Research on Top-Down Design Method of Internal Combustion Engine based on NX Future Development

Zhigang Huang\textsuperscript{a}, Wenping Zhang\textsuperscript{b} and Xinyu Zhang\textsuperscript{c}

Harbin Engineering University, Harbin 150001, China

\textsuperscript{a}384972014@qq.com, \textsuperscript{b}zhangwenping@hrbeu.edu.cn, \textsuperscript{c}zhangxinyu@hrbeu.edu.cn

Abstract. With the development of internal combustion engine, how to design complicated parts of internal combustion engine quickly and effectively is of great significance. In view of the rapid prototyping design research of internal combustion engine parts, we firstly formulate a prototype model design criterion. From the sketch parameterization, shape feature parameterization and assembly parameterization design ideas, we propose a parameterized model construction method in order to meet the requirements of model accuracy and extensibility in the top-down design of internal combustion engine. Then according to the performance of internal combustion engine and the structure characteristics of main parts, we develop a system design process and a part design process. At the same time, we put forward a top-down design platform for internal combustion engine, analyse platform development functions, platform development framework and platform development process. Finally accomplishing the prototype of internal combustion engine based on NX development and a complete development technology system of internal combustion engine platform so as to improve the success rate of internal combustion engine design.

1. Introduction

In the process of internal combustion engine design, traditional bottom-up design is still the mainstream development method, resulting in uneven design levels, poor communication channels between departments, and too many repeated design times. In order to overcome traditional design difficulties, scholars put forward top-down design method [1]. Aleixos [2] proposed a commercial CAD system of hierarchical control framework. Mun [3] used a skeleton model for collaborative development within enterprises and vendors. Zhang Jichun [4] defined a internal combustion engine parameter constraint relationship between product structures and parts through top-down design method.

Although some papers involved top-down design method, they only associated the internal combustion engine design with top-down design method, failing to form a systematic development platform and technical system. On this basis, this paper adopts top-down design method, through NX future development technology, starting from the overall performance and structure of internal combustion engine, to develop top-down design platform of internal combustion engine and achieve rapid prototyping of internal combustion engine parts, so as to make up for the slow speed and repeated modifications in the process of internal combustion engine design.
2. Research on key technologies of top-down design

2.1. Philosophy of top-down design

Top-down design is the design method from the whole to the part. Giving priority to the design purpose and taking into account all kinds of factors related to the product, such as performances, structural characteristics and constraint relations. In the top-down design process, firstly analysing the whole product system, determining the performances and structures of the system, and forming an overall product design scheme. Then taking performance parameters and structure parameters as the core to carry on the parametric design, as well as setting up the automatic constraints of sketch, structure and assembly to form product functions as the core of design scheme.

Compared with the bottom-up design process, the top-down design process has following advantages [5]:

(1) Conform to the product design idea: In the process of product design, designers need to give priority to the function of product, and then take the function as the core to design its size and structure.

(2) Conducive to the collaborative design: In the process of product design, the knowledge used is often complex and diverse. Top-down design process is conducive to the joint participation of designers with different knowledge, so as to better ensure the integrity of product functions.

In the top-down design process, the following principles should be followed:

(1) Combining the conceptual design, detailed design and engineering design of product with the top-down design idea. Reasonably controlling the key parameters of each link through modular design.

(2) Based on the parallelism of products, following the design sequence from the whole to the parts, from the critical parts to the accessories. Finally combining all parts into a system.

(3) Critical components should contain enough information like positioning information, system parameters and assembly structures to ensure the centralized expression of parametric information.

2.2. Prototype model design criteria

Prototype model refers to the basic model used for rapid prototyping and efficient expansion of part models in the top-down design process. A good prototype model should have following characteristics:

(1) Prototype model should ensure the integrity of its main features.

(2) Prototype model should not be too detailed. On the one hand, too detailed prototype model will increase the workload of platform development. On the other hand, a large number of editable controls will make it difficult for designers to pay attention to the core requirements of parts.

(3) Prototype model should have good expandability. For example, in piston structure, spherical pit, ω pit or swirl chamber pit can be created with a combustion chamber prototype model.

Prototype model needs to be built on the basis of parametric model construction. The rapid prototyping of part model can be realized by parameter-driven prototype model. Therefore, defining the design scheme of parametric model is the premise of establishing prototype model.

2.3. Parametric model construction scheme

Parametric design is the core content of top-down design. In the parametric design process, it is necessary to establish a standard for parametric model construction, because effective geometric constraint relations can accurately describe product structure information and highlight dimension driving relations [6, 7]. This paper sets parametric model construction process as the following standards:

(1) Parametric design based on sketch

Constructing dimension constraints and geometric constraints in sketch. Controlling the basic size and shape in sketch by dimension constraints, and performing array and mirror operations on dimensional features by geometric constraints. In the process of product modeling, sketch features will not only have constraint conflicts with features of itself, but also have dimensional relations with other sketches and physical features. Therefore, reasonable sketch parameterization can effectively reduce constraint conflicts and improve design reliability and efficiency.
(2) Parametric design based on shape features

Common shape features contain position features like point, line and surface, as well as drawing and rotation operations for sketch, as well as array and mirror operation for features. When the size constraints of shape features are unreasonable, constraint conflicts will also occur in the process of parameterization, so the integrity and accuracy of shape features also should be considered in the process of sketch parameterization.

(3) Parametric design based on assembly

Constructing assembly feature parameterization in the assembly environment. The parts are combined by assembly constraints, such as fitting, alignment and center of circle, to form a complete product and achieve the linkage of whole product structure and size. The assembly parameterization is based on part model, which in turn affects the structure and size of parts.

3. Research on top-down design method of internal combustion engine

3.1. System design process

Dividing top-down design process of internal combustion engine into system design process and part design process. In the system design process, by analyzing the forms, dynamic performance indexs and main structures of internal combustion engine, we obtain the structure characteristics, size requirements and driving relations between various parameters directly related to internal combustion engine parts [8]. The building flow of system design process is as follows:

(1) Starting from the design requirements of internal combustion engine application, fuel type, and number of strokes, effective power $Ne$ and revolving speed $n$. After the stroke is selected, cylinder number $i$ under the corresponding power is deduced from effective power $Ne$.

(2) Determining the range of average effective pressure $P_{me}$ according to the fuel type of internal combustion engine. Determining the range of average piston speed $C_m$ according to the style of internal combustion engine (high-speed or medium-speed engine). Then, the value of cylinder diameter $D$ can be determined by the formula of $D = \sqrt{\frac{4}{\pi} \times \frac{\pi \times r Ne}{i \times P_{me} \times C_m}} \times 10^3$ according to the number of strokes, $Ne$, $P_{me}$ and $C_m$.

(3) Determining the range of piston stroke and cylinder diameter ratio $S/D$ according to the application of internal combustion engine (vehicle or Marine). Then determining the value of piston stroke $S$ by the formula of $S = (S / D) \times D$.

(4) Determining the accurate values of $S$ and $D$ according to national standard, and then reset the value of piston swept volume $V_h$ by the formula of $V_h = (\pi / 4) \times D^2 S$ and the value of $S/D$.

(5) Determining $P_{ne}$ and $C_n$ by the formula of $p = 30\tau N_e / z \times V_h \times n$ and $C_n = Sn / 30$. If it meets the requirements, continuing to calculate the crank linkage ratio $\lambda$, otherwise returning to the step 2 to readjust the parameters.

(6) Determining the range of $\lambda$, and determining the length of connecting rod $L$ by the formula of $L = S / 2\lambda$.

(7) According to the cylinder arrangement, determining the ratio range between the center distance of cylinder $L_1$ and cylinder diameter $D$. Obtaining $L_1$ by the formula of $L_1 = D \times (L_1 / D)$.

The flow of system design process is shown in Fig 1:
3.2. Part design process

In the part design process, firstly considering the influence of system parameters on part parameters. Dividing the system parameters into six attribute groups: basic type, performance parameter, structure form, driving performance parameter, structure parameter and product number. Then dividing the part parameters into four attribute groups: main performance, basic parameter, advanced parameter and part number. Each attribute group continues with performance or structure refinement. The flow of part design process is shown in Fig 2:

**Figure 1.** Flow chart of top-down system design of internal combustion engine.

**Figure 2.** Flow chart of top-down part design of internal combustion engine.
4. Top-down design platform development of internal combustion engine

4.1. Functions of platform development

Based on the key technologies and methods of top-down design for internal combustion engine, we propose a top-down design platform development plan, including the following development functions:

1. The determination of performances and structural parameters of internal combustion engine: Determining the constraint relationships between parameters is the key element of top-down design of internal combustion engine. Consulting, collecting and forming internal combustion engine design knowledge base is not only the initial work of platform development, but also a task that runs through the overall process.

2. Software interaction function: Software interaction is the basis of platform design. A good interactive interface can provide a convenient and efficient operating environment for designers, so as to accelerate design speed and reduce design mistakes.

3. Model parametric design: By means of parametric design idea, constructing prototype models which conform to the structural characteristics of internal combustion engine. Realizing the rapid prototyping of part model on the premise of ensuring the perfection of model benchmark features and reasonable size.

4. Platform data management: Design team will accumulate a large amount of process data in the process of model design. Database platform can effectively manage and maintain the integrity of product development data and the consistency of enterprise data.

4.2. Platform development framework

The development framework of top-down design platform of internal combustion engine is shown in Fig 3:

![Figure 3. Development framework of top-down design platform of internal combustion engine.](image)

The development framework mainly includes graph library, program library, and prototype model library and information database. When the program starts, the graph library provides users with an interactive interface in NX software and obtains prototype model address from information database. Prototype model library will provide the required prototype model. When designing parts, choosing to create a new model or obtain an old model. Both modes will obtain the prototype model from prototype model library, generate new parts by adding or modifying design parameters, and store their data in information database.

The development framework has the following advantages:
(1) High model extensibility: Model rapid prototyping is realized by prototype model library. More detailed features can be added in subsequent design process to meet more complex structural requirements.

(2) High software scalability: Taking NX future development technology as the underlying technology is convenient to extend the top-down design platform [9].

(3) Simple operation: The interactive interface provided by NX enables designers to conduct model design in the integrated environment of NX with unified and simple operation experience.

(4) Easy management of database: The design parameters of parts in NX are stored in external database, which is convenient for data invocation, addition and deletion. It also facilitates the efficient connection of data information with other information systems.

4.3. Platform development process

Based on the design of NX Open API, this paper proposes a top-down design platform development process of internal combustion engine. As is shown in Fig 4:

Figure 4. Development process of top-down design platform for internal combustion engine.

(1) Establishing user directory: ‘Application’ subdirectories store menu files *.men, toolbar files *.rtb, dynamic link files *.dll compiled by Visual Studio and interface compiled files *.dlx. NX will get the corresponding files through environment variables. ‘Code’ subdirectories store development files from Visual Stido project, such as *.sln, *.vcxproj and *.exp. Each subdirectories contains source files *.cpp and header files *.hpp generated by UI style editor, which is used to associate NX with Visual Studio.

(2) Developing user environment: The user environment is the basis for NX to read all kinds of files in relevant folders.

(3) Establishing custom dialog box: Conducting interactive interface design in block UI style editor.

(4) Compiling dynamic link files: Importing *.hpp and *.cpp in Visual Studio. Adding NX library function in *.hpp and adding function code in *.cpp. Then storing the compiled *.dll in ‘Application’ subdirectories.

(5) Creating menus: *.men provides NX button whose function is provided by *.dll.

(6) Program development: Visual Studio software is used to compile the program and generate *.dll files. NX obtains the function expansion by *.dll [10].

5. Platform interaction application case

Take the crankshaft as an example. Tabbed interactive interface is adopted in the platform to arrange main property, basic parameter and advanced parameter one by one as a ‘Step’ of each ‘TAB’ page, and the product number ‘Step’ is added to record the product number. The ‘crankshaft design TAB’ is shown in Fig 5:
In the crankshaft design process, designers can selectively establish structures like the number of cylinders, ignition sequence, characteristics of oil hole, balance weight connecting hole and flywheel connection hole structure. Main dimension parameters like main journal diameter, length of main journal, crank pin diameter, crank arm length and thickness of crank arm are included in structures like main journal & crank pin, crank arm, input and output structure of crankshaft. The parameterization process of crankshaft is shown in Fig 6:

**Figure 5.** ‘crankshaft design TAB’.

In the crankshaft design process, designers can selectively establish structures like the number of cylinders, ignition sequence, characteristics of oil hole, balance weight connecting hole and flywheel connection hole structure. Main dimension parameters like main journal diameter, length of main journal, crank pin diameter, crank arm length and thickness of crank arm are included in structures like main journal & crank pin, crank arm, input and output structure of crankshaft. The parameterization process of crankshaft is shown in Fig 6:

**Figure 6.** Parameterization process of crankshaft.

6. Conclusion
This paper analyses the key techniques of top-down design, as well as proposes prototype model design criterion and parametric model construction scheme based on top-down design. According to
the interaction between parameters, we develop a top-down design flow of internal combustion engine. With NX future development technology for the underlying technology, we formulate the top-down design platform development technology of internal combustion engine, put forward the platform development functions, development framework, and development process. Finally completing the top-down design preliminary development of internal combustion engine based on NX future development platform and realizing the internal combustion engine parts of rapid prototyping, which simplifies design process, as well as improves the design efficiency of complex parts of internal combustion engine.

References
[1] Liu Ying, The Practical Problems Existing in the Application of the Top-down Design Method for Mechanical Modeling [J]. Mechanical Engineer, 2012 (04): 33-34
[2] N. Aleixos, P. Company, M. Contero. Integrated modeling with top-down approach in subsidiary industries. Computers in Industry (2004), pp.97-116
[3] J. Hwang, D. Mun, S. Han. Representation and propagation of engineering change information in collaborative product development using a neutral reference model. Concurrent Engineering, 17 (2009), p.147.
[4] Zhang Jichun, Xv Bin, Yang Jianguo, Wang Wei. Study on internal combustion engine numeric prototype system [J]. Journal of Harbin Institute of Technology, 2007 (07): 1159-1162.
[5] Li Chao, Shen Jinghu, Wang Binjiang. Top-down design of linkage mechanism based on the Pro/E [J]. Modern Manufacturing Engineering, 2010 (11): 40-43.
[6] Y. Zeng, A. Pardasani, J. Dickinson, Z. Li, H. Antunes, V. Gupta, et al. Mathematical foundation for modeling conceptual design sketches. Journal of Computing and Information Science in Engineering, 4 (2004), p.150.
[7] Yu Yangxiong, Guo Gang, Xv Rongyan. Study on product rapid configuration method based on serial spectrum [J]. Machine Manufacturing, 2007 (04): 12-14.
[8] Yang Yongzhi, Tang Shengli. Application research of virtual prototype technology in internal combustion engine design [J]. CAD/CAM and manufacturing informatization, 2005 (07): 43-45.
[9] Xv Kai, Zhang Yuzhong. The Re-develop Technology of CAD [J]. Packaging and Food Machinery, 2004 (02): 31-34.
[10] Jing Dou. Application of relational database technology in computer network design [J]. Science & Technology Industry Parks, 2018 (08): 235.