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Setup Planning Automation of Turned Parts Based on STEP-NC Standard

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Abstract – STEP-NC(ISO 14649), the extension of STEP(ISO 10303) standard developed for CNC controllers, is a feature-based data model. STEP-NC develops the step neutral data standard for CAD data, and uses the modern geometric constructs to define device independent tool paths, and CAM independent volume removal features. This paper will present an automatic setup planning module integrated in a CAPP system for rotational parts to be machined on a lathe. The developed system will determine the possible setup combinations that are necessary for a complete machining of the part. The applied methodology will take into consideration constraints such as the geometry of both the stock and the final part, the geometry and the capacity of the chuck, and the part tolerances. Finally, the analysis of tolerances charts will be implemented for the sets of surfaces to be machined within each setup. The output can be then used to augment the STEP-NC physical file.

Key words *- setup planning; ISO 14649; CAPP; SetupPlanning*

I. INTRODUCTION

In today's manufacturing industry, products are going to be more and more geometrically complex. Lead time plays an important role in order for customers to choose the manufacturer considering the quality aspects and reduced cost [1]. Computer numerically controlled (CNC) machines which are driven by post processor softwares are emerged to meet these new challenges. During last 5 decades from the first day of CNC machines invention, the capabilities and variety of these machines are increased significantly. The more the number of independent machine axes, the more competent controllers would be needed to make use of the machine. Technologies like multi-axis control, adaptive control, real time quality check and online error compensation demand a more reliable and complete programming language compared to the early generations of CNC machines.

The whole product lifecycle consists of many stages, including programming the CNC machines. Many systems are devised to manage the whole product lifecycle data and make and integration between these stages. Integration minimizes the possible data error and redundancy during information exchange among the whole product lifecycle stages. One of the most successful solutions for such platform is the Standard for Exchange of Product data model (STEP) [2]. The most noteworthy characteristic of STEP is that the data structure is defined in such a way that the information is technology-independent. This type of approach makes it possible not only to exchange the neutral data between different systems, but also provides a suitable infra-structure for the integration in the whole product life cycle. For different aspects and applications of data type, STEP standard has defined different Application Protocols (AP). In general, each AP defines set of format schemas, information requirements and the way to communicate with other AP-defined data in an integrated product model.

Application Interpreted Model (AIM) is defined using an EXPRESS information model to access a library of pre-existing definitions. This model can be used by software developers to implement STEP in different stages. AP 224 is one of application protocols provided by STEP to define mechanical product definitions for process planning using machining features. AP 238 which is known as STEP-NC, is defined to implement micro process planning task for machining operations. Apparently, AP 238 is concerned with connecting CAD and CAM stages. This should be the reason that why the AP 238 is also known as STEP-NC. The works on AP 238 are focused on STEP-based process planning. STEP-NC data model supports a bi-directional information transfer between CAD/CAM and NC. Compared to AP 238, inspection data models are defined in AP 219 for micro inspection planning on CMM machines. These information from two different APs can be integrated based on AIM model. Fig. 1 depicts the relation among the various APs which are integrated to form a neutral product data format [1].

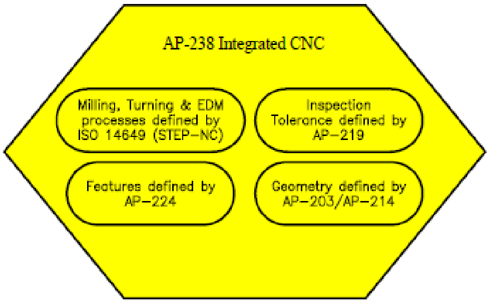

Fig.1 : AP238—STEP integrated version of STEP-NC.

This paper aims at proposing a new setup planning approach based on the data model embedded into a STEP-NC physical file. The developed software tries to get a physical STEP-NC file containing the part manufacturing information, and finds the most suitable setup order and other details considering many related parameters. Finally, the output will be written on the same file. This prototype evidently shows a successful STEP implementation example. In the section 2, a review of related researches on setup planning are presented. Section 3 goes through a brief introduction on STEP-NC data structure. In section 4, the architecture of developed system is described. One example part is also included to prove the possibility of such STEP-NC implementation.

II. SETUP PLANNING RESEARCH

CAPP systems can be divided into two approaches - generative and variant. The generative approach creates a process plan by mapping the part geometry on to the manufacturing databases using process planning logic defined in a program. This method uses algorithms to decide for different stages of process planning. The variant approach makes use of group technology to categorize the parts into part families based on their geometric and manufacturing attributes. Planning for a new part is done by retrieving a process plan for a similar part and making necessary modifications [11,12].

Most of researches on setup planning automatic systems only face with simple parts that remain in a theoretical framework. A system of such type was proposed that applied some precedence constraints based on heuristic rules during planning setups [13]. Wang and Wysk have developed an approach for machining process selection for turning parts based on decision trees. The main drawback of such approach is the decision trees are not capable of being dynamic and flexible in terms of presenting the process plan knowledge. That is, any modification in the input knowledge will result in a whole change in the program. A key factor in setup planning is the influence of tolerances which should be considered with care. A CAPP system applied to rotational components considering setup planning is proposed considering this point [15].

As a result, it can be said that the aforementioned researches provide efficient solutions to certain aspects of setup planning. Many of researches group the features to be machined in different setups, but a few of them determine the clamping surfaces. These surfaces affect the final part precision and it seems logical to carry out the clamping surface selection task with more care.

III. STEP-NC DATA MODEL

STEP-NC data models are developed to retain and maintain information about manufacturing features and process parameters using an object-oriented method in an EXPRESS schema. "Workingstep" is the basic machining task that corresponds to high level manufacturing features with the associated features. In this regard, CNC controllers are responsible for translating workingsteps into machine axes motions. Currently, G-code standard is used for controlling the tool motion relative to the machining part. In fact, STEP-NC is the STEP standard which is extended to NC domain [3].

The principle behind STEP-NC logic is to program in an object-oriented way instead of coding the tool motions. In other words, STEP-NC describes the tasks which should be done in a single machining project and not "how" to do them. These tasks are assigned to different machining features which are described in the STEP-NC physical file. The process data and parameters can be completely defined under this application protocol as it is micro process planning for machining operations.

STEP-NC program format is the same for the one which is described in STEP - ISO 10303-21. The first section of the part program is the header. Header contains general information about the program, date, author and organization. Main body of the program will come after the header section. "DATA" is the keyword for this part, which contains all the information about the geometry description, and machining workingsteps that should be done in the project. Data section can be divided into three categories': Workplan and executables, Geometry description, and technology description. The workplan contains subsets of executable manufacturing tasks [4, 5].

The "executable" is the base entity for executables in the part program. Executables can be divided into sub classes: Workingstep and NC Function are two important sub type of executables. The workplan can combine these executables in a linear order or even parallel depending on the controller capabilities. Fig. 2 shows a schematic structure of a STEP-NC program.

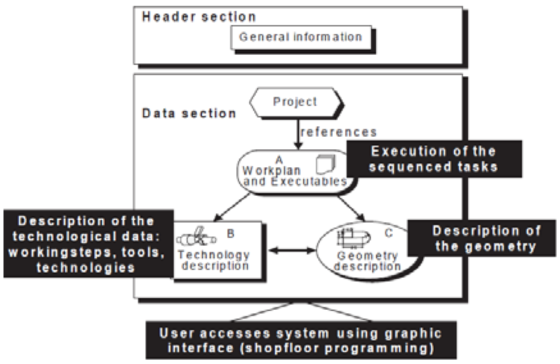

Fig. 2 : Object-oriented STEP-NC data structure

Geometry, technology and process can be accurately described under STEP-NC program. The EXPRESS language allows the parenthood relation between different objects which comprise the pre-existing definitions for the program. Fig. 3 illustrates this concept in a single picture using the real classes defined in STEP-NC.

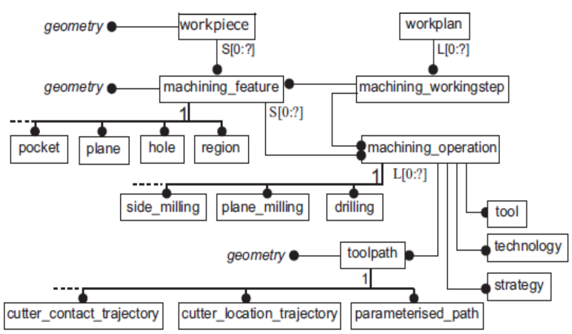

Fig. 3 : EXPRESS information description in STEP-NC data structure

In fact, this physical contain all the information about part geometry and tolerances, workingsteps, process parameters and cutting tool data. The exert from a sample STEP-NC file is shown as below:

ISO-10303-21;

HEADER;

FILE_DESCRIPTION(('EXAMPLE'),'1');

FILE_NAME('EX.STP',$,('ISO14649'),$,'SUH',$, $);

….

ENDSEC;

DATA;

(* ***** Workpiece definition ***** *)

#1=WORKPIECE(‘WORKPIECE',#2,0.01,$,$,$,());

#2=MATERIAL('ST-50','STEEL',(#3));

……

(* ***** Manufacturing features ***** *)

#10=REVOLVED_FLAT('R1',#1,(#22),#172,#176,6,#78);

#11=REVOLVED_FLAT('R2',#1,(#31,#32),#183#87,2,#5);

(* ***** Turning operations ***** *)

……

#20=CONTOURING_ROUGH($,$,'Rough1',30.000,$,#280,#61,#60,#130,#130,#131,0.5);

#21=CONTOURING_FINISH($,$,'Finish1’,30.000,$,#280,#61,#60,#130,#130,#132,0.0);

…..

(* ***** Project ***** *)

#34=PROJECT('TURNING EXAMPLE 1',#35,(#1),$,$,$);

#35=WORKPLAN('WORKPLAN1',(#36,#37),$,#52,$);

(* ***** Functions / Technology ***** *)

#60=TURNING_MACHINE_FUNCTIONS(.T.,$,$,(),.F.,$,$,(),$,$,$,$);

#61=TURNING_TECHNOLOGY($,.TCP.,#62,0.300,.F.,.F.,.F.,$);

….

#57=POLYLINE(‘Second cut of the contour’,

(#29,#30,#31,#32,#33,#27));

ENDSEC;

END-ISO-10303-21;

In the proposed system, geometrical, operational and process data are accurately extracted out of the physical file and saved into a database. This method allows the software to exchange or combine the NC data with different applications. More detailed description of this prototype is brought in the next section. STEP-NC standard is now being implemented in prototypes and end users like Volvo and Daimler Chrysler showed motivation to implement it. As STEP-NC is gradually implemented on the CNC machines, the databases for milling, turning, EDM and other process will be developed and standardized in next few years.

IV. PROPOSED SETUP PLANNING SYSTEM

A multi-agent-based STEP-NC intelligent controller proposed by Lan, Liu, and Zhang for next generation of STEP-NC controllers [7]. These controllers are in charge of interacting between STEP-NC program and machine axes. The emphasis of this research is to focus on 3 distinguished steps: STEP-NC program reading, setup planner agent, and STEP-NC data writer. Setup planning can be inferred as sequencing and detailing the workingsteps in the STEP-NC program.

A setup can be defined as a group of features that can be machined during a single clamping of the part being processed. Apparently, the goal of setup planning is the machining of maximum number of features in the minimized number of setups. In fact, clamping and un-clamping of the part in the same machine tool affects the accuracy of final part significantly. Setup planning is the main contributor to the process planning task in the machining zone. Setup planning is a hard problem itself, since it concerns with many parameters and variables [8].

Feature4 recognition is considered to be a prerequisite for process planning activities. STEP by defining various application protocols has solved this issue. STEP-NC program contains the geometry data for machining features as well as tolerance data. The proposed software in the first step, reads the STEP-NC file and extracts the features information from the program. The whole file data will be saved into a database. The idea is to have a systematic and query-based access to all data inside the program. Processing the features relative data in the same database consists of tolerance analysis, and feature positioning. Tool approach direction for each feature is another output at this stage. Fig. 4 shows a part of the software interface.

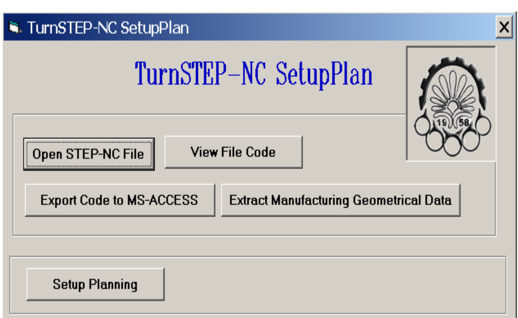

Fig. 4 : Object-oriented STEP-NC data structure

Recognizing the features geometry and related tolerqnces is the cornerstone of a correct setup planning. Main body of the software is focused on setup planning considering the following parameters:

- Cutting tool approach direction
- Chuck size and capacity
- Dimensional and geometric tolerances

As it is stated before, the focus is on minimizing the setup numbers to minimize its effect on machining quality and time. Changing the tool due to limitation in tool life is another important point which can affect the machining quality, but changing the tool is not considered as changing the setup in this research. Turning features in STEP-NC standard are grouped into different classes and sub-classes. Based on the STEP-NC standard, each of these features can be geometrically described using limited number of parameters. The proposed software extracts this information and provides them for the setup planning agent.

Selection of clamping method and clamping surface is the fundamental task in a setup planning job. The software tries to select the surfaces for clamping which have the tightest tolerance with other features. This decision takes advantage of heuristic methods in the software algorithm. Tolerances between two or more features are one of the most important points in selecting clamping surface. To obtain these relations, there are three option in order of priority:

1. Arrange both features in one setup
2. One feature as clamping and machine the other one
3. To machine both features into two different setups

The second method is recommended by many references [9]. Automatic datum selection is one of the critical problems for CAPP systems to generate feasible and economical process plans. Apart from expert systems as a relatively reliable solution for this problem, a neural network is proposed to help the user find the suitable surfaces for clamping the part [10]. Illustration of an example part will come in next paragraphs to show the results of setup planning. The geometry description of the part is depicted in Fig. 5.

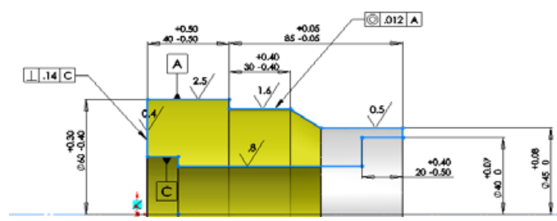

Fig. 5 : Example part geometry description

Fig. 6 shows a snapshot from the database software which is used to maintain the features data. This data structure is found completely suitable for implementing STEP-NC into a software. SQL query commands are used to connect the Visual Basic 6.0 developed program with MS-ACCESS 2007 as the database software.

Line	Feature	Feature_name	placement	Direction	D1	D1_tol1
#09	REVOLVED_FLAT	'REVOLVED FLAT 1	-2.500	0.000,0.000,-1.000	21.0	
#11	REVOLVED_FLAT	'REVOLVED FLAT 2	-2.500	0.000,0.000,-1.000	12.0	
#12	GENERAL_REVOLUTION	'GENERAL_REVOLU	-40.00	-1.000,0.000,0.000	21.0	21.000,0.000,
#14	OUTER_DIAMETER	'OUTER_DIAMETEF	-70.00		56.000	0.100

Fig.6 :Extracted geometric data from STEP-NC program

The user should enter some basic information about the workshop and machine limitations like the machine dimensions and chuck geometry. Based on the algorithm process, the setup planning agent will select setups. Fig. 7 illustrates the output for the example part. The surfaces are coded accordingly, and easily can be recognized from part draft on a counter-clockwise order starting from the right-most one.

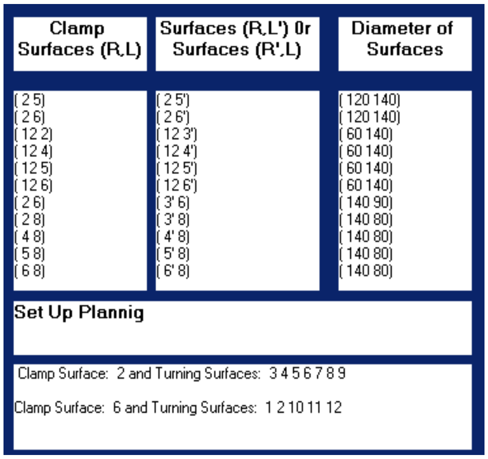

Fig. 7 : Setup Planning output

V. DISCUSSION AND CONCLUSION

Generating an efficient process plan needs to carry out a detailed analysis of resources. Fundamental task in this regard is known as setup planning which determines the way to do each setup in relation to both fixtures and clamping surfaces. This study discussed a developed procedure for setup planning for turned parts based on STEP-NC standard. A case study component was tested to show that the new approach (STEP-NC based setup planning) can generate acceptable setup plans. The output can be used to augment the STEP-NC physical file.

It can be concluded that STEP-NC data can be used for generating a standardized data for generic process planning and setup planning for turning operations. Moreover, it can be said that the setup planning system proposed in this paper can put forward a useful tool in an integrated job shop environment where the job scheduling is needed to integrate with the CAPP systems. An effective integration of these phases should be able to produce process plans that are more feasible considering dynamic changes in shop floor and in the status of the resources.

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