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Exploring the ISO14649 (STEP-NC) for Intelligent Manufacturing System

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Abstract

STEP-NC (ISO 14649) was developed and published by International Standard of Organization on June 2006. It was a replacement for G-Code (ISO 6893) and an enhancement to STEP (ISO 10303). At this moment several CAPP and CAM systems related to STEP-NC compliance try to implement and no commercialized system has been established around the world. This critical review identifies the development of STEP-NC research includes problem of STEP-NC that makes it hard to implement. The fundamental and benefit of STEP-NC is also been reviewed. This research work was motivated by industrial requirements of concurrent engineering, standard product data models and an integrated manufacturing environment, which are further reflected in process planning. This paper describes and illustrates a STEP compliant CAD/CAPP/CAM System for the manufacture of asymmetric parts on CNC milling machine. The information models to support the proposed system together with the data models defined in the ISO14649 standard used to create the NC programs are also described. A structured view of a STEP compliant CAD/CAPP/CAM system framework supporting the next generation of intelligent CNC controllers for turn/mill component manufacture is provided. Finally the authors proposed STEP-NC Code Generator or (Mill-Gen) system and outlined by the modeling of a milling workstation and through the use of user interface dialogs that depict the information held in the models. A case study component has been developed to prove the concept for using the asymmetric parts of ISO14649 to provide a machining CAD/CAPP/CAM environment. It is expected that the recommended future extensions will enhance the usefulness of this paper, and will meet the requirements for global interoperable manufacturing for real-life parts.

Keywords: STEP-NC, ISO14649, Data Exchange Standard, Asymmetric Component, CAD/CAPP/CAM.

1. Introduction

In the last few decades the economic priorities of manufacturing have shifted from being based on low-cost standard product without compromising on consistency and quality, to the use of modern industrial manufacturing facilities with a "production on demand" concept. That concept has been adopted in order to better meet the challenges and take advantage of the opportunities of economic globalization. This concept found expression in DABA, or "Design Anywhere, Build Anywhere"[1], where the changing business environment leads to a need to collaborate beyond geographic boundaries supported by the rapid advancement of information technology associated with manufacturing technology. In a traditional approach design and manufacturing are considered to be separate but in a modern global and modern environment that separation becomes a major weakness leading to slow and costly production cycles. This happens because design has its own team as does manufacturing. The design focus is to design the product and pass information to engineers to decide how to make the product or how to realize the design. If anything happens and there is a need to redesign the product, the engineer will pass information back to the design team. Today, with the use of computer technologies and communication technologies in the manufacturing industries, the methods mentioned above are largely being replaced by CAD and CAM to implement concurrent engineering. Widespread CADCAM systems will reduce human interaction and the result, should be increased production, reduced costs and better quality of product.

The fundamentals of planning a machining process in a numerically controlled environment lie with the control and quality of operation planning and that planning time represents 50 to 80 percent of the actual machining time for single parts or small batches [2]. It becomes more critical for complex situations and new manufacturing technologies tend to extend the time further. Process planning has been defined by Alting as a function within the manufacturing environment which deals with the selection of manufacturing processes and parameters to be used to create the final product [3]. Investigations by Younis showed that an efficient CAPP system could result in reduction of the manufacturing costs by up to 30% and would also reduce the manufacturing cycle and the total engineering time by up to 50% [4]. Hence, the focus has been on process planning as the task of the determination of manufacturing processes, which for instance can determine whether or not a product should be manufactured through turning operations.

2. Previous Research

STEP-NC has been developed as a result of several research projects carried out by companies and university institutes which were focused on machining and inspection. Recently a number of projects involving the areas of STEP-NC based interoperability and research and development for various CNC manufacturing processes have been started. Overall research activities in specific areas of STEP-NC based on manufacturing technology and processes focus more on milling rather than turning activities, due to ISO 14649, Part 11 for milling [5] operation being established before Part 12 (Turning) [6]. Research activities in milling operations are more common than turning in the last five years. Work from Shimamura, is recognized as one of the earliest pieces of research to address an alternative for enhancing the capability of the existing NC machines economically using a PC-based retrofitting scheme for the manufacture of free form surfaces [7]. In 2002, research and development in terms of manufacturing technology and processes began with a proposal for the conceptual framework for designing and implementing an intelligent CNC system by Suh and Sheon [8], followed by Hardwick providing the first outlook on STEP-NC compliant manufacturing [9].

Lee and Bang have successfully developed and built a five-axis milling machine that is run by STEP-NC in XML [10] and another prototype system has been proposed by Newman et al for a STEP-compliant CAD/CAM system based on one of these frameworks using the new ISO 14649 standard for milling components [11]]. Finally test and validation methods have been proposed for testing data for numerical control [12]. It is noticeable that in 2006 researchers were extremely focused on this particular area, and details can be found a special issue edition of the International Journal of Computer Integrated Manufacturing (IJCIM) for STEP-Compliant Process Planning and Manufacturing [13]. Kumar introduced a STEP-compliant framework that makes use of self-learning algorithms that enable the manufacturing system to learn from previous data and results in error elimination and consistent quality products. It has been tested and certified for pocket and hole features for milling [14]. The latest achievement in 2007 is the successful development of a system called ST-FeatCAPP for prismatic parts based on ISO 14649 by [15]. The system maps a STEP AP224 XML data file, without using a complex feature recognition process, and produces the corresponding machining operations to generate the process plan and corresponding STEP-NC in XML format. Liu et al. also proposed a NC programming system for prismatic parts to be machined using STEP-NC machine tools, and the system consisted of three functional modules, namely i) a feature-based modeler, ii) a process planner and iii) a part program generator. The system can read the STEP-NC file and calculate the toolpath automatically compared to current systems that only produce low level control information [16]. One of the aims for the next generation of CNC machines is to be interoperable and adaptable so that they can respond quickly to changes in market demand and the manufacturing needs of customized products [13]. As part of this, 2006 was a time when researchers were particularly focused on proposing a framework for turning.

Most of the researchers proposed prototype systems to support data interoperability between the various CAx systems based on ISO standard 14649 that provided the first data exchange format used in the operation of NC machines [17-23]. Among these systems, G2STEP is the latest system to cover the machine functioning from pre-processor to STEP-NC part program generation including part program verification [19]. This development of a future manufacturing platform to enable different processes and capability such as milling applications, multi-axis and complex components as the basis of the integration of CAD/CAPP/CAM and CNC will be a major research task for years to come. The changing business environment over the past decades including globalization resulted in the standards ISO 10303 and ISO 14649 (STEP and STEP-NC) being introduced to solve the interoperability issues. For the time being many obstacles come from software/hardware vendors as the current approaches give them many opportunities to maintain their market, but the new standards can provide the platform for the future of global interoperable manufacturing [24-26]]. The Shop-floor Programming System (SFPS) introduced by Suh is the first system fully compliant with ISO 14649 [27] and to date, only this system has been patented (US patent references; 6400998, 65112961, 6556879, 6650960 and 6671571). SFPS and other systems related to STEP compliance that have been developed by academia all over the world are shown in Table 1.

Table 1: Review of STEP-Compliant Systems

No	Systems	Input	Output	Domain
1	**SFPS** (Milling) [28]	STEP AP203 & AP214	Part program physical file (text)	Prismatic
2	**STEPTurn [19, 29]**	STEP AP203	Part program physical file (text)	Rotational
3	**TurnSTEP [22]**	STEP AP	ISO 14649 physical file and extensible mark-up language (XML)	Rotational
4	**G-Code Free for lathe [17, 30]**	STEP AP 203	Native CNC language program	Rotational
5	**G2STEP**(2-axis turning machining) [21]	G-codes	STEP-NC part program	Rotational

TurnSTEP clearly defines the number of set-ups as either one set-up or two set-ups dependent on the independent machine format [22]. TurnSTEP has some weaknesses such as threads cannot be automatically generated but need to be defined and the process plan graph edited by the user manually. The output of this system can be in text and XML file formats [22]. As reported TurnSTEP is at a prototype stage and the implementation of another part, which is intelligent and autonomous is still under development. In terms of implementation of bi-directional information flow, none of the systems show how it would work and do not make it clear how the functionality is supported in prototype systems. So far the test components used contain only simple turning operations with z and x axes and do not cover multi-axis machining. The authors strongly agree with the suggestion by Heusinger and Rosso-Jr, for the STEP-NC compliant information structure to support the milling capability of the NC turning centre to meet industrial needs mapped by ISO 14649 Part 11 and 12 (milling and turning) [22, 31]. The author has noticed that all the proposed systems use a feature recognition approach and feature based techniques to allow the user to edit the part program. Xu has stressed that the commercial software, namely ST-Plan, can create STEP AP 224 machining features from CAD files (AP 203 or AP 214) [29]. All the proposed systems comply with ISO 14649 and this is the first stage to develop the universal manufacturing platform for CNC machining as proposed by Choi et al and Newman et al [20, 24]

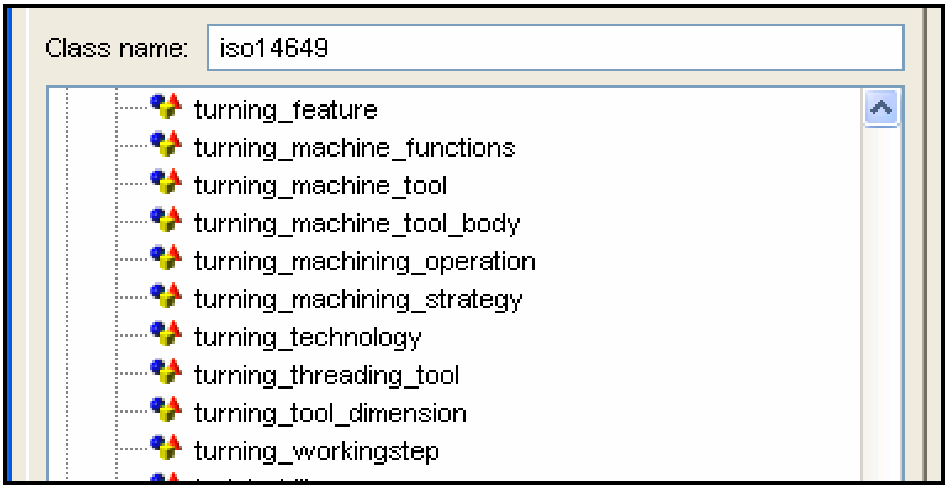
3. STEP-NC Code Generator

In this section, the construction of the proposed STEP-NC Code Generator using JBuilder 2005 and the JDataStore database is described. A STEP-NC compliant CAD/CAPP/CAM prototype system for turn/mill operations is being developed to consider the complexity of turning centre configurations and is based on STEP-NC turning features [6]. Depending on the tasks, the functions of these system are divided into i) work piece definition, ii) manufacturing features, iii) turn/mill operations, iv) project set-up, v) functional/technology, vi) manufacturing strategies, vii) placements/lengths and viii) tools.

3.1. Turning Classes

The process data for turning is provided in ISO14649 Part 12 [6], which specifies in the technology specific data elements that are needed as process data for turning [32] Part 10 [33] describes the general process data. Included in part 12 are features and operation data models for conventional turning, involving x and z movements. This again only represents the standard rotational turning with no representation of features and operations for composite machining such as C-axis milling operations. Figure 2 shows example turning classes based on ISO 14649. This system needs integrated manufacturing information about the product model and manufacturing resources, and is also based on an object oriented platform. Another aspect of information is the description of the manufacturing process, and the product geometry that can be created and manipulated. The structured model approach, in the STEP-NC manufacturing chain starts with the definition of the feature-based design geometry in a CAD/CAM system. An ISO 10303 Part 21 physical file is then generated from a STEP-NC Compliant CAPP/CAM system based on a suite of Java information classes from the STEP-NC ARM model definition, developed by Loughborough University. The operator is able to define STEP-NC features and is prompted for associated manufacturing inputs such as workingsteps, operations, tools, feeds, speeds consistent with the STEP-NC ISO 14649 Part 12 & 121 standards [6, 32]. The ISO 10303 Part 21 physical file is automatically generated. This file is processed by the STEP-NC translator (developed by ISW, Stuttgart and Siemens) and is converted into the Siemens proprietary format .MPF file [22]. The generated file can then be directly machined on any CNC workstation equipped with a Siemens controller and ShopTurn CAM software.

Figure 2: Turning classes



3.2. Information Model

The implementation of STEP-NC Code Generator consisted of three main stages, namely the representation of the information model, the development of the tool database and the construction of the system application as shown in figure 3. The first stage starts with the proposed system framework for STEP-NC Code Generator including an information model designed from the STEP-NC standards. The framework described mainly by the information and functional perspectives of the CAD to CNC process chain. The information model was established by Molina [34] and consists of a product model and a manufacturing model. The product model represents relevant information about the product throughout its life cycle while the manufacturing model is defined as an information model that identifies information describing the manufacturing resources, processes and strategies. The system has been modeled using UML diagrams as shown in figure 4 which clearly shows the system information model in terms of classes, attributes, relationships and operations.

Figure 3: Architecture of STEP-NC Code Generator

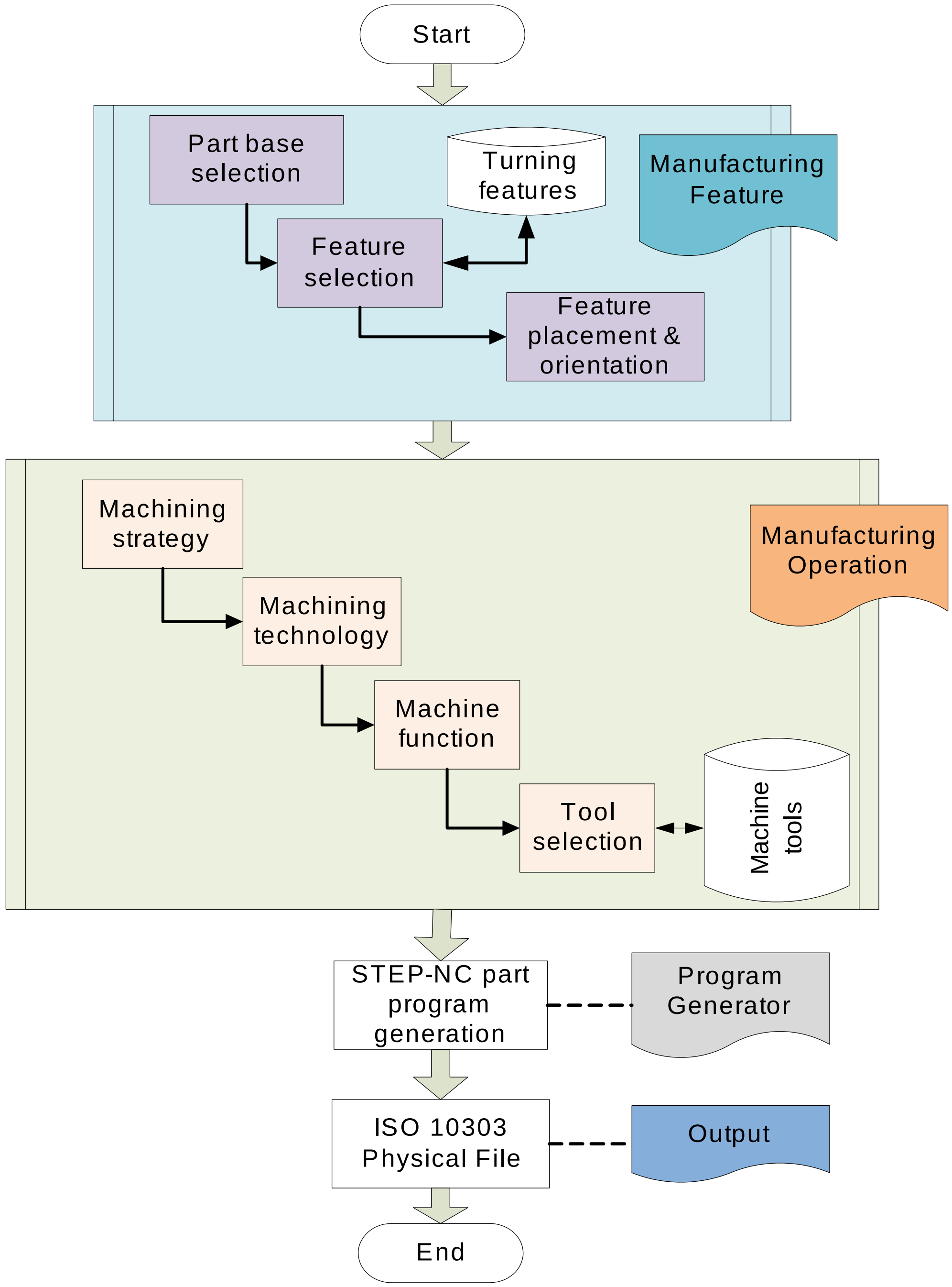
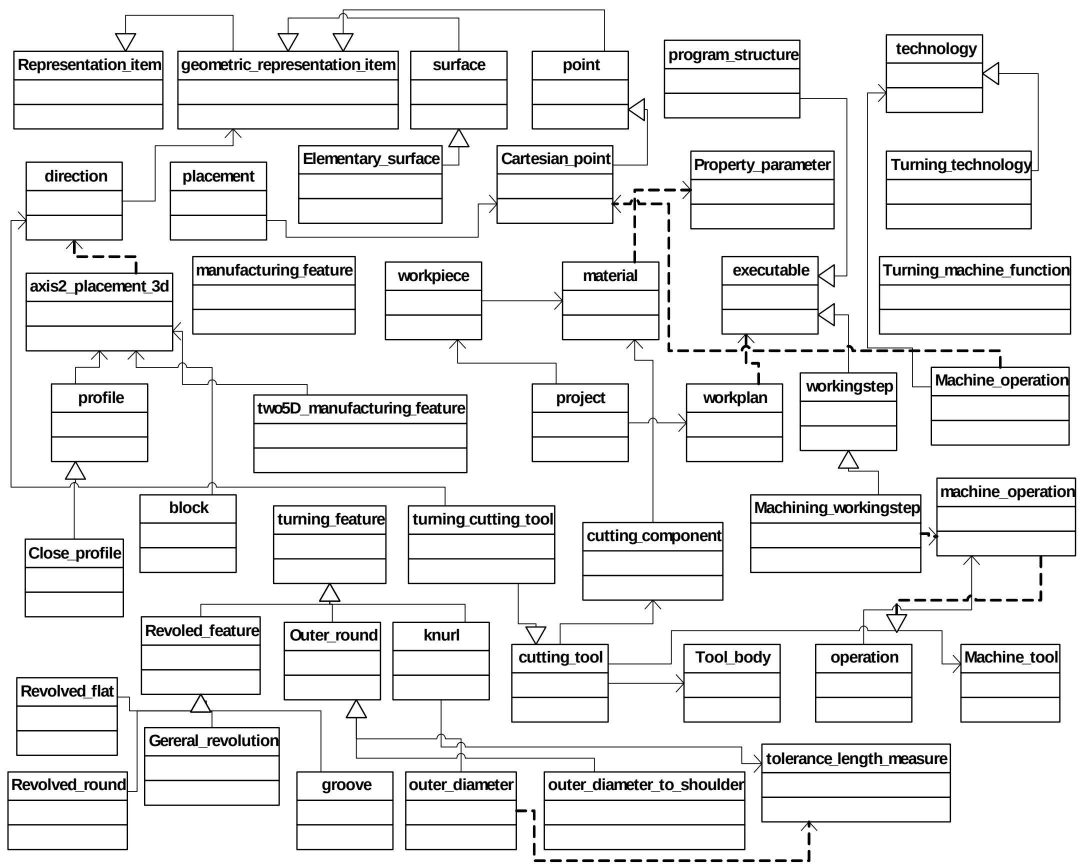


Figure 4 shows various objects in the STEP-NC Code Generator environment and the relationship between these objects. Each of the entities is based on ISO 14649 Part 10, 11, 12, 111 and 121 [5, 6, 32, 33, 35]. The class diagram depicting various classes of product and process data types was created using Rational Rose version 2000. The second stage in constructing the STEP-NC Code Generator is database system developed using JdataStore. In STEP-NC Code Generator the only cutting-tools database involved either turning and milling tools. The process starts with creating a file, establishing connection, test query and database development.

Figure 4: UML Diagram for STEP-NC Code Generator



3.3. The Turning Operation

Turning schema, definitions of technology specific data types representing machining features and processes for turning operation on lathes are defined with reference to the ISO standard [6]. The turning operation has two basic categories of machining operation; either roughing or finishing. All the turning operations are under the *machining_operation* sub class which is based on the operation class. In turning the workingsteps include manufacturing features and machining operations are defined by *turning_feature* and *turning_operations* respectively. The unified modeling language representation was developed for the diagrams, the constraints and the extension mechanisms. UML is the most widely known and used standardized notation for object-oriented analysis and design. The most useful standard UML diagrams are; use case diagram, class diagram, sequence diagram, state chart diagram, activity diagram, component diagram, and deployment diagram. For the purpose of this research, only class diagrams and their notation were used. The UML diagram represents the various objects in the turning manufacturing environment and the relationships between these objects. Each data type in these models is based on ISO 14649 Part 10 and Part 12 [6, 33]. A class diagram illustrating how the object identifies itself through a set package of ISO 14649 for manufacturing features consists of fields, constructors and methods using Java programming approach. The Java programming language was used for the development of software components based on an object oriented methodology and UML was utilized as the modeling language.

3.4. Graphic User Interface

The operational structure of the STEP-NC Code Generator is related to the programming procedure to generate a Part 21 File. It mainly seeks inputs from the system users via dialogs, either by selecting from standard data or keys in dialogs. The process begins with defined turning features; turning operations, turning strategies, tooling and code generation. The user can also define their own data or edit and modify their own data. The project dialog is the first dialog that appears on the screen when a new project is created and this is the starting point of the data input process. This dialog continues with a link to the work piece dialog and *workplan* dialog according to the STEP-NC CODE GENERATOR scheme by selecting the various options featured in a java combo box. After *workpiece* and *workplan* entity entry have taken place, the next entity considered is the turning feature. Figure 5 illustrates the *turning_machine_strategy* dialog depicting the various attributes of the turning strategy entity. Illustration in this dialog were help the user to get some ideas of the feature chosen. Next, the machining *workingsteps*, which are characterized by the *turning_machining_operation*, define all the machining operations and technology specific data needed to define a turning operation. The data is captured via manufacturing operation, machining strategies, turning technology and the machine function dialog. The output of STEP-NC Code Generator is a text file that is compliant with the ISO 10303-21 physical file format. The overall interface of STEP-NC Code Generator is illustrated in figure 6 and the output STEP file show in figure 7.

Figure 5: Turning machining strategy dialog

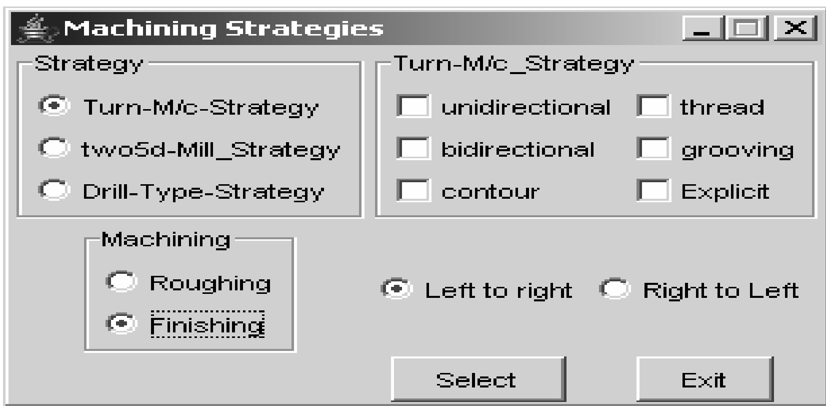


Figure 6: The STEP-NC Code Generator Prototype

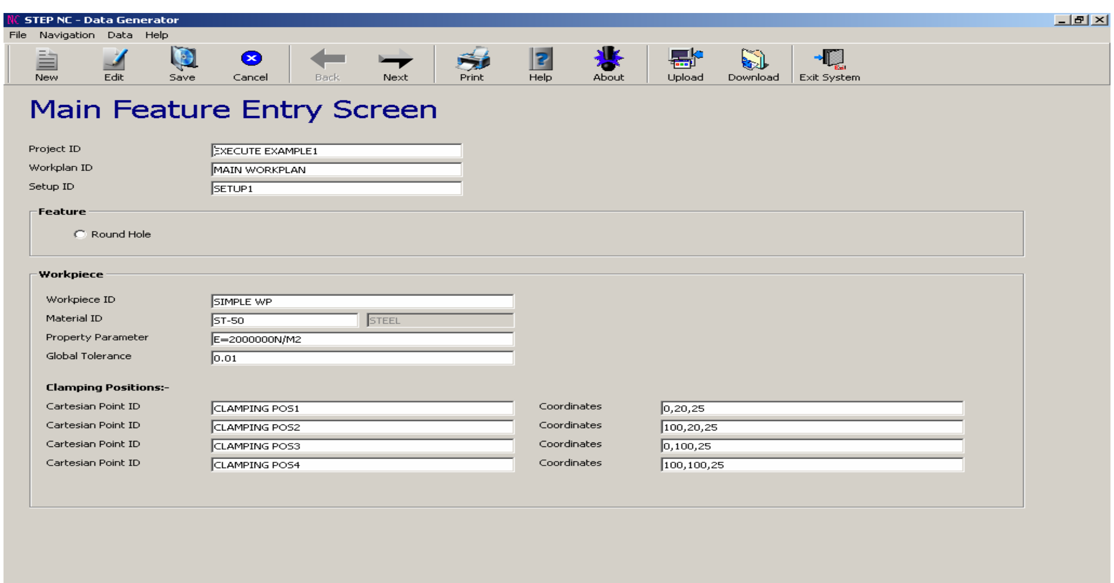
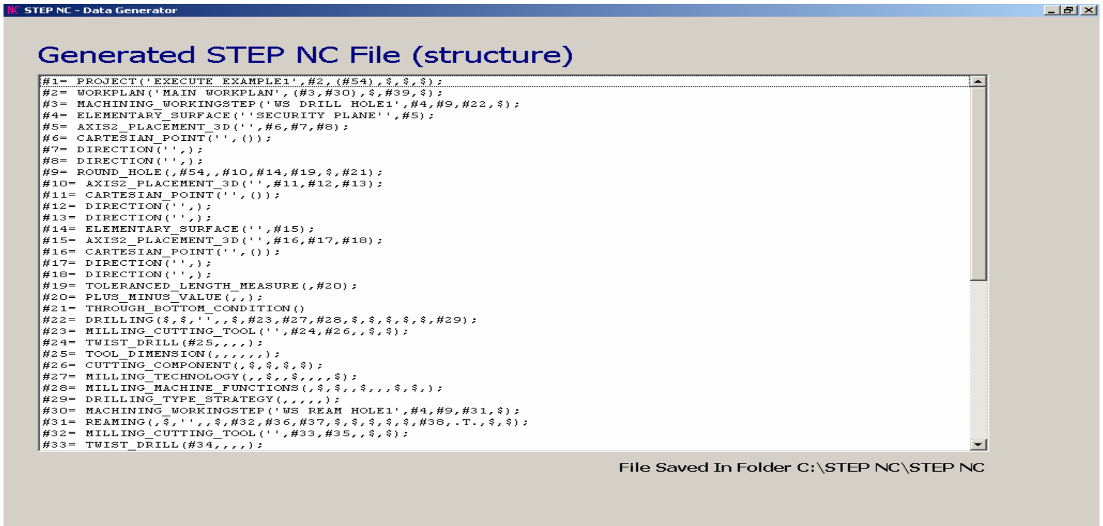


Figure 7: The STEP-NC Code Generator Output File



4. Case Study Component

An industrially-oriented case study component representing a selection of operations and features has been developed to illustrate and demonstrate the system. The case study component was adapted from component photographs in the Mazaktrol brochure. The component consists of turning features defined in STEP terminology as out diameter to shoulder, revolved flat, revolved round, grooves, thread and milling features, such as the revolved surface of the component. The constituent features of the component are shown in figure 8 where the features are not arranged in any particular hierarchy. The main reason for choosing this component is that it provides an introduction to the addition of milled features. This configuration represents the first level of turn/mill CNC turning for just the x, z and z axes as found for example in the Okuma and Homa model HL35M. Milling operations are allowed on the side and face of component. Parts requiring a second set-up are manually rotated and positioned and re-held in the chuck in relation to first set-up operations unless the machine has the capability of a counter spindle to machine the other side with single set-up. Overall configuration for range 2-5 axes turning centre for machining this component. The machining operations for this case study component consisted of turning, grooving, threading, off centre drilling and milling on side face. In terms of general attributes the component is double sided asymmetrical. The final component is shown in figure 9.

Figure 8: Turning centre configuration for case study component

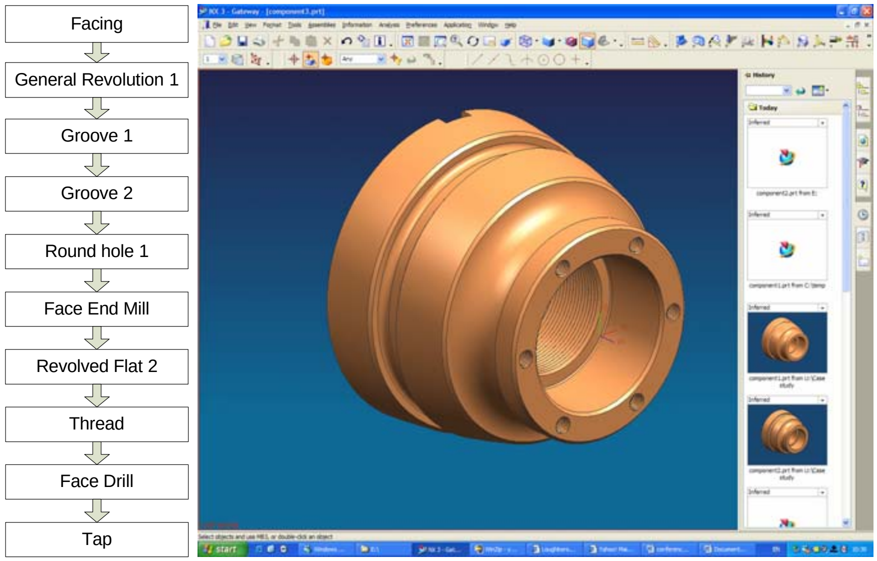


Figure 9: Case study component.

5. Summary and Concluding Remarks

This research work was motivated by industrial requirements of concurrent engineering, standard product data models and an integrated manufacturing environment, which are further reflected in process planning. The conclusions of the work can be elaborated as the information modeling in this area addresses the problem of capturing and representing manufacturing information related to resources and processes. The interaction between the different types of models could provide a description of the products, how they should be manufactured, and what manufacturing resources should be used. This would provide an information platform upon which several different computer-based tools to support the innovation process can be built. This will allow the provision of reliable manufacturing information to assist in the performance of product development life cycle activities and related decisions. STEP-NC Code Generator was developed to generate a Part 21 file based on machining features to support the interactive generation of process plans utilizing feature extraction. The system was constructed using a structured methodology for its planning and object-oriented methods for its implementation. A case study component was tested to show that the new approach (STEP-NC) can generate code which is comparable to the currently used G-code with some benefits such as the elimination of the post-processor. Efforts are under way to fulfill the STEP-NC challenge by combining Parts 11 and 12, for turn/mill operations. STEP-NC forms a possible basis to satisfy the latest requirements and demands with respect to a bi-directional CAx process chain for machining. STEP-NC forms a possible basis to satisfy the latest requirements and demands with respect to a bi-directional CAx process chain for machining. In addition its development as a future manufacturing platform to enable different process models to be integrated for the adaptable integration of CAD/CAPP/CAM and CNC will be a major avenue of research for years to come. It is expected that the recommended future extensions will enhance the usefulness of this work, and will meet the requirements for global interoperable manufacturing for real-life parts. There is no doubt, that so far none of the proposed systems are fully capable of machining turn/mill components. Work to date has focused on the separate parts of ISO 14649 using Part 11 for milling operations including drilling and Part 12 for turning. No significant work has been done on combining the two parts for turn/mill components. However, the authors and other researchers [25, 26, 30, 36, 37] believe that this industrial requirement could be achieved through research and development involving collaboration by researchers, users, manufacturers, academia and the ISO committee. If developers look from the business perspective, and academia focuses on theoretical aspects the objective of combination turning and milling machining compliance with the new standard (STEP-NC) can be realized.

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