Int J Adv Manuf Technol (2007) 31: 663–672
DOI 10.1007/s00170-005-0239-y

ORIGINAL ARTICLE

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KBE-based stamping process paths generated for automobile panels

Received: 17 December 2004 / Accepted: 26 August 2005 / Published online: 3 March 2006

Abstract As automobile body panels are one kind of sheet metal part with groups of free form surfaces, the process planning is more complicated than common sheet metal stamping to implode effectively and practically. Based on KBE, new frameworks have been presented as intelligent master model at the system level and as procedure model at the activity level. In accordance with these frameworks, an intelligent CAPP system has been specifically developed. Based on feature technology, features have been extracted and represented by the object-oriented method. Stamping features and their parameters have been defined and extracted based on feature technology and stamping process rules. The whole product knowledge has been represented by frames which directly map to objects (or features) in the object-oriented sense. Relevant appropriate operations features have been assigned to stamping features of a product based on feature-operation criteria, parameters of the stamping feature and their correlativity. This assignment is a decision-making activity using a set of rules with a decision-making tree and model-based reasoning methods. With knowledge between operations, such as operations order constraint (do-after) and operations combination constraint, process paths have been improved based on relevant intelligent reasoning methods. Based on the relationships (preferred-to) between processes and machines/dies, the structure of die and machine for each process can be identified, since the process route has been determined. In this stamping process planning, the procedure and information have been controlled by a process control structure that is associative and integrated.

Keywords Automobile panel · KBE · Process planning · Feature

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1 Introduction

Recently, research on the computer-aided process planning (CAPP) system for sheet metal has been widely reported. Park et al. [1] constructed an automated process planning system for axisymmetric deep drawing products. Tisza [2] and Kang and Park [3] presented a group technology and modularity to construct a CAPP system for process sequence design in an expert system for non-axisymmetric deep drawing products with elliptical shape. Gao et al. [4] developed an advanced software toolset used for the automation of sheet metal fabrication planning for aircraft components. Zussman and Horsch [5] proposed a motion planning approach for robot-assisted multiple-bent parts based on C-space and a potential field. Wang and Bourne [6] proposed an automatic process planning system with the features well investigated and the production plans researched with near-minimum manufacturing costs. De Vin et al. [7, 8] developed a sheet-metal CAPP system called PART-S, which integrates cutting, nesting, bending and welding processes for bending sequences. Streppel et al. [9] showed the ambiguity of conventional tolerances and presented a method which replaces conventional tolerances with geometrical tolerances for process planning in small batch sheet metal part manufacturing. Aomura et al. [10] proposed a method which generated feasible bending sequences of a sheet metal part handled by a robot, and discussed the determination of the best grasping positions and repositions. Aomura and Koguchi [11] proposed a method to generate bending sequences of a sheet metal part handled by a robot. Liao and Wang [12] proposed an evolutionary path-planning approach for robot-assisted handling of sheet metal parts in bending. Lutters et al. [13] developed a generic architecture for computer aided process planning based on information management for sheet metal manufacturing in a small batch part environment. Kumar and Rajotia [14] had proposed a method of scheduling and its integration with CAPP, so that on-line process plans can be generated taking into account the availability of machines and alternative routes. The contents above are mainly for process parameter calculating, path-planning and some sketch map of work-pieces for specific types of sheet metal, such as axisymmetric and non-axisymmetric deep drawings, complex bendings and shearings, and so on.

The automobile body panel is one kind of sheet metal part, which is complicated in shape, with groups of free form surfaces, a large figure in size and is always manufactured by stamping processes. Automobile panels can be considered as a combination of some common stamping, such as irregular drawing, flanging/bending, trimming and piercing, etc. The process planning of these panels is more complicated than common sheet metal stamping, which is generally dependent on engineers experience to complete. It is believed that the process path plan for automobile panels is requisite and acquirable.

In essence, the stamping process path for automobile panels is to determine the necessary forming processes and their sequences in order to produce a particular part economically and competitively. Process paths generation is a decision-making process. Decisions on stamping operations for a particular feature have to be formed on various independent conditions such as which operation should be performed with which die and tools and under what forming parameters. A CAPP system for these should be an integrated environment to deal with knowledge to reduce the dependence on engineers or experts, and realize the process planning with scientism. Thus, knowledge based engineering (KBE) is applied to advance the stamping CAPP system for automobile panels, and even to improve the competitiveness for the automobile industry. This paper is particularly concerned with the construction involved with developing a CAPP system based on KBE.

2 KBE in CAPP system for stamping

2.1 KBE

Knowledge based engineering (KBE) is one innovative method of artificial intelligence for engineering design developed in the 1980s. So far, there is no generally accepted and mature definition for KBE. However, it is recognized that KBE is an intelligent method to resolve engineering problems, which can realize inheritance, integration, innovation and management of domain expert knowledge through the drive, multiplication and application of knowledge. A knowledge-based system (KBS) is one that captures the expertise of individuals within a particular field (the "domain"), and incorporates it and makes it available within a computerized application [15]. The level of complexity of the tasks performed by such a system can vary greatly. However, it can generally be said that while a domain expert would find them routine, they would be outside the capabilities of a person unfamiliar with the domain [16].

KBE provides an open architecture and reuse ability of experience and knowledge, which can deal with multi-domain and multi-expression of knowledge, and can form an integrated environment. A KBE application is further specialized, and typically has the following components of geometry, configuration, and engineering knowledge:

- Geometry – there is very often a substantial element of computer-aided design (CAD). Most of the software used to create KBE applications either has CAD capabilities built in, or is able to integrate closely with a CAD package.
- Configuration – this refers to the matching of valid combinations of components.
- Engineering knowledge – this enables manufacturing and other considerations to be built into the product design.

When a candidate application area requires a high degree of integration of the above elements, KBE is likely to be the best method for its integration. KBE is sometimes termed rule-based engineering, as within the discipline, knowledge is often represented by rules. These may be mathematical formulae or conditional statements, and although simple in concept, they may then be combined to form complex and powerful expressions. KBE systems, on the other hand, are usually provided with specialized geometrical capabilities, with the ability to embed engineering knowledge within a product model.

The following examples of typical KBE applications demonstrate some of the considerable benefits to be gained from its use.

1) Lotus engineering. This used the integrated car engineer (ICE) system in the design of the Lotus Elise. ICE consists of a vehicle layout system, and modules to support the design of suspension, engines, power-train, wheel envelope and wipers [17].
2) The Boeing Commercial Airplane Group. This uses KBE as a tool to capture airplane knowledge to reduce the resources required for producing a design [18].
3) Jaguar cars. The company's KBE group devised a system that reduced the time taken to design an inner bonnet from 8 weeks to 20 min [19].

2.2 Problem to solve in a CAPP system based on KBE

A stamping CAPP system should deal with all knowledge including geometry, non-geometry, engineers experience, rules and criteria, results of tests and numerical simulation, or even successful cases, because of the complexity of automobile body panels. The knowledge is involved in diverse fields, such as metal forming technology, metal forming mechanics, modern design methodology, numerical simulation technology, and artificial intelligence. Accordingly, the CAPP system has to solve the problems with expression and application of all knowledge, and integration of all multidisciplinary design.

A CAPP system is essentially a set of instructions and guidelines on how to perform a complex procedure. It details the individual sub-tasks, how they should be carried out, in what order, and how the work should be documented. Furthermore, as system requirements change, new solutions tend to evolve from existing ones, so computer applications and their descendants can outlive the personnel involved in their initial development. All in all, a stamping CAPP system for automobile panels based on KBE should readily solve the following problems:

(1) Representations for all knowledge.
(2) Reasoning based on all this knowledge.
(3) Appropriate operation features acquired from stamping features and process rules incorporated with formability analysis.
(4) Process routes based on process sequencing and process combination knowledge.
(5) The control or management of process procedures for rapid response to all changes.

3 Framework of a CAPP system

3.1 The integrated master model for a CAPP system

To solve all corresponding problems mentioned above, the integrated master model is advanced at the system level to control and frame the CAPP system for automobile panels. It is a common concept and framework to generalize and specialize the function, course control, process planning circumstance, and activities involved in the development of an integrated and intelligent system into abstract groups, and to make them carry out all contents and processes. This model is suitable for knowledge expression and application, process controlling, information integration, change response, etc.

The intelligent master model (IMM) of stamping process planning for automobile panels is composed of a knowledge base, process control structure (PCS), process planning optimization (PPO), process information model (PIM), and linkable environment (LE), which are integrated and combined based on KBE. The structure of the IMM is shown in Fig. 1. The IMM of process planning is

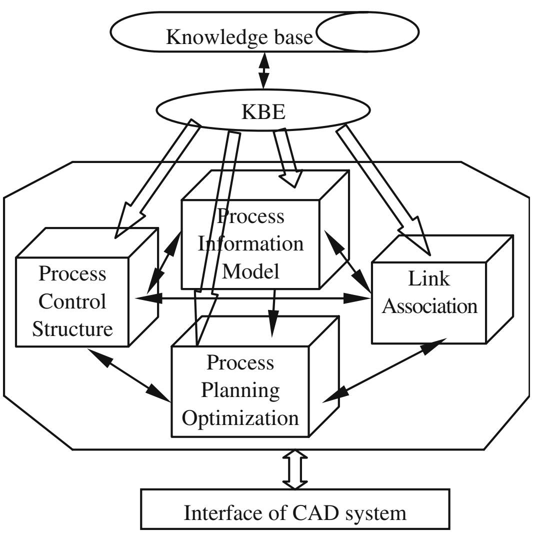


Fig. 1 IMM of process planning

not only the foundation of intelligent CAPP for automobile panels, but also the integration of knowledge and methods, which combines the KBE system with the process planning. With this model, KBE acts as a knowledge source to drive PCS, PIM, and LE, which makes process planning integrated and associative.

The PIM is a dynamic expanded information model, in which the information can be added and updated along with process planning. Using knowledge multi-expression format, the integrated information model of process planning is built based on a feature model. For the hierarchy and framework of the features, semantic net and object-oriented methods are adopted to express knowledge and establish an information model in which process knowledge, e.g. database, parameter, rules, and experience, act as rules and attributes of the objects, and where whole product knowledge acts as a framework for relationships of objects. With a process information model, the process planning can be completed through knowledge-reasoning and decision-making based on knowledge encapsulated in the objects.

The PCS is a key point to ensure process planning is integrated and consistent; it manages the process information model, process planning to generate stamping process plans and detail design, and controls the changes of the planning. In IMM, the PCS comes into being dynamically along with the process planning. If one part of PCS is created, it will monitor and control relevant planning and information subsequently. When results of process planning are deleted, the corresponding PCS part will fade away accordingly.

The LE provides several methods to deal with the links among process planning procedures, the geometry between product and detail design of workpieces. To achieve intelligent process planning for large complicated stampings, there are problems to solve, i.e. linking of process planning procedures, the geometry link between product and detail design of workpieces. The LE provides several methods to deal with these links, e.g. parameters variable link, data structures link, and geometrical link.

The PPO is a methodology of design optimum for complex engineering, which can deal with the complicated optimization problem of process planning in an economic view.

3.2 The framework of CAPP system based KBE

The stamping CAPP system for automobile panels based on the intelligent master model above consists of several stages such as stamping features extraction from product data, operation features reasoning from stamping features to form a process information model, process planning to get the sequence of operations and relevant tools, detail design for workpieces, simulation for detail design, and finally the process plans and 3D die-face model generation which is shown in Fig. 2. It is a tangible activity level to control and frame a CAPP system for automobile panels.

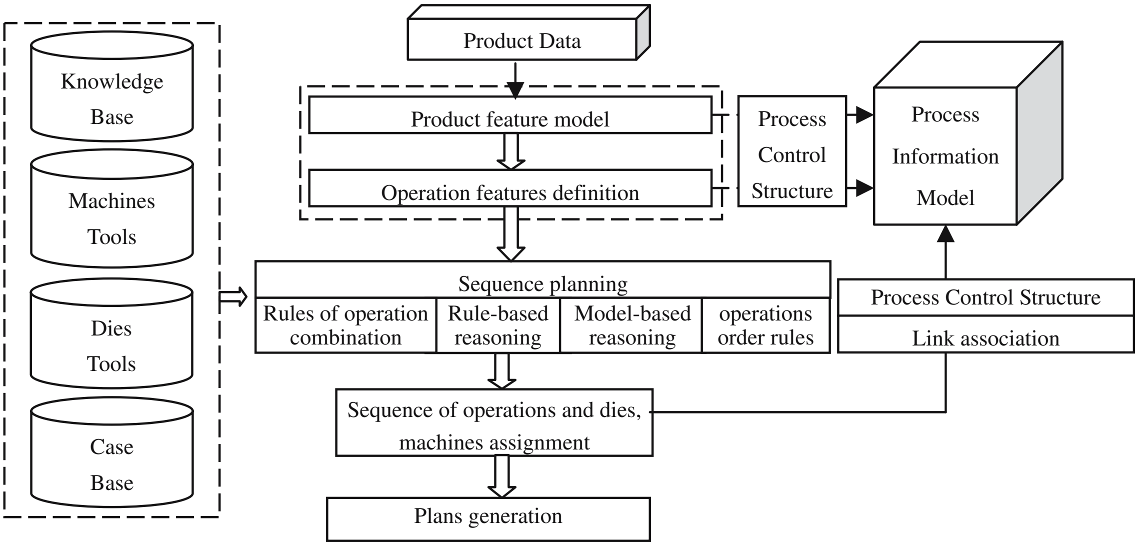


Fig. 2 Overview of the process plan generation based on IMM

In the CAPP system, stamping process planning of automobile panels needs to first establish a process information model based on a 3D model product and feature technology. Stamping features are extracted, and operation features are attained subsequently. The features all carry knowledge about themselves, the process and constraints. Then the PIM and PCS are established. Thereafter, the sequence planning is setup based on PIM and knowledge such as operation sequence rules, operation combination guides and reasoning methods, and then the dies and machinery are options.

Along with the process of the planning, PCS, PPO and LE of IMM are built by knowledge driving. PCS consists of an integrated collection of tasks that can initiate, control, manage, evaluate and update all the planning information and results timely. PPO optimizes process paths and enterprises resource environments, and PCS and PPO carry out the optimization and find the optimal solution. PCS and LE make process planning associated and linkable.

4 Key points of process path generation

Unigraphics has several features that provide a subset of the capabilities of a KBE language—UG/KFL, which provides a way to specify knowledge rules that can cover all Unigraphics applications. The stamping CAPP system for automobile panels has been developed based on the frameworks advanced above, which choose C and UG/KF language as the implementation language, and ACCESS as its database on the UG/CAD development environment. UG/Open and UG/Open++ allow customization and extension of Unigraphics using a standard procedural language (C and C++). UG/KFL provides a way to specify knowledge rules that can cover all Unigraphics applications. Rules of UG/KFL are easily written by the developer, easy to read, understandable, and reusable by the user. Furthermore, UG/Open can be integrated with KBE by accessing C programs from the KBE language described under External Function. For access to named attributes from C, there will be a utility program that takes a design definition in the language and produces C bindings to access the attributes of an object instance of that design. The access consists of functions and methods for getting and setting the value of the named attributes of object instances. Additionally, there are UDF and UDO in UG/CAD and UG/KF, which can be dealt with by UG/Open and UG/KF. What is more, Unigraphics is integrated with many other knowledge tools and sources, such as spread sheets, other ICAD KBE language systems, finite element analysis, CAM, etc.

4.1 Stamping feature

To generate appropriate process plans, the product data requires the original inputs, which includes the geometry, topology, tolerance, material and quantity of product. Based on the feature technology and stamping technology, a stamping feature is the portion of a part which can be formed by means of certain stamping operations. For example, a drawn feature or bend feature is defined as the main feature, which is to describe the near net shape of a component, while flange, hole, emboss, bead, notch and flange-hole are defined as the auxiliary ones, which are required to describe the local part of the final shape.

Using feature technology and the geometry extraction method, the stamping design features, such as the main forming feature (e.g. drawing, bend), flange, hole, emboss, bead, notch, and so on, can be extracted from a 3D solid model, which are first defined as UG/UDO. For example, Fig. 3 shows the stamping features of one automobile panel.

The stamping feature model should then be defined to represent product knowledge integrated and unambiguous. The stamping feature is represented as object-oriented class or object and instance using UG/KF language (UG/KFL); it

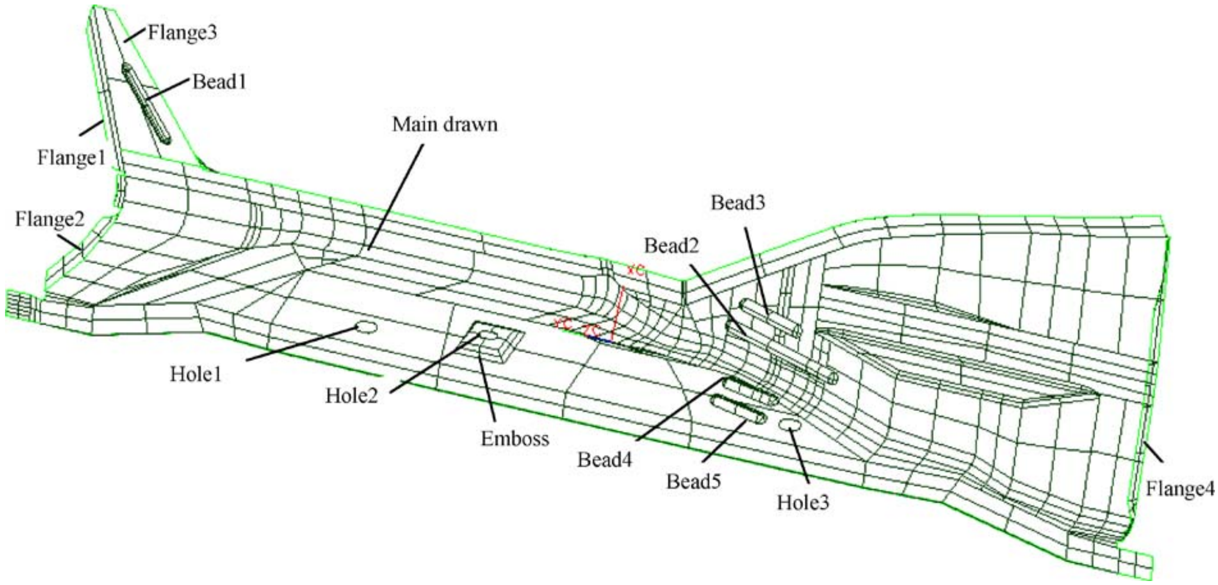


Fig. 3 Stamping features of automobile panel

not only represents feature parameters, tolerance, material, etc. as attributes of class or instance, but also represents geometrical objects by importing UG/UDO and UG/UDF referenced solid geometry as an instance attribute or child. And this realizes the connectivity and integration between the symbol of a feature and its geometrical object. It can also get an attribute value from a function, rule, expression and database. The following is the hole class created by UG/KF. If the attribute parameters of the class are valued, the object or instance of the hole is confirmed concretely. Others can also be expressed similarly.

DefClass: pdcapp_hole_feat(ug_base_part); # name for hole feature class

(string modifiable parameter) hole_id: "variable"; #name of hole.

(integer modifiable parameter) hole_type: variable; # the typeof hole.

(string) geomtry_id: "udo_name"; #reference name of edges group.

(string) parent_feature: "feature name"; # reference name of parent feature.

(number) radius: askholeradius (hole_id:); #get value from function.

(integer modifiable parameter) tolerance: variable; # tolerance level.

(Number modifiable parameter) part_Thickness: number variable;

(string modifiable parameter) material:"material_ name" ;

(list)parameter_material:@{rec:moveFirst:();rec:Get Record:()};#ask material property from database

(integer)feature_control:variable;# level of process planning state.

....

 # the following is a function passed from C function. The first variable is the hole id; the second #oneis the library name of KBE; the third is the name of C function. The end of the function is the #variable type of the output value.

Defun:askholeradius(string $name; String ($lib; "pdcapp_kbe") String ($name; "PDCAPP_KF_ask_hole_ radius")) @{ CFunc(" UF_KF_invoke_user_function"; "libufun");}number;

(Child) db: { Design; ug_odbc_database; dsn; "pdcapp_db";}; # create child connection between variable of database and database Material.

(String) query: "select parameter_material" + " from Material where Stringr = "+ " '" + "material_name"+ " '";

#record query sentence: query propertiy of given material_ name.

(Child) rec: { Design; ug_odbc_recordset; database; db:; sqlStatement; query: }; #create child procedure for record query.

....

*** Incidentally # - declarator: the letters after it are the illustration for relevant sentences or functions.*

The "*feature_control*" above is an extraordinary parameter for PCS to make tracks for process states, for example: 0—only stamping feature; 1—operation feature have gotten; 2—process routes success; 3—stamping feature assigned to relevant work-piece; 4—work-piece designed.

The whole product knowledge is represented by frames which directly map to objects (or features) in the object-oriented sense. Hierarchical abstraction is effectively exploited in modeling and representing the relationship and constraints. The structure of a product is represented by the stamping feature as the constructive element (or basic note). The first layer of the construction for form features is the main feature of the product. Other stamping features that are attached to the main feature are termed as auxiliary features, making up the second layer of form features. In a similar manner, the third layer form features are attached to the second layer form features, and so on. For example, shown in Fig. 4 is the hierarchical structure model for the part shown in Fig. 3.

4.2 Operation feature

Accordingly, stamping operation features are categorized into initial and subsequent, such as drawing, bending, flanging, trimming, hemming, re-striking, piercing and so on. The relevant appropriate operations are assigned to form stamping features of products based on feature-operation criterion, parameters of the stamping feature and their correlativity. This assignment is a decision-making activity using a set of rules with decision-making tree and model-based reasoning methods. For example, drawing → trimming is reasoning from the main draw feature, flanging is reasoning from the flange feature, and piercing is reasoning from the hole. Fig. 5 show the typical illustration of flanging operation features reasoning from its stamping feature, and the sequence rules of these operation features are attached to the operation features.

Customarily, relationships between features, especially the hierarchy, should be an important factor, while the operation feature is the reasoning. In Fig. 4, the features flange3, flange1 and bead1 should be in the form of a set together to deduce relevant appropriate operations. In this way of reasoning, the operation features can get fundamental knowledge for subsequent planning.

In this paper, the operations features reasoned from stamping features are represented as object-oriented entities and UG/UDO, and the relationships are expressed as network based on the stamping feature model of the product (shown in Fig. 6). The operation features not only refer themselves to stamping features, but also relate to other operations, such as relevant forming dies and machinery with the relationships among them. The relationships between operations consist of operations order constraint and operations combination constraint. Another type of relation between processes and machines/dies is preference (preferred-to). For example, flanging is always preferred to flanging die and relevant press machine, while trimming is always preferred to trimming die and press machine. ALL these constraints and relationships among them are represented as attributes, rules and methods in the operations. It is through the citation of stamping features that the description of the geometrical objects are realized in the operation features; while the relevant dies and machinery can be represented in operation by options and the constraints expressed as relevant rules, functions or methods.

4.3 Process information model (PIM) for path planning

Now the PIM of process planning can be defined as the foundation to process planning. And the PCS of IMM is created to control and monitor the stamping feature and its operation features by the control variable or state variable.

The process planning of large complicated stampings is a dynamic process. The PIM must involve all data, such as process planning data, analysis data, die design data, and circumstance, etc. The basic knowledge expression of the model should have adaptability to the changes of geometry, attribute, features, constraints and the way of thinking.

Using the knowledge multi-expression format of KBE technology, the integrated information model of process planning for large complicated stampings is built based on the feature model. The process information model is shown in Fig. 7. The object-oriented method and feature technology are adopted mainly to form the model. There are three basic classes of features: stamping design features, operation features, and sequence features, in which process knowledge, e.g. database, parameter, rules, and experience, acts as rules and attributes of the objects. Using feature technology and the geometry extraction method, the stamping design features, such as the main forming feature (e.g. drawing, bend), flange, hole, emboss, notch, and so on, that are defined first as UG/UDO, can be extracted from a 3D solid model. Relevant appropriate operations can then be assigned from stamping design features of a product using a set of rules with a decision-making tree and model-based reasoning methods of feature-operation criteria. Hierarchy and framework of the product model and semantic net of feature-operation-tools are used to establish the relationship information for PIM. With PIM, where the knowledge is encapsulated in objects or decision-making knowledge procedures, the process planning can be completed through corresponding sets of knowledge-reasoning.

This model is a dynamic expanded information model, in which the information can be added and updated along with the process of planning. Information management and control is a part of PCS in IMM of process planning, which can monitor the change or modification of process planning, and timely update the information to insure the process information model and process planning synchro-

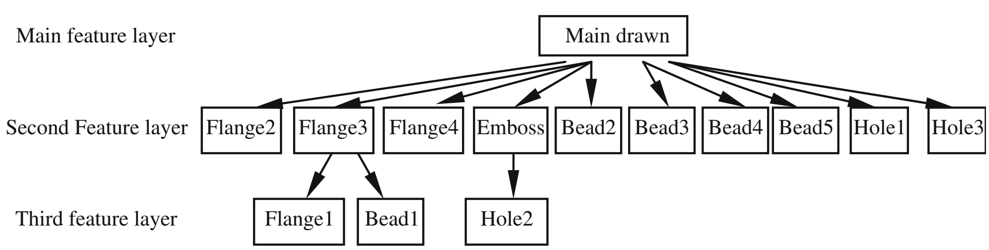


Fig. 4 Structure feature model for product data

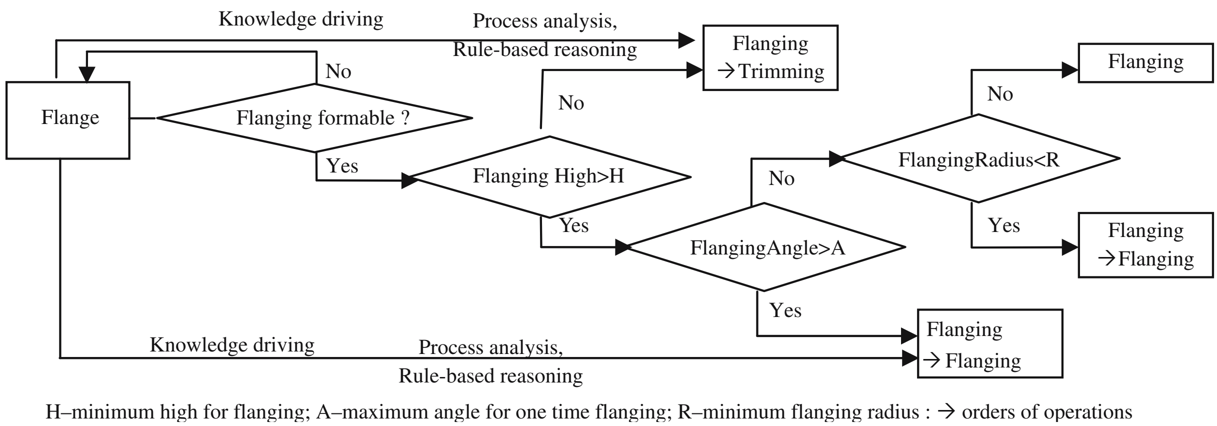


Fig. 5 Flanging operations reasoned from its stamping feature

nization. In process planning, the information management and control begins its control and judgment from the time that the stamping design features have been created until the planning ends.

4.4 Process path planning and tools option

Generally, the forming of an automobile panel includes several operations, such as drawing, trimming, flanging, piercing, re-striking, hemming, etc. Among the operations, drawing, trimming and flanging are the main operations to form the main shape of the product, and other operations are auxiliary operations, which work together with the main operations to form complex shapes of the product. To get precedence relations among operations based on the PIM, the main operations must first be determined, and then the decisions are made about how to arrange the initial main operations, how to combine the auxiliary operations with the main operation, and how to insert auxiliary operations to the operation sequence. For the integration of planning, it should consider the stamping dies' capability, cost and capacity of machinery or workshop as critical issues at the sequencing level.

Theoretically, case-based reasoning (CBR), rule-based reasoning (RBR), and model-based reasoning (MBR) are all applied for process planning. In this paper, CBR, RBR and artificial neural network are joined up as the decision-making methods after model-based reasoning during process planning, which is shown in Fig. 8. Firstly, the model-based reasoning is used to form a code of the product and operation for CBR based on feature entities and their interrelationships, and relevant rules or knowledge for others reasoning. Then the CBR is selected to get similar plans for the case base; if CBR is not suited, the RBR and ANN are select to complete the task cooperatively. During sequencing of forming operations, the structure of the die for each operation can be performed from the operations and assigned stamping features. The system can plan the equipment and operators for each operation to meet design specifications, and to achieve minimum machining time and maximum efficiency based on the above activity and knowledge. Finally, the optimal process plans obtained can be added into the case base of plans for the planning of other similar products.

Customarily and practically, the relationships between operations consist of operations order constraint (do-after), which relates to the necessary order of operations to be

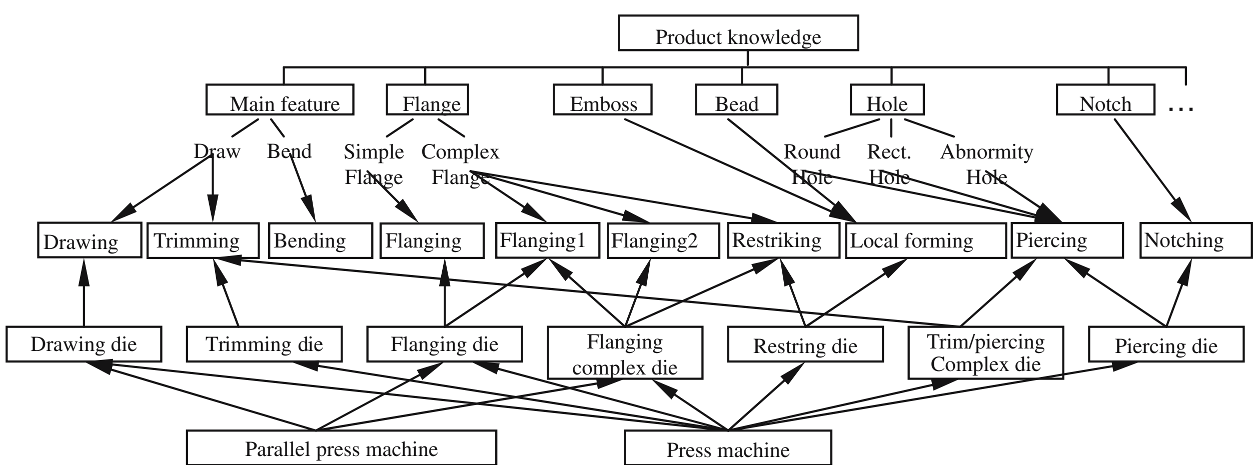
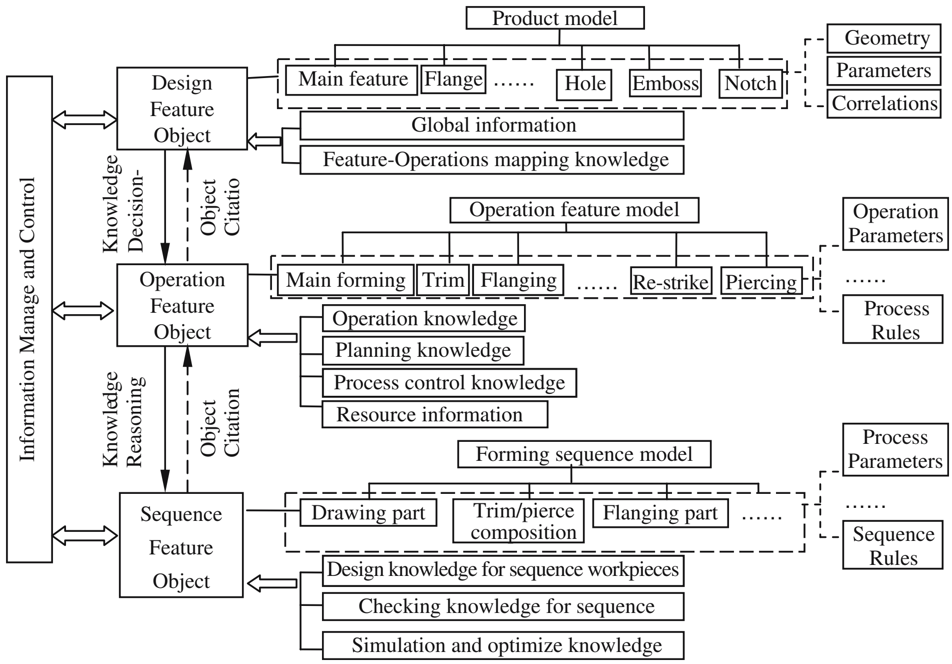


Fig. 6 The semantic network for feature, operations and tools based on object-oriented entities

Fig. 7 PIM for large complicated stampings



used, and operations combination constraint, which relates to relevant operations that can be formed at one process and die together (mentioned in Sect. 4.1). For example, flanging is after trimming, while piercing and trimming are always formed in one process.

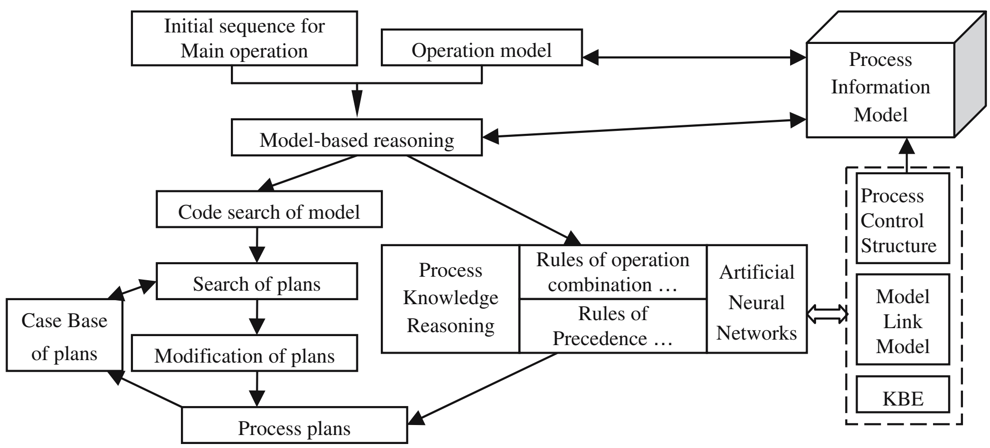
For the aims of economic efficiency and top-quality, it is always recommended to combine the potential operations together, while making the sequence operations practical. Therefore the initial main operation sequence is Blanking→ Drawing → Trimming → Flanging for a flange feature comprised part, and Blanking→ Drawing → Trimming for no flange feature part. With operations sequencing and combination rules, auxiliary operations are added to the initial main operation sequences to form final process routing. The following is the combination rules for hole1 and hole3 shown in Fig. 3:

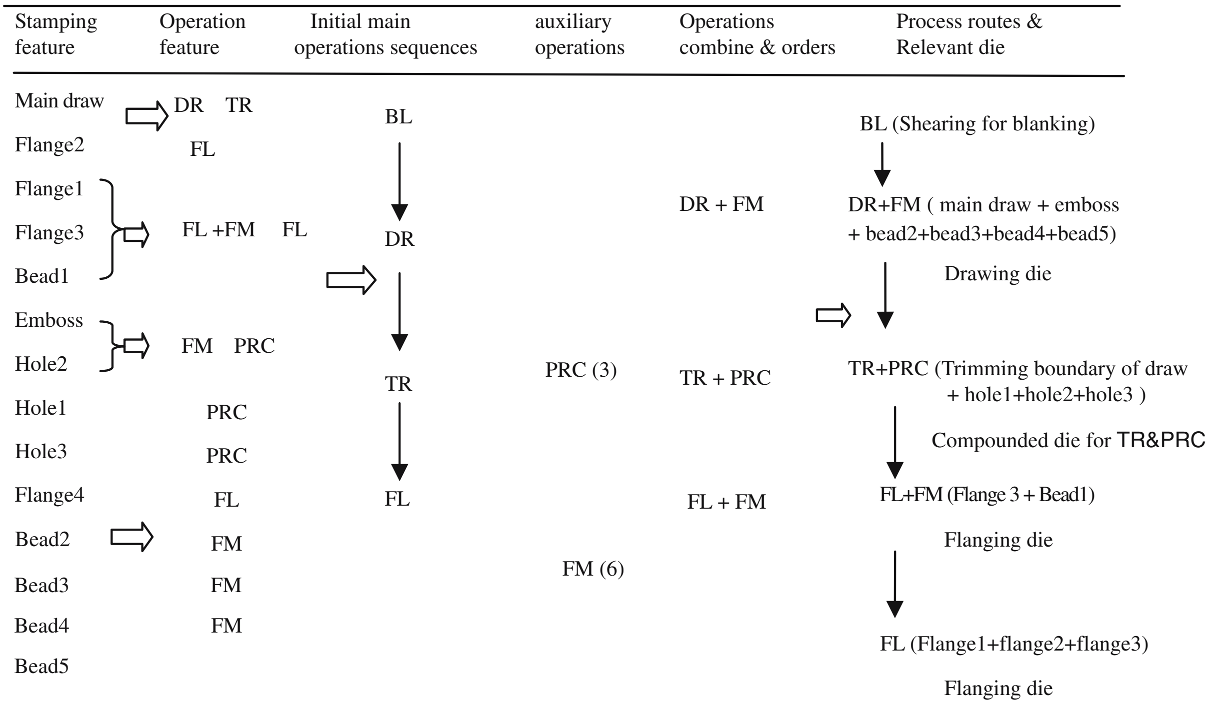
(Logical) combination (for hole1 and hole3): IFdistance between hole1 and hole3 >DIS && the angle of the vectors of the two hole<15· THEN TRUE ELSE FALSE;

Thereafter, the structure of the die for each process can be performed from operations and the assigned features, while the process route is determined. Then the equipment such as a set of machinery or the product line can be selected to insure the stamping die meets design specifications. For example, Fig. 9 shows generation routes of process planning for the automobile panel shown in Fig. 3.

During process planning, different process routes can be found by different planners; therefore, the best process route should be selected according to the batch of production, design and manufacturing of stamping dies, cost, etc. while tool options, the equipment and dies for each process should be assigned to meet design specifications, and to achieve minimum maching time and maximum efficiency. Finally, the optimization of process planning [20] is realized for multiple purposes (best-quality, maximizing efficiency, minimizing cost and time) by PPO based on KBE.

Fig. 8 Sequence planning of operations





Supplement: BL—Blanking; DR—Drawing; TR—Trimming; FL—Flanging; PRC—Piercing; FM-- Forming

Fig. 9 The decision route of process planning for one automobile panel

4.5 PCS in process path generation

Since the process planning is a dynamic course with several plans and design stages, PCS is a key point to ensure process planning is integrated and consistent. PCS manages the process information model, assists in generating stamping process plans and detail design, and controls the changes during planning. There are several control variables for PCS including state variables for process planning, control variables for IMM, and state variables for stamping features, etc. The process control structure is shown in Fig. 10.

In this CAPP system, the process planning is defined as a project. The project control can create a project, insert the part or work-pieces to suitable positions of the project, and decompose the process planning task into subtasks.

In IMM and process planning, according to the knowledge expression and decision-making rules, the planning process control can set up the process information model based on features and their state variable, monitor planning process, feed the planning information and changes back to IMM, and control information transfer.

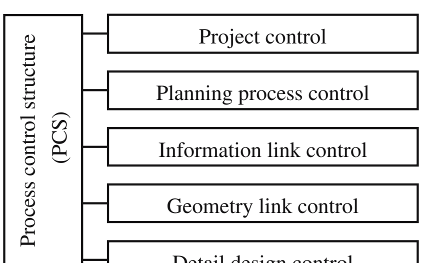


Fig. 10 The process control structure

The process planning is a dynamic process of information flow and transfer. The information link control ensures process planning information is associative and consistent. The added, extended, and modified information and its effects on the planning can be fed back to PIM and IMM so that the information of process planning can be updated timely and shared by different parts of the system.

For the complicated and mass geometry information involved during the process planning, the links between features and product geometric information have been dealt with. The geometry link control can monitor and control the links and transfer the geometry information between different parts of the process planning.

In IMM, the parts of PCS come into being dynamically along with proceeding of the process planning. If one part of PCS is created, it will monitor and control relevant planning and information subsequently. When some results of process planning are deleted, the corresponding PCS part will fade away.

5 Conclusion

As the automobile body panel is one kind of sheet metal part with groups of free form surfaces and large size, the process planning is more complicated than common sheet metal stamping. Yet the automobile panels can be considered as a combination of some common stamping, such as irregular drawing, flanging/bending, trimming, and piercing, etc. However, because of over-complexity, stamping CAPP system for automobile panels is more difficult to implode effectively and practically. It should deal with all knowledge from geometry, non-geometry, engineers' experience, rules and criterions and successful cases of planning process-paths for automobile panels. The process plans should instruct or guide how to perform a complex procedure.

Based on KBE, new frameworks have been presented as an intelligent master model in the system level and as a procedure model in the activity level. This master model brings forward a new concept and notion that knowledge, and thus KBE, is the kernel object of technology for specific domains in the manufacturing industry. In accordance with these frameworks, an intelligent CAPP system has been specifically developed. Based on feature technology, features have been extracted and represented by the object-oriented method. Stamping features and their parameters have been defined and extracted based on feature technology and stamping process rules. The whole product knowledge has been represented by frames which directly map to objects (or features) in the object-oriented sense. Relevant appropriate operations features have been assigned to stamping features of products based on feature-operation criteria, and parameters of stamping features and their correlativity. This assignment is a decision-making activity using a set of rules with a decision-making tree and model-based reasoning methods. With knowledge between operations, such as operations order constraint (do-after) and operations combination constraint, the process path has been improved based on relevant intelligent reasoning methods. Based on the relation (preferred-to) between processes and machines/dies, the structure of the die and machine for each process can be performed, while the process route has been determined. In this stamping process planning, the procedure and information have been controlled by the process control structure to be associative and integrated.

This study can be used as the basis for future studies to enhance the complicated system. Indisputably, much effort will be required in advancing the establishment of the practicality process planning function blocks and their mutual interaction. Moreover, the conversion of these architectures into a prototype CAPP system will be a considerable endeavor.

Acknowledgments This paper has been supported by the key technologies R&D program in the 10th National five-year plan and the National Natural Science Foundation of China.

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