Stimulation Generation Method of STEP-NC Process Routing Based on FBM Constrained Relationship

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Keywords: Process route, STEP-NC, Feature based machining (FBM), Stimulation

Abstract. The excitation selection sort method of manufacturing feature was proposed based on the characteristics oriented to manufacturing feature of STEP-NC to realize the process route planning of STEP-NC. First, match the recognizing manufacturing feature, the manufacturing feature with multi machining operation was disintegrated in order that every manufacturing feature has only a processing operation. Then, the rationality constraint problems of machining operation was translated into the processing order problem of manufacturing feature, and the optimal constraint problem of machining operation was translated into the corresponding manufacture feature set. The process route was generated by the operations of excitation, selection, deletion and transfer for the feature of different manufacture feature set. The last, the feasibility and effectiveness of the process route excitation generation method was verified by an example, and show that this method was better solved the problems of process rules and the representation of knowledge.

Introduction

The integration of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) and Computer Aided Process Planning (CAPP) and Computer numerical control (CNC) is the key problem to build digital integrated manufacturing system. Standard of STEP-NC Standard for the exchange of product data numerical control supply the effective way for the data exchange of different CAX system and the duplex connections between CAX and CNC[1].

The essence characteristic of the STEP - NC is object-oriented, which describe all of the processing tasks from the blank to the finished product. Bridge between product design and manufacturing of CAPP system has become an important part of digital integrated manufacturing system. Liu riliang [2] study early NC machining processing model oriented STEP - NC controller, the step is sorted by heuristic algorithm. Dae-Hyuk Chung [3] study process planning of compound machining based on branch constraint and engineering experience, and the nonlinear process planning method is proposed based on STEP-NC(ISO 14649). P. Li[4] develop process planning system fused with CNC controller based on STEP-NC, the process planning system can generate optimized tool path based on knowledge and rules. Due the generation of process routes involves a large number of constraints, it is often difficult to get effective process route, or the process route is not fully consider the optimal manufacturing resources constraint problems. Therefore, aiming at the generation of STEP-NC process routes, the identify characteristic is decomposed based on machining operations, the corresponding knowledge of processing constraints are represented by using the division of manufacturing feature set, and the corresponding manufacturing feature set is selected by motivational techniques to generate the feasible process route.

Data model and Feature processing unit of STEP-NC

Processing steps of ISO l4649 consists of manufacturing characteristics and processing operations. Among them, manufacturing feature refers to the specific structure need to work out in the work piece, which can be divided into Region feature, 2.5D manufacturing feature and Transition feature etc. Machining operations is a general description of manufacturing characteristics processing, which include processing cutting tool, tool path, the process and processing strategy, etc.[5]. A processing step can only use a knife and constant technical parameters in the existing definition of process steps, therefore, Machining Unit of Feature (MUF) is defined to better describe the relevant process information in the machining process, which is to emphasize the main body of characteristics for processing operations to better adapt the generation of process route.

Definition 1: Feature machining unit. The feature machining unit is expressed as $ME = \{MF, OP, M, CS, T\}$, $\{MF\}$ represent manufacturing feature, $\{OP\}$ represent machining process, $\{M\}$ represent machine tools, $\{CS\}$ represent clamping, $\{T\}$ represent tools.

The definition and identification of the existing manufacturing characteristics are gotten by Boolean subtract calculation of initial blank and the work piece, obviously, there will be $n_{op} (n_{op} \geq 1)$ machining operations for one specific feature. If an initial classification characteristic has multiple machining operations, the concept of In Process Work piece (IPW) is loaded, the residual amount of unfinished processing form new derived character in the previous machining operation.

Constraint relation and feature classification method of parts feature machining

The rationality constraint of manufacturing feature. The complex parts have more processing characteristics; the processing units of basic characteristics exist more constraint relation. The constraints can be divided into rationality and optimality constraints, Rationality constraint is the conditions must to be satisfied in the generation of process route, the optimality conditions are required to meet as possible. The basic idea of process routes generation is to find all feasible route set under the feasible restriction, then evaluate according to the optimal constraint to get better process route. The key problem of process route generation is the recognition of machining feature; the generation of derived character is directly related to the last processing operations especially for a certain characteristics with multiple processing operations. Therefore, rationality constraints mainly show that derived features can begin after corresponding characteristics of the previous step processing operation have finished. Then, the recognized feature has intersection relation, the intersect characteristics exists the rationality constraint of processing sequence in machining process.

In addition, the recognition features exist processing order constraints due to the clamping of processing and benchmark and positioning etc. Suppose the positioning of essential feature MF_2 begin after the essential feature MF_1 finished, which is expressed as $(MF_1)MF_2$. Introduce "and" and "or" logic relationship to show complex constraints, for example, (MF_1 and MF_2) MF_3 means the basic feature MF_3 cannot be processed until MF_1 and MF_2 are done. (MF_1 or MF_2) MF_3 means the basic feature MF_3 can be processed if each of the MF_1 and MF_2 is done.

Manufacturing features and processing unit selection. Aiming at the specific manufacture feature, the main purpose of the processing unit is to select the feasible processing method, and gives the processing optional operation type machine tools and cutting tools, and finally determines the manufacture characteristics of the clamping scheme. For the not involved 4 or 5axis machining operations of the machining methods, the clamping scheme of a manufacturing feature is mainly related to the direction of the cutting tool travel. So the determining steps of the feature processing unit are as follows:(1) Determine the manufacture feature to be step process or not; (2) If it does not need to be step process, the machining operation type can be given to choose the optional machine tools and cutting tools, and determine the direction of the cutting tool travel; (3) If it need to be step process, the features derivative graph is generated, and the information of derived features processing unit is determined for all the leaf nodes on the features derivative graph based on the step (2) from left to right. In the course of determining the information of derived features processing unit, the visual machining simulation and the IPW preservation methods are used to choose the optional machine tools and cutting tools according to the information of its derived geometric features.

Feature set processing precedence relations, clamping and tool division. Through the above analysis, the order of characteristics processing is mainly determined by the rationality constraint, and the rationality constraint is mainly due to characteristics of intersection, positioning and benchmark. Thus, characteristic processing precedence relation is defined by feasibility constraint of characteristics processing.

Definition 2: Precedence relation of characteristics processing. The processing sequence of manufacturing feature is restrained, and gives the possible precursor and post processing characteristics relation in machining of parts. It is expressed as $\{MF, A, B, C\}$, $MF = \{MF_1, MF_2, \cdots, MF_n\}$, the features in $\{A, B, C\} = \{(MF_j, \cdots, MF_k)MF_i\}$, the characteristics in the brackets using "and" and "or" compose logical expression, A means features intersecting reasonable constraints, B means location reasonable constraints, C means reference reasonable constraints.

If the manufacture of a feature needs to derive operation, delete the features before the deriving operation and the derived features as a whole inserts into feature set, and then the intersection reasonable constraints between the derived features should be added. Because of the replacement of the machine tools, clamping and cutting tools in the process of constraint of feature manufacturing, the influences of the feature manufacturing are mainly on processing costs and processing time.

Definition 3: The feature Set clamping division. Supposing the part Machining clamping type set is $\{Cs_1, CS_2, \cdots CS_k\}$, the machinable features set of the clamping can be expressed as $CS_i = \{MF_{i1}, MF_{i2}, \cdots, MF_{im}\}$, if the machining of a feature in S_i has finished, and the next manufacturing feature is not in the CS_i , it means the clamping will need to be changed.

Definition 4: The feature Set Tool division. Supposing the part Machining cutting tool type set is $\{T_1, T_2, \cdots, T_i\}$, the machinable features set of the cutting tool can be expressed as $T_i = \{MF_{i1}, MF_{i2}, \cdots MF_{ir}\}$, if the machining of a feature in T_i has finished, and the next manufacturing feature is not in the T_i , it means the cutting tool will need to be changed.

Stimulus generation method of process route

In the standard of STEP - NC, the parts are described by the way of manufacturing feature. Processing of parts are transformed into the processing of manufacture feature set, process route planning is to sort the order of the manufacturing feature set machining steps. Due to some dependencies relationship between the process steps and recognition manufacturing characteristics, defining the feature machining units is to make the manufacturing feature become its key. So the process route generation under the STEP-NC environment can be transformed into the order problems of the manufacturing feature, and its main steps are as follows: i) Manufacturing feature recognition and intersect determination. All manufacturing features to be machined parts can be distinguished by feature recognition technology, and then the identified characteristics are carried on the crossings determination. ii) Feature processing unit generation. The manufacturing feature set can be gotten by derivative from the identification feature, and then the selection programs of the machine, clamping and the cutting tool are given for the manufacturing feature set. iii) Feature set division and the priority rule generation. The feature set is divided by clamping and cutting tool, and the machining priority rule is mainly to transform the constraints of positioning, benchmark and intersection and so on into the expression of the logic operation. The manufacturing feature, which does not appear in the processing of priority rules, and priority processing feature merge into the set MF_{ji}, and the other features in the feature set are expressed as MF_{tj}, in which all the features have priority processing conditions. IV)Routing stimulus generation. The parts get the order of the manufacturing feature machining, and then the touting of the feature machining can be gotten. v) Feature processing unit clustering. The formed template subtype machining operations is suitable for NC.

Specific routing stimulus generation methods are elaborated, and the description of excitation process can be expressed as follows:

Step 1: Feature activation. A feature MF_i selected from the feature set MF_{jl} randomly is moved into the process route set MF_{gy}, and the feature MF_i is deleted from the feature set MF_{jl}. Activation volume can be given based on the formula (1):

$$\alpha_0(MF_i) = 1 \; MF_i \in MF_{jl} \tag{1}$$

Step 2: Rationality constraint processing. Judging the feature added into the MF_{gy} is compliance with reasonable constraint condition or not. If the condition is satisfied, its subsequent processing features will be added to the feature set MF_{jl}, and this feature is deleted from the MF_{tj}, and delete its rationality Constraint.

Step 3: Propagation calculations of the clamping and the cutting tool feature set. Previous activations are positive spread in similar clamping and cutting tool feature set, and assuming the amount of spread is 0.7 in the clamping, and one is 0.3 in the cutting tool. The feature MF_i is deleted from the clamping and the cutting tool set.

Step 4: Feature selection after activation. Selecting the feature MF_j is according to the activation volume size. If the size is the same, select the feature randomly, if the feature $MF_j \in MF_{jl}$, the selected feature is added to MF_{gy}, deleted from the MF_{jl}. If $MF_j \in MF_{tj}$, return to the step 2, and select the feature again, deleting the feature MF_j from the respective clamping set and cutting tool set, and using Step 2 to carried on the rationality constraint processing.

Step 5: Repeat Step 3 and Step 4 until the corresponding clamping and cutting tool feature sets are no longer feature selection, if the corresponding clamping or cutting tool feature sets have features, it means the rationality constraints is in other clamping and cutting tool sets. Return to Step 1, and activate the second time.

Step 6: Stop until all features are selected and added to the routing set MF_{gy}.

Application examples

To verify the proposed method, and the rough of the part is use of a long enveloped box, whose surface has been the corresponding treatment and does not need to process, which is shown in Fig. 1.

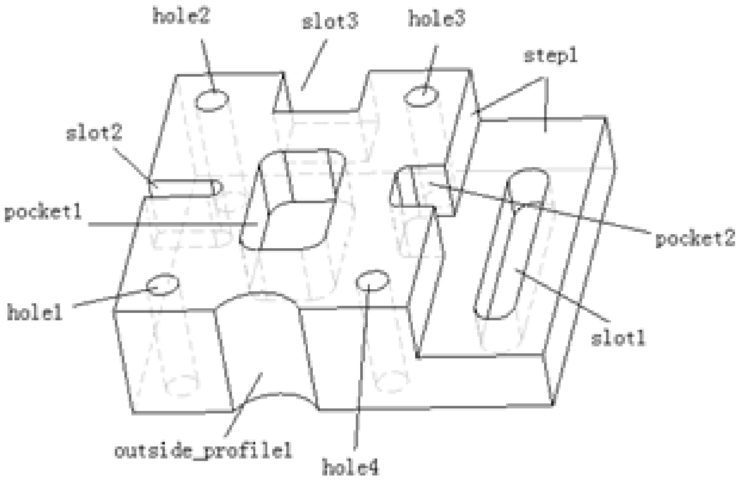

Fig.1 parts to be processed and manufacturing features

It is obvious that the part has 11 features. Firstly, the part has to carry on the derived features. The step 1, slot 1, pocket 1and pocket 2 need to use the coarse and fine processing two steps to finish, so there are 15 features after the derived feature. The specific characteristics of processing unit are shown in table 1:

Table 1 Feature Machining Unit of the Part

Number	Feature	Operation	Machine	Clamping	Cutting Tools	Processing Description
1	Step1-1	Milling	Milling machine M1	S_1	T_1	Roughing
2	Step1-2	Milling	Milling machine M1	S_1	T_1	Roughing
3	pocket2-1	Milling	Milling machine M1	S_1	T_2	Roughing
4	pocket2-2	Milling	Milling machine M1	S_1	T_3	Roughing
5	slot 1-1	Milling	Milling machine M1	S_1	T_2	Roughing
6	slot 1-2	Milling	Milling machine M1	S_1	T_4	Sidewall finishing
7	hole 1	Drilling	Drilling M2	S_2	T_5	Direct drilling
8	hole 2	Drilling	Drilling M2	S_2	T_5	Direct drilling
9	hole 3	Drilling	Drilling M2	S_2	T_5	Direct drilling
10	hole 4	Drilling	Drilling M2	S_2	T_5	Direct drilling
11	pocket1-1	Milling	Milling machine M1	S_1	T_2	Roughing
12	pocket1-2	Milling	Milling machine M1	S_1	T_3	Finishing
13	o_profile1	Line cutting	Line cutting M3	S_3	T_6	Molybdenum wire
14	slot 2	Line cutting	Line cutting M3	S_3	T_6	Molybdenum wire
15	slot 3	Line cutting	Line cutting M3	S_3	T_6	Molybdenum wire

Processing reasonable constraints of the above features mainly depend on the deriving features, reasonable constraints are shown as follows: i) Derived features: $(MF_1)MF_2$, $(MF_3)MF_4$, $(MF_5)MF_6$, $(MF_{11})MF_{12}$, ii) Characteristics intersection: $(MF_1)MF_2, (MF_1)MF_5$ .The features set $MF_{jl} = \{1, 11, 7, 8, 9, 10, 13, 14, 15\}$, and MF_{tj} is the set of the other features. As shown in table 1, The feature sets divided by clamping are shown as follows: $S_1 = \{1, 2, 3, 4, 5, 6, 11, 12\}$, $S_2 = \{7, 8, 9, 10\}$, $S_3 = \{13, 14, 15\}$.The feature sets divided by cutting tool are shown as follows: $T_1 = \{1, 2\}$, $T_2 = \{3, 5, 11\}$, $T_3 = \{4, 12\}$, $T_4 = \{6\}$, $T_5 = \{7, 8, 9, 10\}$, $T_6 = \{13, 14, 15\}$.

The stimulus generation of the routing can use above information. Setting the Initial activation feature is 1, and the feature 1 is added to routing set MF_{gy}, deleted from the feature set MF_{ji}. The rationality constraints are processed, and the constraints of feature 1 condition are deleted. The feature 2, 3, 5 are transformed from the set MF_{tj} to set MF_{ji}. The propagation calculations of the activation volume are done for S_1 and T_1, it is obvious that the activation volume of the feature 2 is 1, and the feature 2 is transformed to routing set MF_{gy}, and the activation propagation of the cutting tool is finished. The feature 4, 6, 12 of the S_1 still have reasonable constraints, so the feature has to be selected among the feature3, 5, 11 of the S_1. It supposed that the feature 3 is selected to do the rationality constraint processing, and the feature 4 is added to MF_{ji}, deleted its related reasonable constraints. The feature 3 activates the cutting tool T_2, so the feature can be chosen feature 5 or 11. The selected feature 5 is to do the rationality constraint checking, transforming the feature 6 to MF_{ji}. And then the feature 11 is selected to do the rationality constraint checking, transforming the feature 12 to MF_{ji}. Up to now, the feature set MF_{tj} and T_2 are empty sets. While the remaining features in S_1

are feature 4, 6, 12, if the feature 4 is chosen, the T_3 will be activated, and the feature 12 and 6 will be chosen sequentially. When the all features in S_1 are activated, return to the set MF_{ji}, then the set MF_{jl}={7， 8， 9， 10， 13， 14， 15}. When the feature 7 is selected to activate, the feature 8, 9, 10 can be chosen by any sort. Return to set MF_{ji}, the feature 13 is activated; similarly, the sorts of feature 14 and 15 can be gotten.

The result is that1→2→3→5→11→4→12→6→7→8→9→10→13→14→15 is the generating process route. The appropriate processing cluster can be done for the characteristics processing unit of the above routing.

Conclusions

STEP-NC is a structure based on STEP, which is further extended to the processing field and has been the data exchange interface between the CAM and CNC, and it provides a wide development space for CNC openness and intelligence. To meet the development needs of the STEP-NC technology and solve the process route generation problem in the process planning of the STEP-NC, a stimulus generation method of routing based on the feature machining constraint is proposed. This method is mainly through the identification of the features, which is dismembered based on the machining operation, to make the dismembered manufacturing features become the primary key of the processing unit. The problem of process route generation is turned into the order of the manufacturing features, so it can easily apply a variety of reasonable constraints and the optimality constraints for machine tool, clamping and cutting tool, and the detailed steps of process route excitation generation are given.

Overall, the application research of STEP-NC is still in the development stage, the decision problem of routings is influenced by the part feature recognition, process rules knowledge representation and so on. The proposed method of this paper is better to solve the problem of process rules knowledge representation, but in some places, its formal representation still needs to be a further improvement to reduce the interactive between the machine and the human, achieving the goal of generating routing automatically.

Acknowledgements:

This paper is supported by Zhejiang Provincial Natural Science Foundation of China (LY13E050021), Jiaxing city science and technology plans (2014BY28004) and so on.

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