

STEP-NC-Compliant Systems for the Manufacturing Environment

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Abstract— The paper provides a literature review of the STEP-NC compliant research around the world. The first part of this paper focuses on projects based on STEP compliance followed by research and development in this area based on machining operations. Review the literature relating to relevant STEP standards and application in the area of turning centers. This research will review the various research work, carried out from the evolution of STEP-NC of the CNC manufacturing activities. The paper concludes with discussion of the applications in this particular area.

Keywords— STEP-NC, CNC, Machining and Turning.

I. INTRODUCTION

Since the late 90s, many efforts have been made based on implementation of the STEP concept as the data interface between CAD/CAM and CNC [1]. One of the pioneer projects, OPTIMAL [2], proposed a new data interface framework for the milling process. STEP-NC has been developed as a result of several research projects carried out by companies and university institutes. In recent years there have been a number of projects involving STEP-NC based interoperable research and development for various CNC manufacturing processes. This paper focuses on two projects, namely the Intelligent Manufacturing System (IMS) based on worldwide participants and Intelligent Manufacture for STEP-NC Compliant and Inspection, STEP compliant research work based at Loughborough University and the University of Bath. In the second half of the 1990s an effort from the international community backed by ISO started the major change in the concept of NC programming, through an international intelligent manufacturing systems (IMS) program [3]. The STEP-based interface scheme was extended to 2.5D milling and other operations, such as turning and EDM in the subsequent European Project ESPRIT IV 29708 between 1999 and 2001 [3]. The IMS project was endorsed in November 2001 and it was a true international project with participants from four different regions (European Union, Korea, Switzerland and USA). Table 1 shows the participants and the distribution of the technological scope within each region. The participants included end users, academic institutions and manufacturers of CAD systems,

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controllers and machine tools.

II. STEP-COMPLIANT NC: RESEARCH AND DEVELOPMENT SYSTEMS

STEP-NC has been developed as a result of several research projects carried out by companies and university institutes as shown in table 2 which is 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 operation being established before Part 12 (Turning). Table 2 clearly shows that 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 [4]. 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 [5], followed by Hardwick providing the first outlook on STEP-NC compliant manufacturing [6]. Lee and Bang have successfully developed and built a five-axis milling machine that is run by STEP-NC in XML [7] 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 [8]. Finally test and validation methods have been proposed for testing data for numerical control [9]. 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 [10].

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 [11]. The

latest achievement in 2007 is the successful development of a system called ST-FeatCAPP for prismatic parts based on ISO 14649 by [12]. 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 [13]

III. 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 [10]. 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 (see table 3). 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 [14]. 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.

TABLE I
 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 [15].
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 paper shows the high potential to aid the development of new CNC turning systems [16].
Shin et al., 2007	Presented development of a prototype G2STEP system to convert G-codes to a STEP-NC file [14].
Choi et al., 2006	Introduced the development process for TurnSTEP using structured and object oriented methodology to provide a distributed architecture for e-manufacturing [17].
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 [18].
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 [19].
Yusof, Case et al., 2007	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 [20].

IV. 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 [10]. 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 [21].

The Shop-floor Programming System (SFPS) introduced by Suh is the first system fully compliant with ISO 14649 [22] 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 4.

TABLE I
 REVIEW OF STEP-COMPLIANT SYSTEMS

NO	SYSTEMS	INPUT	OUTPUT	DOMAIN
1	SFPS (Milling) [22]	STEP AP203 & AP214	Part program physical file (text)	Prismatic
2	STEPTurn [19, 23]	STEP AP203	Part program physical file (text)	Rotational
3	TurnSTEP [17, 18]	STEP AP	ISO 14649 physical file and extensible mark-up language (XML)	Rotational
4	G-Code Free for lathe [15, 24]	STEP AP 203	Native CNC language program	Rotational
5	G2STEP (2-axis turning machining) [14]	G-codes	STEP-NC part program	Rotational

A. 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) [22]. This system has been proposed for prismatic components, as shown in figure 1, 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.

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 recognized 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 [22, 24,

25]. 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.

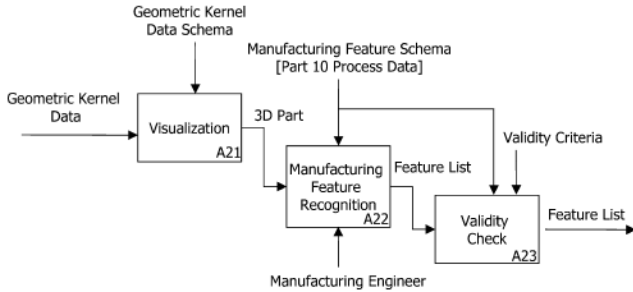


Fig. 1 Machining feature recognition for SFPS [22]

B. 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 [19, 23]. STEPTurn is a CAPP system bridging the gap between CAD and CAM as shown in figure 2 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 [19, 23]. According to Heusinger, the stages in using STEPTurn are [26]; i) Input of AP 203 file, ii) Display of the workpiece, iii) Generation of operations, strategies and technology, iv) Definition of the workplan and v) Output of the STEP-NC program.

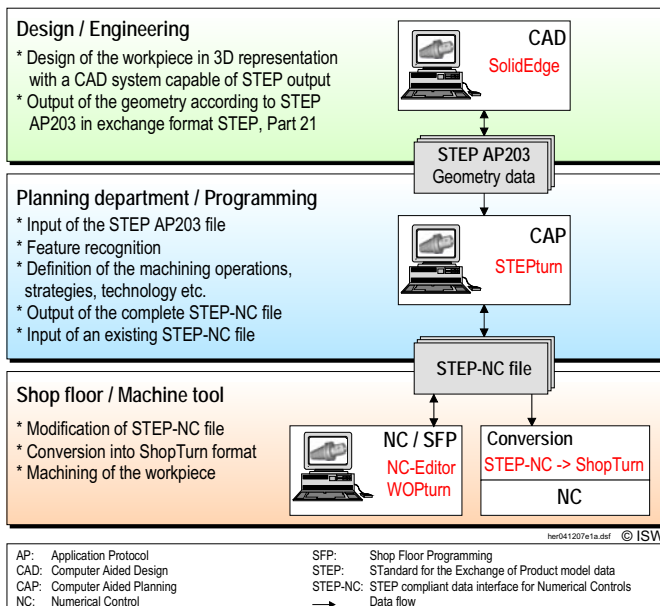


Fig. 2 Implemented process chain for turning [19]

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 [19]. 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 [27].

So far STEPTurn has been tested only for simple workingsteps for machining cylinders and cones using standard turning machines (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 [19]. As clearly presented in the Heusinger paper STEPTurn only works on a specific machine [19].

C. TurnSTEP

TurnSTEP is claimed by Choi to be fully compliant with ISO 14649 and suitable for e-manufacturing [17, 18]. TurnSTEP has been developed using three sub-systems namely; i) CGS (Code Generating System) to generate neutral independent STEP-NC code based on ISO 14649, ii) CES (Code Editing System), to edit or customize machine tool data to be used for execution of STEP-NC code and iii) ACS (Autonomous Control System) as shown in figure 3 [17, 18]. 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.

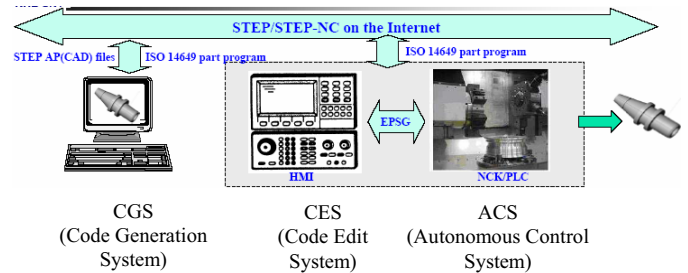


Fig. 3 Three subsystems of the TurnSTEP [17]

- From the design perspective this system needs [17];
- i. to provide a distributed architecture for e-manufacturing;
 - ii. to support intelligent and autonomous execution of NC machines by fully utilizing rich STEP-NC information;
 - iii. to optimize the machining sequence of a target manufacturing process;
 - iv. to support automated and interactive generation of a process plan utilizing feature recognition, alternative generation, process sequence, cutting condition, etc;
 - v. 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 [18]. 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 visualizes 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 [18]

D. 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 [15]. The proposed system has two parts i) retrofitting an existing CNC lathe and ii) a STEP CNC converter that is run with four phases; i) generation of generic STEP-NC programs, ii) generation of a native STEP-NC program, iii) generation of a native CNC language file and iv) execution of the process plan on a CNC machine as shown in figure 4 [15]. Xu describes how the low level language rather than G-codes is interpreted by STEP-NC into this axis movement language by using a 6K program and passed on to the retrofitted lathe [15, 23].

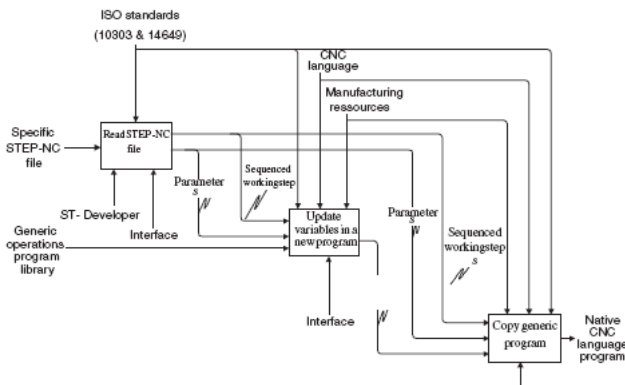


Fig. 4 IDEF0 diagram of the STEP-compliant CAD/CAPP/CAM/CNC system [15]

E. 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 [14]. 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 has been developed for 2-axis CNC Turning using the C++ language and runs on a Windows platform used a geometric modeling kernel and OpenGL for the GUI [14]. 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 figure 5. 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.

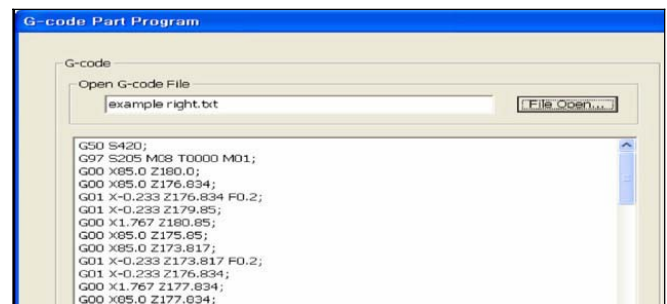


Fig. 5 G-code load to G2STEP system [14]

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 [14].

V. 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 [19] 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.

If we focus on turning operations, only three proposed systems are available, STEP-Turn, TurnSTEP and G2STEP. But, if we scope for e-manufacturing, STEP-Turn 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 [18]. 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 [18]. 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 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) [19, 28].

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 [17, 21].

VI. CONCLUSION

This paper 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 second part of the paper 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), STEP-Turn, 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 first hand

experience.

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