Title:
STEP-Compliant CAD/CNC Systems for Feature-Oriented Machining

Authors:
Yazui Liu, liuyazui@buaa.edu.cn, Beihang University
Gang Zhao, zhaog@buaa.edu.cn, Beihang University; MIIT Key Laboratory of Aeronautics Intelligent Manufacturing, Beihang University, Beijing
Oleksandr Zavalnyi, sanyzav1992@gmail.com, Beihang University
Xian Cao, 546944945@qq.com, Beihang University
Kang Cheng, 1747624296@qq.com, Beihang University
Wenlei Xiao*, xiaowenlei@buaa.edu.cn, Beihang University; MIIT Key Laboratory of Aeronautics Intelligent Manufacturing, Beihang University, Beijing

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Introduction:
Since numerical control technology has been developed in 1950s, G/M code was used as the data exchange standard between CAD/CAM and CNC machine [4]. However, it is a low-level language that delivers only partial information (axis motion) to CNC that makes CNC isolated without understanding high-level information. The information barrier between upstream and downstream of manufacturing hinders the development of next generation CNC system.

STEP-NC is the extension of STEP in the field of numerical control that is under developed by ISO TC184. With the help of object-oriented programming and neutral description, the whole product data throughout the life cycle of manufacturing can be represented that is independent from any CAx systems, and considered as the next generation of CNC programming language. STEP-compliant CNC (also called STEP-CNC) is the CNC system that can directly use STEP-NC data for manufacturing. Due to these charming characteristics of STEP-NC, STEP-CNC has the capability of online toolpath generation that attracts large amounts of research interests. Many researchers work on STEP-compliant CAD/CAM [1,7] and STEP-CNC systems [2,3] individually. However, until recent years there has been very little practical use of STEP-compliant CAD/CAM and STEP-CNC systems. Hence, it is urgent to develop a STEP-compliant CAD/CNC system.

In this paper, we proposed a STEP-compliant CAD/CNC system that consists of STEP-NC file generator module, STEP-compliant data interpreter module, online toolpath generation module for 2.5D features and freeform surface. In addition to this, a prototype machine tool is developed to verify the feasibility of manufacturing using the proposed system.

Main Idea:
STEP-compliant CAD/CNC system

STEP-NC is the next generation of data exchange standard between CAD/CAM and CNC that is widely researched in the field of STEP-compliant CAD/CAM or STEP-CNC individually. In the paper, a complete STEP-compliant CAD/CNC system is proposed and a practical machine tool is constructed to verify the feasibility of the system. With the help of the system, 2.5D feature and freeform surface can be machined efficiently. Due to the drawbacks of the NURBS that is the only standard in STEP, T-spline is introduced for the freeform surface exchange between CAx systems that makes it possible for the complex surface machining using the proposed system.

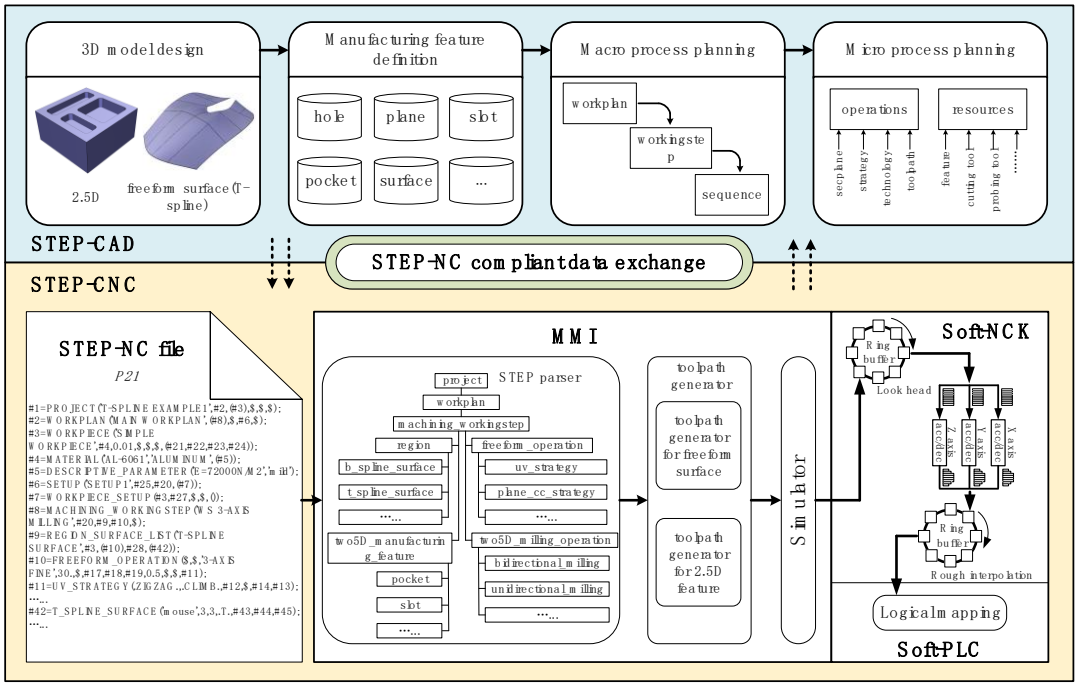


Fig. 1: A complete STEP-compliant CAD/CNC system.

STEP-compliant CAD/CNC system contains two subsystems: STEP-CAD and STEP-CNC as shown in Fig 1. A STEP-compliant CAD system (STEP-CAD) is proposed to design the model and generate STEP-NC file that includes machining information. For 2.5D features, the system is developed as a plug-in component into the Solidworks/UG that have a powerful secondary development platform for the CAD/CAM applications. The 2.5D manufacturing features can be created easily using the API. Other attributes are determined based on its definition automatically. Wherein, machine strategy and tool information can be set up automatically. Beyond that, the open-source library T-SPLINE developed by our team is used to organize the STEP-NC data information for freeform surface. In the end, a typical STEP-NC file is exported from Solidworks/UG or T-SPLINE kernel and delivered to STEP-CNC system.

The proposed STEP-compliant CNC system (STEP-CNC) is developed based on the open-architecture CNC platform TwinCAT that consists of three key modules: MMI (Man Machine Interface), PLC (Programmable Logical Control), and NCK (Numerical Control Kernel). MMI is the major difference between conventional CNC system and STEP-compliant CNC system that should have the capability of online toolpath generation for 2.5D features and freeform surface (T-spline).

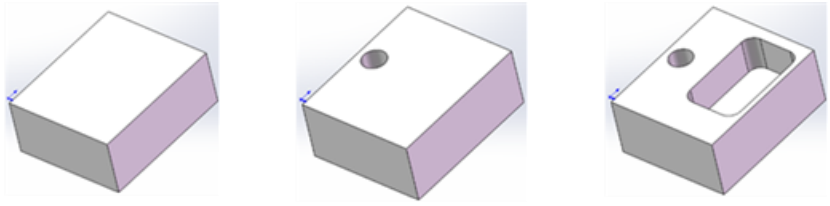
STEP-CAD system for 2.5D feature machining

STEP-CAD is a new type of CAD system that can append manufacturing information when designing models, and the standard STEP-NC file can be generated automatically. There is little commercial software using T-spline for the freeform surface modeling, hence, the proposed STEP-CAD system is developed for 2.5D feature manufacturing based on SolidWorks/UG secondary development technology. Product is designed by combining STEP-NC defined manufacturing features. Meanwhile, user interface is provided to set up the process and machining tool parameters.

Three kinds of information are defined in STEP-CAD system:

- Geometric information that is used to describe the volume to be removed.
- Processing information such as security plane, feed rate, spindle speed, etc.
- Machining tool information consists of tool diameter, tool length, etc.

The first step of STEP-CAD system is to construct feature based on geometric information that means the user can generate the manufacturing feature directly through one interaction step. The modeling process of the example product defined in STEP-NC standard is showed as in Fig 2.



a.planar_face b. round_hole c. closed_pocket

Fig. 2: Modeling process of the product defined in STEP-NC standard.

Each manufacture feature is associated with one or more machining operations in STEP-NC file. In the STEP-CAD system, machining operation is defined through user interface. As shown in Fig 3, user can select a valid machining operation for a closed pocket feature from a list box, and the relevant processing parameters is displayed that can be adjusted if necessary.

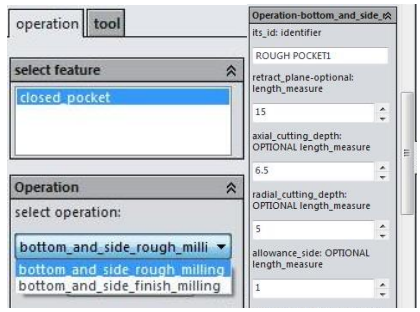


Fig. 3: Processing information determination for different features.

In the proposed STEP-CAD system, machining tool information is acquired from the constructed database that is very important for machining. A user interface is provided for the user to verify and select the appropriate tool as shown in Fig 4.

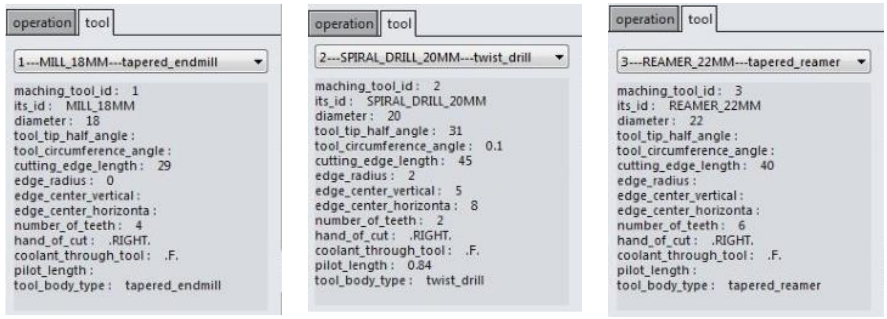


Fig. 4: Machining tool user interface.

T-spline compliant freeform surface machining

Freeform surface manufacturing is important and widely used in the aerospace, automotive, and shipbuilding. Hence, STEP-compliant CNC system should have the capability of freeform surface manufacturing, especially for the complex surface. NURBS owns some characteristics such as local support, affine invariance, and convex hull property. Hence, NURBS is the only mathematical representation for the exchange of freeform surface in STEP. However, there are two inherent drawbacks of NURBS. When using a single surface to represent the complex model, a lot of redundant control points are introduced that only to satisfy the topology of the surface. Trimming and joining surface could represent the complex model using less control points. Nevertheless, there will be some gaps between two adjacent surfaces. The limitations that become the roadblock for the complex surface manufacturing using STEP-compliant CNC system.

T-spline was introduced to solve the limitations that can significantly reduce the number of superfluous control points and using a single surface to describe complex model without joining or trimming operations [5].

T-spline allows the control point terminate at partial row or column, a single T-spline surface can be used to represent the complex surface without introducing redundant control points. It is necessary to integrate T-spline into STEP-compliant CNC system. The STEP-compliant data models of T-spline are constructed in our previous work [6] as shown in Fig 5. A STEP parser is developed to make it conveniently for the integration of T-spline and CAx systems that can convert the EXPRESSS data into C++ language and read STEP file into the memory.

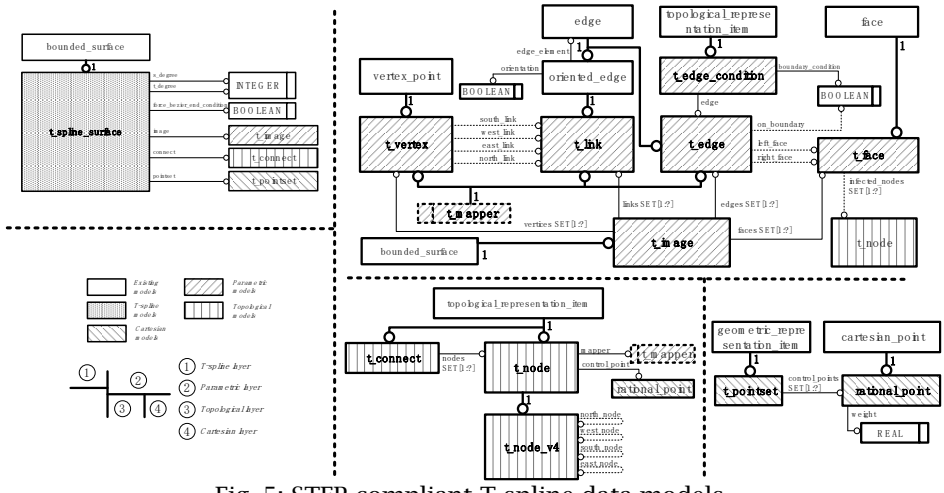


Fig. 5: STEP-compliant T-spline data models.

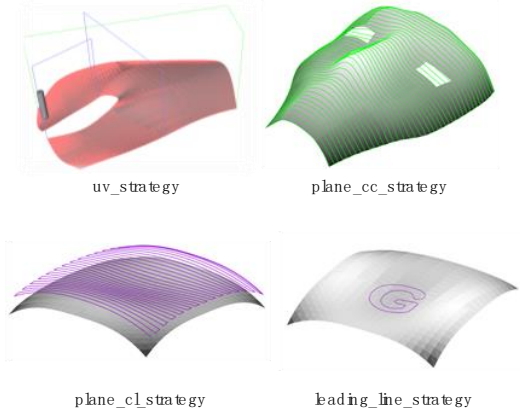


Fig. 6: Four kinds of STEP-NC strategies for T-spline surface.

STEP-compliant CNC system has the capability of online toolpath generation based on the tolerance and machining strategies. There are four kinds of strategy defined in STEP-NC standard: uv_strategy, plane_cc_strategy, plane_cl_strategy, leading_line_strategy. With the help of STEP-compliant data models of T-spline, the toolpath generation capability for STEP-compliant CNC system has been verified using uv_strategy in our previous research work [8]. As shown in Fig 6, different toolpath generation algorithms for T-spline surface are developed based on the rest of strategies that will be the fundamental for the intelligent STEP-compliant CNC system.

Experiment

A practical 3-axis machine tool is constructed to verify the proposed STEP-compliant CAD/CNC system. The machine tool consists of three axes for the motion of X, Y, Z respectively, lubrication system, cooling system, controller, and other additional parts like IO, power. All the parts are connected via EtherCAT fieldbus that is a fast industrial Ethernet technology can support a synchronized cycle time up to 100 μs. There are four models have been tested to demonstrate the possibility of the proposed system.

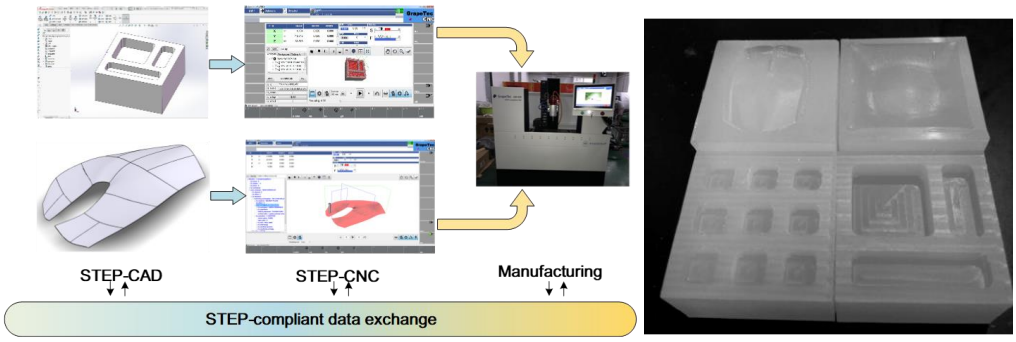


Fig. 7: (a) A practical machine tool base on the STEP-compliant CAD/CNC system, (b) Test models.

Conclusion:

In this paper, STEP-compliant CAD/CNC system is developed for the feature-oriented machining that includes 2.5D features and freeform surface. The proposed system consists of two subsystems: STEP-CAD and STEP-CNC. STEP-CAD is used to design models and generate proper STEP-NC file. A secondary development of Solidworks/UG based on STEP-NC is realized that can build the connection between CAD and CNC for 2.5D features. And T-SPLINE kernel is used to create STEP-NC file for freeform surface. STEP-CNC has the capability of online toolpath generation. Toolpath generation algorithms for 2.5D features are supported. Beyond that, four kinds of toolpath generation algorithms are realized based on the STEP-NC strategy for the T-spline surface machining. A practical machine tool is constructed under the STEP-compliant CAD/CNC system. Some workpieces are tested to verify the capability of system for the feature-oriented surface machining. In the future researches, intelligent manufacturing based on STEP-compliant CAD/CNC system will be studied, such as machining optimization for complex surface, cloud-based manufacturing, intelligent senor-based control, etc.

Acknowledgements:

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