CAD/CAM solutions for STEP Compliant CNC Manufacture

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ABSTRACT
The ability to generate an NC tool path is now common place in CAD/CAM systems, but the technology used for programming and control of NC machines is still based on 1950’s standards. Today under the IMS project called STEP-NC in Europe and Asia, and Super Model in USA, industrialists and academics are collaborating to deliver a new data model as an ISO 14649 standard for CNC machines. This standard will enable software vendors to revolutionise the programming of these machines. This paper provides a futuristic view of how this standard could be used in manufacturing and highlights a number of possible generic frameworks for how CAD/CAM systems may evolve using the ISO 14649 standard. Finally, the paper proposes a prototype STEP compliant CAD/CAM system based on one of these frameworks using the new ISO 14649 Standard for milling components.

Keywords: STEP, ISO14649, CNC, CAD/CAM

1. INTRODUCTION
The goal of customised, rapid, efficient and automated NC code generation has been sought after over many decades since the development of the first NC machine tool introduced in 1952 at MIT, USA. With the advent of computer numerical control (CNC) in the 1970’s together with the 1990’s use of PC and Open CNC technology [1] there is a major opportunity to improve the programming of CNC equipment through intelligent programming of today’s highly sophisticated CNC machine tools.

In parallel with these machining developments significant progress has been made with the rapid development of CAD/CAM software with sophisticated programming capabilities for highly configurable NC code generation. Though these developments have revolutionised CNC processes and programming capabilities; the programming language has basically stayed the same as the G/M code programming which was developed in the 1950’s and later became the ISO 6983 standard [2] that is based on the tool path and machine status description.

Today a new standard namely ISO14649 recognised informally as STEP-NC [3] is being developed which represents a data model for Computer Numerical Controllers. The data model represents a common standard specifically aimed at NC programming, making the goal of a standardised CNC controller and NC code generation facility a reality.

This paper presents research relating to the impact of the ISO14649 standard on CAD/CAM system design; it is divided into two major sections. The first part of the paper provides a view of how this standard could be used in manufacturing and highlights a number of possible generic frameworks for how CAD/CAM systems could implement the ISO 14649 standard. The second part of the paper outlines a proposed agent-based CAM system, termed AB-CAM, based on one of these frameworks. The design of the AB-CAM system is shown, illustrating the major activities within a STEP compliant structure.

2. STEP COMPLIANT NC PROGRAMMING
Although there have been significant developments which have improved the software and architecture of CNC machine tools, vendors and users are still seeking a common language for CAD, CAPP, CAM, and CNC, which integrates and translates the knowledge of each stage. It is with this aim that the STEP-Compliant NC (STEP-C-NC) programming is being developed to provide consistent standards for automatic and quality oriented CNC component manufacture.

To this end in the second half of the 1990’s an effort from the international community backed by the International Organization for Standardization started a major change in the concept of NC programming. A new NC data interface called ISO 14649 [4] is being developed under the ISO technical Committee TC184 sub-committees SC1 and SC4 based on the ISO 10303[5] known as STEP. Contrary to the current NC programming standard ISO 6983, known as G & M codes, the ISO 14649 is not a method for programming and does not describe the tool movements for a CNC machine. Instead, ISO 14649 provides an object oriented data model for CNC’s with a detailed and structured data interface that incorporates feature based programming where there is a range of information such as the feature to be machined, type of tools used, the operations to perform, and the work plan.

For each operation performed on one or more features, a statement called a workingstep is defined. These workingsteps provide the basis of the workplan to manufacture the component. Figure 1 illustrates the actual extract of such data for a part with a workplan consisting of workingsteps, for slotting, drilling, and pocketing [6,7].
The development of ISO 14649 provides a number of options for interpretation and implementation of this standard within CAD/CAM systems. The implementations in this paper are defined by the authors as ISO 14649 compliant, and referred to as STEP compliant NC (STEP-C-NC). Framework I has been defined for STEP-C-NC which are outlined below [8]:

Framework I: A CAD/CAM system which imports & exports STEP-C-NC data;
Framework II: A CAD/CAM Systems with STEP-C-NC data support structures;
Framework III: A CAD/CAM environment with kernel STEP-C-NC data structure.

3.1 A CAD/CAM System which Imports & Exports STEP-C-NC data

The first form of STEP-C-NC framework provides a CAD/CAM System with the ability to both import and export STEP-C-NC data, and is depicted in figure 2. With this framework the CAD/CAM system is used in its normal operational form using its own native feature representation and manufacturing strategies for the design and manufacture of components. The generation of the ISO14649 output is created by mapping the native CAD/CAM information structures onto the STEP compliant data through a post processor specifically for ISO 14649. A major issue for this basic form of STEP compliance is that the CAD/CAM information stored on manufacturing technology (eg. materials, tooling, clamping and machining strategy data) has to be converted into ISO 14649 format via the post processor. It should be noted that many of the current CAD/CAM systems will probably not have the flexibility to incorporate this STEP output, as the output is so different to the normal G/M code output plus further data is required on the geometry of the component not just machining data.

The imported STEP compliant data is translated into the native geometric and manufacturing data structures of the CAD/CAM system using a reverse post-processor. The user would then use the system in its normal operating manner, and have the ability to generate STEP-C-NC output.
Figure 4– Framework II (b) An internally shared STEP-C-NC CAD/CAM environment

3.3 A CAD/CAM Environment with Kernel STEP-C-NC Data Structure

Framework III depicted in figure 5, represents the highest level of compliance for a CAD/CAM system, and uses ISO14649 and ISO 10303-224 [9] for both geometric and manufacturing data models. The authors believe this structure, will form the basis of new developments for CAD/CAM vendors and will also provide the direct and simplest generation of ISO14649 NC code. One overhead of this framework will be the need to post process the STEP data into ISO6983 G/M code output for conventional CNC controllers.

Figure 5 - Framework III – An internal STEP-C-NC CAD/CAM environment

4. OVERVIEW OF THE AB-CAM APPROACH

Based on the first variant (a) of Framework II, the authors have designed and developed a STEP compliant Agent-Based Computer Aided Manufacture System (AB-CAM). The system combines STEP compliant, feature-based design with agent-based computer aided process planning (CAPP). The proposed system is outlined in Figure 6, and consists of a STEP compliant CAPP system, with supporting product and resource models.

Figure 6 – STEP compliant Agent-Based Computer Aided Manufacture

The introduction of Artificial Intelligence (AI) and knowledge-based systems has provided researchers with a wide range of opportunities over the last 50 years. Today the next generation of AI systems are being developed based on a new and exciting area of research in manufacturing termed “Agent Technology”. Agents exhibit many of the attributes required to meet the increasing demand for agility in conventional approaches to design and manufacture. Chiariglione [10] provides seven attributes to define an agent: autonomy, social ability, reactivity, pro-activeness, mobility, temporal continuity and adaptivity. These seven attributes make the use of agent technology in the development of CAPP/CAM systems particularly useful. The agents can be programmed to accomplish various planning activities such as selecting machine types, cutting tools and cutting parameters to machine specific geometries or features.

STEP compliant machining features are used in the AB-CAM system to break down complex component models into simple items e.g. a hole, a pocket or a boss. Features have now been commonplace in CAD/CAM for a number of years, it is the feature functionality that is key to the operation of the AB-CAM system. A single feature is coupled to a Manufacturing Feature Agent(MFA) to enable machining information to be created. The generated machining information can also be stored and reused for common features. There will be instances when it is more practical to machine more than one feature at the same time for example when two pockets overlap. The combination of features is performed by a workingstep optimiser. The optimiser determines the best sequence for features to be machined and where two or more features should be combined into one.

Figure 6 illustrates the use of a Machining Feature Agent (MFA) in the execution of the AB-CAM System. The MFA is responsible for the acquisition of manufacturing data e.g. tools, machining parameters, fixture data etc. required to machine the feature. The AB-CAM system has three working modes: automatic, semi-automatic and manual. Automatic for relatively simply components and semi-automatic/manual for more complex components, which require more human interaction.

4.1 Operation Structure of the AB-CAM Framework

The overall operational structure of the AB-CAM framework is illustrated in the IDEF0 diagram in figure 7. This outlines the main input to the system, which is a product model of the desired workpiece, which would generally take the form of a CAD model containing information relating to raw material final product design and tolerances. The outputs from the system are two fold namely, an ISO 14649 part program, which would be used to control the next generation of intelligent machine tool controllers. In addition the second output, is the AB-CAM system capability to post process this information into a conventional ISO 6983 part program for use on existing machine tool controllers. The reason for the second output is that the authors believe that although it is important to design new systems that can generate ISO 14649 output there will be a significant amount of time before industry invests in new controllers to support the new standard. For this reason any new CAM system currently being designed should support both standards.
4.2 Design of a STEP Compliant NC Program Generator

The sub-level design of the STEP Compliant NC Program Generator in Figure 8, illustrates the activities, which transform a product model into a process plan and part program. These activities are divided into three major parts namely: a feature extractor activity, generation of STEP compliant NC process plan and the generation of a controller specific part program. The feature extractor is used to generate process information. The STEP compliant NC process plan is generated using the information from the feature extractor and interfaces with process parameter libraries, to output an ISO 14649 part program. It is envisaged that the next generation intelligent machine tool controllers will handle the tool trajectory calculations [11]. For today’s CNC machine controllers some traditional CAM functionality has been included which will generate tool trajectory information from the STEP compliant NC process plan and part program resulting in the output of a conventional ISO 6983 part program.

Generate STEP compliant Process Plan

The IDEF0 representation Generate STEP compliant Process Plan illustrated in Figure 8) requires two inputs, (i) feature tree information, and (ii) the product model of work piece. This is achieved through the design by features approach as described above.

The functionality of this IDEF0 representation is to select a process type, e.g. rough mill, drill etc. Select the machine tool, cutting tool and cutting parameters. Define fixture methods and clamping locations and finally to determine the ISO 14649 workingsteps and workplan. The workingstep defines an operation e.g. rough out pocket and the workplan defines the sequence of workingsteps.

Extract Features

The AB-CAM system incorporates a design by features methodology. The commercial CAD/CAM system PowerMill from Delcam Plc [12] has been used as the base product to implement the ABCAM system. Dialogs have been created in PowerMill to define ISO14649 compliant feature information and an OLE link is used to create these features within the PowerMill software, as shown in figures 9 and 10. This is useful so that the user can visualise the features being machined. In the future it is envisaged that an AP224 file will be read to define the feature geometry so that the designer will not be limited by the functions within PowerMill, which is primarily a CAM system, not a CAD system.

On creation of a feature within PowerMill the information is stored in the Microsoft® Access database system, which can be accessed later by the ABCAM system to develop the workingstep and STEP-C-NC (STEP Compliant Numerical Code).

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The user is given the option to define their own workingsteps with all the machining information, which is related to the workingstep or it can be created automatically with the use of an intelligent agent and a machining knowledgebase. If the user accepts to have the workingsteps created automatically they will still have the option to change any attributes that are listed in dialogs within the ABCAM system.

Intelligent agents namely MFA’s, are allocated to a feature, the MFA analyses the manufacturing knowledge base to determine the best solution for cutting tools, feeds and speeds etc. The workplan is defined by the workingstep optimiser which consists of an intelligent agent/agents that use feature interaction rules such as feature precedence, overlaps and thin wall sections [13]. It may be preferable in certain instances where two pockets overlap that they should be considered as a single feature or feature region this means that they will be machined in the same workingstep. Agents can then be merged together when required by a method known as agent fusion.

The AB-CAM system has been developed using the Java language, due to its ability to be platform independent and Java’s supporting libraries methods for the development of intelligent agents.. The system’s data structure is based upon ISO14649 and is able to take information from Access databases which are populated through the PowerMill dialogs. Alternatively the user can generate just the feature geometry and let the java-based intelligent agents (MFA’s), create the information automatically. Dialogs can be used to edit this information if the user is not satisfied with the solution. Finally the data is post processed into a functional STEP-C-NC part program as illustrated in figure 10.

Generate a Controller Specific Part Program

The functionality of IDEF0 representation Generate a Controller Specific Part Program in Figure 8 is required only for conventional CNC controllers. The main input is the STEP compliant part program. The system also needs the product model of a workpiece as an input in order to generate tool path trajectories and check for collisions.

The first activity is to generate a data structure from the STEP compliant NC process plan / part program which can be understood by a commercial CAM system. The commercial CAM system is used to generate the tool trajectories. An NC simulator is used to check for part and machine tool collisions and finally the commercial CAM system will use a post processor to generate a controller specific ISO 6983 part program.
5. DISCUSSION

5.1 STEP Compliant CAD/CAM Frameworks

The three STEP compliant CAD/CAM frameworks outlined in section 3 provide an increasing level of sophistication for the internal representation of the ISO14649 standard within each CAD/CAM system. Framework I allows STEP-C-NC data to be imported and exported, which is the current method used by CAD/CAM vendors for implementing ISO14649 standard today [3]. The major advantage of this approach is that the user can use legacy CAD/CAM designs/manufacture data and convert it to the new STEP-C-NC format.

The two variants of Framework II have the advantages of being able to represent CAD/CAM data in its native format and its equivalent STEP-C-NC format. It provides the ability to consistently generate both ISO14649 code and comparable machine specific ISO6983 part programmes. In addition, the legacy data in Framework II provides the solution, which harmonises the native CAD/CAM structure with its equivalent STEP-C-NC data structure. The authors believe this provides a sound basis for CAD/CAM development.

The final framework III represents a fully compliant ISO14649 CAD/CAM system and would provide total compatibility with STEP-C-NC controllers. It should be recognised as noted earlier that this framework would have a greater overhead in generating traditional ISO6983 G & M code programs.

5.2 AB-CAM System

A number of advantages can be attributed to the use of a STEP Compliant - agent based CAM system such as AB-CAM. The system enables data to be transferred in a standard format between different CAM systems and machine tools providing data on the component geometry, machining operations, tooling, fixturing and detailed process plan.

The use of agents within the system provides a method for each feature to be considered individually at first and then as a whole in order to provide optimal machining solutions. The agents add intelligence to the CAM system to satisfy the operational design criteria for automatic, semi-automatic and manual operation. Agents also have the ability to leave the local area network, enabling the knowledge base to be easily and regularly updated as outside influences such as tooling vendors generate new tooling/information. It is worth noting that the operation of the AB-CAM system may be more closely described as a computer aided process planner, which generates STEP-C-NC part programs as an output. In addition, the new ISO14649 controllers will take the role of the traditional CAM function in determining optimal toolpath trajectories to cut the component. These new emerging boundaries or more aptly overlaps of CAD, CAPP and CAM will be a major topic for discussion and future software developments over the coming years.

6. CONCLUSIONS

This paper has discussed three frameworks for the future implementation of STEP compliant CAM systems. Considering the advantages and potential overheads involved in each implementation the authors believe that the most suitable framework at present is Framework II. Framework II requires that the commercial CAM system be interfaced with the new STEP-C-NC data structure. This enables all the native feature information to be kept in place undisturbed while a seamless link to the STEP-C-NC features provides functionality to satisfy both the new ISO14649 and older ISO6893 code machine controllers.

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8. REFERENCES


