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Making CNC machine tools more open, interoperable and intelligent—a review of the technologies

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Abstract

The aim of the next generation of computer numerically controlled (CNC) machines is to be portable, interoperable and adaptable. Over the years, G-codes (ISO 6983) have been extensively used by the CNC machine tools for part programming and are now considered as a bottleneck for developing next generation of CNC machines. A new standard known as STEP-NC is being developed as the data model for a new breed of CNC machine tools. The data model represents a common standard specifically aimed at the intelligent CNC manufacturing workstation, making the goal of a standardised CNC controller and NC code generation facility a reality. It is believed that CNC machines implementing STEP-NC will be the basis for a more open and adaptable architecture. This paper outlines a futuristic view of STEP-NC to support distributed interoperable intelligent manufacturing through global networking with autonomous manufacturing workstations with STEP compliant data interpretation, intelligent part program generation, diagnostics and maintenance, monitoring and job production scheduling.

Keywords: CNC; Interoperability; STEP; STEP-NC

1. Introduction

From the start of craft production in the 1800s to the pioneering mass production of the early 1900s there have been a number of revolutionary changes to manufacturing system's configurations. The most recognised traditional configuration of manufacturing systems was the dedicated transfer (machine) line, which enabled mass production at high efficiency and low cost. With the need of the 1970s and 1980s to produce a wider range of parts, ''flexible'' manufacturing was developed to meet these needs for the production of smaller batches of different parts. These systems used groups of computer numerically controlled (CNC) machines that could be reprogrammed to make different parts combined with automated transport systems and storage. These CNC machines became the central elements in the systems such as flexible transfer lines, flexible manufacturing systems (FMS) and flexible manufacturing cells (FMC).

However, the amount of flexibility existing in these systems was still believed to be limited. In order to prepare manufacturing companies to face increasingly frequent and unpredictable market changes with confidence, interoperable and more open manufacturing systems are needed. In the process of designing and operating interoperable and open manufacturing systems there is a need to distinguish from among system-level issues, component-level (i.e. machine and control) issues, and ramp-up time reduction issues [1,2]. Most of the research effort has been spared on the issues at the system level, some at the component level and little on the ramp-up time reduction issues. At the component level, research work has primarily centred around the control issues concerning machine tools, with the aim to provide enabling CNC technologies for modular and open-architecture control [3,4].

CNC machine tools are the main components in any manufacturing system. There are demands and new opportunities to empower the current CNC machines with the much-needed features such as interoperability, adaptability, agility and reconfigurability. To this end, there are two major issues that need to be addressed namely product data compatibility/

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interoperability and adaptable CNC machines. Up till now little research has been carried out in this field, but due to the developments of the new CNC data model known as STEP-NC, there has been a surge of research activities in trying to address the above-mentioned issues. This paper reports on these research activities and tries to address the issues of interoperability and adaptability for CNC machine tools.

2. Impediments of current CNC technologies

Today's CNC machine designs are well developed with capabilities such as multi-axis control, error compensation and multi-process manufacture (e.g. combined mill/turn/laser and grinding machines). In the mean time, these capabilities have made the programming task increasingly more difficult and machine tools themselves less adaptable. Some effort has been made to alleviate this problem, in particularly the trend towards open architecture control, based on OSACA [5] and open modular architecture controller (OMAC) [6], where third party software can be used at the controller working within a standard windows operating system. One further recognisable industrial development is the application of software controllers, where PLC logic is captured in software rather than in hardware.

Although these developments have improved software tools and the architecture of CNC systems, vendors and users are still seeking a common language for CAD, CAPP, CAM, and CNC, which integrates and translates the knowledge of each stage with no information loss. Though there are many CAM tools supporting NC manufacture, the problem of adaptability and interoperability from system to system was and is still seen as one of the key issues in limiting the wider use of these tools.

2.1. Product data compatibility and interoperability

CNC machine tools complete the product design and manufacturing lifecycle, and more often than not they have to communicate with upstream sub-systems, such as CAD, CAPP and CAM. In the case when neutral data exchange protocols, such as SET, VDA, and initial graphics exchange specification (IGES) are used, information exchange can happen between heterogeneous CAD and/or CAM systems. This is however only partially successful since these protocols are mainly designed to exchange geometrical information and not totally suitable to all the needs of the CAD/CAPP/CAM industry. Thus, the international community developed the ISO10303 [7] set of standards, well known as STEP.

By implementing STEP AP-203 [8] and STEP AP-214 [9] within CAD systems, the data exchange barrier is removed. Yet, data exchange problems between CAD/CAM and CNC systems remain unsolved. CAD systems are designed to describe the geometry of a part precisely, whereas CAM systems focus on using computer systems to generate plans and control the manufacturing operations according to the geometrical information present in a CAD model and the existing resources on the shop-floor. The final result from a CAM system is a set of CNC programs that can be executed on a CNC machine. STEP AP-203 and STEP AP-214 only unify the input data for a CAM system. On the output side of a CAM system, a 50-year-old international standard ISO 6983 (known as G-Code or RS274D) [10] still dominates the control systems of most CNC machines. Outdated yet still widely used, ISO 6983 only supports one-way information flow from design to manufacturing. The CAD data are not utilised at a machine tool. Instead, they are processed by a post-processor only to obtain a set of low-level, incomplete data that makes modification, verifications and simulation difficult. The changes made at the shop-floor cannot be directly fed back to the designer. Hence, invaluable experiences on the shop-floor cannot be preserved and re-utilised.

2.2. Inflexible CNC control regime

The ISO 6983 standard focuses on programming the path of the cutter centre location (CL) with respect to the machine axes, rather than the machining tasks with respect to the part. Thus, ISO 6983 defines the syntax of program statements, but in most cases leaves the semantics ambiguous, together with low-level limited control over program execution. These programs, when processed in a CAM system by a machine-specific post-processor, become machine-dependent. In order to enhance the capability of a CNC machine, CNC controller vendors have also developed their own tailored control command sets to add more features to their CNC controllers to extend ISO 6983. These command sets once again vary from vendor to vendor resulting in further incompatible data among the machine tools.

The current inflexible CNC control regime means that the output from a CAM system has no adaptability, which in turn denies the CNC machine tools of having any interoperability. The main reason is that a G-code based part program only contains low-level information that can be described as "how-to-do" information. The CNC machine tools, no matter how capable they are, can do nothing but "faithfully" follow the G-code program. It is impossible to perform intelligent control nor machining optimization.

3. The STEP-NC standard

Today a new standard namely ISO 14649 [11–16] recognised informally as STEP-NC is being developed by vendors, users and academic institutes world wide to provide a data model for a new breed of intelligent CNCs. The data model represents a common standard specifically aimed at NC programming, making the goal of a standardised CNC controller and NC code generation facility a reality. Currently two versions of STEP-NC are being developed by ISO. The first is the Application Reference Model (ARM) (i.e. ISO 14649) and the other Application Interpreted Model (AIM) of ISO 14649 (i.e. ISO 10303 AP-238 [17]). For more information on the use and differences between them readers are referred to [18,19].

Contrary to the current NC programming standard (ISO 6983), ISO 14649 is not a method for part programming and does not normally describe the tool movements for a CNC machine. Instead, it provides an object oriented data model for