Computer-Aided Design AND APPLICATIONS
www.cadanda.com

CAD Integration of Mechanical Numerical Control Board Parts Based on Machining Features

Baoli Wei and Meng Lv

Department of Mechanical and Electrical Engineering, Zhengzhou Railway Vocational and Technical College, Zhengzhou 450000, China, ztxyweibaoli@126.com
Meng Lv, lvmeng@zzrvtc.edu.cn

Corresponding Author: Baoli Wei, ztxyweibaoli@126.com

Abstract. The development and application of computer-aided design (CAD) technology has led to rapid improvements in product design automation, crafting process automation and numerical control programming automation. Machining feature refers to basic configuration units that constitute part shapes and the collection of non-geometric information with engineering semantics attached to it. The integration of mechanical numerical control parts is the integration of part design features and machining features, and each feature corresponds to a set of processing methods. Based on the summaries and analyses of previous research works, this paper expounded the current status and significance of mechanical numerical control board part integration, elaborated the development background, current status and future challenges of machining features and CAD technology, introduced a data transfer method of CAD integration and machining features-based part integration system, analyzed the design and machining features of CAD integration of board parts, constructed the graphics processing model and information reorganization model for CAD integration of board parts; conducted the feature description and modeling analysis of CAD integration of plate parts; discussed the crafting information similarity of mechanical numerical control plate part integration; explored the feature information and expression of feature library for plate parts integration.

Keywords: Computer-aided design (CAD); CAD integration; Board part; Machining features; Mechanical numerical control
DOI: https://doi.org/10.14733/cadaps.2021.S3.176-187

1 INTRODUCTION

Computer integrated machining system is an important subject of high-tech development, which can organically combine all links in the production process into a complete system. This requires that in the product design process, the design of parts and process planning must have good characteristics integrated and smooth information flow. With the development and application of computer-aided design (CAD) and other systems, product design automation, process design automation, and numerical control programming design automation have been rapidly improved, which greatly shortens the development cycle of new products [1]. However, these are independent system and cannot realize automatic transmission, exchange and sharing of information between systems. The most critical issue in CAD information integration is the description of part information and information extraction and sharing [2]. There are many ways to describe part information, including code description method, feature surface description method, orientation feature description method, flexible feature description method, etc. However, the information needs to be manually input and is incomplete, and CAD integration cannot be achieved. Feature-based numerical control machining technology includes numerical control programming technology and detection technology [3]. Feature-based numerical control programming technology uses features as information carriers and can effectively integrate machining knowledge and experience, which is an important trend in the development of numerical control programming technology.

Machining feature refers to basic configuration units that constitute part shapes and the collection of non-geometric information with engineering semantics attached to it; and this information is connected as a whole through a variety of relationships [4]. The application of CAD and machining technology to modern machinery machining has achieved significant improvements in the precision, flexibility, efficiency, and quality of machinery machining. Process decision is the basis of numerical control programming, and numerical control programming is the source of tool path for numerical control machining of parts [5]. The process decisions of parts include the selection of machine tools, the design of clamping, the selection of machining tools, the selection of machining parameters, the ordering of machining features, etc. The CAD integrated system is based on the design concept of concurrent engineering and feature modeling in the design stage, facing the entire design process and processing process, which automatically inherits the product design information generated by the CAD system during process planning, and is consistent with the processing method [6]. Correspondingly, the integration can completely and comprehensively describe the information of each link of the part production process and the relationship, so that the parts can realize the unimpeded information collection, transmission and processing process in the entire computer integrated machining, thereby realizing design information and machining Integration of information and functions.

Based on the summaries and analyses of previous research works, this paper expounded the current status and significance of mechanical numerical control board part integration, elaborated the development background, current status and future challenges of machining features and CAD technology, introduced a data transfer method of CAD integration and machining features-based part integration system, analyzed the design and machining features of CAD integration of board parts, constructed the graphics processing model and information reorganization model for CAD integration of board parts; conducted the feature description and modeling analysis of CAD integration of plate parts; discussed the crafting information similarity of mechanical numerical control plate part integration; explored the feature information and expression of feature library for plate parts integration. The detailed chapters are arranged as follows: Section 2 introduces the data transfer method of CAD integration and machining features-based part integration system; Section 3 analyzes the design and machining features of CAD integration of board parts; Section 4 conducts the graphic processing, information reorganization, feature description and modeling analysis of board parts CAD integration; Section 5 discusses the crafting information similarity and feature library expression of board part CAD integration; Part 6 is conclusion.

2 METHODS AND PRINCIPLES

2.1 Data Transfer Method for CAD Integration

From a machining point of view, processing refers to the sum of a series of work done by product parts from blanks to finished products. Numerical control processing inevitably requires the selection of machine tools, tools, measuring tools and cutting parameters according to the characteristics of the parts and the requirements of precision, roughness, which is to search and match the actual processing capabilities of the factory according to the feature information of the parts. Processing capabilities include the economic precision and surface roughness that can be achieved by various processing methods. After the system analyzes and recognizes the features of the part, it searches and selects the appropriate processing method according to the relevant information (Figure 1). Because the system is based on feature technology, the expression and selection of part processing methods need to be analyzed from the perspective of features. Since the concept of feature processing method is introduced into the system, it is necessary to analyze the feature processing method accordingly. In the traditional process design, the process personnel not only make preliminary matching according to the accuracy and roughness of the parts, but also according to the shape characteristics of the parts and the processing molding methods of the processing equipment in the past experience, and select feasible processing methods. Le et al. (2018) used the idea of set operations to summarize the mathematical expressions that abstracted out characteristic information [7].

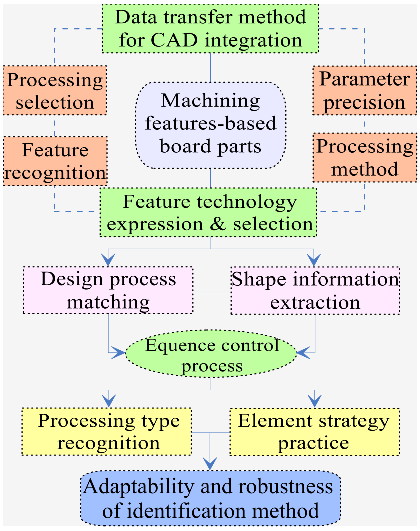

Figure 1: Framework of data transfer method for CAD integration.

Feature type discrimination and information extraction process, this process realizes feature type judgment and feature detailed information extraction based on the current main processing surface and its adjacent surface information. The recognition sequence control process must ensure that all features under the main processing direction are recognized, and that all features under a certain main processing direction are recognized. Faced with complex and changeable parts, to study the feature recognition method and make the method universally practical, it is necessary to study the feature recognition strategy, which can extract the most essential elements associated with the feature in the part. On the basis of analyzing the information of these elements, determine the sequence and process of feature recognition, thereby simplifying complex parts, decomposing a complex part into independent or interactive features, and then using corresponding methods to extract key information for the type of feature. This strategy abandons the idea of obtaining all the feature types of the entire part and extracting feature information. Instead, the entire part is decomposed into independent or interactive features, and the recognition sequence between features is provided by the recognition sequence control process. It has truly realized the complexity of simplifying, greatly reducing the difficulty of analyzing and processing the entire part, and improving the adaptability and robustness of identification method.

2.2 Part CAD System Based on Machining Features

The CAD system of board parts adopts the application mode of generative expert system and the process knowledge base module is the core part of the system. The module stores the decision rules for the process design of board parts and the process data related to the decision rules, which is mainly composed of process set, work step set, tooling set, processing technology route selection rule set and final processing method selection rule set. The process generation module is a key module of the CAD system, which is composed of an inference engine and a dynamic database. Its function is to complete the selection of part processing methods, arrange processing routes, and select machine tools and process equipment based on the data in the established part information processing module and the process decision-making knowledge and data in the application rules. Chu et al. (2016) pointed out that establishing the feature pixel level is actually to construct a program library, that is, to compile a parametric drawing program library for each pixel [8]. In the design process of board parts, there are many drawing pixels with the same structure. The feature pixel level is to combine the pixels with the same structural features to form a collection of drawing pixels. When drawing parts with similar structural features, designer can call a pixel from pixel level and enter graph feature size of the element can be drawn (Figure 2).

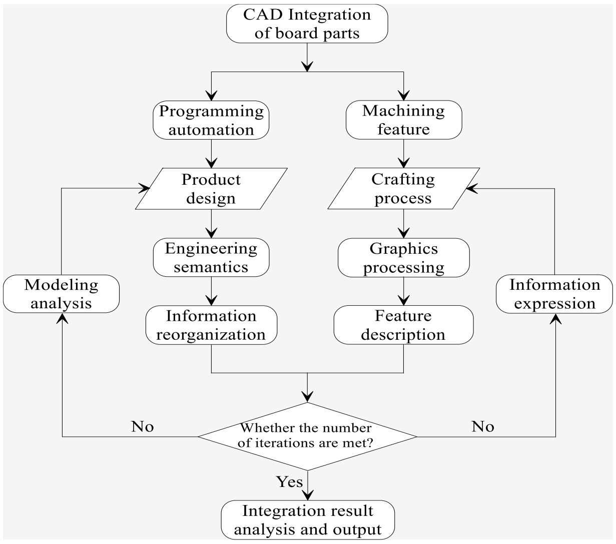

Figure 2: Workflow of part CAD system based on machining features.

The application of automatic feature recognition in the field of production and processing is becoming more and more popular. It is used to check models, determine features of work pieces, convert design features into machining features, and provide a basis for subsequent processing of work pieces. Each CAD model contains complete product information, and there is no need to waste time to select the characteristic information of each processing object during processing programming. Through the function of automatic feature recognition, the CAD modules are more closely integrated, making the transmission of information simple and intelligent, so as to simplify the programming operation, shorten the programming time, and realize the purpose of automatic programming. Although the feature information data is lost in the non-parametric model, the geometric topology structure data of the feature is still stored in the part during the CAD design modeling process. The machining feature starts from the selected surface and traverses the geometric elements in this model, finds the surface that matches the pattern feature, collects the eligible surfaces, and realizes the reasoning to form the recognition feature that matches the pattern feature. Finally, the non-parametric model feature information extraction is matched with the feature recognition knowledge base to complete the feature recognition, and the function is used to measure the parameters of the matching feature to complete the non-parametric model feature recognition.

3 MACHINING FEATURE ANALYSIS OF MECHANICAL NUMERICAL CONTROL BOARD PARTS

3.1 Design Features of Mechanical Numerical Control Board Parts

According to the geometric shape of the structural part and the corresponding different processing and machining methods according to each shape feature, it can be divided into main feature, auxiliary feature and datum feature. Main features are divided into basic main features and structural main features. The basic main feature is the main shape and main function of the component: such as outer cylinder, outer cone, etc. The main feature of the structure is a feature composed of multiple main features or a combination of main features and multiple auxiliary features, such as a parametric feature, which is composed of a section of contour. Auxiliary features refer to features that are attached to the main feature and realize auxiliary functions, such as chamfering and rounding. Benchmark features refer to features that are used as positioning benchmarks in process planning, such as center holes and end faces. Generally speaking, a part is composed of multiple features, and it can be seen from the above that there are specific relationships between features. For example, there are usually two major connections between the features of parts: the attachment relationship between geometric features and the adjacent relationship between geometric features, primary and secondary relationships, and array relationships (Figure 3). Some features may belong to a composite feature type, so in the process planning, they are decomposed into several simple features and processed separately. A complete part model can be formed through the topological combination of each feature.

The system supports two methods: feature-based split design and part contour parametric design. The geometric structure information of the part and the description of the machining information on the conceptual level can be completed by the feature combination method provided by the system. For parts whose engineering drawing annotations do not meet the input requirements of characteristic parameters, parts with complex surface contour structures can adopt parametric design methods. The result of parametric design can be converted into corresponding feature description after feature conversion, so as to realize the integration of local structure design and machining information by feature design. Faludi et al. (2015) suggested that the numerical control program simulation subsystem can check the correctness of the machining process through the simulation of the part machining process, whether there is interference between the tool and the work piece, machine tool, and fixture, which can more truly reflect the actual cutting process [9]. The numerical control programming subsystem selects specific tool path generation algorithms to generate numerical control programs according to the determined machining process route and part surface contour. Among them, rough cutting cycle path planning and finishing tool path is the key to tool path generation and the tool path for finishing is the combination of all the feature boundary points to be processed in the part.

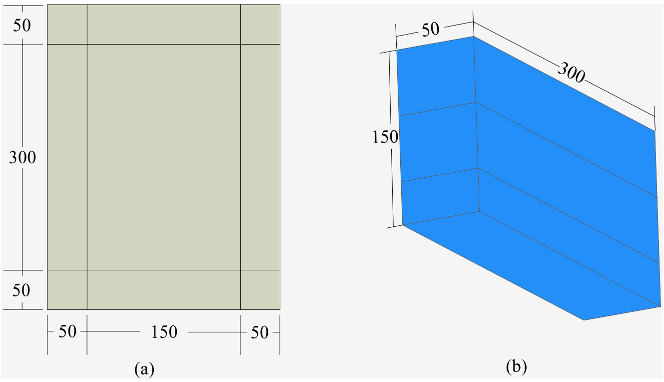

Figure 3: Board part section (a) and board part specimen (b) used for CAD integration.

3.2 Machining Features of Mechanical Numerical Control Board Parts

The description information of plate parts can be divided into two categories: positive features and negative features. Positive features are divided into basic features and functional features of parts and the basic feature is a special feature, and other features are attached to it. They describe the basic contour shape of the part, such as cylinder, cone, ball, etc., and also describe the processing attributes of each surface of the substrate, such as surface roughness, shape tolerance, positioning size and tolerance of other features relative to the basic surface, and position tolerance, etc. T Sencer et al. (2015) concluded that the basic positive features describe the functional properties of the part, and the negative features are used to describe the various shapes formed by cutting the material of the part [10]. The features are predefined and each feature is uniquely identified by the feature mark. In the feature library, when used, the actual parameters are taken out from the feature library and assigned to the part information system by means of human-computer interaction through the dialog box (Figure 4). The feature-based modeling method is based on the collection of a series of basic geometric bodies and composite geometric bodies that are often used in the design of mechanical parts and can be usually processed, and design functions and processing process attributes are assigned to these geometric bodies. The feature information uses implicit parameters and the description method is driven by variables.

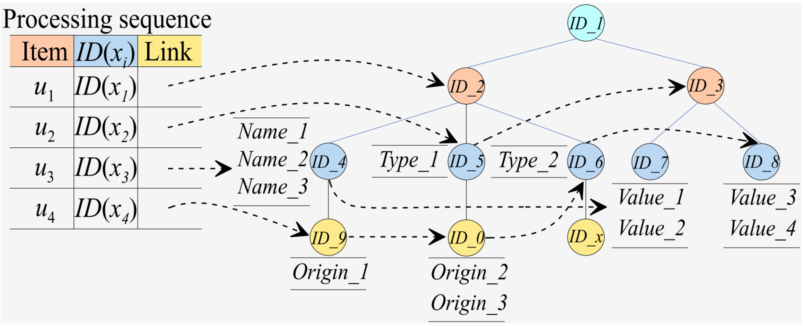

Figure 4: Processing sequence of machining features for board part CAD integration.

Processing features are the component units of processing behaviors, used to express geometric information, process information, and machining information of parts processing. This paper uses a self-defined method to supplement and perfect the processing feature information of plate parts.

According to the geometric shape of the processing features and the classification of the tool trajectory, the processing feature library of the plate parts of marine diesel engine is constructed. At the same time, the method based on model definition is adopted to describe all the information of the processing characteristics on the three-dimensional model, so that the three-dimensional model is used as the only basis for the product from design to machining, and the uniqueness of the data is guaranteed. In the attribute labeling method, the product information label is used to express the geometric information of the processing feature; the definition attribute in the product machining information is used to describe the machining information of the processing feature. Each attribute description is composed of attribute identification names and attributes values, and different attributes are established. Column to identify different information, the attribute value on the left expresses the machining information of the processing feature, and the geometric information expressed by the product machining information is displayed on the right to complete the customization of the processing feature of the reference panel. In order to describe the feature from the tool path form, the tool path type of the feature is divided into four types: single straight line, multiple straight line, circular arc and straight line plus circular arc.

4 CAD INTEGRATION OF MECHANICAL NUMERICAL CONTROL BOARD PARTS

4.1 Graphics Processing and Information Reorganization

The information in the product definition model includes several shaft segments, benchmark features and technical information. Each shaft segment includes a series of main features, and each main feature can be attached with several auxiliary features. The main feature describes the main shape of board parts. The auxiliary feature determines the additional auxiliary processing method after the main feature is formed. Technical information includes information on part names, materials, heat treatment, and production batch size, etc. This information is necessary for process planning and the datum feature is used to select the fixture and clamping method used to determine the machining (Figure 5). Therefore, this part model provides complete information for part design, process planning and numerical control programming, and can be used as the core information unit in the integrated system. In the CAD subsystem, the designer can use the features provided by the system feature library to construct parts, and precede in two stages, namely, the external shaft section design and the internal shaft section design. In each design stage, first select the external or internal main features, design in the order from left to right, and then add various auxiliary features on different shaft segments. Li et al. (2015) believed that this numerical control program simulation system is a general-purpose system, which can be used as a subsystem of an integrated system, and it is suitable for different numerical control programs [11].

Feature-based numerical control programming research status Feature-based numerical control programming technology includes part machining process decision, numerical control programming, machining simulation and post-processing. Numerical control integrated technology is a modern machining technology that integrates mechanical machining technology, computer network technology, and sensor detection technology, which has many advantages such as high precision, flexible automation, and high efficiency. The service layer uses standard interface communication to realize information integration application and information exchange in the form of data interaction between the data layer and the application layer, such as generating numerical control machine tool processing control information and receiving numerical control machine tool processing status information. The mechanical numerical control integrated system is convenient for batch change processing or the development of mechanical parts. It can quickly change the machining process parameters, set parameters and clamp the work piece at one time to complete the whole batch processing, and use modular standard tools to shorten the tool change time and processing interval time guarantees the processing accuracy and the complete processing flow, and its mechanical processing is highly standardized. The application layer is an information interaction application platform for the mechanical design and processing personnel of the CAD-based mechanical numerical control integrated system, which can provide various control information generated by various mechanical processing, tool option information, and can also realize information through remote service functions Share and remotely operate numerical control machine tools for machining.

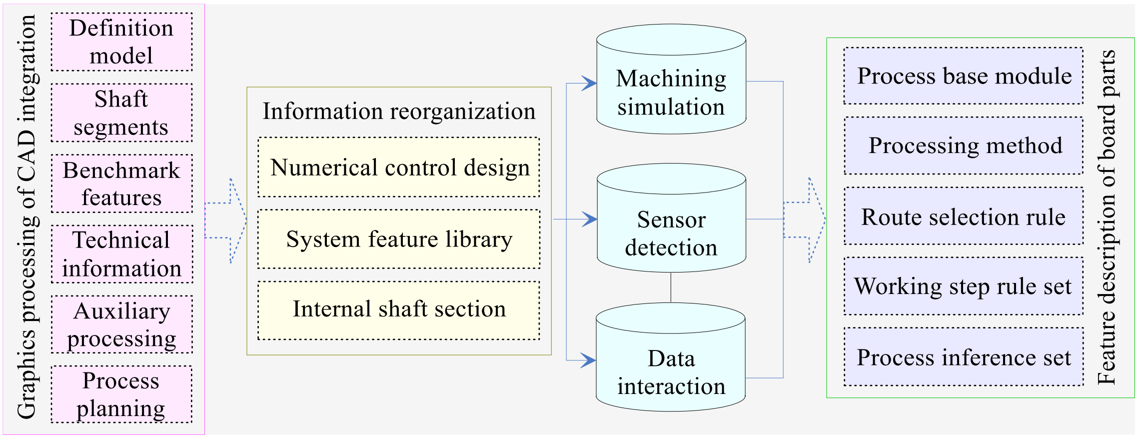

Figure 5: Graphics processing and information reorganization of CAD integration for board parts.

4.2 Feature Description and Modeling Analysis

The features of parts can be divided into shape features, management features and fine hair features; the shape features of parts are the main body of the feature information model, which can be divided into main features and auxiliary features. The main features mainly describe the basic geometric shapes and surface elements of the inner and outer surfaces of the part, such as the cylindrical outer surface of the shaft and the inner hole. The process of drawing the work drawing of board parts in CAD can be attributed to the process of feature-based modeling. Here, the segmented assembly modeling method is introduced to generate the work drawing of the part. Auxiliary features describe the secondary geometric shape of the part and the features required for combination in function, structure, and process characteristics, such as chamfers, ring grooves, etc. Since the function of the part is mainly determined by the shape of the part, and the processing method of the part is directly related to the surface, in the description of the shape feature, a combination of body and surface is used. The management feature and accuracy feature describe the management information and accuracy information of the part by adding shape features. With the input of accuracy information, the system dynamically establishes and maintains the reference geometric linked list, thereby establishing the relationship between features, geometric elements and accuracy, and integrating geometric and non-geometric attribute information to form a complete product that can meet the integration needs Information model.

The modeling process first loads the model to be processed, matches the type of the processed part, and then enters the complex part processing template, reads the tool information and process information from the integrated system database, and matches the processing feature tool path. If it does not match, re-start carry out tool path planning; if it matches, continue to generate tool path. After generating the tool motion path, designer can flexibly edit and modify the tool path manually. The database module integrates functions related to database operations, and all calls related to database operations use this module. The tool path generation module contains the relevant tool path generation rules of various types of tool paths in the current system, and is the core of the actual tool path generation algorithm. The overall process module realizes process management of user operations. The machining navigation is responsible for the tool path generation function, which is the core of the entire software, and the machining configuration and system configuration are auxiliary functions. Processing configuration management tool database, machine tool database, post-processing database and template database are all closely related to processing navigation. System management is mainly responsible for user maintenance and catalog setting. When using general purpose numerical control processing software for numerical control processing programming, process information needs to be set repeatedly, which results in low processing efficiency.

5 DISCUSSIONS

5.1 Process Information Similarity Analysis

According to the structure and process characteristics, plate parts are geometric shapes or entities that integrate design features and machining features, and are meaningful for design and machining. It can also be considered that the description of a feature in an integrated environment must include two types of information, feature geometric information and process information, so that design and machining activities are unified on the basis of features. Feature geometric information is the geometric parameters related to the features that must be provided in the process of part CAD, so that the features can be used for CAD modeling, and the process feature information reflects the processing feature parameters required by the CAD system. The main feature is the feature that constitutes the main shape and main function of the part, and the auxiliary feature is the feature that is attached to the main feature and realizes the auxiliary function (Figure 6). The CAD system only needs to input the name of the part during the process design of the part, and the system can automatically read in the design information of the part from the corresponding data file, and establish the part description frame inside the CAD system. Then the process decision-making module of the CAD system applies process decision-making knowledge and data based on the data in the established part frame, selects surface processing method of the part, determines processing route, machine tool, fixture, and cutting parameters.

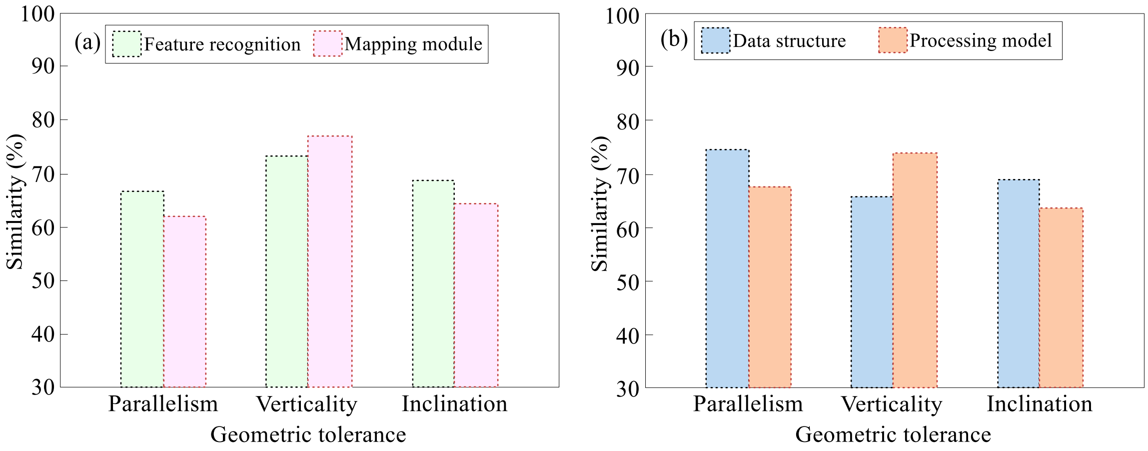

Figure 6: Similarity of different geometric tolerance for feature recognition and mapping module (a) and data structure and model (b).

The CAD integrated system consists of a parametric drawing subsystem, a feature library subsystem, an interface subsystem, and a database subsystem. The parametric drawing subsystem is used to splice and edit the characteristic graphics selected by the user, and to perform global control on the graphics to determine the position of the title bar, schedule, etc. The feature library subsystem is composed of features and the features are generated on the basis of decomposing the gear parts drawing. Altintas et al. (2017) suggested that it includes components that need to be used frequently in the gear parts drawing, and the feature parameters related to the component are attached to them, which are called feature primitives [12]. Generally speaking, features include shape features, precision features, process features, functional features, material features, etc. The database subsystem realizes data transmission and information sharing between CAD and expert system, so as to realize the intelligent integration of the whole system and the parameterized shape unit of the entire geometry, attributes, and machining information. The division of characteristic units should satisfy geometric reparability, relative independence in technology, and relative integrity in function. Designers built the frequently used structural parts in the gears into a graphic library and users can retrieve, draw, modify, delete and other operations on the components in the graphic library, thereby freeing designers from tedious drawings.

5.2 Feature Information and its Expression

The model is composed of design models, annotations and attributes; among them, the part design model is the designer's three-dimensional geometric description model of the product object, which is composed of geometric models and reference geometry; annotations refer to processes such as dimensions, tolerances, text, and symbols information. The CAD technology has completely replaced two-dimensional engineering drawings with digital three-dimensional solid geometric model data, and has become the only data source in the digital development process. Since the data model not only contains the geometric shape information of the product, but also includes non-geometric information such as dimensions, tolerances, material description information, and engineering instructions (Figure 7). The CAD model uses three-dimensional annotations, which can completely define the process information scattered in the two-dimensional engineering drawing in the past, reducing the drawing generation work. When the three-dimensional model is changed, the CAD non-geometric information related to it will be automatically changed, reducing product the problem of large amount of change. At the same time, the intuitive CAD model is adopted, and the machining personnel can easily and quickly obtain the machining information in the three-dimensional model without reading the two-dimensional drawing, reducing processing errors and rework problems caused by misunderstanding.

CAD information integration is closely related to the establishment of a complete information model and the way of data exchange. In the entire life cycle of product design, machining, use and maintenance, it realizes the completeness and consistency of product information generated and used by different software systems and exchanged in a heterogeneous environment. The feature recognition method can be divided into artificial auxiliary feature recognition and automatic feature recognition. In the former, the user directly picks up the graphics to define the geometric elements required by the geometric features, and adds the feature parameters, precision features, and technical features as attributes to the feature model, but this method has a low degree of automation. Automatic feature recognition is to identify features from existing three-dimensional entities for information system integration. Because it not only contains the geometric shape information of the product, but also builds the tolerance, roughness, hole, groove and other process information in the feature model, so it is easy to integrate with CAD and it is easy to compile numerical control machining programs for automated production. Application protocol is mainly used to refine the source information model, describe application problems, and provide special functions required by the application. This agreement must not only give a series of entities, but also the source of the data used, as well as the mapping to indicate the special tasks completed, and finally complete a consistent and unambiguous product performance abstraction for different applications.

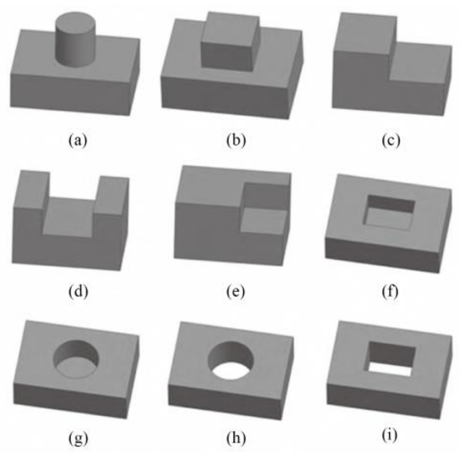

Figure 7: Examples of machining features for CAD integration of mechanical numerical control board parts [13].

6 CONCLUSIONS

This paper introduced the data transfer method of CAD integration and machining features-based part integration system, analyzed the design and machining features of CAD integration of board parts, conducted the graphic processing, information reorganization, feature description and modeling analysis of board parts CAD integration and discussed the crafting information similarity and feature library expression of board part CAD integration. The CAD integrated system consists of a parametric drawing subsystem, a feature library subsystem, an interface subsystem, and a database subsystem. The main feature of the structure is a feature composed of multiple main features or a combination of main features and multiple auxiliary features, such as a parametric feature, which is composed of a section of contour. The recognition sequence control process must ensure that all features under the main processing direction are recognized, and that all features under a certain main processing direction are recognized. Since the function of the part is mainly determined by the shape of the part, and the processing method of the part is directly related to the surface, in the description of the shape feature, a combination of body and surface is used. Feature type discrimination and information extraction process, this process realizes feature type judgment and feature detailed information extraction based on main processing surface and its adjacent surface information. The feature recognition and mapping module, the features used in the processing of the chassis parts of this subject, provides a separate feature processing scheme for each machining feature model. The research results show that the feature description in an integrated environment includes two types of information: part geometry feature and part crafting feature, so that the design and machining activities are unified on the basis of these features; the application of CAD and machining technology to modern machinery machining has achieved a significant improvement in the precision, flexibility, efficiency, quality of mechanical machining.

BaoLi Wei, https://orcid.org/0000-0001-7050-4042
Meng Lv, https://orcid.org/0000-0001-8238-3970

REFERENCES

[1] Ma, H.; Zhou, X.; Liu, W.; Li, J.; Niu, Q.; Kong, C.: A feature-based approach towards integration and automation of CAD/CAPP/CAM for EDM electrodes, The International Journal

of Advanced Manufacturing Technology, 98(9), 2018, 2943-2965. https://doi.org/10.1007/S00170-018-2447-2

[2] Amalnik, M. S.; Moayyedi, M. K.; Mirzaei, M.: Expert system approach for CAD/CAM integration & optimization based on international standard (STEP) and computer based concurrent engineering, International Journal of Computers & Technology, 14(5), 2015, 5695-5706. https://doi.org/10.24297/ijct.v14i5.1933

[3] Maruccio, C.; Bene, P.; Gerardi, A.; Bardaro, D.: Integration of CAD, CAE and CAM procedures for ceramic components undergoing sintering, Journal of the European Ceramic Society, 36(9), 2016, 2263-2275. https://doi.org/10.1016/J.JEURCERAMSOC.2016.01.001

[4] Benaouali, A.; Kachel, S.: An automated CAD/CAE integration system for the parametric design of aircraft wing structures, Journal of Theoretical and Applied Mechanics, 55(2), 2017, 447-459. https://doi.org/10.15632/JTAM-PL.55.2.447

[5] Kirkwood, R.; Sherwood, J. A.: Sustained CAD/CAE integration: Integrating with successive versions of step or IGES files, Engineering with Computers, 34(1), 2018, 1-13. https://doi.org/10.1007/S00366-017-0516-Z

[6] Jamayet, N. B.; Nizami, M. U. I.; Rahman, A. M.; Twinkle, A. B.; Rashid, Q. F.; Farook, T. H.; Alam, M. K.: Fabrication of ear prosthesis with the integration of CAD/CAM system, Pediatria i Medycyna Rodzinna, 15(3), 2019, 327-331. https://doi.org/10.15557/PIMR.2019.0057

[7] Le, V. T.; Paris, H.; Mandil, G.: Extracting features for manufacture of parts from existing components based on combining additive and subtractive technologies, International Journal on Interactive Design and Manufacturing (IJIDEM), 12(2), 2018, 525-536. https://doi.org/10.1007/S12008-017-0395-Y

[8] Chu, W.; Li, Y.; Liu, C.; Mou, W.; Tang, L.: Collaborative manufacturing of aircraft structural parts based on machining features and software agents, The International Journal of Advanced Manufacturing Technology, 87(5), 2016, 1421-1434. https://doi.org/10.1007/S00170-013-4976-Z

[9] Faludi, J.; Bayley, C.; Bhogal, S.; Iribarne, M.: Comparing environmental impacts of additive manufacturing vs. traditional machining via life-cycle assessment, Rapid Prototyping Journal, 21(1), 2015, 14-33. https://doi.org/10.1108/RPJ-07-2013-0067

[10] Sencer, B.; Ishizaki, K.; Shamoto, E.: A curvature optimal sharp corner smoothing algorithm for high-speed feed motion generation of NC systems along linear tool paths, The International Journal of Advanced Manufacturing Technology, 76(9), 2015, 1977-1992. https://doi.org/10.1007/S00170-014-6386-2

[11] Li, C.; Tang, Y.; Cui, L.; Li, P.: A quantitative approach to analyze carbon emissions of CNC-based machining systems, Journal of Intelligent Manufacturing, 26(5), 2015, 911-922. https://doi.org/10.1007/S10845-013-0812-4

[12] Altintas, Y.; Aslan, D.: (2017). Integration of virtual and on-line machining process control and monitoring, Cirp Annals-Manufacturing Technology, 66(1), 349–352. https://doi.org/10.1016/J.CIRP.2017.04.047

[13] Liu, X. J.; Ni, Z. H.; Cheng, Y. L.; Liu, J. F.: Machining feature recognition method for machining process facing plate parts, Computer Integrated Manufacturing Systems, 19(12), 2013, 3130-3138. https://doi.org/10.13196/j.cims.2013.12.liuxiaojun.3130.9.20131225