A STEP-compliant process planning system for CNC turning operations

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ABSTRACT

Over the last 50 years, there have been many significant enhancements in computer aided systems which have influenced the CNC technology. One area that can be considered as a bottleneck to these CNC enhancements, and in particular to interoperability in CNC manufacturing is G&M part programming (ISO 6983). To overcome this bottleneck, the new standard ISO 14649, known as STEP-NC, is being developed to provide detailed information on component design, process planning and machining strategies to manufacture parts for the next generation of intelligent CNCs. This standard forms the basis of a new paradigm shift in the CNC domain to support digital modelling of CNC manufacturing resources. The research in this paper aims to identify major issues and develop new software tools to demonstrate the feasibility of interoperable CNC manufacturing based on STEP-NC. Besides the literature review on recent research and development on STEP-NC, this paper proposes a Process Planning System (PPS) with surface roughness chosen as the process planning objective. PPS consists of five modules: program reader, process planner, STEP-NC CAD viewer, STEP-NC CAM viewer and program writer. The reader is responsible for interpreting the geometry and the manufacturing data from a STEP-NC text file into a stored data list. The process planner uses this data list and enables users to evaluate surface roughness based on a mathematical model. Through the STEP-NC CAD viewer, the part geometry can be shown and via the STEP-NC CAM viewer the toolpath can be verified. Finally, the writer converts the stored STEP-NC data of the system into an updated STEP-NC file. An example case study component is used to demonstrate the PPS and show the interfacing of the STEP-NC data.

1. Introduction

From its emergence in 1952, the Numerical Control (NC) machine tool has undergone significant improvements and has provided an ever-increasing important part in manufacturing. Many other relating technologies, including Computer Aided Design (CAD), Computer Aided manufacturing (CAM), Computer Aided Process Planning (CAPP), have advanced greatly coupling with the enhancement of computer technology. The term used to refer to an NC machine has evolved into Computer Numerically Controlled (CNC) machine, while the capability has been upgraded to support multi process, large volume range and high precision and geometrical complexity component production. It is possible to machine a complicated part involving different processes such as milling, turning and laser hardening on one CNC machining centre in a single setup, which is also contributing to the efficiency and machining quality like precision and surface roughness.

Compared with these machine tool and process developments however, the early NC machines and today's modern CNCs utilise the same standard for programming, namely G&M codes formalised as ISO 6983. This old fashioned programming language is famous for its low band-width information transferring ability, as it just describes the machine switch functions and the cutting tool movements. The manufacturing knowledge from the previous CAx (CAD/CAM/CAPP) systems has to be transformed into a set of low level machine tool actions by a post-processor, which isolates the CNC from the manufacturing chain. As a result of this single direction flow means, any information on the shopfloor level cannot be relayed back to the planning department. On the other hand, the increasing computing capability enables the CNC controller to manipulate more manufacturing information. However, only with the availability of comprehensive manufacturing knowledge the next-generation CNCs can realise the dream of intelligent control.

Generally, it is commonly recognised that the ISO 6983 standard has become a bottleneck for the advancement of CNC manufacturing because of the data noncompliance through the CAD/CAPP/CAM/CNC chain [1]. To eliminate this problem, a new standard known as STEP-NC has been developed since the late 1990s, which is formalized as an ISO 14649 [2]. As the replacing

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data interface for CNC, one of the expected benefits from STEP-NC is bringing the component geometry information into the controller. However, STEP-NC goes much further with a comprehensive data model that overcomes the lack of process planning information in ISO 6983 files [3]. Unlike the G&M codes, STEP-NC associates the machining objectives (CAD design data) with solutions (CAM process data required) in an object-oriented way. It does not need to define precisely the detailed axis movement of the machine tool, although it has the mechanism to incorporate it in the STEP-NC file. The aim of an STEP-NC is to provide the CNC with a comprehensive manufacturing data model and an interface to establish an intelligent controller. Furthermore, the new data interface is compliant with an STEP (ISO 10303), which is the major ISO standard for product information exchange throughout the product lifecycle. Through incorporating STEP data, STEP-NC builds up a bi-directional information highway between the CAD/CAM and CNC systems, without using the post-processor [4] and makes interoperable process planning and manufacturing feasible and a future reality [5].

STEP-NC provides a real opportunity and challenge to promote the improvement of manufacturing capability utilising high level and detailed information. As the potential interface for CNC, STEP-NC is still an evolving and improving international standard. It is expected that the implementation of STEP-NC will bring great changes to current CAD, CAM and CNC. These changes will provide industrial users and software vendors with new challenges to identify the new boundaries of current CAx systems [6]. For example, the STEP-NC compliant CNC will incorporate a CAM system which will take over some of the tasks from the offline CAM system, namely to adjust and optimise the STEP-NC programs, according to the available manufacturing resources and implement greater intelligence across the CAx process chain. Thus, both offline and shopfloor (CNC) CAM systems will play a critical role for STEP-NC to be a success and gain any significant advantage of an STEP-NC compliant CNC manufacture.

To date, the majority of STEP-NC research has focused on milling operations. In this research, a Process Planning System (PPS) for the next generation controller for turning is proposed. This paper introduces the PPS and outlines the mathematical model on which process planning is carried out. Finally, an example component is used to demonstrate the application of the system.

2. Literature review

Since its emergence, an STEP-NC has been one of the most popular research areas in the field of CAM engineering for more than ten years. This section reviews the specific area of STEP-NC based research and development for turning operation, process planning and new CNC controllers. It is worth mentioning that currently two versions of STEP-NC are being developed by an ISO. The first is the Application Reference Model (ARM) version of ISO14649 (i.e. ISO14649) and the other is the Application Interpreted Model (AIM) version of ISO14649 namely AP 238 [7]. These versions and developments with them in relation to interoperability and the CNC process chain are reviewed by Newman et al. [8].

The use of STEP-NC in manufacturing of asymmetric rotational parts have been explored by Rosso Jr. et al. [9]. They investigated the implementation method of STEP-NC to combine the turning and milling operation to solve the issue of complete machining of an asymmetric component on a single turning machine. The paper concluded that there is no need to develop new STEP schema specific for asymmetric parts, as the ISO 14649 Part 10 [10] is capable of supporting the feature representation of complex components. Chung and Suh [11] also addressed the problem of complete machining. They proposed a nonlinear process planning method utilising STEP-NC for the optimisation of complex parts and a branch-and-bound approach is used to minimise the total cycle time. Heusinger et al. [12] proposed a methodology for implementation of a standardised CAx process chain for rotational asymmetric parts, employing a technology-oriented process model. In this approach, the STEPTurn programming system has been developed to generate the STEP-NC program, which is converted into the program for ShopTurn to enable a test component machined on a current machine tool. Yusof et al. [13] extended this research direction to investigate the STEP-NC implementation on turn-mill operations and develop a STEP-NC compliant CAM system, for representing and machining of turn-mill parts. Yusof et al. [14] investigated the combination of ISO 14649 Part 11 [15] and Part 12 [16] to fulfil the STEP-NC challenge for turn/mill operations. In this research, a prototype system entitled SCSTO was developed to show the benefits of STEP-NC replacing G&M codes, such as the elimination of post processors.

Xu et al. [17] reported a G-code free CNC machine retrofitted from a conventional lathe based on STEP-NC. In this research, a new package called STEPcNC has been developed with a converter used on an existing CNC machine tool to enable it to be STEP-NC compliant. During this process, STEP Tools STIX software has been used to read and process STEP-NC information, where STIX is a C++ library providing useful functions to extract manufacturing information from STEP AP 238 format files. Then, 6K programs (a machine native format) for the CNC system were generated by the interface STEPcNC, based on the manufacturing information contained in an STEP-NC. However, this kind of program is still low level and the machine specific language is similar to G&M codes [8].

Regarding STEP-NC compliant controller development, Chen et al. [18] proposed a software-based framework for a STEP-NC control system. A RTCORBA-based soft bus was utilised to communicate among the functional modules in this system. Lan et al. [19] proposed a framework for a multi-agent-based STEP-NC controller with a prototype system, developed from the STEP Tools Inc. software tool of ST-developer.

Based on the analysis of the STEP-NC information content and the role of CNC on the shopfloor in an intelligent manufacturing system, Suh and Cheon [20] proposed a conceptual framework of an intelligent CNC system. The framework was extended to include an implementation method for a milling machine [21]. In order to support and integrate with the new controller, a shopfloor programming system, PosSFP, was proposed by Suh et al. [22]. It can recognise features from a CAD file to generate a process plan, and finally the complete STEP-NC file. Together with the controller, it enables a STEP-compliant based CAD/CAM/CNC chain solution. This PosSFP system can be implemented in two different ways according to the relationship with the controller: built-in and external. In the research area of STEP-compliant process planning, a three-stage process planning model was proposed by Liu et al. [23] using a feature-based approach, which divides process-related issues into three levels: offline process planning, shop-floor process planning and real-time process planning.

Suh [24] also reported on TurnSTEP, which can be used as a tool to create CNC turning programs. It is one of the earliest STEP-NC compliant systems, primarily aiming at evaluating the validity and effectiveness of the STEP-NC data model for turning [25]. Then, Suh et al. [26] gave a detailed and upgraded TurnSTEP implementation method with novel architecture for an intelligent turning CNC controller. This architecture is similar to those developed for milling by the same team [20,21]. TurnSTEP works like a combination of CAPP and CAM system which processes