International Journal of the Korean Society of Precision Engineering, Vol. 4, No. 5, September 2003.

Development of ISO14649 Compliant CNC Milling Machine Operated by STEP-NC in XML Format

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ABSTRACT

G-code, another name of ISO6983, has been a popular commanding language for operating machine tools. This G-code, however, limits the usage of today's fast evolving high-performance hardware. For intelligent machines, the communications between machine and CAD/CAM departments become important, but the loss of information during generating G-code makes the production department isolated. The new standard for operating machine tools, named STEP-NC is just about to be standardized as ISO14649. As this new standard stores CAD/CAM information as well as operation commands of CNC machines, and this characteristic makes this machine able to exchange information with other departments. In this research, the new CNC machine operated by STEP-NC was built and tested. Unlike other prototypes of STEP-NC milling machines, this system uses the STEP-NC file in XML file form as data input. This machine loads information from XML file and deals with XML file structure. It is possible for this machine to exchange information to other databases using XML. The STEP-NC milling machines in this research loads information from the XML file, makes tool paths for two5D features with information of STEP-NC, and machines automatically without making G-code. All software is programmed with Visual C++, and the milling machine is built with table milling machine, step motors, and motion control board for PC that can be directly controlled by Visual C++ commands. All software and hardware modules are independent from each other; it allows convenient substitution and expansion of the milling machine. Example 1 in ISO14649-11 having the full geometry and machining information and example 2 having only the geometry and tool information were used to test the automatic machining capability of this system.

Key Words : STEP-NC, XML, PC, milling machine, open architecture, tool path

1. Introduction

Various packages of software adapted to the hardware of high performance are developed and used widely in production departments. However, in the machining department, operation commands of ISO6983 called G-code that was standardized in the early days of NC machine development is still used, and all operation software and interface are customized to this standard. This standard only describes the motions of tools and miscellaneous commands for the machines, so following problems arise from using G-code.

- Long command lines of simple geometry
- Unintuitive commands - commands are written in single alphabets and two digit numbers
- Difficult exchange of information between departments due to the lack of G-code information - isolated machining department due to lost CAD and CAM data
- Difficult updates and reusability of the command lines - update commands of G-code are different among NC machines companies.

To overcome these problems and use new abilities of

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Accepted: August 8, 2003
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advanced machines, each company adds original commands that are unable to use other companies. This limits the selection of NC machines at machining department and the problems of using the G-codes made by others.

The development of the new standard minimizes such problems and allows for the use of high performance machines. The ISO14649 STEP-NC, which is about to be standardized[1], includes all information produced by the entire production process as well as operation commands of the machines. Because this standard is based on 3D CAD data written in ISO10303 STEP, and includes machining information and NC commands with tool paths, there is no loss of information. 3D CAD drawings of STEP and machining information of CAM enables the machine to generate tool paths and the user to omit making and inputting tool paths to the machines. This updates the old style of production chain that is drawing CAD, making G-code, and machining with separate CAD, CAM, CNC software, to the new one that is analyzing, machining, and editing CAD drawings completed in one software or one machine.[2]

To make STEP-NC machine that has all information of production, machines automatically, and communicates with other databases of production departments, the new software treating STEP-NC commands, and the new hardware of STEP-NC controller are needed[3].

Many researches on these software and hardware are in progress. Demonstrations of STEP-NC milling machines of Germany and USA[4] were held in 2001, and that of Korea was held in 2002. These machines use the original STEP-NC file. Though making the machine able to communicate with CAD/CAM and other production departments[5], there is a limit that STEP-NC machines cannot exchange information with other departments not related to machining directly because they use XML databases. In this paper, the STEP-NC milling machine, which uses the XML file that has the same contents and structure as the original STEP-NC file is developed and tested. To make the CNC machine, an existing table milling machine was rebuilt with stepping motors and motion control board for PC. All programming was done in Visual C++ and MSXML, and tested under Windows98, Windows NT and Windows 2000 OS environments.

2. Contents and structure of STEP-NC

STEP-NC stores almost all information generated by the preceding production departments. The structure and contents of STEP-NC are shown in Fig. 1. Workpiece entities have material information and geometric information of the machined material. The setup entities have the setting of the milling machine and workpieces. The WORKPLAN has the order of each machining step and all processes are accomplished according to this plan[6]. Information of each machining step is written as workingstep entities. The workingsteps are used to describe each machining step and to bind and store CAD, CAM and machining data together. A workingstep is defined as one step for machining of one feature with one tool. Entities of CAM have machining information, tool information and tool paths; however, tool paths are frequently omitted because they are optional entities. Entities of CNC variables have commands for CNC machines irrelevant to motions of the machine axes. This research does not use the original STEP-NC file but uses the STEP-NC file in XML form.

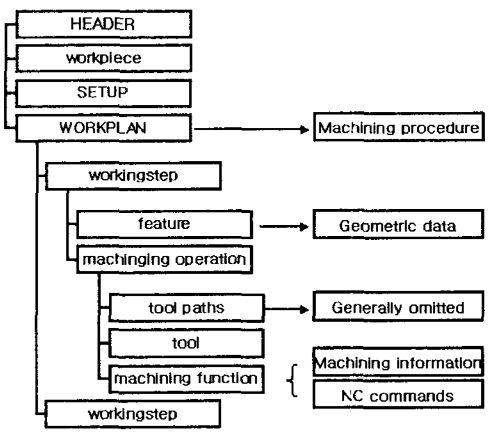

Fig. 1 Example of STEP-NC, ISO 14649-11 example 1

3. XML file data input

The STEP-NC milling machine of this work differs from other prototypes in the data input method. This system does not use the original STEP-NC file like other machines[7], but uses the XML file that has the same contents and data structure.

```
<main_workplan name="WORKPLAN" id="#2">
  <its_id name="identifier">'MAIN WORKPLAN'</its_id>
+ <its_elements name="MACHINING_WORKINGSTEP" id="#10">
+ <its_elements name="MACHINING_WORKINGSTEP" id="#11">
  <its_elements name="MACHINING_WORKINGSTEP" id="#12">
    <its_id name="identifier">'WS REAM HOLE1'</its_id>
  + <its_secplane name="ELEMENTARY_SURFACE" id="#62">
  - <its_feature name="ROUND_HOLE" id="#17">
      <its_id name="identifier">'HOLE1 D=22MM'</its_id>
    + <its_workpiece name="WORKPIECE" id="#4">
    + <feature_placement name="AXIS2_PLACEMENT_3D" id="#81">
    + <depth name="ELEMENTARY_SURFACE" id="#64">
    + <diameter name="TOLERANCED_LENGTH_MEASURE" id="#58">
      <change_in_diameter name="taper_select" />
      <bottom_condition name="THROUGH_BOTTOM CONDITION" id="#26" />
    </its_feature>
  + <its_operation name="REAMING" id="#21">
    <its_effect name="in_process_geometry" />
  </its_elements>
+ <its_elements name="MACHINING_WORKINGSTEP" id="#13">
+ <its_elements name="MACHINING_WORKINGSTEP" id="#14">
  <its_channel name="channel" />
+ <its_setup name="SETUP" id="#8">
  <its_effect name="in_process_geometry" />
</main_workplan>
+ <its_workpieces name="WORKPIECE" id="#4">
  <its_owner name="person_and_address" />
  <its_release name="date_and_time" />
  <its_status name="approval" />
</PROJECT>
</STEP XML>
```

Fig. 2 Part of XML file used for data input

The tree structure corresponds to the hierarchy of STEP-NC and the tag name corresponds to the entity name of STEP-NC[8]. Therefore the XML file that has the same structure and contents as STEP-NC file can be made. Fig. 2 shows part of the STEP-NC file in XML form. Following are some of the advantages of using the XML file.[9]

- Readily available tools and methods
- No additional data structure to deal with STEP-NC file in Visual C++ programming for XML file itself can be the structure.
- Easy adjustment of the system to Internet environment and connection with other e-business since other e-businesses use XML format for their standard of data exchange and storage.
- XML support from Microsoft and IBM

To deal with the XML file, in this research, DOM structure is constructed in Visual C++ program by MSXML. The MSXML is the XML parser produced by Microsoft for Visual C++ programming. It makes the DOM structure and enables to control it with Visual C++ functions.

4. STEP-NC milling machine software

The software of this research divides into three modules. The first is the main program that loads and analyzes the XML and activates the tool path generator. The second is the tool path generator that makes tool paths of two5D features with STEP-NC information loaded by the main program. The third is the tool motion generator that transforms tool paths to motor motions. All software modules are written in Visual C++. Detailed explanation of each module is as follows.

4.1 STEP-NC interpreter

This module loads the XML file and activates each module. The XML file is loaded in the Visual C++ and parsed by MSXML. This module searches the WORKPLAN entity, activates tool path generator for each feature of workingstep along the order written in WORKPLAN, and, if necessary, calculates machining information. The information loaded by this module is as follows,

- Geometric information: sort, boundary, depth, position, and boss of features
- Machining information: cutting speed, RPM of spindle, machining tool
- NC variables: NC commands not involved to axis interpolation.

Machining information can be calculated as follows, if it is invalid.

- Workingstep separation: this system can separate one workingstep to 2 or 3 workingsteps if the geometry is complex or rough machining is prerequisite.
- Feed rate and RPM of spindle: with specific energy for machining of material, tool information and the power of machine, this system can calculate the cutting speed.

This module prepares these values, activates the tool path generator, and hands the data to the tool path generator.

4.2 Tool path generator

The system of this research has the tool path generator for two5D features. In STEP-NC two5D features are separated into two groups by the tool motion for cutting, so they differ in tool path generation. Features of the first group are machined by vertical cutting that is referred to as drilling type strategy. For example hole feature belongs to it. Features of the other group are machined by milling type strategy that is the machining method by vertical and horizontal cutting movements. Pocket, planar face, step, slot belong to this type. The tool path generator of this research has two

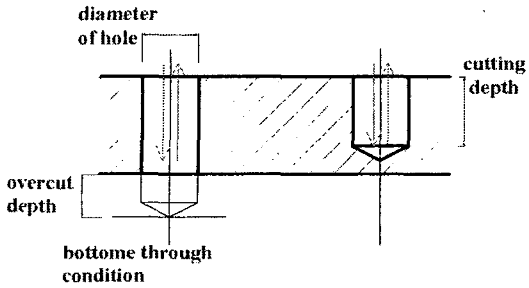

Fig. 3 Geometric information of hole features

types of individual tool path generator for milling and drilling. Each individual features are fitted to the generalized two5D feature of each machining type, and then machined.

4.2.1 Two5D feature machined by drilling type strategy

Hole feature of STEP-NC and its geometric information are shown in Fig. 3. Every single hole machining operation except boring performs the same machining motion. First, the tool moves to the center point of the hole, then digs through the surface of workpiece vertically until it reaches a desired cutting depth. A hole has different information with bottom condition. Hole of bottom-through condition has no cutting depth, but has an overcut depth. The cutting depth of such type is calculated by adding the workpiece thickness to the overcut depth. A hole diameter matches the diameter of the machining tool. Thus, the diameter of a hole feature is generally omitted. Multi-step drilling is occasionally required when drilling deep holes or removing chips. Under such situations, STEP-NC provides a retract length and cutting amount of one step. When tapping operation exists, command for synchronizing feed with cutting speed is given.

4.2.2 Generalized two5D feature machined by milling type strategy

Typical two5D feature that can be machined by milling type strategy is shown in Fig. 4. This feature is divided into two sectors by boundary lines; inside of it has a cutting depth below the surroundings. A two5D feature has side and bottom surfaces. The open boundary and bottom-through condition can remove the side surfaces or the bottom surface.

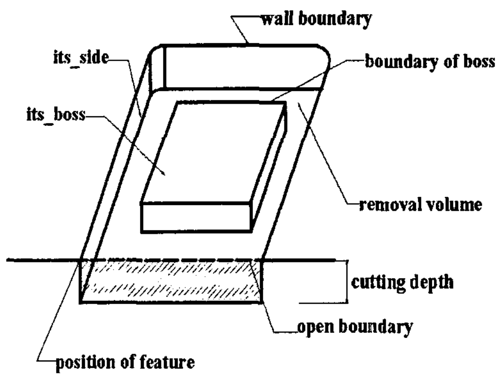

Fig. 4 General geometry of two5D feature of milling type strategy

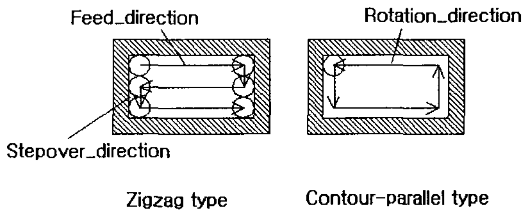

Fig. 5 Two types of tool paths of milling type strategy

The volume on the boundary is removed by machining operation, but some material can remain intact after machining that is called boss in STEP-NC. This boss area is not assigned as an independent machining feature, but is an attribute of its higher feature. Every two5D feature except the hole can be modified to fit this general frame.

If the tool path generator is made for generalized feature, duplicated works can be omitted.

The machining methods of two5D features are the parallel method[10] and the contour method. These methods are shown in Fig. 5. Every workingstep has the machining information to make the tool paths for an appropriate machining method. These two methods have common information as below.

- Offset: the distance between each unit tool paths
- Overlap: Overlapped width of each unit tool paths
- Tool information: the description of tools is defined in ISO14649-111. STEP-NC offers all dimensions of tool body, tool tip and their materials. The diameter of tool is an important value for deciding offset and overlap values. The length of tool plays a decisive

role for deciding the cutting depth

- Feed rate: the cutting depth for unit rotation of the tool
- Rotation of spindle: the rotational speed and direction
- NC commands: the handling operations or manufacturing descriptions that do not involve interpolation of axes

General information mentioned above as well as information dependent on the machining type is shown in Fig. 5 and Fig. 6. The directions of tool rotation and spiral rotation are given when contour type tool path is required. When parallel type is required, feed direction that is the tool path for major cutting and stepover direction that is the jump direction between each unit tool paths are provided. All of information written above is optional. Possibly some information other than diameter of the machining tool and geometry of feature, is not available or not provided. If such circumstances occur, STEP-NC machine selects the appropriate values by checking the geometry and material data. These new values can be updated to the original STEP-NC formed XML by DOM and Visual C++.

4.2.3 Feature with NURBS boundary

If the feature boundary is a curve, curved boundary is replaced by the polygon at rough milling workingstep. The difference between segments of the polygon for rough milling and curves should be less than the diameter of the finish milling tool, because the error area should be removed by finish milling. STEP-NC provides the entity of tolerance for approximated line segments of finish milling workingstep. Fig. 6 shows the relation between the polygon for rough milling and the offset curve of the original boundary for finish milling.

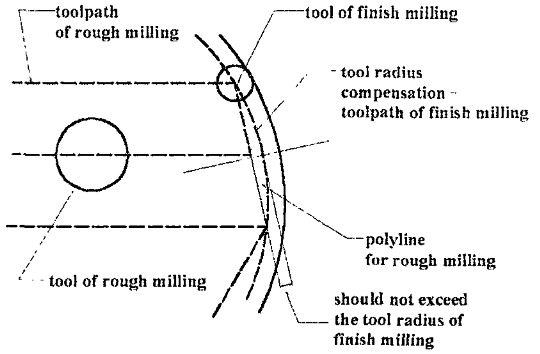

Fig. 6 Relationship between polygon of rough milling and curve of finish milling for curved boundary

4.3 Tool motion generator along tool paths

The STEP-NC milling machine makes tool paths and handles them directly after generation, so this tool motion generator does not exist in a separate module but exists in the form of sub-function of the tool path generator. The primary performance of this module is transformation of tool paths of STEP-NC to motions of the motors. Because only this module is affected by hardware, the modification of this sub-function enables the entire system to be adjusted to the change or expansion of hardware components.

5. Hardware part of the STEP-NC milling machine

Because almost all of the current milling machines use G-code, there are limits in making STEP-NC milling machine with these machines using the G-code controller. The CNC machine of this research is built by modifying an existing table milling machine with stepping motors and motion control board for PC. The table milling

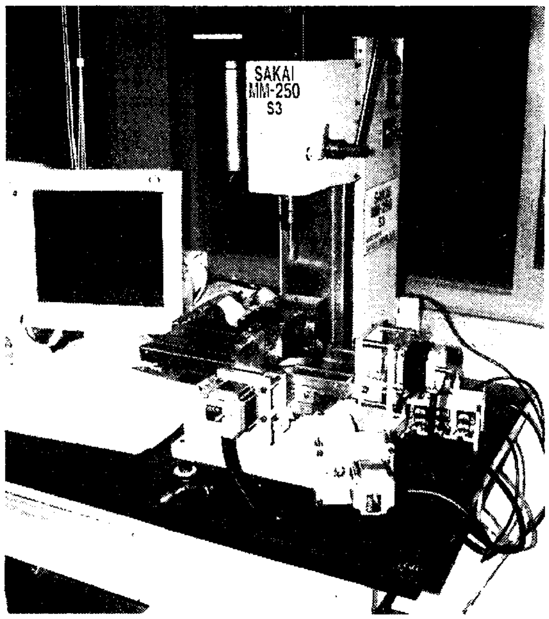

Fig. 7 STEP-NC milling machine of this research

machine is MM250-s3 of SAKAI Co., stepping motors are PK266-02B of Oriental Motors Co., and the motion control board is PCI-7212c of Interface Co. Fig. 7 shows the milling machine. This system has open architecture by using a PC and independent modules. Also, this machine operates without G-code during the entire process by using a PC and Visual C++ functions for motion control. This system is operated in Windows 98se OS environment, and also it was tested in Windows NT and Windows 2000.

6. Test of automatic machining by the STEP-NC milling machine

To test the developed STEP-NC milling machine, two examples are used. The first example corresponds to the case of the STEP-NC file having every geometric and machining information. The other corresponds to the case of the STEP-NC file having only tool and feature geometry such as the STEP-NC file made by STEP file only. The example 1 on ISO14649 part 11 is used for the first test. The file is shown in Fig. 8. It contains 3 features and all information for machining and geometry. To test the second case, the feature shown Fig. 9 is used. It is the pocket feature that has two boss and boundaries of lines and NURBS. In the second case, the machine calculates the machining information from the geometry, the machining tool, and power of the machine. The result of tool path generation of example 2 is shown in Fig. 10. The machining results of the first and second test are shown in Fig. 11 and Fig. 12. All tests are completed fully automatically with the STEP-NC file in the format of XML.

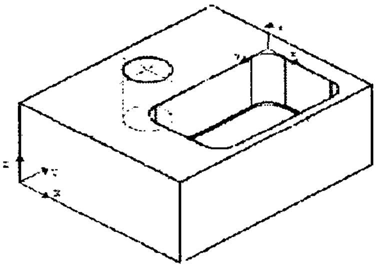

Fig. 8 ISO14649-11 example 1

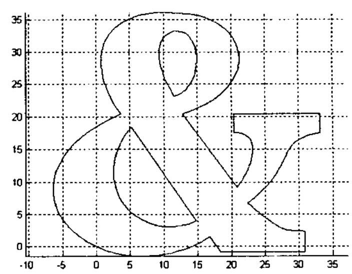

Fig. 9 Example 2 to test automatic machining under insufficient information

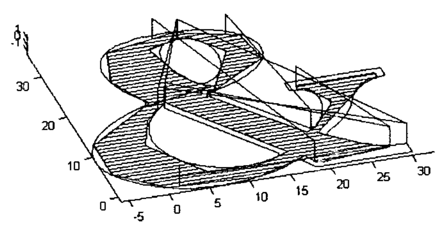

Fig. 10 Tool path generation result of example 2

7. Conclusion

This paper presents the development of STEP-NC milling machine using XML, and shows the test results of automatic tool path generation and subsequent machining. The main characteristics of the STEP-NC machine of this research are as follows.

- Automatic tool path generation of two5D features by STEP-NC
- G-code-less operation during the entire machining process
- Simultaneous management of tool path generation and machining
- Easy exchange of information with other databases based on XML
- Automatic calculation and replacement of machining data for insufficient information
- Network adapted design using PC and XML based system
- Independent software and hardware modules from open architecture, which allows for easy expansion and exchange of each modules

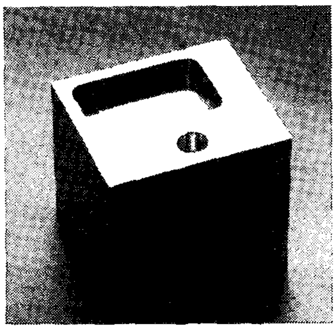

Fig. 11 Test result of example 1

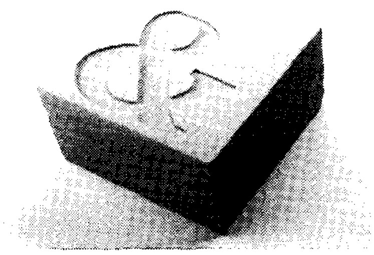

Fig. 12 Test result of example 2

Acknowledgements

This research is supported by Korea Institute of Industrial Technology, Korean Secretariat of International Intelligent Manufacturing System (IMS) project. We thank the laboratory of Professor Chong-Ho Choi, another partner of Korean IMS project for making XML files.

References

1. International Standards Organization, ISO14649-1 DIS, Industrial Automation Systems and Integration - Physical Device Control - Data Model for Computerized Numerical Controllers, Overview and Fundamental Principle, 2000.
2. Lee, W. S. and Bang, Y. B., "Development of PC-based STEP-NC Milling Machine," 6th International Conference on Progress of Machining Technology (6th ICPMT), pp. 482-487, 2002.
3. Cheon, S. U., "Shop Floor Programming System for STEP-NC," Korea-Germany Workshop on STEP-NC Technology, pp. 72-93, 2001.
4. STEP-TOOLS Inc, http://www.steptools.com
5. Jo, J. H. and Seo, S. H., "Tool path generation based on feature of STEP-NC and its Renewal," (In Korean) Journal of Korean Society of CAD/CAM Engineering, Vol. 4, pp. 295-311, 1999.
6. International Standards Organization, ISO14649-10 FDIS, Industrial Automation Systems and Integration - Physical Device Control - Data Model for Computerized Numerical Controllers, 2001.
7. Lee, W. S. and Bang, Y. B., "Development of STEP-NC milling machine based on PC," (In Korean) 2002 Korean workshop of Korean Society of CAD/CAM Engineering, pp. 335-341, 2002.
8. Lee, W. S. and Bang, Y. B., "STEP-NC for Milling based on XML," (In Korean) 2003 Korean Workshop of Korean Society of CAD/CAM Engineering, 2003.
9. Lee, W. S. and Bang, Y. B., "PC based STEP-NC milling machine operated by STEP-NC in XML," Korean-German Joint Workshop on Manufacturing and Control, 2003.
10. Park, S. C. and Choi, B. K., Tool-Path Planning for Direction-Parallel Area Milling, Computer-Aided Design, pp. 17-25, 2000.