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# Review of STEP-compliant Manufacturing for Turning Operation

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**Abstract:** Much software and hardware has been developed around the globe to organise and integrate the different phases of a Product Life-cycle Management (PLM) in conception, design, manufacture, service or disposal phases. This study focuses just on the design (CAD) and manufacture (CAPP, CAM and CNC) where there is potential to integrate a wide variety of software applications. In order to achieve this principal aim, a number of research problems have been identified. The current CNC regime is considered to rely on low level codes such as the description of tool movements and switching instructions. Today with the latest technology the information beyond tool movement and switching instruction such as tooling, manufacturing features and process sequences are needed to support global adaptability for manufacturing with a specific focus on CNC-based manufacture. STEP-NC is considered to have the necessary rich information including what to make and how to make. Interoperability problem; particular companies use various systems for different components which come from more than one supplier and need to be able to exchange information reliably and rapidly. Another example is when a manufacturer needs to move machining operations to another location. The new location has different software applications for the same function, so all software programs must be rewritten, potentially resulting in very considerable cost because of product launch delay, additional labour costs and loss of product quality. ISO 6983, commonly known as G and M codes, focuses on programming the path of the cutter Centre Location (CL) with respect to the machine axes, rather than the machining task with respect to a part. This study aims to explore the application of new data standards for CNC machining of turned parts to enable data exchange of manufacturing rich information from CAD to CNC to support interoperable manufacture. This study provides a literature review of the STEP-NC compliant research around the world based on machining operations and reviews of STEP-NC-Compliant systems for the manufacturing environment, focused on turning operations.

**Key words:** STEP-NC, ISO14649, CADCAM, CNC

## INTRODUCTION

In the last few decades the economic priorities of manufacturing have shifted from being based on low cost of a standard product without compromise 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 globalisation. This concept found expression in DABA, or Design Anywhere, Build Anywhere (Normile and Tyrka, 2000), 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 and manufacturing has its team. The design focus is to design the product and pass information to engineers to decide how to make the product or how to realise 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 Computer Aided Design (CAD) and Computer Aided Manufacturing (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.

## STANDARD PRODUCT DATA EXCHANGE

During the design process and production, both teams have to work closely until the final product is realised. One of the issues in that process is data transfer and data exchange. If the product is very complex such as those found in aerospace and automotive industries, the final product comes with varieties of sub-components that have been designed by different departments using a variety tools or software. For example the part design information might be transferred using any one of a number of industry data exchange standards such as IGES, DXF and other formats. To eliminate the problem resulting from a variety of standards, new standards have been developed. ISO 10303 (informally known as STEP) and more recently ISO 14649 (informally known as STEP-NC) have been introduced as part of an international effort aimed at achieving fully interoperability and bi-directional information exchange (ISO 2003). To date, two different ISO subcommittees are working towards such a STEP-NC standard with two different focii; ISO TC 184/SC1 is working on ISO 14649 termed the Application Reference Model (ARM) whereas ISO TC 184/SC4 is developing STEP AP-238, termed the Application Interpreted Model (AIM). Both models represent the data model information to program intelligent CNC controllers, but the AIM is fully STEP compliant, whereas the ARM contains the information required to program a CNC machine. The ARM is to be used in an environment in which CAM systems have exact information from the shopfloor, whereas AIM is more suitable for a complete design and manufacturing integration (Xu *et al*., 2005).

## STEP-NC ENVIRONMENT FOR MANUFACTURING

ISO 14649 is referred to as STEP-NC due to its interaction with ISO 10303 (STEP) and was initiated to provide a data model for a new breed of intelligent CNC controller that is well-structured with workplans and working steps. ISO 14649 aims to model the complete information requirement that must exist in a controller to control a machine tool by defining what-to-make and plans how-to-make. STEP-NC has been developed as a result of several research projects carried out by companies and academic institutions. In terms of international research and development into these standards, projects such as OPTIMAL

(ESPRIT, 1997) largely overcame the legacy standards of ISO 6983. OPTIMAL is one of the earliest STEP-compliant systems and is based on feature information and machining strategies. The research does not stop there, because the researchers now focus on identifying and defining interoperable manufacturing and STEP-NC compliance in the context of concurrent engineering. In particular, information reviews of STEP-NC, manufacturing processes and manufacturing resources are also major foci in this research area.

STEP-NC is aimed at overcoming the problems left from ISO 6983 which focuses on programming the path of the cutter Centre Location (CL) referred to the machine axes rather than machining tasks. One approach to the problem is to exchange a high level of information between CADCAM systems and NC controllers. STEP-NC works by manufacturing features, operations and the working steps. The STEP-Compliant Data programming interface for numerical controls has been introduced and proposed for standardization by the International community, where its higher level of information aims to overcome the shortcomings of contemporary NC programming. The new NC programming data model purports to support a well structured hierarchical interface and object-oriented and two way communication from the CAD environment down to the shop floor (Muller, 2000). STEP-NC is an improved interface between the CAD world and the manufacturing arena. It is recognized as such since it provides process information at the time and place of the manufacturing activity. The proposed STEP-NC data format supports accurate and timely adaptive control of the production equipment and provides feedback for information back to the planning activity.

The current standard of programming NC namely G and M codes or ISO 6983 has had no significant change since the format of NC machines was developed at MIT in 1952 (Muller, 2000; Fortin and Chatelain, 2001; Ahlquist, 2002; Newman, 2004; Allen *et al*., 2005; Xu *et al*., 2006). Figure 1 shows (Michaloski, 2005) the evolution of NC machines since using hardwired configurations to the current fully-integrated systems that can be found almost everywhere, from small job shops in rural communities to multi-national companies in large urban areas. During the pre-Computer-Numerical Control (CNC) epoch the program language had been modified by vendors and controller developers who added their own commands. Since, the 1970's significant developments have been made towards more automatic and reliable computer numerically controlled machines with new machining processes.

Today's highly sophisticated Computer Numerically Controlled (CNC) machines utilise a variety of cutting technologies such as multi-turret and multi-spindle in complex axial configurations and this machine capability increases the level of flexibility and capability compared to the previous decade (Nassehi *et al*., 2006). A large number of Computer Aided Systems (CAx) have been developed and implemented in recent years to support all stages of product life by computer systems and many can simulate virtual CNC machining with the

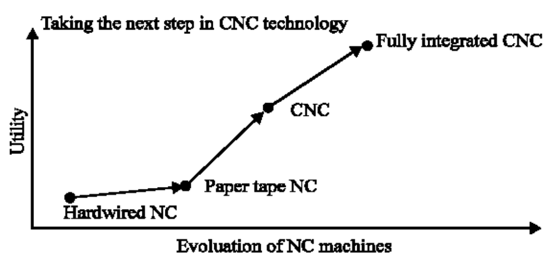


Fig. 1: Evolution of NC Machines (Michaloski, 2005)

complete machine toolpath (Newman, 2004). Since, the first NC machine was introduced in 1952, various process plan packages have been developed and each system tried to interpret the part data format more reliably. Most of these systems are specialized to support certain applications and are based on an information model that handles the application specific view of the product. These current trends are aimed at open systems but they are predominantly used in retrofitting applications for conventional NC machines. Some of the CAx systems do not share common databases for the product information due to the resistance from software and hardware vendors in terms of business strategy.

**Single Standard**

Manufacturing companies invariably have more than one CNC machine model due to business development, technology and market demand. To date there nearly 2000 CNC models around the globe from more than 300 CNC machine manufacturers. Of course this variety of models needs a single standard particularly in the area of machining to improve productivity by increasing the richness of interactions and transactions. An initial standard is ISO 10303, informally known as the Standard for the Exchange of Product Model Data (ISO) which aims to provide a single International Standard for all aspects of technical products (ISO, 1994). Before that data exchange standards such as SET (Bhandarkar and Nagi, 1997), VDA and IGES (Roger and Walt, 1980) were proposed to meet the requirements of the CAD/CAPP/CAM industry but have still not solved the portability and interoperability issues.

The majority of researchers have focused their attention on milling operations, while this research opens the opportunity for the author to explore the lack of knowledge in the area of turning. During this study, commercial software from established CNC controllers has still not been launched as the products are still at the research and development stage. In terms of ISO documents, not all ISO 14649 documents have been finalised, some are at the draft version and still subject to discussion among ISO committee members (ISO TC184 SC1 and SC4).

**Feature Research Related to Rotational Parts**

Li successfully developed a system for a part feature recognition for a conversion language from CAD to CAM for rotational parts (Li, 1988). Yang *et al.* (1994) introduced a case-based process planning system called PROCASE which generates new process routines through learning from existing process routines for machining of rotational parts (Yang *et al.*, 1994). Tseng and Joshi extended the feature recognition domain to include the classes of parts with interacting rotational and prismatic features to develope the machining volume generation method (Tseng *et al.*, 1998). Subsequently Aslan *et al.* (1999) proposed the approach of starting from part design, extracting data from the CAD model and finally making preparations for a feature called FMPA for rotational parts (Aslan *et al.*, 1999).

Shunmugam *et al.* (2002) described a method for preliminary process planning to determine feature sequence and precedence in asymmetric parts using genetic algorithms Shunmugam *et al.* (2002). They categorised the features in a hierarchical structure that has primary features (face, cylinder and cone) and secondary features (groove, chamfer, thread and C-axis features). In their structure the C-axis features are a radial hole, axial hole, slot and keyway. Figure 2 depicts the hierarchical structure for the form features. Fidan developed a STEP AP224 feature generator where the features were used as the basic entities for part design consisting of three phases (1) feature library, (2) feature modeller and (3) pre-processor (Fidan, 2004). Yildiz *et al.* (2006) developed an automatic feature recognition

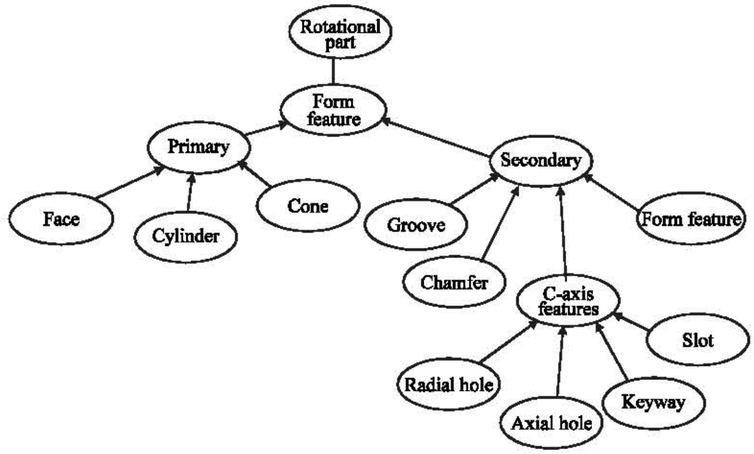


Fig. 2: The hierarchical structure of form features proposed for asymmetric parts (Shunmugam *et al*., 2002)

and CNC code generation system for rotational parts using the Delphi 7 programming language and using DXF format as data input to the system (Yildiz *et al*., 2006).

## REVIEW OF STEP-COMPLIANT MANUFACTURING FOR TURNING

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 (Xu and Newman, 2006). 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 (Table 1). 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 (Shin *et al*., 2007). 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.

### Review of STEP-Compliant Systems

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 (Xu *et al*., 2006). The changing business environment over the past decades including globalisation 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 (Newman *et al*., 2007).

The Shop-floor Programming System (SFPS) introduced by Suh is the first system fully compliant with ISO 14649 (Suh *et al*., 2003) and to date, only this system has been patented

Tables 1: Summary review of STEP-compliant manufacturing for turning operations

| Author(s) | Concerns |
|---|---|
| Xu and Wang (2004) | Developed a STEP-NC Converter and a retrofitted CNC lathe realizing a G-code free machining scenario |
| Wei *et al.* (2005) | Proposed a framework for a CNC turning system based on STEP-NC with eighteen functional modules, involved in the software-based framework of a STEP-NC control system. As a result, this study shows the high potential to aid the development of new CNC turning systems (Wei *et al.*, 2005) |
| Shin *et al.* (2007) | Presented development of a prototype G2STEP system to convert G-codes to a STEP-NC file. |
| Choi *et al.* (2006) | Introduced the development process for TurnSTEP using structured and object oriented methodology to provide a distributed architecture for e-manufacturing. |
| Suh *et al.* (2006) | Presents a STEP–CNC system for turning, named TurnSTEP and demonstrated the potential and power of STEP-NC based CNC systems compared with conventional CNC systems |
| Heusinger *et al.* (2006) | Presented a prototype methodology using technology based on ISO14649-12 for implementing a standardised CAx process chain for rotational asymmetric parts |
| Yusof and Case (2009) | Presents the current CAPP and CAM systems related to STEP-NC created by other researchers and the development of a STEP-NC compliant CAD /CAPP /CAM system (Yusof and Case, 2009) |

Table 2: Review of STEP-Compliant systems

| Systems | Input | Output | Domain |
|---|---|---|---|
| SFPS (Milling) (Suh *et al.*, 2003) | STEP AP203 and AP214 | Part program physical file (text) | Prismatic |
| STEPTurn (Heusinger *et al.*, 2006; Xu, 2006) | STEP AP203 | Part program physical file (text) | Rotational |
| TurnSTEP (Choi *et al.*, 2006; Suh *et al.*, 2006) | STEP AP | ISO 14649 physical file and extensible mark-up language (XML) | Rotational |
| G-Code Free for lathe (Xu and Wang, 2004; Xu *et al.*, 2005) | STEP AP 203 | Native CNC language program | Rotational |
| G2STEP (2-axis turning machining) (Shin *et al.*, 2007) | G-codes | STEP-NC part program | Rotational |

(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 2.

**Shop-Floor Programming System (SFPS)**

The Shop-floor Programming System (SFPS) has been developed by researchers from POSTECH, South Korea as a computer assisted part programming tool capable of interfacing with a new CNC controller called STEP-CNC (STEP-compliant CNC) (Suh *et al.*, 2003). This system has been proposed for prismatic components, as shown in Fig. 3, for generating ISO 14649 part programs based on the ISO documents such as ISO 14649 Parts 10, 11, 111 and ISO 10303 Parts 21, 22, 23, 42, 203 and 224 (ISO, 2004). Suh *et al.* (2003), provided a useful definition of architecture and functionality including.

- **Full compliance with ISO 14649 and STEP APs:** This is the fundamental requirement for SFPS for STEP-CNC
- **Feature recognition/mapping capability:** An ISO 14649 part program is depicted with respect to the machining features. If the part geometry is given by AP203 feature recognition (mapping) is required for SFPS before proceeding to the process planning procedure

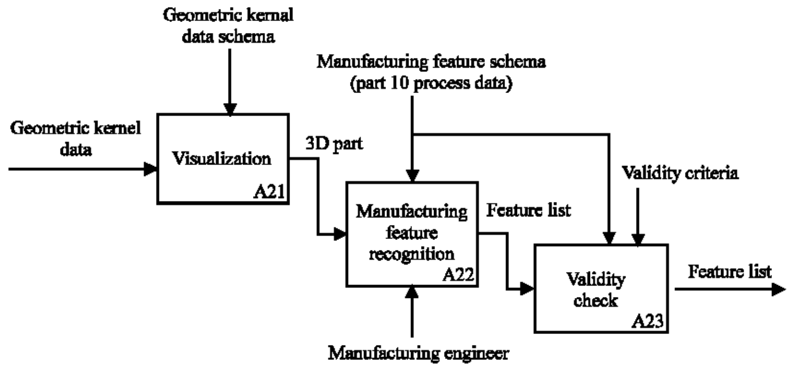


Fig. 3: Machining feature recognition for SFPS (Suh *et al*., 2003)

- **Database structure for STEP interface:** The database of SFPS is structured such that it can interface with other STEP databases such as a STEP-repository storing all information, using a complete suite of STEP schema
- **Accommodation of conventional CNC:** As mentioned earlier, there are three types of STEP-CNC depending on how ISO 14649 is interfaced with CNC. The first type uses conventional CNC based on ISO 6983 via post-processing. To accommodate conventional CNC, SFPS should be designed to output in the form of ISO 6983 as well as ISO 14649
- **Editing capability:** SFPS is also used for editing existing ISO 14649 part programs. For such a purpose, SFPS should be able to read (interpret) the ISO 14649 part program and check the logical and syntax errors in it
- **Human interface:** For accuracy and efficiency of part programming, SFPS should be designed to be user friendly. A graphic user interface and diagnostic messages together with visual verification are necessary
- **Process sequence editor:** Conventionally, the process sequence is given in a linear (sequential) fashion. In practice, however, there often exist situations where the process sequence is not necessarily linear. In ISO 14649, the sequence of working steps (program_structure ) can be given in a non-linear fashion. This is to give flexibility to CNC in executing the tasks. However, programming a non-linear process plan is not easy for the programmer and hence a process sequence editor should be provided by SFPS
- **Optimization/knowledge-based system:** Completion of an ISO 14649 part program requires technical information. Even if a push-button interface is used, specifying all the entries may be cumbersome. Thus, minimization of input and provision of optimized values (cutting conditions, tool selections) are necessary using knowledge-based algorithms and technical databases

SFPS provides a method for generating a part program for a STEP-NC system based on seven steps (Suh and Cheon, 2004):

- Generating geometric kernel data by interpreting a STEP physical file or an ISO 14649 part program
- Recognizing manufacturing features from the geometric kernel data
- setting a process plan according to the ISO 14649 on the basis of the manufacturing features

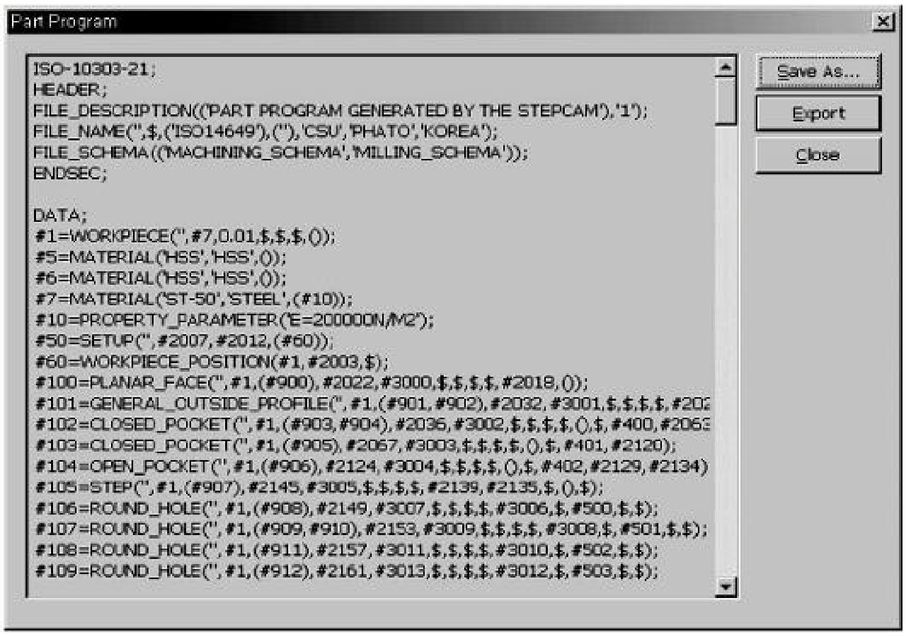


Fig. 4: Generated ISO Part Program from SFPS (Suh *et al.*, 2003)

- Editing the process plan
- Generating an ISO 14649 part program from the edited process plan as shown in Fig. 4
- Generating a tool path based on manufacturing feature information specified in the ISO 14649 part program
- Verifying the produced tool path in a CNC (computer-based numerical control) apparatus

SFPS is a pilot system created by one of the ISO 14649 authors during the time when ISO 14649 was at the draft and final draft for ISO documentation and had been presented to the ISO 14649 committee. SFPS is recognised as one of the pioneer systems to have successfully generated a part program from a design file format in either AP 203 or AP 214 (Suh and Cheon, 2004; Suh *et al.*, 2003; Xu *et al.*, 2005). This pilot system is becoming the basic platform for future improvement to milling operations. It also provides a possible method that could be applicable to turning operations.

**STEPTurn**

STEPTurn has been developed by researchers from the Institute for Control Engineering of Machine Tools and Manufacturing Units at the University of Stuttgart (ISW), Germany. ISW adopted the STEP and STEP-NC standards for turned parts (Heusinger *et al.*, 2006; Xu, 2006). STEPTurn is a CAPP system bridging the gap between CAD and CAM as shown in Fig. 5 and it reads geometry data firstly from a STEP AP-203 Part 21 file and displays the part geometry and performs normal process-planning tasks such as feature recognition and Workingstep sequencing in order to generate a STEP-NC physical file (Heusinger *et al.*, 2006; Xu, 2006). According to Heusinger, the stages in using STEPTurn are (Heusinger 2001); (1) Input of AP 203 file, (2) Display of the workpiece, (3) Generation of operations, strategies and technology, (4) Definition of the workplan and (5) Output of the STEP-NC program.

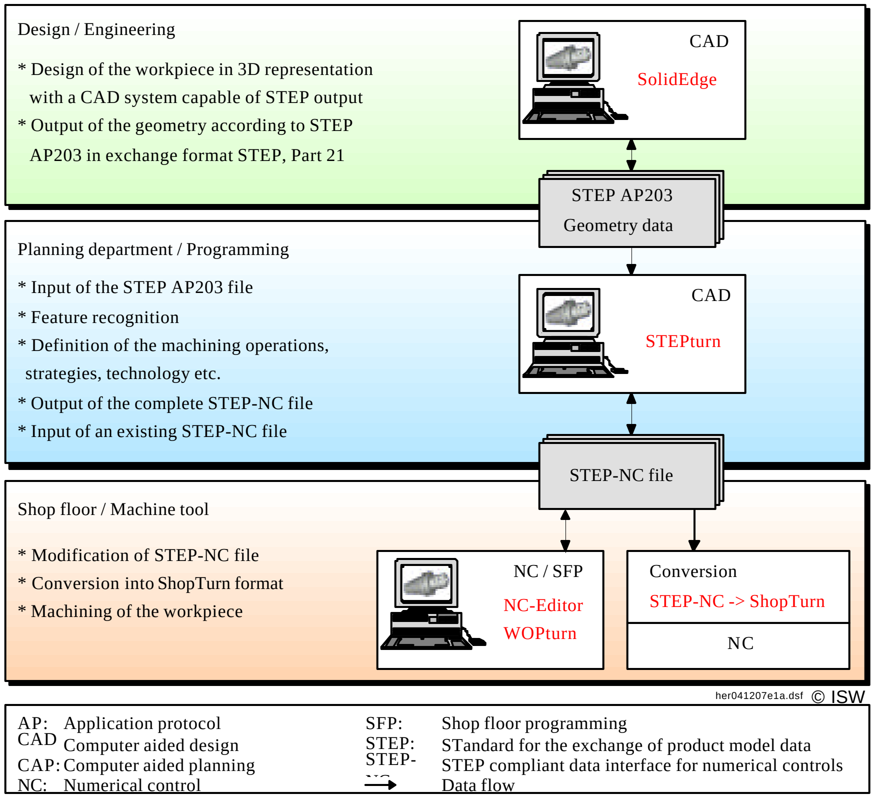


Fig. 5: Implemented process chain for turning (Heusinger *et al*., 2006)

ShopTurn is used as the conversion data format of Siemens which is the input format to generate tool paths for the Siemens 840D NC controller of the Boehringer machine tool as shown in Fig. 6 (Heusinger *et al*., 2006). The data filling the shop-floor-oriented feature dialogs was mapped onto the internal STEP-NC data representation. After definition of features and their assignment to setups, operations were generated automatically. Where the operations have to be adapted to any other purpose, the operation data may be modified in operation dialogs (Muller, 2004).

So, far STEPTurn has been tested only for simple working steps for machining cylinders and cones using standard turning machines as shown in Fig. 7 (z and x axis only) and does not really represent the capability of the proposed system. As stated by the researchers the prototype system needs to be extended for mill-turn components and to produce output in XML schemas (Heusinger *et al*., 2006). As clearly presented in the Heusinger study STEPTurn only works on a specific machine (Heusinger *et al*., 2006).

**TurnSTEP**

TurnSTEP is claimed by Choi to be fully compliant with ISO 14649 and suitable for e-manufacturing (Choi, *et al*., 2006; Suh *et al*., 2006). TurnSTEP has been developed using three sub-systems namely; (1) CGS (Code Generating System) to generate neutral independent STEP-NC code based on ISO 14649, (2) CES (Code Editing System), to edit or

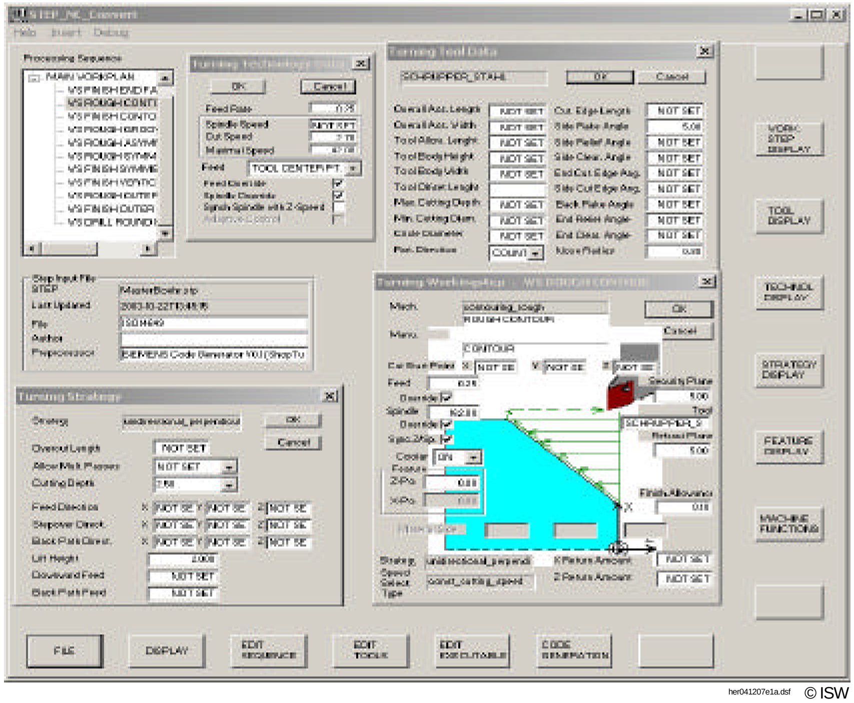

Fig. 6: Conversion tool for translating STEP-NC to ShopTurn format (Heusinger *et al*., 2006)

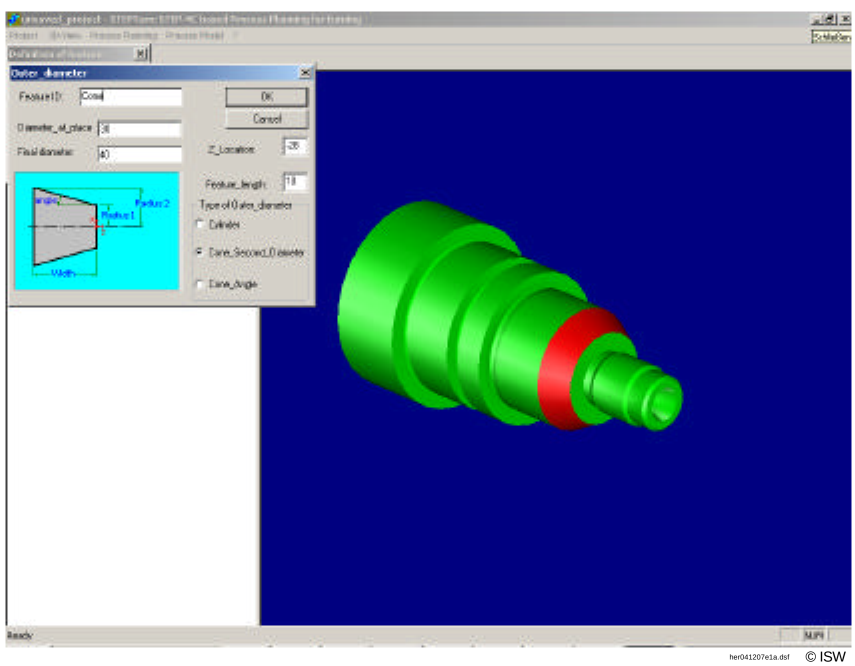

Fig. 7: Prototypical CAP system: STEPTurn (Heusinger *et al*., 2006)

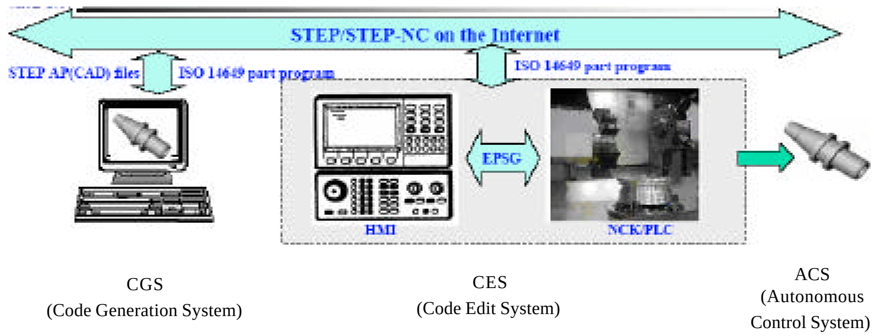


Fig. 8: Three subsystems of the TurnSTEP (Choi *et al*., 2006)

customise machine tool data to be used for execution of STEP-NC code and (3) ACS (Autonomous Control System) as shown in Fig. 8 (Choi *et al*., 2006; Suh *et al*., 2006). In terms of turning machining, TurnSTEP is one of the earliest systems to have been developed for compliance with STEP-NC and supported by XML schema. From the design perspective this system needs (Choi *et al*., 2006):

- To provide a distributed architecture for e-manufacturing
- To support intelligent and autonomous execution of NC machines by fully utilizing rich STEP-NC information
- To optimize the machining sequence of a target manufacturing process
- To support automated and interactive generation of a process plan utilizing feature recognition, alternative generation, process sequence, cutting condition, etc.
- To provide a variety of data interfaces for e-manufacturing including physical files and Extensible Markup Language (XML) translation capability

TurnSTEP uses input geometry in an AP 203 format file to convert geometry information to an internal data form and map it to machining features by producing the machine independent format process planning (Suh *et al*., 2006). TurnSTEP also allows the operators to edit existing files using a user interface and the output can be stored by as a nonlinear process plan graph. This system has been tested using the simple example component in ISO 14649 Part 12 with standard turning operations. It loads an AP 203 file from a CAD system via the internet and visualises the part geometry. The blank part material is then defined, followed by determination of the number of set-ups and finally it generates a virtual machining simulation and machines the part (Suh *et al*., 2006).

**G-Code Free Lathe**

This STEP-compliant CAD/CAPP/CAM/CNC system has been developed in the Manufacturing Systems Group at the University of Auckland, New Zealand and was aimed at making product data interchangeable, product information flow seamless and a system that is independent of any CAD/CAM system (Xu and Wang, 2004). The proposed system has two parts (1) retrofitting an existing CNC lathe and (2) a STEP CNC converter that is run with four phases; (1) generation of generic STEP-NC programs, (2) generation of a native STEP-NC program, (3) generation of a native CNC language file and (5) execution of the process plan on a CNC machine as shown in Fig. 9 (Xu and Wang, 2004). Xu describes

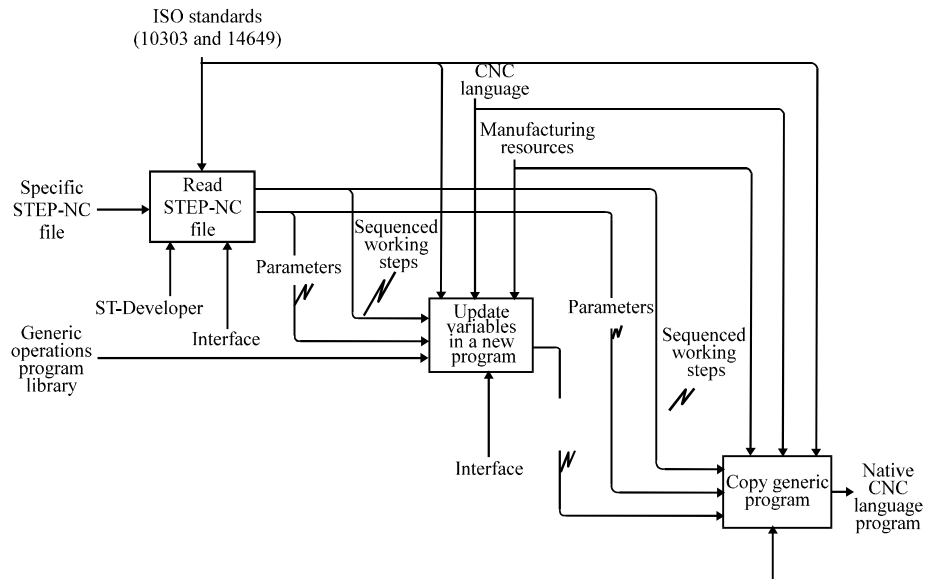


Fig. 9: IDEF0 diagram of the STEP-compliant CAD/CAPP/CAM/CNC system (Xu and Wang, 2004)

how the low level language rather then G-codes is interpreted by STEP-NC into this axis movement language by using a 6K program and passed on to the retrofitted lathe (Xu and Wang, 2004; Xu, 2006).

**G2STEP**

The G2STEP system has been designed based on design and functional considerations developed by researchers from the National Research Laboratory for STEP-NC, POSTECH, South Korea together with a researcher from the EPFL, Switzerland and is based on the ISO 14649 data model, the ARM model and instruction schema on G-code based on the FANUC0 series (Shin *et al*., 2007). The main proposal for G2STEP is to generate a STEP-NC part program from a G-code program with additional information related to real machining that is easily generated by skilled operators. G2STEP comes with nine functions as summarised below:

- **Pre-processor function:** Each block of a G-code part program together with other information is interpreted and stored in the pre-defined data structure. These blocks are divided using some clues as to which G-codes form boundaries to start new machining operations and these blocks are grouped into working steps, the basic unit of STEP-NC
- **Machine tool generation function:** The tool holder and insert, expressed by the tool maker's catalogue model number, is converted into functional requirements for the model defined in ISO 14649 Part 111 (ISO/FDIS 2004) and Part 121 (ISO, 2005)
- **Technology generation function:** Technology information such as spindle speed control, feedrate and so on is generated to interpret an S or F-code
- **Machine function generation function:** Machine functions such as coolant on-off, are generated as interpretations of the miscellaneous code (M-code)


Fig. 10: G-code load to G2STEP system (Shin *et al*., 2007)

- **Machining operation generation function:** The machining operation is mainly generated and divided into roughing and finishing. This information needs to use information about tools and technology and hence the machining operation generation function follows the functions which generate these
- **Feature recognition function:** The feature profile remaining after a workingstep is generated and the manufacturing feature, defined by STEP-NC, is recognized by a profile and pre-determined machining operation
- **Machining strategy generation function:** The approach/retract strategy and machining strategy for tool paths are generated
- **STEP-NC part program generation function:** The enriched information of the working steps is stored in succession, one workplan entity includes these working steps and finally these are included in one project entity, the first interpreted entity in the STEP-NC data model. This information is instanced in the STEP-NC schema and is printed in a physical file format according to the ISO 10303 Part 21 rule (ISO, 2002)
- **Part program verification function:** The STEP-NC part program is verified and modified through visualization. The machined feature profile is shown and each workingstep can be examined and edited through the workingstep editor

G2STEP has been developed for 2-axis CNC Turning using the C++ language and runs on a Windows platform used a geometric modelling kernel and OpenGL for the GUI (Shin *et al*., 2007). As mentioned, one of the functions for G2STEP begins with a pre-processor to interpret G-code blocks such as instructions, location coordinates, feedrate, spindle speed control and allocated tool number which are stored into groups according to workingstep as shown in Fig. 10. For machining operation generation, G2STEP allows the skilled operator to control the spindle speed and feedrate based on either strong, normal or weak rules that have been determined in each machining operation rule. The subsequent process is feature recognition, based on machining features using Boolean operations with workpiece with machining areas. As stated in ISO 14649, the machining strategy for turning operations refers to bidirectional, unidirectional, contour or grooving strategies. Again the machining strategy is determined from strong, normal or weak rules.

The commercial controller to interpret STEP-NC part programs has not been launched yet and this prototype provides a basic simulation only. G2STEP has been verified through Virtual NC software from Delmia. G2STEP is at the prototype stage and future work is needed to add milling applications, multi-axis and complex machining (Shin *et al.*, 2007).

**Review Discussion**

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 author and some researchers (Heusinger *et al.*, 2006) 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 realised.

If we focus on turning operations, only three proposed systems are available, STEPTurn, TurnSTEP and G2STEP. But, if we scope for e-manufacturing, STEPTurn leads in this aspect due to the capability of internet file transfer. TurnSTEP clearly defines the number of set-ups as either one set-up or two set-ups dependent on the independent machine format (Suh *et al.*, 2006). 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 (Suh *et al.*, 2006). 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 author strongly agrees with the suggestion by Heusinger *et al.* (2006) 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) (Heusinger *et al.*, 2006; Yusof and Case, 2009).

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) (Xu and Newman, 2006). 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.*, 2006; Newman *et al.*, 2007).

## CONCLUSION

This study presents a comprehensive literature review of the background to the evolution of CNC manufacturing, past and current standards for machine programming and the current implementation of a new standard focusing on ISO 14649 or STEP-NC. The relevant research issues for the development and introduction of reconfigurable machines tools are presented focussed on turning operations. The study focused on theoretical research consists of the proposed system framework and information models. For the experimental research section, a prototype STEP-NC compliant CAD/CAPP/CAM system has been implemented and an industrially-oriented case study has been developed to illustrate and demonstrate this system.

This study provides a literature review of the STEP-NC compliant research around the world focused on STEP-Compliant NC Research Projects; the Intelligent Manufacturing System (IMS) and the intelligent manufacture for STEP-NC compliant machining and inspection as an overall view based on STEP-NC. The IMS and intelligent manufacture for STEP-NC compliant machining and inspection project was successful developed and involved both industries and academia around the world. The study concentrated on the systems or prototypes which have been developed by other researchers. STEP-Compliant systems for the manufacturing environment have been reviewed focused on turning operations such as the Shop-Floor Programming System (SFPS), STEPTurn, TurnSTEP, G-code free for lathe and G2STEP. All the systems have advantages and disadvantages and the opinions are based on published information rather than firsthand experience. Finally, express the realisation that many opportunities exist beyond the boundaries of this research for future work related to global interoperable STEP-NC systems and a full solution is a long way away even with full commitment from all participants.

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## REFERENCES

Ahlquist, F., 2002. A Methodology for Operation Planning. Lund, Sweden, Lund University, pp: 89.

Allen, R.D., J.A. Harding and S.T. Newman, 2005. The application of STEP-NC using agent-based process planning. Int. J. Prod. Res., 43: 655-670.

Aslan, E., U. Seker and N. Alpdemir, 1999. Data extraction from CAD model for rotational parts to be machined at turning centres. Turkish J. Eng. Environ. Sci., 23: 339-347.

Bhandarkar, M.P. and R. Nagi, 1997. STEP Product information models in agile manufacturing. Int. J. Agile Manufacturing, 1: 65-75.

Choi, I., S. Suh, K. Kim, M. Song, M. Jang and B. Lee, 2006. Development process and data management of TurnSTEP: A STEP-compliant CNC system for turning. Int. J. Comput. Integrated Manufactur., 19: 546-558.

ESPRIT, 1997. Project 8643, Optimised preparation of manufacturing information with multi-level CAM-CNC coupling (OPTIMAL). Final Report For Publication.

Fidan, T., 2004. Feature based design of rotational parts based on STEP. Engineering Department, Middle East Technical University, Ankara, Turkey, pp: 164.

Fortin, E. and J.F. Chatelain, 2001. Improving information flow from CAM to CNC : An innovative architecture based on BNCL virtual machine. Proceedings of the 29th International Conference on Computers and Industrial Engineering, Nov. 1-3, Montreal, Canada, 465-470.

Heusinger, S., R.S.U. Rosso-Jr, P. Klemm, S.T. Newman and S. Rahimifard, 2006. Integrating the CAx process chain for STEP-compliant NC manufacturing of asymmetric parts. Int. J. Comput. Integrated Manufacturing, 19: 533-545.

ISO, 1994. International organization for standardisation - ISO 10303-1:1994, Part 1: Overview and fundamental principles. product data representation and exchange. http://www.iso.org/iso/catalogue_detail?csnumber=20579

ISO, 2002. International organization for standardisation - ISO 10303-Part 21 Industrial automation systems and integration - product data representation and exchange. Part 21: Implementation Methods: Clear Text Encoding of the Exchange Structure.

ISO, 2003. International Standard 14649-1: Part 1 : Industrial automation system and integration - Physical device control - Data model for computerised numerical controllers - Part 1: Overview and fundamental principles. http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?ics1=25&ics2=40&ics3=20&csnumber=34743

ISO, 2004. International standard 14649-10: Part 10 : Industrial automation system and integration - physical device control - Data model for computerised numerical controllers.Part 10 : General process data. http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?ics1=25&ics2=40&ics3=20&csnumber=40895

ISO, 2005. International standard 14649-121: Part 121: Industrial automation system and integration - physical device control - Data model for computerised numerical controllers. Part 121: Tools for Turning Machines.

ISO/FDIS, 2004. Industrial automation systems and integration - Physical device control - Data model for computerized numerical controllers - Part 111: Tools for milling machines. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54124

Li, R.K., 1988. A part-feature recognition system for rotational parts. Int. J. Prod. Res., 26: 1451-1475.

Michaloski, J., 2005. Case Study in the Challenges of Integrating CNC Production and Enterprise Systems. ISA EXPO, Chicago, Illinois, US.

Muller, P., 2000. STEP-NC – New data interface for NC programming. STEP-NC Newsletter, Erlangen, Germany: 1-2. http://www.step-nc.org/data/newsletter1.pdf

Muller, P., 2004. STEP-compliant data interface for numerical controls - final technical report. Erlangen, Germany, IMS STEP-NC Consortium: 1-41.

Nassehi, A., S.T. Newman and R.D. Allen, 2006. STEP-NC compliant process planning as an enabler for adaptive global manufacturing. Integrated Manufacturing, 22: 456-467.

Newman, S., 2004. Integrated manufacture for the 21st century development of the STEP-NC standard and its implications for manufacturing processes worldwide. Metalworking Prod., 148: 13-16.

Newman, S.T., A. Nassehi, W.X. Xu and L. Wang *et al.*, 2007. Interoperable CNC for global manufacturing. Proceedings of the 17th International Conference on Flexible Automation and Intelligent Manufacturing, Jun. 07, Philadelphia, USA., pp: 1-13.

Normile, D. and K. Tyrka, 2000. Design anywhere, build anywhere-product data management and the Internet are redefining the relationships between manufacturers, customers and suppliers. Global Design News. November. http://www.highbeam.com/doc/1G1-85461756.html

Roger, N.N. and B.W. Walt, 1980. Initial graphics exchange specification IGES. Version 1.0, NBSIR 80-1978. Washington (DC), National Bureau of Standards.

Shin, S.J., S.H. Suh and I. Stroud, 2007. Reincarnation of G-code based part programs into STEP-NC for turning applications. Comput. Aided Design, 39: 1-16.

Shunmugam, M.S., P. Mahesh and S.V.B. Reddy, 2002. A method of preliminary planning for rotational components with C-axis features using genetic algorithm. Comput. Indus., 48: 199-217.

Suh, S.H., B.E. Lee, D.H. Chung and S.U. Cheon, 2003. Architecture and implementation of a shop-floor programming system for STEP-compliant CNC. Comput. Aided Design, 35: 1069-1083.

Suh, S.H. and S.U. Cheon, 2004. Method for automatically generating part program for use in STEP-NC (US Patent 6795749). http://www.patentstorm.us/patents/6795749.html

Suh, S.H., D.H. Chung, K.M. Kim, I. Choi, S. Shin and B.E. Lee, 2006. STEP-compliant CNC system for turning: Data model, architecture and implementation. Comput. Aided Design, 38: 677-688.

Tseng, Y.J. and S.B. Joshi, 1998. Recognition of interacting rotational and prismatic machining features from 3-D mill-turn parts. Int. J. Prod. Res., 36: 3147-3165.

Wei, Y., K.T. Chong, T. Takahashi, S. Liu, Z. Li, Z. Jiang and J.Y. Choi, 2005. A framework for CNC turning system based on STEP-NC. ICMIT 2005: Mechatronics, MEMS and smart materials. The International Society for Optical Engineering.

Xu, X. and J. Wang, 2004. Development of a G-code free, STEP-compliant CNC lathe. Proceedings of the 2004 International Mechanical Engineering Congress and Exposition, Nov. 13-19, Anaheim, California, U.S.A., 1-104.

Xu, X.W., H. Wang, J. Wang, S.T. Newman, T.R. Kramer, F.M. Proctor and J.L. Michaloski, 2005. STEP-Compliant NC Research: The search for intelligent CAD/CAPP/CAM/CNC Integration. Int. J. Prod. Res., 43: 3703-3743.

Xu, X.W., 2006. Realization of STEP-NC enabled machining. Robotics Comput. Integrated Manufactur., 22: 144-153.

Xu, X. and S.T. Newman, 2006. Making CNC machine tools more open, interoperable and intelligent. Comput. Industry, 57: 141-152.

Xu, X.W., P. Klemm, F. Proctor and S.H. Suh, 2006. STEP-compliant process planning and manufacturing. Int. J. Comput. Integrated Manufactur., 19: 491-494.

Yang, H., W.F. Lu and A.C. Lin, 1994. PROCASE: A case-based process planning system for machining of rotational parts. J. Intelligent Manufacturing, 5: 411-430.

Yildiz, Y., Y. Korkut and U. Eker, 2006. Development of a feature based CAM system for rotational parts. G.U J. Sci., 19: 35-40.

Yusof, Y. and K. Case, 2009. A STEP Compliant Approach to Turning Operations. Springer London, London. ISBN 978-1-84882-738-7, pp: 105-124.