

A Modeling Method of Cylindrical Turning Processing Behavior

Hongtao Li^{1,2}, Gang Zhao¹, Yi Chen Zhang¹, Yingxin Ji¹

¹ School of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin, China

² Center for Engineering Training and Basic Experimentation, HeiLongJiang University of Science and Technology, Harbin, China

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Abstract—This paper put forward the theory of processing behavior through research on conceptual system of advanced manufacturing technologies and production modes such as cloud manufacturing and systematic classification of processing technology, and gave the concept of processing behavior primitive element. The processing behavior was classified and the relationship between different levels of processing behavior was clarified. To realize the standardization of NC processing technology for parts of automatic turning programming. Embed turning behavior into the design elements, realize the combination of design and manufacturing, shorten the time and space of coordination and product cycle, reduce product design and manufacturing costs, and achieve green, low consumption, high quality, high efficiency and effective manufacturing of turning parts.

Keywords— Systems Theory, Applied Control, System, Analysis, Signal Processing, Manufacturing Systems, Applied Systems Theory, Advanced Manufacturing, Processing Behavior, Primitive Element, NC Processing, Automatic Turning.

I. INTRODUCTION

Manufacturing industry constantly explored and cultivated new and sustainable manufacturing methods and models, promoted the transformation and upgrading of manufacturing, and accelerated the transformation of economic development mode [1]. Cloud manufacturing which is an emerging manufacturing model based on collaboration among manufacturing enterprises in a cloud computing environment. Li Bohu and other scholars[2]-[4]systematically put forward the concept of cloud manufacturing, and proposed a network-based, service-oriented intelligent manufacturing model, which integrated the existing networked manufacturing technology with information technology such as cloud computing, big data, internet of things, high-efficiency computing. Users can acquire various resources and capabilities on demand and their manufacturing life cycle activities can be completed by the cloud, regardless of time and place. Gilseung Ahn [5] proposed a framework based on the

PGM for estimating the collaboration level between enterprises in cloud manufacturing. Professor Wang [6] proposed two operating modes for cloud manufacturing. The primary mode platform mainly deals with some products or equipment with clear functions and low price. The advanced mode platform intelligently allocates resources according to the specific needs of users. Wang and other scholars [7] analyzed the strategies needed to build cloud manufacturing applications, and proposed new ideas for cloud manufacturing research, such as cloud manufacturing platform, reconfiguration technology and security strategy. Zhang and other scholars [8]-[9] compared cloud manufacturing with other manufacturing modes, systematically analyzed the definition, background and development status of cloud manufacturing, expounded the differences between cloud manufacturing and other manufacturing modes, and clarified the characteristics and connotation of cloud manufacturing.

In order to solve the heterogeneity of service description in cloud manufacturing environment, Professor Liu Ye and Shi Minghua[10]-[11]proposed three-tuple modular manufacturing service description method, and constructed a manufacturing and processing semantic network composed of core ontology and extensible ontology. The information model and application user-oriented architecture of manufacturing services are given, and the rapid screening and matching of manufacturing tasks and services under the information environment are basically realized. From the perspective of service granularity, Wang Jingfeng and others[12]-[15] focus on the description of manufacturing services and the definition of the composition of manufacturing services in the process of building collaborative manufacturing service chain under service-oriented architecture. According to the particularity of product structure, manufacturing services are divided into product granularity, component granularity and component granularity. Professor Zhang Yingfeng [16]-[18] took the underlying manufacturing equipment resources as the research object, and processes them from four aspects: basic information of equipment resources, processing capacity, real-time status of resources and quality of historical service of resources. According to the characteristics of manufacturing resources, Kong Lingjun [19] put forward the concept, structure and classification of resource service templates, extracted service templates using existing software, and defined template

description language which is suitable for the templates, thus proposed a method of modeling and encapsulating manufacturing resources based on service templates. Kumar[20]-[23] used WSRF standard to model manufacturing resources, encapsulated manufacturing resources as Web Services, to shield the heterogeneity and complexity of manufacturing resources, so as to achieve efficient sharing of heterogeneous resources and task collaboration. Cho and other scholars [24] applied cloud computing technology to the simulation resources of manufacturing engineering, built a shared simulation platform in cloud manufacturing environment, modeled and encapsulated soft resources such as CAD and CAM, and provided an open interface to the demanders. A. Maciol [25] proved that the rule-based approach could provide means to integrate all stages of technological design, and solving the problem of unified management and decentralized invocation of manufacturing soft resources.

The service-oriented modeling of resources and capabilities is the key to the implementation of cloud manufacturing. At present, there is no unified standard solution to the technical problems, such as how to classify resources and capabilities, how to standardize the description, how to package and publish. In the study of manufacturing capacity, there is little research on processing technology.

According to the characteristics of parts and the processing procedures in the process, this paper classifies NC machining behaviors, and establishes the corresponding classification criteria. A reasonable and optimum design of NC processing technology for parts mainly includes determination of processing benchmark, planning of processing area, planning of processing strategy and processing procedure, and selection of processing parameters. It realizes standardization of NC processing technology for parts and automatic NC programming of parts to make the processing and manufacturing into production. A specific case is analyzed to verify the effectiveness of this processing behavior method. It achieved the ultimate goal of manufacturing, that is, design is manufacturing and design is service.

II. PROCESSING BEHAVIOR

A. Definition of processing behavior

In the manufacturing service system, designers need to distribute their design requirements information to the manufacturing service platform. At the same time, manufacturers must fully express their manufacturing capabilities and their ability to obtain more processing orders. Therefore, the information needed by both parties in a proper model is the basis of the operation of manufacturing service system. The processing behavior carries the information needed by both the designer and the manufacturer. The processing behavior should be easy to reorganize the process and serve the designers.

Processing behavior is characterized by cutting the material part removed from the blank, which can be described by parameter or mathematical boundary representation. The characteristics of processing behavior can be defined

mathematically.

$$P = B_L - \{M_{F_1}, \dots, M_{F_i}, \dots, M_{F_n}\} \quad (1)$$

$$M_{F_i} \cap M_{F_j} \cup B_{MF_j} \neq \Phi \quad (2)$$

$$\forall_{i,j}, i \neq j, \Rightarrow I_{RF_{i,j}} \neq \Phi \quad (3)$$

P represents the parts obtained after processing; B_L represents the blanks or semi-finished products; M_F represents the processing characteristics; B_{MF} represents the boundary of the processing characteristics; I_{RF} is the relationship between the features; I is the interference; D is the deformed geometric data.

The whole process of product from design model to finished product essentially is that: firstly, it is clear that the design requirements in specific manufacturing environment match the manufacturing capacity of manufacturing resources, and then the producer processes raw materials through a single or combined processing process until the product meets the design requirements.

The structural of a part is a series of geometric features formed by processing technology essentially, which are combined in a certain order. Processing behavior refers to the behavior of process characteristics completed under the constraints of manufacturing resources and capabilities of specific design requirements between parts from raw materials to final products. Processing behavior contains all the parameters of the corresponding process characteristics, such as processing method, geometry, size information, accuracy information, location information, and so on. In addition, it also includes the production and processing resources information necessary for processing behavior which contains multiple process behaviors.

Processing behavior primitives refer to the minimization of processing behavior, which can entirely express certain processing characteristics, and can be combined according to a certain sequence to represent higher-level processing behavior. Minimization means that the elements of processing behavior are inseparable. Taking turning behavior as an example, the minimization elements can be regarded as a set of tool tip trajectories, and can represent certain processing characteristics, such as the cylindrical, chamfer and cone.

Table 1 describes the processing behavior parameter model of the cylindrical turning. The first three parameters 002 in the behavior ID which represent turning, the next 001 represent cylindrical circle, and the last number is randomly allocated for marking processing behavior. The starting point (x1, y1, z1), the end point (x2, y2, z2); the end point can be the starting point of the second segment. Boolean operation (+) and (-) represent outer cylinder and inner contour machining respectively. The surface roughness is Ra, and the size deviation is (de1, de2). In addition, the private domain contains some information related to the manufacturer, such as processing methods, processing time, processing costs and raw materials.

Table 1 Processing behavior of cylindrical turning

Header	Process action(Turning)	ID(00200100X)	Deviation(de1,de2)
Ra(/)	Start point(x1,y1,z1)	End point(x2,y2,z2)	Boolean operation(+)/(-)
Direction vector(0,0,1)	Raw materials(D,L)	Material(AI)	Treatment methods(/)
Factory(01)	Enterprise size(S,M,L)	Time/Cost(/)	Process method()
m_cylindrical turning (NPP,MID,FALZ,FALX,FAL,FF1,FF2,FF3,VARI=9,0,0,0)			

B. Classification of processing behavior

According to the assembly information of product composition, the processing behavior is divided into process elementary level, part level, component level and product level. Different levels include their own processing behavior, as shown in Figure1.

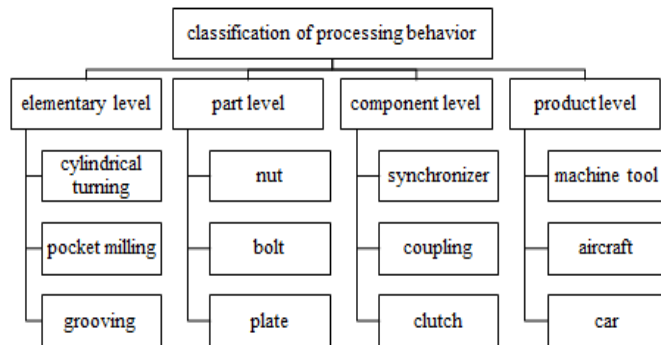


Fig.1 Classification of processing behavior

Low-level processing behavior can show the characteristics of high-level processing according to a certain sequence combination. Similarly, high-level processing behavior can be divided into many low-level processing behaviors.

C. Publishing of processing behavior

Publishing and sharing of processing behavior must be conformed to the data standard of manufacturing service platform, and must be true and effective. It is of great significance for manufacturers to formulate a reasonable and perfect mechanism for publishing processing behavior. Processing behavior publishing of manufacturing service platform can be roughly divided into four processes: template selection, behavior input, submission and audit, publishing and sharing.

- 1) Template selection means that the manufacturer should analyze the current process behavior, determine the category of the process behavior in the manufacturing service platform, and then select the corresponding process behavior template.
- 2) Behavior input refers to that after the manufacturer determines the category of processing technology behavior, the manufacturer should query the information template made by the manufacturing service platform, extract its own processing technology behavior according to the information template.
- 3) Submission and audit refers to that the manufacturer submits their processing technology behavior information to the manufacturing service platform for audit, so as to determine the authenticity and reliability of the

information.

- 4) The publishing and sharing stage is to allow the manufacturing process behavior to be shared in the manufacturing service platform after the manufacturing service platform completes the audit of the processing behavior information.

III. NC CODE GENERATION OF PROCESSING BEHAVIOR

A. NC code generation function

The innovation of processing behavior needs the matching of machining ability. The NC code generation function of processing behavior will realize the whole process from designing geometric model to completing parts. The design of parts is the process of mapping the combination of process methods, and the combination of design elements is the combination of processing behavior. Processing behavior maps to process method, and then maps to NC program, as shown in Figure 2.

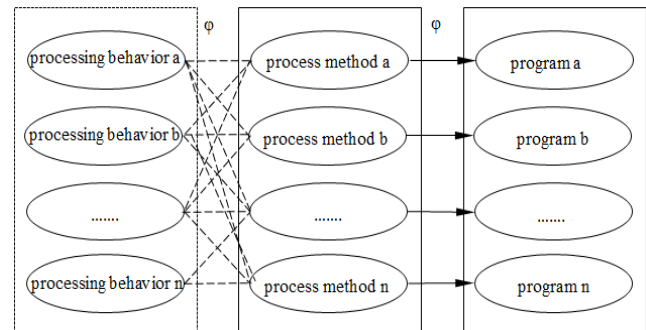


Fig. 2 Mapping of processing behavior

B. NC code generation process

According to the publishing and sharing of the processing behavior, a library is built for designers. Designers can select the required processing behavior to build parts, and generate NC programs synchronously. Process analysis and calculation are automatically completed by the NC code generation function of the processing behavior database. The NC code generation process is shown in Figure 3.

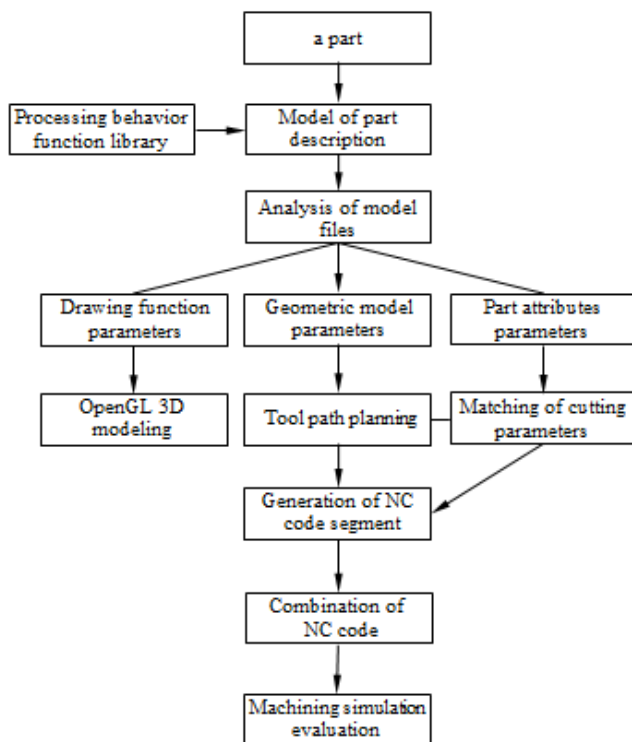


Fig. 3 NC code generation process

The automatic generation process of NC program mainly includes the following procedure: Firstly, invoke the processing behavior function, the library describes manufacturing behavior. Secondly, analyze the part file and extract the direct and indirect parameters. Thirdly, part processing sequence optimization. The model of part features is arranged by using adjacency graph algorithm and Boolean subtraction method to generate part feature optimization model, the NC code generation function of part feature is called and cutting parameters are matched. Finally, segments combination to form a complete NC program.

IV. PROCESSING APPLICATION AND ANALYSIS

A. Model files description

Processing behavior not only needs to complete the purpose of manufacturing, but also to meet the requirements of design. Therefore, the data model of processing behavior should include the data of function expression and parameters of processing requirements. The model files include the information of geometric features, basic dimensions, material selection and machining accuracy requirements. It will always track the whole life cycle of product.

The application of processing behavior definition method can solve the problem of design and manufacturing collaboration greatly, and realize seamless connection. Figure 4 shows a drawing of a turning part.

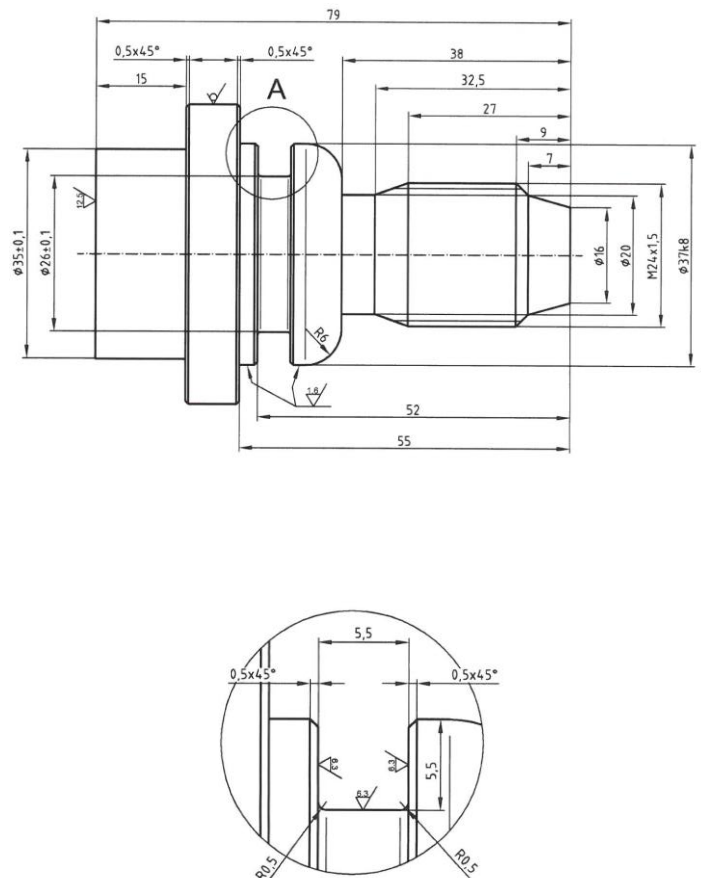


Figure.4 Drawing of a turning part

The part consists of outer contour, groove and thread. The model can be built based on processing behavior function library, as shown in Table 2.

Table 2 Model of turning part

Processing behavior	ID	Remarks
cylindrical turning	002001001	right side; aluminum;1.6
	m_cylindrical turning (
	NPP,MID,FALZ,FALX,FAL,FF1,FF2,FF3,VARI=9,0,0,0)	
	(
	0,0;16,0;-7,20;-9,24;-27,24;-32.5,20;-38,20;-38,37,R6;-55,37;50,-55,C0.5;50,-8	
	0)	
cylindrical turning	002001002	left side; aluminum;3.2
	m_cylindrical turning (
	NPP,MID,FALZ,FALX,FAL,FF1,FF2,FF3,VARI=9,0,0,0)	
	((0,0;35,0;-15,35; 50,-15,C0.5;50,-25)	
external grooving	002002001	Aluminum;6.3
	m_external grooving (
	SPD,SPL,WIDG,DIAG,ANGLE,R1,R2,INFEED,0,VARI,0)	
	(37;-47.5;5.5;4.5;0; -0.5;-0.5)	

external threading 002003001 M24; aluminum;-
 m_external threading (PIT,MPIT,SPL,FPL,D1,D2,TDEP,N1,N2,1,1,0)
 (1.5;24;-7;-32.5)

Table 5 Scale definition table

Importance comparison	Equal	Former is slightly important	Former is obviously important	Former is obviously more important	Former is absolutely important
a_{ij}	5:5=1	6:4=1.5	7:3=2.33	8:2=4	9:1=9
Intermediary between them					
5.5:4.5=1.22;6.5:3.5=1.86;7.5:2.5=3;8.5:1.5=5.67					

B. Model analysis and cutting parameters assignment

According to the model information, such as material and machining tolerance. To assign Cutting parameter function data to each processing behavior automatically. The process of cutting parameters assignment is as follows.

- 1) Determine the spindle speed and feed rate interval value by the function library.
- 2) The surface roughness of parts decreases with the decrease of spindle speed and the increase of feed speed, matching of the surface roughness to determine the specific value.
- 3) The infeed depth is determined by the cutting stability function, which is obtained by cutting stability experiment.

Some cutting parameters obtained by the above methods of cylindrical turning are shown in Table 3.

Table 3 Processing behavior cutting parameters

ID	Roughness	Spindle speed	Feedrate	Infeed
002001001	1.6	220m/min	0.06mm/r	0.25m
	3.2	200m/min	0.1mm/r	0.25m

In the optimization of processing method, the influence of processing cost, processing time and processing quality on processing scheme are mainly considered. Enterprises have different requirements for each evaluation. Therefore, linear weighting method is used to construct fitness function, and AHP is used to establish the hierarchical model of evaluation, and the weight of each influencing factor is determined. Process matching based on machining accuracy is shown in Table 4.

Table 4 Process matching based on machining accuracy

Processing behavior	Processing scheme	Roughness	Machine tool
Cylinder turning	Roughing-semifinishing-finishing	1.25-5	T450
			T250
Shaftend-external-Thread	Thread roughing-Thread finishing	1.25-5	T155 T150
Shaftend-internal-Thread	Thread roughing-Thread finishing	2.5-5	

The 1-9 scale of analytic hierarchy process is used to construct the judgment matrix of each layer. In the process of calculating the weight of judgment matrix, when considering the average treatment of multiple opinions, non integer value will appear. Therefore, the improved scale definition table in Table 5 is closer to the actual judgment.

There are several machine tools to meet the processing requirements. The most suitable machine tool can be selected by analytic hierarchy process (AHP). Figure 5 is the hierarchy chart.

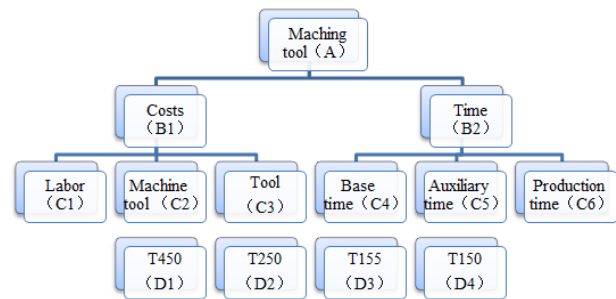


Figure 5 Hierarchy chart

Table 6 Weight vector hierarchical calculation results

C1	Vector	C2	Vector	C3	Vector
D1	0.2500	D1	0.0773	D1	0.2500
D2	0.2500	D2	0.1883	D2	0.2500
D3	0.2500	D3	0.2948	D3	0.2500
D4	0.2500	D4	0.4396	D4	0.2500
CR	0	CR	0.000574	CR	0
C4	Vector	C5	Vector	C6	Vector
D1	0.2500	D1	0.1496	D1	0.3795
D2	0.2500	D2	0.2155	D2	0.2499
D3	0.2500	D3	0.3087	D3	0.2040
D4	0.2500	D4	0.3262	D4	0.1666
CR	0	CR	0.0018	CR	0.0138
A	Vector	B1	Vector	B2	Vector
B1	0.5000	C1	0.3407	C4	0.4777
B2	0.5000	C2	0.0744	C5	0.3148
CR	0	C3	0.5849	C6	0.2074
		CR	0.0091	CR	0.00013

Through the analysis of total ranking results, it is concluded that the decision-making scheme of selecting T150 machine

tool, as shown in Table 7.

Table 7 Total ranking results of D level

D1	D2	D3	D4
0.24118925	0.24225159	0.25612324	0.26038592

C. Tool path planning and NC code generation

Analyze the part file model, match the process method and cutting parameters, and complete the NC program code generation process automatically. The basic dimension, geometric tolerance, quality requirements, roughness requirements, processing behavior requirements and auxiliary information of parts are processed and optimized automatically. The automatic NC program generation process is shown in figure 6.

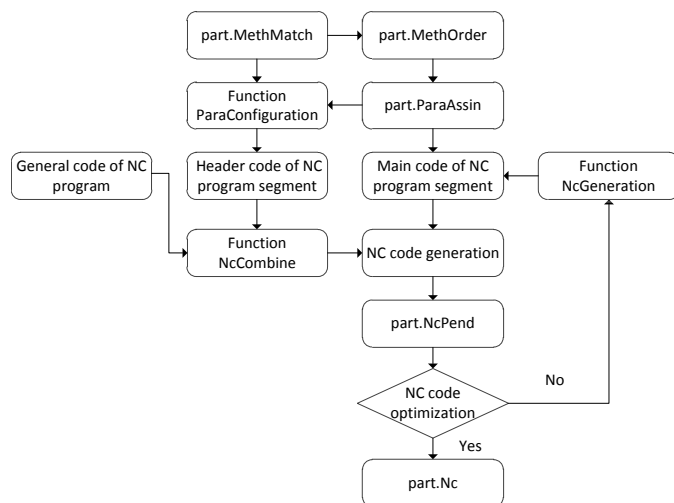


Figure.6 Automatic NC program generation process

The first step is to match the processing method according to the design concept. Through the matching of processing quality and the evaluation method of processing time and processing cost, the matching file of process method of parts is obtained.

In the second step, the function “paraconfiguration” is used to assign the cutting parameters of each machining process to generate the NC program segment header code. The function of “ncgeneration” is to call the NC code generation function library to generate the NC program main code corresponding to each processing method.

The third step is the combination of NC codes. The function of “nccombine” is to combine the NC program header code with the NC program main code to generate the completed NC program. Insert general program segment commands such as turning end face, returning to tool change point, etc.

The fourth step is NC code optimization to determine whether the program is optimal. After confirmation, NC program is generated directly. Otherwise, return to the second step, restart “ncgeneration” function to generate NC program again.

The program generates the following NC program sections

for Siemens 840D systems. Contour Roughing, contour finishing of the different segments determined by surface roughness.

CYCLE95("out1",3,0.25,0.25,0,0.2,0.2,0.1,1,0,0,0),CYCLE 95("out1",3,0.25,0.25,0,0.2,0.2,0.06,5,0,0,0), CYCLE93(37,-47.5,5.5,4.5,0,0,0,-0.5,-0.5,,0,0,2,0,5),CYCLE 97(0,24,-7,-32.5,24,24,0,0,0.92,0,0,0,5,2,3,1).

The cutting parameters of fragment <-38, 37, R6;-55, 37 ;> are given separately from the contour of the subroutine to meet the requirements of processing quality.

D. Machining evaluation

The programming of Siemens system and CATIA software are both depend on processing technology and skills of technicians. It takes a lot of time to generate NC program after the process analysis of drawings.

The required NC program is directly generated by using the processing behavior model which proposed in this paper. Compared with Siemens system and CATIA software, the design-oriented processing behavior method shortens the corresponding time of design and machining greatly, as shown in Figure 7. It is worthy of further promotion and study.

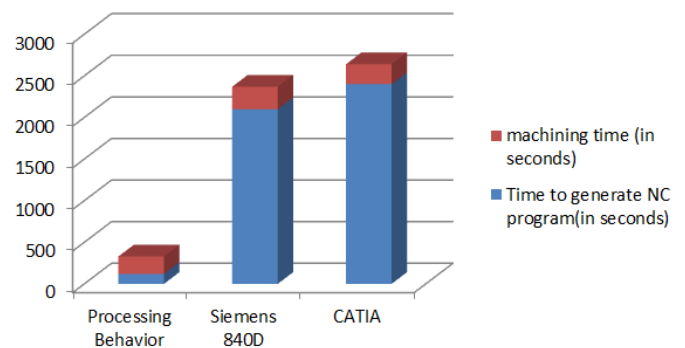


Figure.7 Time spend comparison of three different methods

V. CONCLUSION

In this paper, a theory of processing behavior was put forward to design services oriented based on the research of the conceptual system of advanced manufacturing technology and production mode, such as "cloud manufacturing". The design elements were integrated into manufacturing, which realized the combination of design and manufacturing, and shortened the time and space of coordination. The main achievements of this paper include the following aspects.

- 1) The concept of processing behavior was proposed based on classifies and studies of the processing methods in the field of mechanical manufacturing. The description standard of turning behavior was formulated and the theory of manufacturing-oriented modeling of processing behavior was put forward. The relationship between processing behavior at different levels was studied, the requirement of service-based modeling of process behavior was analyzed, and the attribute model of process behavior primitive was created.
- 2) According to the mapping method and mapping template, the processing behavior resources were mapped to specific

processing procedures, which were used to serve the designer and provide constraints for the dynamic optimization of parts and manufacturing methods.

- 3) The research lays a theoretical foundation for the development of manufacturing support system, the establishment of processing behavior database and the research of network architecture of intelligent manufacturing collaborative service system in the next stage.

Some other relevant studies can be found in [26] and [27].

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