote the integration of CAD/CAM system. Now STEP-NC, a new extension of STEP, is being developed. A truly integrated CAD, CAPP, CAM and CNC paradigm is now in sight. This paper introduces the STEP Methodology first, and then describes the methodology of STEP-based integrated product modeling used in a prototype called LONICERA, and finally discusses STEP-NC and STEP-NC-compliant CAD/CAM integration.*

Keywords: STEP, Product model, STEP-NC, CAD/CAM Integration

1 Introduction

The STEP (ISO 10303) Product Data Representation and Exchange standardization initiative covers computer-interpretable representation of product data, and its exchange. The objective of ISO 10303 is to provide a means of describing product data throughout the life cycle of a product that is independent from any particular computer system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing product databases and for archiving data. In practice, the standard is implemented within computer software associated with particular engineering applications and so its use and function will be transparent to a user. The descriptions are information models that capture the semantics of an industrial requirement and provide standardized structures within which data values can be understood by a computer implementation.

Some authors use STEP as an acronym for STandard for the Exchange of Product data but the purpose of the standard is to provide information models for the representation of product data. The exchange of data is one

of the uses for a standardized representation, but it is not the only use. [1]

The part of STEP that is currently most widely used is AP 203('Configuration-controlled design'). This is concerned with the transfer of product shape models, assembly structure, and configuration control information (e.g. part versioning, release status, authorization data etc.). All major mechanical CAD vendors now have STEP translators available, mostly for AP 203, but increasingly for AP 214 ('Core data for automotive mechanical design processes'). Its scope is considerably wider than that of AP 203. For example, it handles raw materials data, manufacturing tools and plans for a range of manufacturing methods, standard (catalog) parts, tolerance data, features, numerical control (NC) data, data for kinematics simulation, 2D drawings, and certain classes of product data management (PDM) information [2]. These APs promote the interoperability among CAD, CAM and PDM systems.

Now a new specification for the definition of the data input to CNC controllers, STEP-NC, is being developed. Currently NC machines still use ISO 6983 standard developed in the 1960's as the data interface, in which a set of linear and circular tool movements is given as input to drive CNC machines. ISO 6983 is limited in its expressivity and portability. It is also unable to support program adaptability that may be necessary due to resource restrictions on the shop floor. The current-used interface becomes a bottleneck in the manufacturing process.

To overcome limitation of G-codes STEP-NC model defines a CNC part program as a series of operations that remove material defined by features [3]. The operations are sequenced into a work plan that converts the stock into the final part. STEP-NC tells the controller what needs to be machined, not how to machine the product like G-codes. The most important functionality enabled by STEP-NC is more efficient data exchange between CAD/CAM systems and CNC controllers. STEP-NC will allow the data input to these controllers to be updated to 3D models annotated

with design tolerances, manufacturing features, process sequence and cutting tool requirements [4, 5].

The STEP-based integrated product modeling methodology has been researched, and an integrated CAD/CAM system based on STEP AP214, called LONICERA, was implemented. With the emergence of the new standard, a research on the STEP-NC-compliant CAD/CAM integration is under way.

In the paper, the STEP Methodology is introduced first. Then the methodology of STEP-based integrated product modeling used in LONICERA is described. STEP-NC and STEP-NC-compliant CAD/CAM integration is discussed next. Followed by conclusion.

2 THE STEP Methodology

The STEP methodology contains three principal components:

(1) The EXPRESS language. (2) An architecture that maps the information requirements of application into a set of integrated resources. (3) Implementation Methods for a variety of technologies and programming environments.

2.1 The EXPRESS Language

The STEP community invented the EXPRESS language to model 3D geometry. It was decided that a new language was desirable because of the extensive inheritance relationships that occur between geometric entities and because many mathematical rules can be defined to validate 3D geometry. EXPRESS defines information models as schemas. Each schema contains entities first, and ancillary type, function and rule definitions second. An entity is the EXPRESS equivalent of a relation in a database or an element in XML. The ancillary type, functions and rules are defined to support the entity definitions [6].

2.2 The STEP data Integration Architecture

The STEP methodology supports developing APs and the resources required by those APs. A principal feature of the STEP architecture is the layering of data specifications. Of primary interest are the context-independent integrated resources and the context-dependant application protocols. [7] The IRs contain abstract generic constructs that accommodate different ways of looking at the same products through life cycle dependent product definition. APs capture particular ways of looking at one or more products for specific purposes. An AP contains a standard representation of its perspective that employs the constructs of IRs. This representation portrays its perspective as a

compatible member of an indefinite number of possible perspectives about a product [8]. The idea is to allow STEP to grow over time to include more information about the product life cycle.

The STEP data integration architecture requires a STEP Application Protocol to be developed in two phases. In the first phase an Application Requirement Model (ARM) is developed using an information modeling language. The next stage maps the ARM model into the integrated resources using mapping tables to create the Application Interpreted Model (AIM). The result is a much more robust model. [6]

2.3 Implementation Method

Each STEP information model is implemented by mapping the integrated definition of the model into an implementation technology [6]. The available implementation technologies include:

(1) An EXPRESS driven file format called Part 21. (2) A variety of programming language bindings that allows an application programmer to open EXPRESS defined information sets and access values in entity instances. Bindings have been developed for C, C11 and Java. (3) A new configuration language for mapping EXPRESS into an XML Schema.

3 STEP AP214-based Integrated CAD/CAM System: LONICERA

As mentioned above, STEP provides representation of product information model first, so it can be used as core model of a CAD/CAM system. In this section, an integrated product modeling methodology is presented. It is proposed on the basis of STEP standards, and EXPRESS is used as the information description language. The proposed STEP-based integrated product modeling methodology has been implemented to develop a CAD/CAM integration system called LONICERA [9, 10].

3.1 Architecture of Integrated product model Based on STEP AP214

In the authors' opinion, the successful implementation of product modeling depends upon the effective architecture of an integrated product model. According to the compositions of the knowledge from the product design and development, the proposed integrated product model (IPM) consists of the following components: a geometric model, a feature model, a product definition model (including the domain product model), and an integrated core model. The architecture and relationship of these models are described below; see **Fig. 1**.

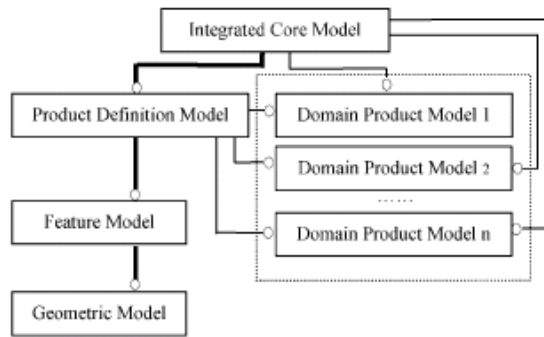


Fig. 1 The architecture of integrated product model

1. The geometric model is the basic description and definition of the product geometric shape using the combination of CSG and B-rep solid representation. From the initial concept shape description in conceptual design to further elaboration of product detail design, geometric information about one specific product can be dealt with in a geometric model. As the result of geometric modeling, the data structured in a STEP AP214 schema are provided for the following feature model. STEP AP214 is used as the framework of the geometric shape description.

2. The feature model is an extension of the geometric model. The features with different definitions and attributes specify the geometric characteristics and engineering semantics of the objects. The information generated from the geometric model can then be prepared to support the design and manufacturing of the product. The feature model is the basis for creating mechanical parts and composing the product definition model and domain product models. STEP AP214 provides the feature related entities as a type of shape-aspect like machining feature, replicate feature, and transition feature. In addition, the shape aspect has self-defined features like a design feature and an assembly feature. The feature model can be used to support the whole product design process with the advantages of easier information transformation and integration.

3. The product definition model, including domain product models, is the parametric feature-based product model. It is generated during the process of defining the engineering description and structure of the product in order to meet the requirements of product design and process. The identifier, descriptive text, product definition formation, and product definition context are the main components of the product definition model. The product definition model considers the product and process as a whole, while the domain product model refers to the specific domain of the implementation aspects, such as the machining process, NC fabrication and the assembly process. A mapping mechanism between the product definition model and its related domain product models is set up to support the data exchange, such as the link

between the product definition data and the assembly domain data.

4. The integrated core model is a description of architecture for the implementation of the information management from the product definition model and domain product models via the feature model to the geometric model. It also manages the knowledge required to define and implement all the product design and development activities.

3.2 The Abstract Class of Integrated Product Model

The representation of the abstract object of the product is described in **Fig. 2**, where Product is an abstract SUPERTYPE that consists of the characteristics of domain product information such as design view, process view and machining view. Each of the view models is the SUBTYPE of the product in which the view model data can be respectively configured by the requirements. The entities of structure and management, which deal with the functions of managing the structure model and implementing the operation for the model and related model data, are the two important attributes of the product.

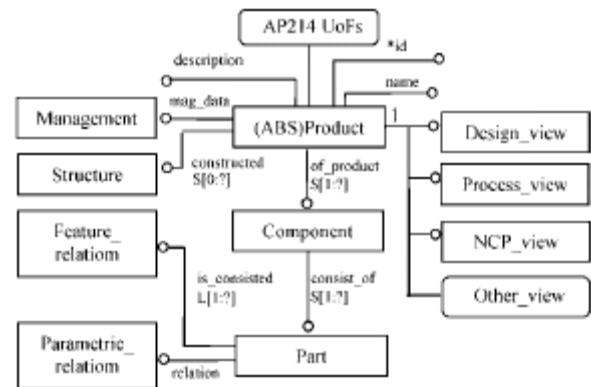


Fig. 2 Abstract product class.

A product consists of components and parts. A part has the attribute of a parametric feature and a feature relation. The geometric description can be defined by two dimensions, namely, form feature and location feature. As these two dimensions can be described by parameters, the geometric model is called a parametric feature model. The parametric features can be developed according to the form feature and UoFs drawn from the product requirements.

The relationship of features in the integrated product model consists of location relation, through which the location between features is elaborated, and hierarchy relation, through which the dependent relation among features in the product development cycle is described.

3.3 A Prototype of Proposed Integrated Product Model: LONICERA

The proposed STEP-based integrated product modeling methodology has been implemented to develop a CAD/CAM integration system called LONICERA. The implementation architecture of the LONICERA system is simply described in Fig. 3. As discussed above, the modeling process of LONICERA consists of two parts. One is the product definition model and the other is domain product model. Both of these models are set up on the basis of the elements Feature and Geometry, which are described in STEP AP214 AIM but these two models are designed to perform different functions within the different stages of the product development process. The domain model is designed to follow the definition model. With the support of integrated product modeling methodology, the product definition model is located within the first stage of the product development process to support product requirement analysis, development preparation and product conceptual design. The information, which is collected from the market or customers in the requirement analysis phase, will be transferred into a standard information format with the help of the product definition model. Then, as the input to the conceptual design toolkit, the information is considered as the original data to perform the conceptual design for a new product. Through the conceptual design, the prototype of the new product is described in the product definition model data with initial three-dimensional visualization. This implementation process is totally controlled by the workflow management toolkit. The work of refinement and reorganization of this information is implemented by interaction. In the second modeling process, the domain product model aims to provide sufficient domain information to meet the requirements of the following product manufacturing process. The activities such as machining process planning,

NC fabrication, and assembly, etc. are all supported by this domain model. It is the core model for manufacturing. This process is managed by the design for X toolkits, such as DFA, DFM. After this domain development stage, a new product with new features will be delivered quickly to the customer. As these models are all developed based on STEP AP214 the model data can be exchanged and modified easily between different commercial CAD/CAM systems, which have the interfaces for STEP files. The LONICERA system is fully supported by the proposed integrated product model methodology, as illustrated in Fig. 4. Figure 4(a) gives the example of a function of feature modeling for the part called Aeroengine, and the wire frame model representation is demonstrated in Fig. 4(b). Figure 4(c) and figure 4(d) express modifying the dimension feature and adding a new feature respectively.

4 STEP-NC-Compliant CAD/CAM Integration

The second half of the 1990s saw the intensive development work on extension of STEP towards the CNC domain. This extension led to the introduction of a new concept of NC programming – STEP-NC and a truly integrated CAD, CAPP, CAM and CNC paradigm is now in sight.

4.1 STEP-NC

Today, a new ISO standard often known as STEP-NC is being developed to provide a data model for a new breed of intelligent CNC Controllers. Its ARM has been given the number ISO 14649[11], which represents a common standard specifically aimed at NC programming, making the goal of a standardized CNC controller and NC-code-generation facility a reality. Coupled with the ARM is the STEP-NC AIM, ISO 10303 Part 238[12].

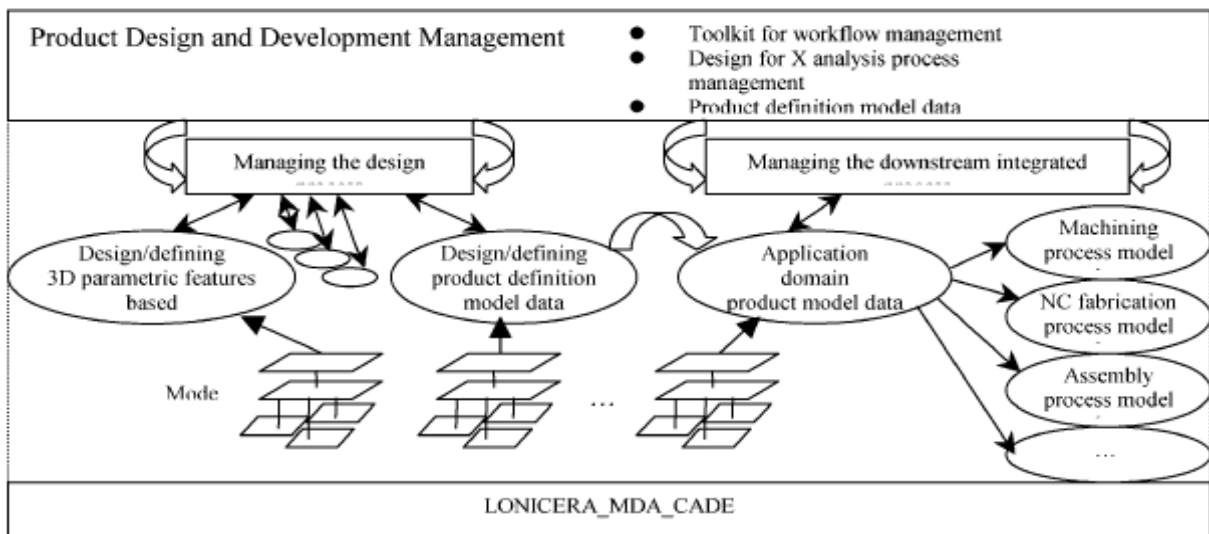


Fig. 3 The architecture for developing LONICERA based on STEP

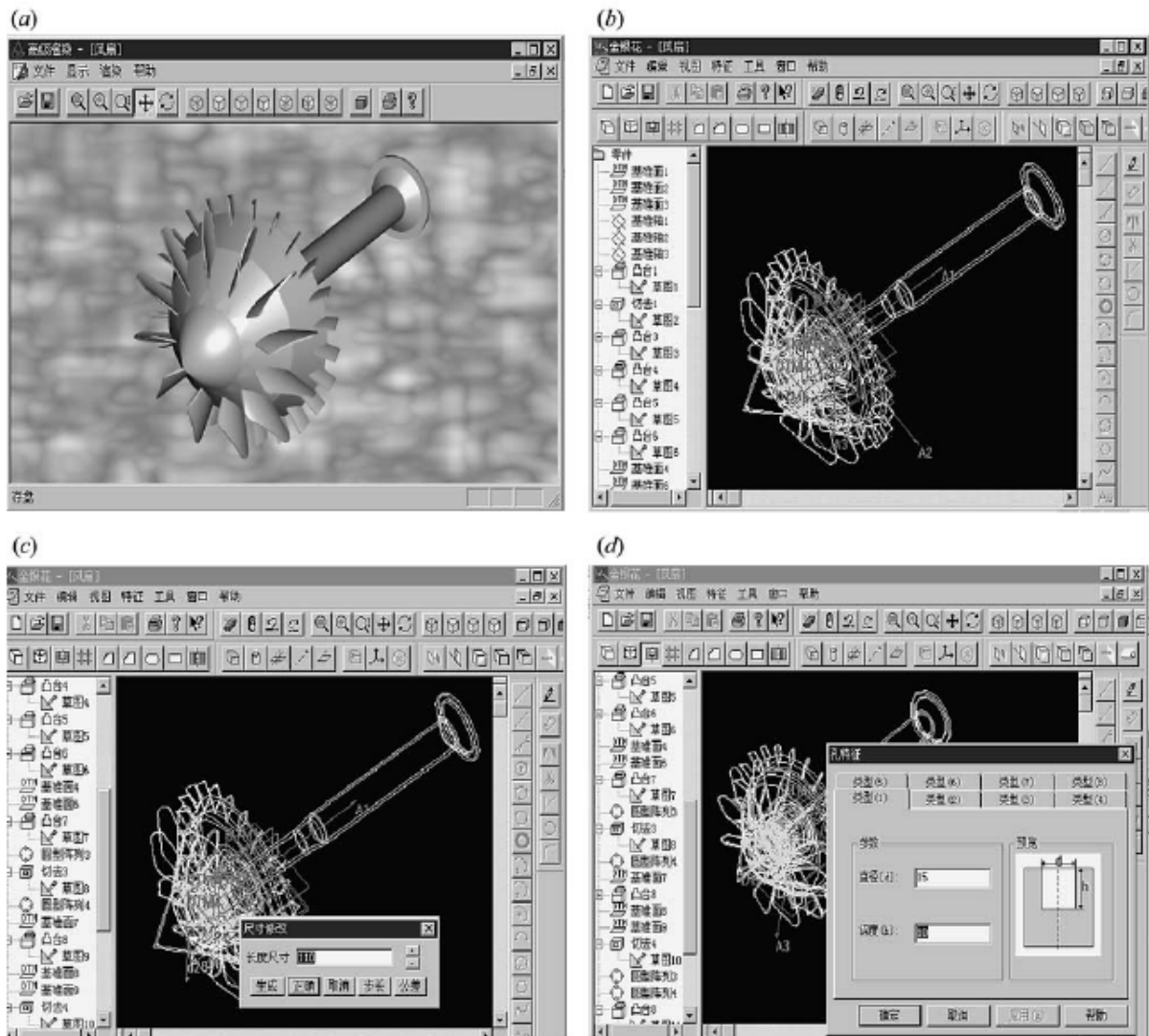


Fig. 4 Aeroengine:(a) Feature modelling (Advanced Rendering). (b) Wire frame model representation. (c) Modifying the dimension feature. (d) Adding a new feature hole

(1)ISO 14649

The STEP-NC ARM (ISO 14649) provides an object-oriented data model for CNCs with a detailed and structured data interface that incorporates feature-based programming where there is a range of information such as the features to be machined, tool types used, the operations (Workingsteps) to perform, and the process plan (Workplan). **Fig. 5** shows the information model of ISO 14649. Though it is possible to closely define the machine tool trajectory using STEP-NC, the aim of the standard is to allow these decisions to be made by a STEP-NC-enabled controller. The aim is that STEP-NC part programs may be written once and used on many different types of machine tool controller providing the machine has the required process capabilities [13].

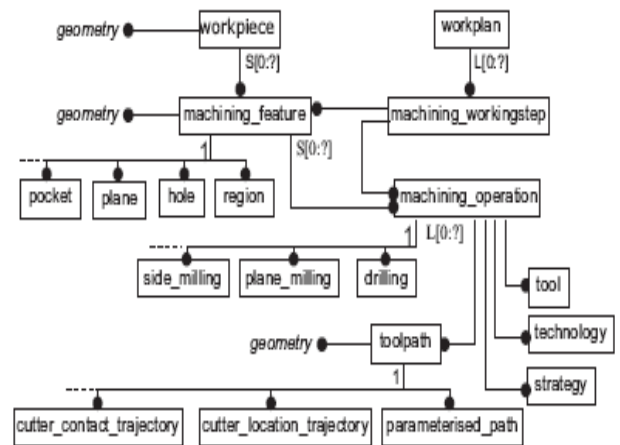


Fig. 5 geometry, technology and process sequence In ISO 14649

(2) AP238

AP238 begins with the information requirements set forth by the ISO 14649 data model for computerized numerical controllers and describes how to represent those within the larger view of product data defined by the combined set of ISO 10303 application protocols [12].

To fully integrate CAD/CAM and CNC systems, a product information model that includes product and process data, manufacturing resource data and manufacturing control data is needed. The emerging standard, AP238, pulls together information of machining process, tool requirement, geometry, tolerances, and PDM [14]. It covers all the information in the design-manufacturing life cycle, i.e. geometry information defined by AP203/214, feature information defined by AP224, dimension and tolerance defined by AP219, and machining processes defined by ISO 14649. Different Aps of STEP can share and exchange information seamlessly, so the changes made in CNC can be read and interpreted back in CAD, CAPP and CAM systems. The high level AIM of STEP-NC is shown as Fig. 6 [15]. Workingsteps are linked to three-dimensional geometry, feature definitions, tool requirements and explicit toolpaths. In keeping with the STEP concept, these workingsteps are generic descriptions that can be incorporated into a product model.

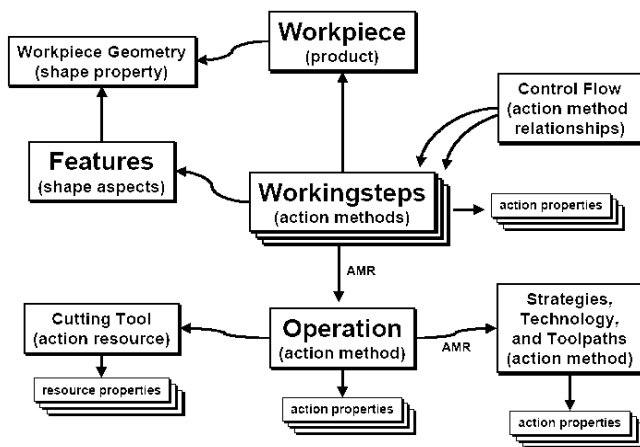


Fig. 6 STEP-NC high-level AIM view

For the ethos of STEP-NC to be successful, the necessity to identify a consistent model definition of the product that maps to a manufacturing model is critical. Product modeling is recognized as a well-matured area of research. Manufacturing modeling, on the other hand, is still at an earlier stage of development, but its need is as vital, with standards needed to map CNC resource and process information on to the product manufacturing requirements. The US Super Model project has tried to address this goal with the use of an AP238 integrated CNC

model consisting of ISO 14649, AP203/AP214, AP224 and AP219, and may well yet be the total solution for product modeling [13].

(3) Benefits of STEP-NC

A STEP-NC file contains all the information required to produce a part, therefore, manufacturing operations may be adjusted to maximize production efficiency. It enables bi-directional data exchange between CAD/CAM and CNC systems, so any changes made on the controller could be encoded in the STEP-NC file and sent back to the CAM system. STEP-NC not only eliminates the costly and inefficient process of generating post processors, but also establishes a collaborative environment for the exchange of information between product design applications, manufacturing process planning, and the machine tool [16].

For design it means machine readable information can be sent to manufacturing instead of drawings making the process of design more efficient. For manufacturing it means faster, safer, more intelligent machining because a control can dynamically check the safety and optimize the performance of a part program for the tooling available at run time.

STEP-NC is not only a new CNC language, but also is the fundamental means for realizing for e-Manufacturing, where the collaborative manufacturing's cycle on the Internet via standard information is required. The new standard, which doesn't require machine-specific post-processors, enables Web-based Develop Anywhere and Manufacture Anywhere (DAMA) strategies.

4.2 STEP-NC Compliant CAD/CAM System

Because Process Plan and NC data models in AP214 don't satisfy requirements of CAD/CAM integrated system, many models of process-view and NCP-view in the integrated product model mentioned in section 3 are self-defined [17], [18]. For example, in the original machining system of LONICERA the process of tool-path generation was divided into two steps: decomposition calculation and area interpolation, and those two steps were performed by NCFU-based NCP system and CNC system respectively. The concept of NC Feature Unit (NCFU) was introduced in the LONICERA machining system [18]. The output of decomposition is a list of small continuously machined areas called NCFUs, in which no interference occurs during cutting, so the area interpolation is easy enough to be processed on a CNC machine in real-time. The NC process information model was defined following STEP syntax. LONICERA/NCP implements 2.5D milling and 3D surface milling successfully, but the NC information model does not cover four or more axis milling and other machining methods, such as turning, EDM, etc.

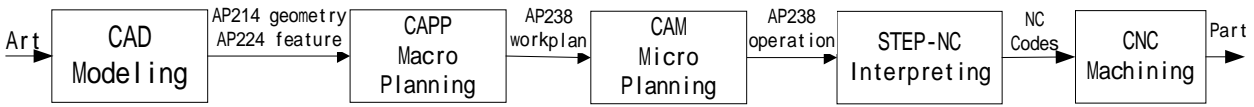


Fig. 7 STEP-Compliant CAD/CAPP/CAM/CNC Scenario

In order to take advantage of the benefits of STEP-NC, a research on upgrading LONICERA system to a STEP-NC compliant CAD/CAM system is in progress. **Fig. 7** shows a STEP-NC compliant CAD/CAM system scenario. AP224 features and AP214 geometry information are authored by the CAD system and sent to a CAPP system. According to these manufacturing features the CAPP system performs macro process planning and generates the workplan information such as workingsteps sequence and tools needs. The output of the CAPP system is AP240 in the future. The CAM system performs micro process planning and generates operation and toolpaths. The interpreter generates NC codes automatically. Finally the CNC machine machines the part.

5 Conclusions

On the basis of the lessons learned from this research work, the following points are highlighted:

1. ISO 10303 STEP is a product modeling approach that takes into account all the aspects of a product development project, so that it is suitable for supporting the establishment of the integrated product model.

2. A prototype integrated product model based on STEP AP214 has been developed, which is the combination of the geometric model, the feature model, the product definition model (including domain product model) and the integrated core model.

3. STEP-NC extends STEP to include manufacturing control information, thus a fully integrated CAD/CAM/CNC system will be enabled.

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