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Automatic CNC part programming for through hole Drilling

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Abstract

This paper describes a novel method for automatic generation of process plans and numerical control (NC) part programs from STEP data files. Using proposed system, it is possible to achieve fully automation of recognition of through hole features, generation of process plans and NC part programs. Thus, it becomes possible to go from neutral file to finished product in a fully automated fashion. The algorithms have been implemented on mini-computer to process product data, and display recognized hole features, process plans and creates output files containing NC part programs. These NC part programs are tested through BMV45TC24 CNC Vertical Machining Centers. The results are satisfactory.

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Keywords: Integration of CAD/CAM; Automated process planning; Automatic CNC part programming; Feature recognition; STEP

1. Introduction

Integration of CAD/CAM systems reduces human interaction and the result is increased production, reduced costs and better quality of product. This paper focuses on the development of a new generic methodology for automatically defining workpiece drilled external surfaces (prismatic parts only) from STEP data file. The methodology can extract and interpret manufacturing information in the database and identify drilled surfaces on a

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workpiece without any human intervention. The extracted information is then sent to a computer-aided process planning (CAPP) system for generating manufacturing process plans and/or NC part programs.

2. Literature review

Integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) to support the various stages of the product's lifecycle is essential. An integrated CAD/CAM system is the main component of computer integrated manufacturing environment in which information exchange between different systems is crucial (Dong-Won Kim et al. 2013).

Based on the literature, it is observed that few complex systems have been developed to extract data from a CAD model for specific applications (Huikang et al. 2002, Zhou et al. 2008). In some studies, the NC codes were generated directly from the CAD model (Hou and Faddis 2006). This method worked well for a particular CAD system and not for other systems. Further, this method has specific advantages of generating NC codes based on the data extracted from models generated in any commercially available software.

In this paper, controller-dependent G codes are generated from the STEP file. The generated G codes can be directly executed in the CNC machine which is an advantage over STEP NC. In addition, STEP NC format cannot be used directly in commercial CNC systems. The objective of this paper is to reduce time spent on process planning and NC part programme preparation, thereby improving productivity and minimizing the overall cost of the part.

3. Integration of manufacturing system

Firstly, a part model is created using any CAD software. The geometrical information of the part is converted into a STEP AP203 file. Later, a program to extract geometrical information of the part is developed and NC codes are generated from the extracted information. The parts are manufactured using the generated NC codes and finished parts are inspected using CMM. The results are compared with the reference data extracted from the STEP file. Fig. 1 shows the General view of developed system in the present work.

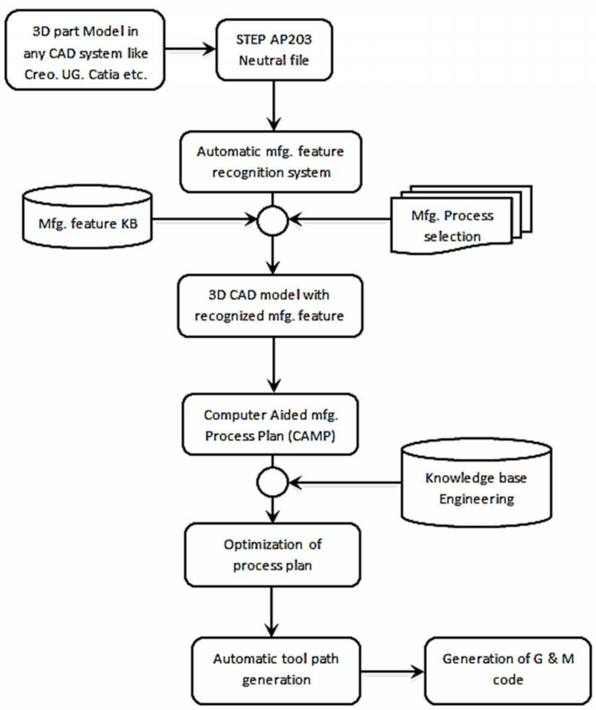

Fig. 1 General view of developed system

Six major steps involved in this work are as follows:

- Generation of the CAD model in any CAD software.
- Exporting CAD model to STEP format.
- Extraction of data from the STEP file (Automatic mfg. feature recognition).
- Generation of process plan and NC code.
- Manufacturing of parts using the generated NC code.
- Inspection of parts using CMM.

6. Process Planning and its optimization

Process planning is defined as the activity that translates part design specification from an engineering drawing into the manufacturing operation instructions required to convert a given raw stock into a final desired component. Traditionally, process planning is based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes and tooling. Process planning is very time consuming and tedious, and the results vary based on the person doing the planning. In the present work, the optimum sequence of drilling operation is considered to generate process plans from the drilling features data base. Many alternative solutions are possible by following the algorithm shown in Fig. 2.

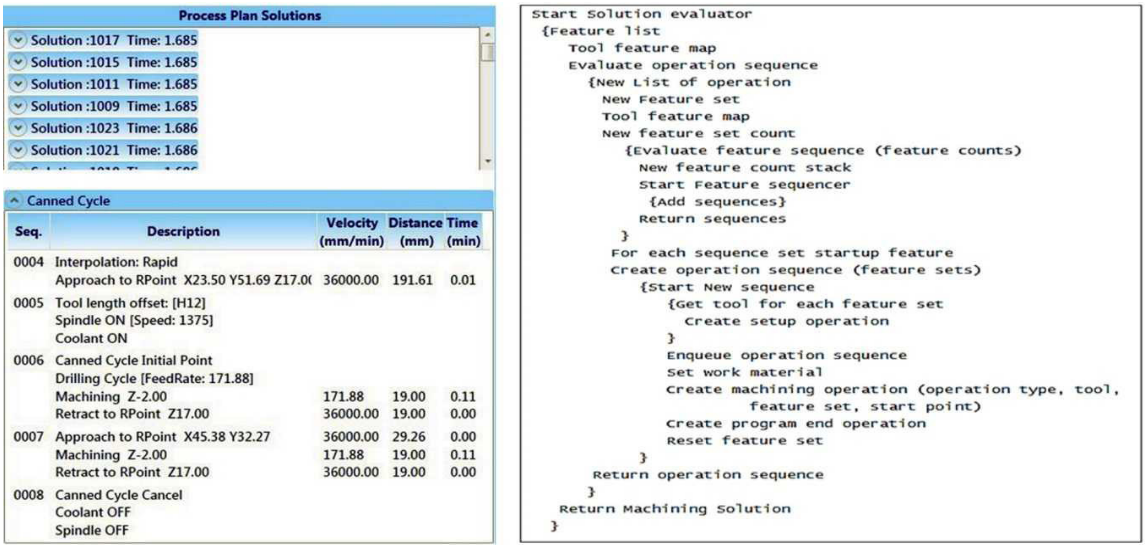

Fig. 2 Algorithm to determine number of solutions in process planning

Computer-aided process planning (CAPP) is one of the most important steps in a manufacturing system. Various conditions and resources affect the total efficiency of the manufacturing system. The tool traveling and tool changing time comprises of a large portion among the total time in a manufacturing process while the optimization of these processes can contribute greatly to the total efficiency of a manufacturing system.

Fig. 3 shows part with different diameter holes to be drilled and distance between holes in the sequence of drilling operation. Hole groups are formed based on similar diameter holes. If holes are more than one, this has assigned canned cycle of drilling operation. Sequence of group executions is performed on the basis of alternative sequence possible. Every possible sequence is evaluated for the time required to travel to the tool from one hole to other. This contributes to the total machining time calculations. In this study hole depth is constant and is equal to

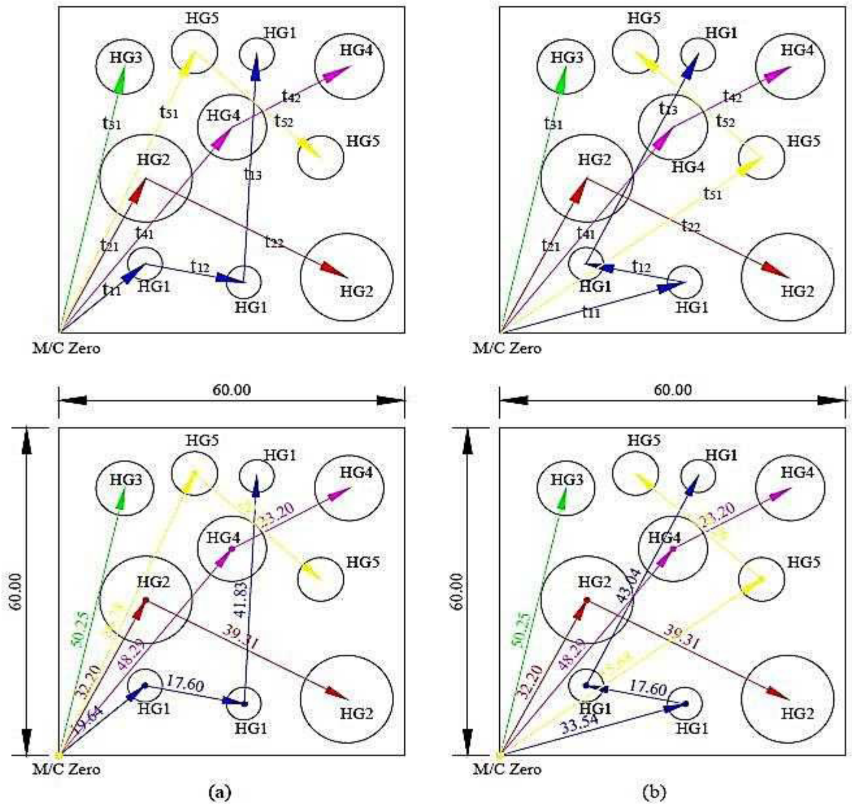

Fig. 3 Hole groups sequencing

thickness of plate i.e. hole is through hole. Various possible alternative sequences and their time calculations are carried out using this method. Table 1 shows tool travel distances between holes for various hole groups. There are n numbers of solutions available for various groups of holes. This can be determined using formula (1).

Table 1 Tool travel Distance calculations for case (a) and (b) shown in fig. 3

Case	HG1			HG2		HG3	HG4		HG5		Total (mm)
	t_{11}	t_{12}	t_{13}	t_{21}	t_{22}	t_{31}	t_{41}	t_{42}	t_{51}	t_{52}	
(a)	19.64	17.60	41.83	32.20	39.31	50.25	48.29	23.20	56.78	29.26	358.36
(b)	33.54	17.60	43.04	32.20	39.31	50.25	48.29	23.20	55.68	29.26	372.37

$$S_n = N_{HG1} \times N_{HG2} \times .... \times N_{HGn} \quad (1)$$

Where S_n = No. of solutions

$$N_{HG1} = \text{No. of holes in hole group 1}$$

$$N_{HG2} = \text{No. of holes in hole group 2}$$

$$\vdots \qquad \vdots$$

$$N_{HGn} = \text{No. of holes in hole group n}$$

After getting n numbers of solutions they are optimized for minimum total time required for machining. Optimization is done in the area of tool travel distance between the holes. This is done by using formula (2). Optimum solutions will be the one, which has minimum travel time of spindle between the holes. Therefore,

Optimum solution with minimum machining time,

$$t_{\min} = \min \sum_{i=1}^{n} \left(\sum_{j=1}^{n} t_{ij} \right) \tag{2}$$

Where t_{ij} = tool travel time from machine zero or previous hole to j^{th} hole in i^{th} hole group
i = 1 to n ……………… value for the hole group number.
j = 1 to n ……………... value for hole number in sequence of operation in respective hole group.

8. NC part program generation

In this algorithm first a blank nc file is created. Then optimum solution is called in the routine. This solution is converted in nc codes. Each solution uses tool-feature mapping. There are number of tools used in single operation. Number of operations are performed using one tool. Different activities are involved for each operation like machine setup, rapid approach, actual machining, retract to R point etc. Machine setup includes the activities like coolant on/off, spindle on/off etc.

9. Case Study

A prototype system is developed on the platform of visual C# based on the proposed system. A prototype system

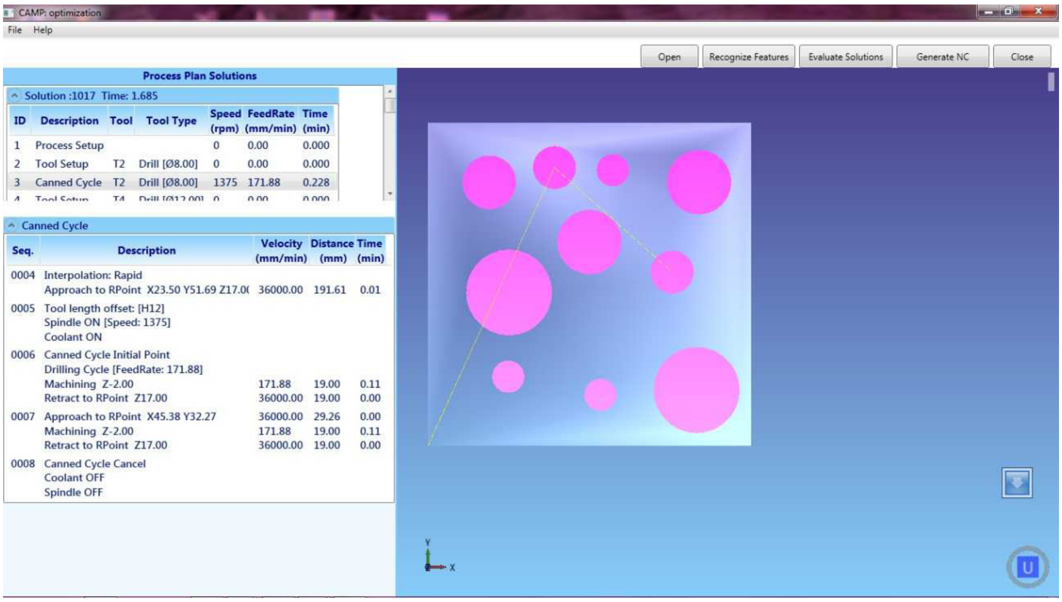

Figure 4 Sample part with process plan and NC code

includes import STEP data, recognition of features, automatic generation of process plan and generation of NC code for optimum process plan. System also uses machining knowledge database like work material, cutting tool database, cutting speed and feed rates. The file generated by the system include NC code information file. Machining time calculations is also done in the automatic generation of process plan module.

Fig. 4 shows the UI used for case study on NC code generation of test part in order to illustrate how the prototype system works and comparison of accuracy CNC programming against other methods. The size of part is $60x60x15mm^3$.

In the present case study the test part model is created using Creo Parametric software which is exported to STEP data file. This STEP data is imported in prototype system wherein features of test part are recognized using automatic feature recognition module. Generation of alternative process plans and its optimization is done in Process Planning module. This also determines the time required by each step and total machining time required to machine the part. Lastly the NC generation module generates NC file from the optimum solution obtained in the previous module. Machine parameters are taken from machine manufacturer's catalogue. For the test part manufacturing we used BMV45TC24 CNC Vertical Machining Centers.

10. Manufacturing of parts using NC code generated

Parts are manufactured using CNC machines with close dimensional tolerances, greater accuracy, and good surface finish. A CNC machine operates based on a program in the form of NC codes. In this work, a program is written in visual C# to generate the NC codes using the data extracted from a STEP file.

In this work, a rectangular plate made of mild steel of size 200x65x15 mm is taken as the raw material and machined using BMV45TC24 CNC Vertical Machining Centers. The BMV45TC24 CNC Vertical Machining Centers has a Fanuc OiMD control system with three-axis movement (X, Y and Z). Machining is done with the help of a HSS drill tool. For checking the consistency of the overall system, different hole groups are machined on the plate.

11. Inspection of parts manufactured using CMM

Though the machining of parts using CNC machine leads to higher accuracy, surface finish and close tolerances, the parts need to be inspected. In this work, the machined parts are inspected using CMM and the results are compared with the reference data extracted from STEP file for validation.

12. Comparison of Data of Inspection and Extraction

In this work, six hole groups of different diameters and locations are manufactured on single part on VMC, using the NC code generated from optimum solution of process planning and their dimensions are measured using CMM. The results are validated by comparing dimensions extracted from STEP and measurement of manufactured part using CMM and tabulated in Tables 6 to 10.

Table 2 Comparison of % deviation for hole diameter for HG1, HG2, HG3

Hole #	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG1	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG2	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG3
1	15.00	15.01	0.067	12.00	11.941	-0.492	10.00	10.007	0.070
2	15.00	15.048	0.320	12.00	12.077	0.642	10.00	10.034	0.340
3	15.00	15.146	0.973	12.00	12.212	1.767	10.00	10.143	1.430
4	15.00	15.036	0.240	12.00	12.013	0.108	10.00	10.056	0.560

Table 3 Comparison of % deviation for hole diameter for HG4, HG5, HG6

Hole #	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG4	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG5	Dimension extracted from STEP (mm)	Measurement of manufactured parts using CMM (mm)	HG6
1	8.00	8.018	0.225	6.00	6.024	0.400	20.00	20.127	0.635
2	8.00	7.954	-0.575	6.00	5.943	-0.950	20.00	20.012	0.060
3	8.00	8.099	1.238	6.00	6.092	1.533			
4	8.00	8.179	2.238	6.00	6.102	1.700			
5				6.00	6.007	0.117			
6				6.00	6.043	0.717			

Table 4 Comparison of average % deviation for hole location for HG1 and HG2

	HG1							HG2						
Hole #	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev
	x	y	x	y	x	y	(x+y)/2	x	y	x	y	x	y	(x+y)/2
1	15.00	17.00	15.049	17.132	3.127	1.253	2.190	55.00	20.00	55.002	20.018	0.004	0.090	0.047
2	37.00	17.00	37.034	17.132	0.092	1.253	0.672	72.00	25.00	72.165	25.013	0.229	0.052	0.141
3	37.00	45.00	37.034	45.012	0.092	0.027	0.059	72.00	45.00	72.165	45.012	0.229	0.027	0.128
4	15.00	50.00	15.049	50.129	3.127	0.258	1.692	55.00	46.00	55.002	46.001	0.004	0.002	0.003

Table 5 Comparison of average % deviation for hole location for HG3 and HG4

	HG3							HG4						
Hole #	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev
	x	y	x	y	x	y	(x+y)/2	x	y	x	y	x	y	(x+y)/2
1	85.00	10.00	85.230	10.210	0.271	2.100	1.185	108.00	11.00	108.101	10.954	0.094	-0.418	-0.162
2	92.00	24.00	92.213	24.003	0.232	0.013	0.122	112.00	25.00	112.106	25.025	0.095	0.100	0.097
3	90.00	39.00	90.041	39.124	0.046	0.318	0.182	108.00	39.00	108.101	39.124	0.094	0.318	0.206
4	90.00	54.00	90.041	54.024	0.046	0.044	0.045	108.00	54.00	108.101	54.024	0.094	0.044	0.069

Table 6 Comparison of average % deviation for hole location for HG5 and HG6

	HG5							HG6						
Hole #	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev	Dimension extracted from STEP (mm)		Measurement of manufactured parts using CMM (mm)		% deviation		Avg % dev
	x	y	x	y	x	y	(x+y)/2	x	y	x	y	x	y	(x+y)/2
1	123.45	10.00	123.451	10.032	0.001	0.320	0.160	142.00	20.00	142.141	20.021	0.099	0.105	0.102
2	123.45	24.00	123.451	24.003	0.001	0.013	0.007	160.00	45.00	160.007	45.012	0.004	0.027	0.016
3	123.45	37.03	123.451	37.032	0.001	0.005	0.003							

4	123.45	50.00	123.451	50.124	0.001	0.248	0.124
5	137.75	39.00	137.705	39.124	-0.033	0.318	0.143
6	137.75	50.00	137.705	50.124	-0.033	0.248	0.108

The measurements taken after manufacturing using CMM are compared with the data extracted from CAD model and shown in Figures 5 and 6. From these figures, it is clear that a measurement taken using a CMM has a minimum deviation of -0.95% and maximum deviation of 2.24% from the reference data extracted from STEP file for hole diameter and for hole location it is -0.16% (minimum deviation) and 0.12% (maximum deviation).

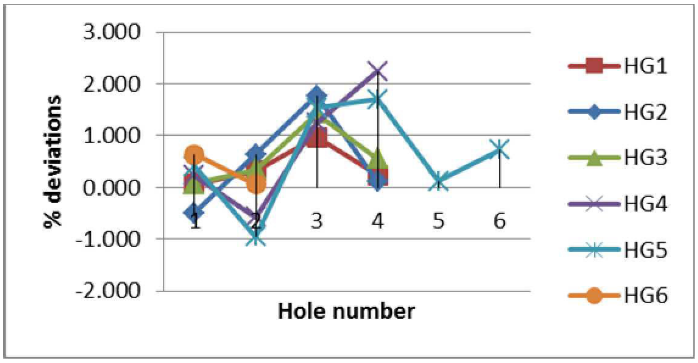

Figure 5 Percentage deviation in hole diameter

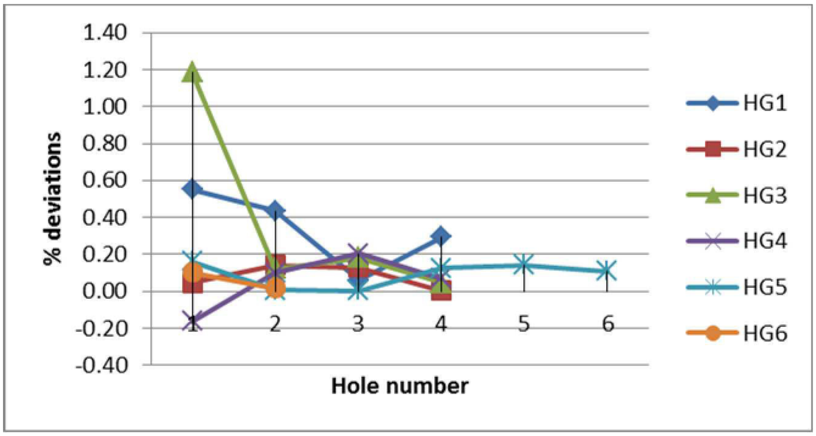

Figure 6 average % deviation of hole location for various hole groups

From the graph, it is clear that measurements taken using CMM methods have a slight deviation from the data extracted from STEP file. This deviation may be due to machining errors.

13. Conclusion

In this work, a simplified and generalized methodology is used to integrate CAD and CAM based on feature extraction for prismatic parts. The generated part model information is extracted from STEP AP203 file and this input is used to do process planning by the use of knowledge base. After generating the number of process plans they are optimized to generate the NC code using the software developed. Using the generated NC codes, the parts are machined on CNC. The parts machined are inspected using CMM and the results are validated by comparing it with data extracted from STEP. In conclusion, the present work provides the scope for the integration of CAD and CAM.

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