STEP-NC Based Manufacturability Evaluation

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Abstract. This paper presents an evaluation method for part manufacturability. The data model used is the STEP-NC data model, i.e. ISO 14649. Firstly, the evaluation indices such as workpiece clamping, performance of machine tools, resources of cutting tools and auxiliary performances are presented. Then, an information resource model of machine tools is established, and an evaluation algorithm is designed. Finally, a prototype system is discussed which verified the model and algorithm developed.

Keywords: STEP-NC, NC Program, Manufacturability.

1 Introduction

Since numerical control technology was developed 50 years ago, it has undergone significant changes to an extent that high-speed machining with ultra-high precision has become possible (Martin and David, 2007). However, the current CNC language, so called G & M codes formalized by ISO6983, is considered as a low-level language that delivers only limited information to CNC and is unfit for shop-floor programming purposes. Furthermore, the use of G-code exclusively among the CNC machines, makes these machine tools isolated from the rest of the manufacturing resources and hard to cope with the information-based, modern manufacturing scenario such as e-manufacturing (Xun and Newman, 2006). To realize true integration between design and manufacturing via sharing product information among CAD/CAM/CNC chain, a new and comprehensive data model for NC programming formalized as in ISO14649 has been published by the International Organization of Standardization. ISO 14649, which is usually named STEP-NC, describes an interface between CAM and CNC to support a direct use of computer-generated product data based on the STEP standards. Since the standard of STEP-NC suggests a possible revolutionary change on the ways CNC machine tools are run and, great attentions have been given to it throughout the research communities around the world (Shin et al, 2007).

Contrary to the current NC programming standard (ISO 6983), ISO14649 is not a method for part programming. It does not normally describe the tool movements for a CNC machine. Instead, it provides an object-oriented data model for CNCs with a detailed and structured data interface that incorporates feature-based programming where a range of information is represented such as the features to be machined, tool types to be used, the operation to perform, and the sequence of operations to follow.

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STEP-NC provides a complete and structured data model, linked with geometrical and technological information, so that it is possible for a machine tool to machine a part with some intelligence (Kumar et al, 2007). A STEP-NC program may be written once and used on many different types of machine tools with differing controllers. In order to do this, the STEP-NC controller must possess the ability of evaluating the manufacturability of a part program according to the own resources (Suh et al, 2003; Nassehi et al, 2006). In this paper, we first review the relevant information contained in a STEP-NC file. Then, we propose indices of part manufacturability evaluation and a machine tool model, which provide necessary information for manufacturability evaluation of a STEP-NC program. After that, an algorithm is presented, which is followed by developing the system to demonstrate the feasibility of the proposed method. At last, the conclusions are presented.

2 STEP-NC Data

Effectively, STEP-NC defines a data model for CNC systems. Like other STEP applications, STEP-NC files also conform to ISO 10303-21 (ISO, 2006). That is, the file contains two sections marked by the keywords HEADER and DATA, respectively. In the HEADER section, some general information and comments concerning the part program are included. These are, for example, file name, author, date and organization. The DATA section is the main part of the program, containing all the information about manufacturing tasks and geometries.

Description of a part in this section mainly includes three types of data. Firstly, the basic information concerning the location of the wokpiece, the clamping position, the material and geometry of the part, the security plane, the restricted area and etc. These data are specified through two entities: workpiece and setup. The workpiece entity contains the entire description of the workpiece. This includes material, surface condition and geometric data. The workpiece entity contains the raw part dimension in terms of its enclosing box or cylinder. The setup entity includes information concerning the location of the workpieces' coordinate systems. Through setup's attribute its_origin, a Cartesian coordinate system is defined relative to the machine coordinate system. It is the frame of reference for locating the workpiece in the setup. Figure 1 is the data structure for both workpiece and setup entities (ISO, 2006).

The second type of information in a STEP-NC file is machining Workingsteps and their sequence(s). It includes a PROJECT entity that is an explicit reference for the starting point of the manufacturing tasks in the data section of a STEP-NC file. The PROJECT entity contains a main 'Workplan' which contains sequenced executable manufacturing tasks called 'Workingsteps'. Therefore, the STEP-NC file has an 'object-oriented' data structure. Executable objects initiate actions on a machine and are arranged in a pre-defined, but a changeable order. In Figure 2, there are seven machining features in a part (Liu, 2004). The Workplan prescribes 12 Workingsteps and their sequence, that is: rough Face1 → rough Side1 → rough Pocket1 → finish Pocket1 → drill Hole1 → drill Hole2 → drill Hole3 → countersink Hole3→ rough Slot1 → finish Slot1 → finish Face1 → finish Side1. Typically, there are many feasible Workingstep combinations. It is up to the machine tool to decide an optimal

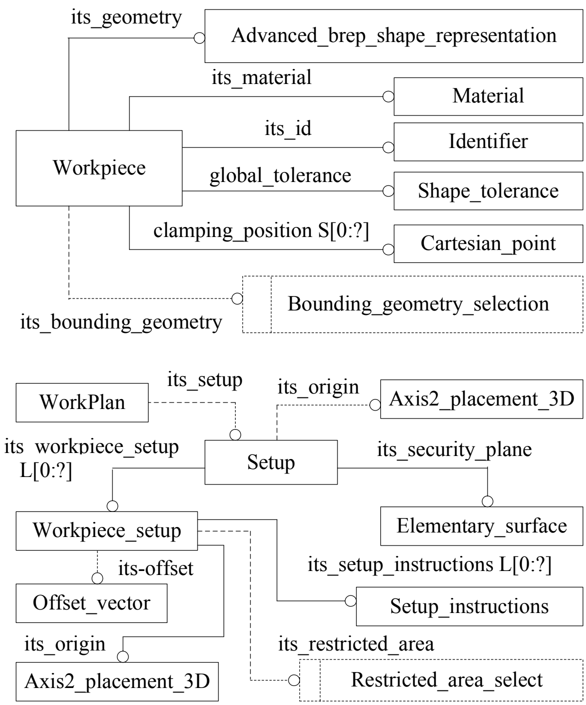


Fig. 1. The data structure of workpiece and setup

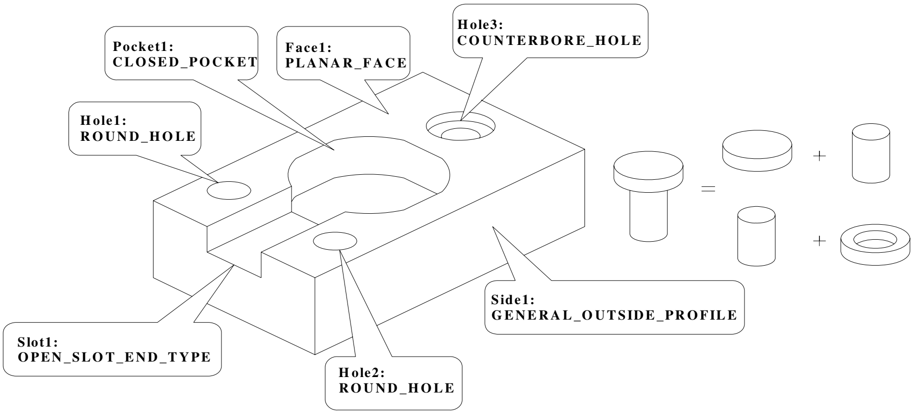
machining sequence according to its resources and conditions if the machine tool's NC controller has the required intelligent functions.

The third type of information in the STEP-NC data model is specifically related to a specific Workingstep. This may include tool data (dimensions, tool type, conditions and usage of the tool), machine functions, machining strategies, other process data and a workpiece definition (surfaces, regions and features of the finished part). Figure 3 shows a typical process description and data structure of bottom and side milling and its technology in STEP-NC (ISO, 2006).

3 Manufacturability Evaluation Model

STEP-NC files provide the necessary information for making decisions about how to machine a specific manufacturing feature using certain resources. However, they do not always contain the information about procedures of how a machine tool may machine a part. It is clearly a machine tool's responsibility to decide how to properly machine a part.

In essence, STEP-NC files are supposed to be universal to all types of NC machine tools. Since the machining resources and status are different from one another, there is a necessity of evaluating the STEP-NC file against these resources and capabilities before the part is machined in this machine tool.




```
…
#2=WORKPLAN('Main workplan',(#20,#21,#22,#23,#24,#25,#26,#27,#28,#29,#30,#31,#32),$,#16,$);
…
#20=MACHINING_WORKINGSTEP('Rough Face1',#20,#40,#41,$);
#21=MACHINING_WORKINGSTEP('Rough Side1',#220,#42,#43,$);
#22=MACHINING_WORKINGSTEP('Rough Pocket1',#220,#44,#45,$);
#23=MACHINING_WORKINGSTEP('Finish Pocket1',#220,#46,#47,$);
#24=MACHINING_WORKINGSTEP('Drill Hole1',#220,#48,#49,$);
#25=MACHINING_WORKINGSTEP('Drill Hole2',#220,#50,#51,$);
#26=MACHINING_WORKINGSTEP('Drill Hole3',#220,#52,#53,$);
#27=MACHINING_WORKINGSTEP('Countersink Hole3',#220,#54,#55,$);
#28=MACHINING_WORKINGSTEP('Rough Slot1',#220,#56,#57,$);
#29=MACHINING_WORKINGSTEP('Finish Slot1',#220,#58,#59,$);
#30=MACHINING_WORKINGSTEP('Finish Face1',#220,#60,#61,$);
#31=MACHINING_WORKINGSTEP('Finish Side1',#220,#62,#63,$);
```

Fig. 2. An example of the Workingstep sequence in a STEP-NC file

3.1 Evaluation Indices of Manufacturability

As mentioned before, STEP-NC files contain all operations and their related information from the stock to its final part. It is therefore possible to decide whether a specific machine tool can machine the part if a machine tool's information model is established. To evaluate the feasibility of a STEP-NC file to be executed on a specific machine tool, evaluation indices are proposed in this research. Based on the information provided by a STEP-NC file, we classify the evaluation indices into four types (Table 1), i.e. workpiece setup, machine tool capability, machine tool resources and auxiliary devices.

3.2 Machine Tool Model

To evaluate the feasibility of a part to be machined on a designated machine tool, the machine's information such as status, performance, the configuration of cutting tools, etc. is required. Therefore, it is necessary to create an information model for CNC machine tools, with which required information for machinability evaluation can be

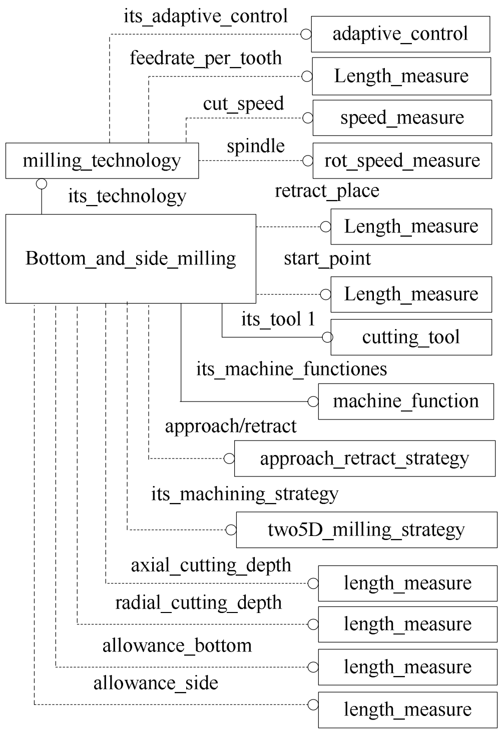


Fig. 3. The basic process data concerning a Workingstep in STEP-NC

Table 1. Evaluation indices of manufacturability

Evaluated entity	Index	Description
Workpiece setup	Length of the workpiece	Determine if the working table of the selected machine tool can meet the requirement of clamping the part.
	Width of the workpiece	
	Height of the workpiece	
	Material of the workpiece	
	security plane	
machine tool capability	Dimensional precision of the part	Determine if the performance of the selected machine tool can meet the requirements of machining the part.
	Required spindle speed	
	Required feed speed of each axis	
	Cutting distance of each axis when machining the part	
machine tool resources	Types of machining features	Determine if the cutting tools owned by the selected machine tool can meet the requirements of machining the part.
	The basic parameters of each feature	
	The minimum radius of all corners	
Auxiliary devices	Coolant	Determine if the auxiliary devices of the selected machine tool can meet the requirements of machining the part.
	chip removal	
	axis clamps	

made available. The STEP-NC data model contains six types of information about a machine tool, i.e. the shape and size of its working table, the range of speed and power of its spindle, the type of its cutting tools, the range of feeding speed of each axis, the machining precision and its auxiliary devices. Figure 4 shows the structure and relationship of these entities about a machine tool.

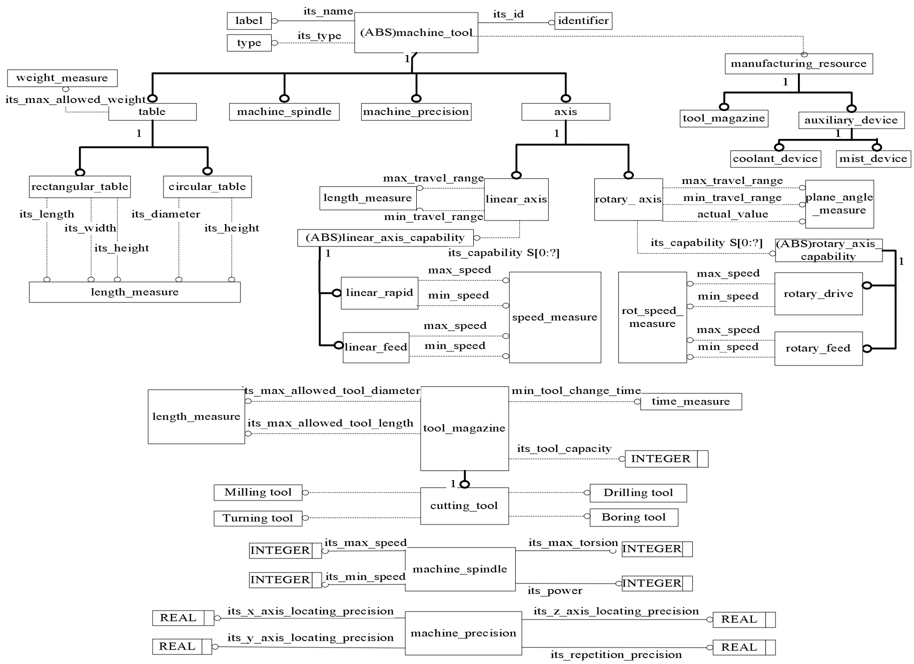


Fig. 4. Information model of a machine tool

4 Manufacturability Evaluating Algorithm

According to the evaluation indices proposed by section 3.1, an evaluation algorithm is presented. Figure 5 illustrates the algorithm. There are four steps involved to evaluate the feasibility of a STEP-NC file to be executed on a designated machine after extracting the information from the STEP-NC file. Firstly, the designed machine tool must have the capacity to hold and clamp the workpiece, which means that the size and weight of the workpiece have to be within the range of the machine's capability. Secondly, the performance of the machine tool has to meet the requirements of the STEP-NC file. Then, the cutting tools installed in the machine have to be suitable for machining the manufacturing features described in the STEP-NC file. Finally, the designated machine tool must have the required auxiliary devices such as coolant device, chip removal devices and etc.

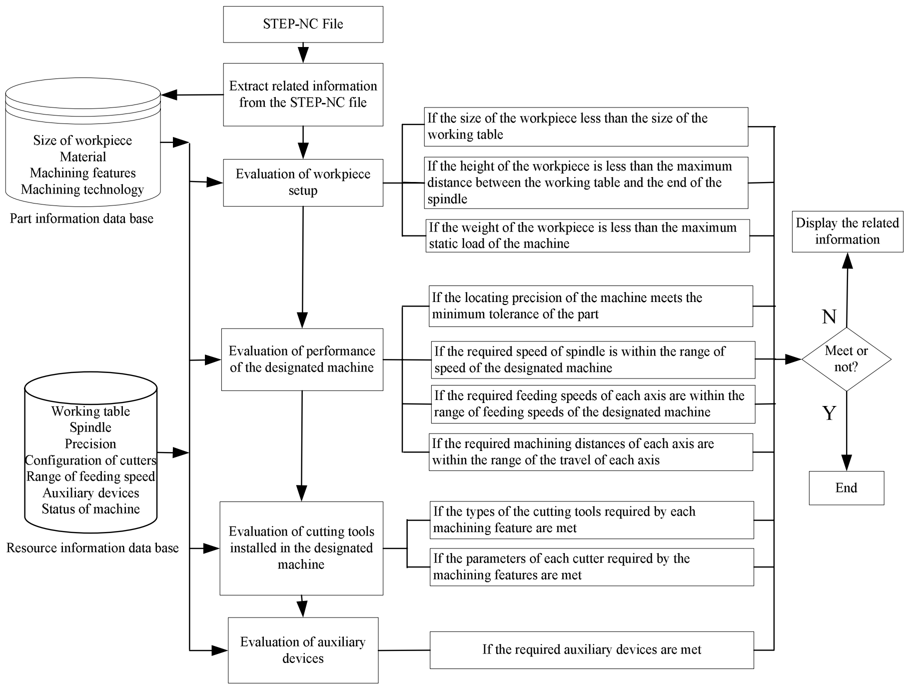


Fig. 5. Flow diagram of manufacturability evaluation of STEP-NC files

5 Development of a Prototype System

Based on the evaluation indices, the resource information of machine tools, and the proposed algorithm, a prototype system was developed. The system is composed of four modules as shown in Figure 6 - (1) interpreter, (2) machine resource database, (3) manufacturability evaluation, and (4) task scheduler.

The interpreter can load an AP 238 file which based on the structure of the ISO 14649 data model. C++ files corresponding to the ISO 14649 schema were developed. Note that the schemas represent the structure of a data file based on the physical file format of STEP Part 21, and the class file represents the structure of instance of a class. A physical file contains instances of classes that are formed by: (1) reading/compiling the physical file, (2) creating instances of classes corresponding to the entities defined in the schema, and (3) setting the values of instances as the attributes of the entities. The extracted information is stored in a part information database.

To implement a networked manufacturing environment, we established a global manufacturing resource information database based on the proposed model in section 3.2 at the sever side. Therefore, the selected STEP-NC file can be evaluated by matching the appropriate machine tools.

The manufacturability evaluation module was developed based on the algorithm proposed in section 3. According to the four steps of evaluating STEP-NC files, the manufacturability evaluation module finds the right machine tool(s) from the machine resource database and lists them as candidates for the job.

The task scheduler module makes a final decision about how the machining tasks in the STEP-NC file should be sent to the machine tool for efficient and effective machining. Figure 7 shows the interface of the prototype system.

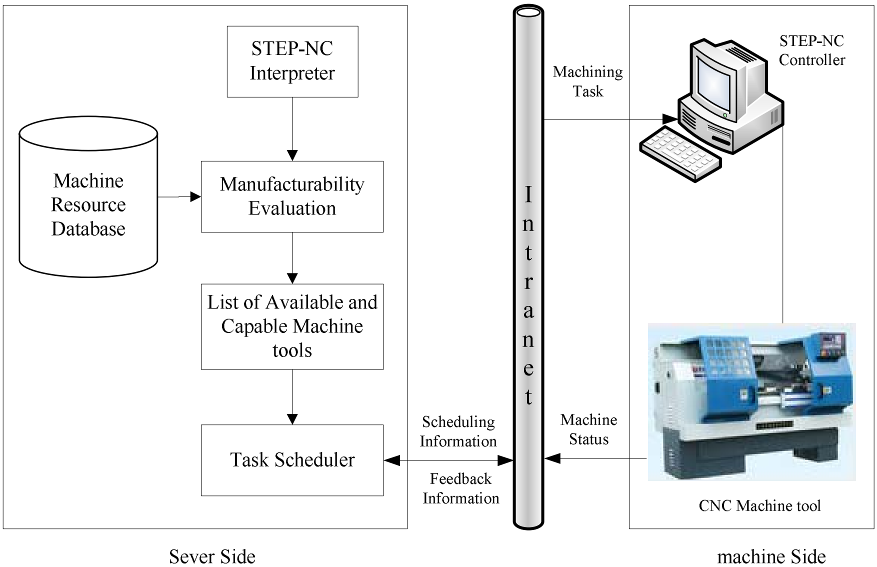


Fig. 6. The architecture of the prototype evaluation system

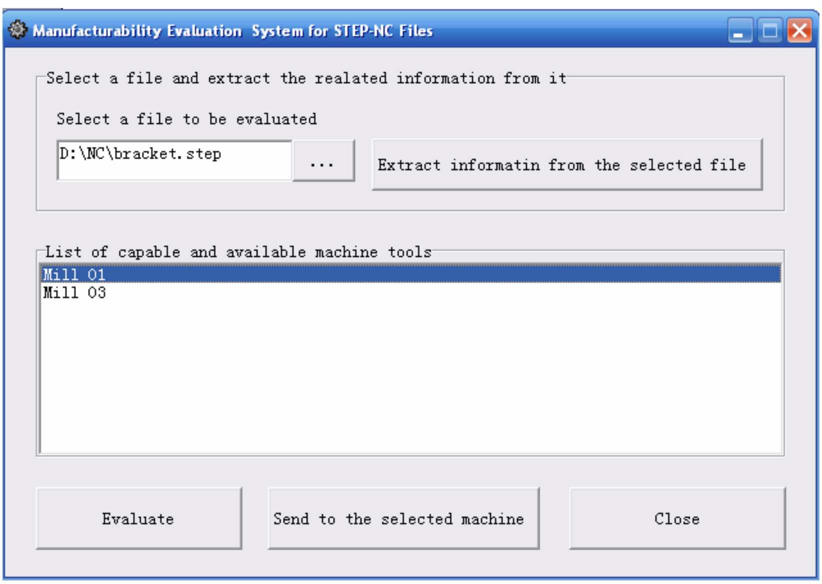


Fig. 7. The interface of the prototype manufacturability evaluation system

6 Conclusions

STEP-NC is suggesting a new paradigm for CNC control and execution. This is possible through a high-level data model speculated in ISO 14649 and ISO 10303 AP238. The standards are effectively defining a new interface for CNC controllers. To realize the true benefits of STEP-NC, that is written once and used on different types of machine tools, a manufacturability evaluation algorithm has been developed. The algorithm is based on a set of indices for evaluating a STEP-NC file. An information resource model of machine tools helps provide the necessary information about the machine tools. The prototype system developed demonstrated that the desired functionality and verified the proposed model and algorithm.

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