Research on part innovation design based on feature elements

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Abstract. Based on the mechanical manufacturing process and machining characteristics, the concept of feature elements is proposed and the feature elements are defined and classified in this paper. According to the mapping relationship between the feature elements of the mechanical parts and the geometric structure, the feature elements drawing function is developed, and the graphic library of the feature elements is constructed. By studying the combination of parts feature elements, a combination relationship model of part feature elements is established. Finally, in the condition of matching design requirements and manufacturing resources, a part innovation design platform is developed based on the combination relation model of feature elements to combine feature elements drawing function, and the efficient and innovative design of mechanical parts has been realized.

1. Introduction
Mechanical parts are the basis of mechanical design, manufacture, and assembly [1], and their design cycles directly affect the production cycle of mechanical products. With the rapid development of science and technology, the design methods and scientific theories of mechanical parts have been developed and perfected continuously. Many researchers have used advanced technology to design the design scheme of mechanical parts. However, the modern mechanical parts design method still continues the traditional mechanical design ideas, and does not fundamentally innovate the design method of mechanical part. According to the motion plan and overall design requirements, the traditional mechanical parts design method master design the structural shape, selected materials, and the determination accuracy of the parts, and then perform the failure analysis and work performance calculation, and finally draw the parts drawings. With the continuous improvement of the design requirements of mechanical parts and the diversified development of industrial market demand, the traditional design method of mechanical parts gradually exposes its cumbersome design process, long cycle, low efficiency, difficulty in rework and high cost.

Therefore, some researchers have begun to study the parts design methods, parts features, parts serialization, three-dimensional parts drawing and other issues, and have also obtained corresponding research results. In 2009, Wang Li of China Electronics Technology Group proposed a serial design method based on SolidWorks, which simplifies the serial design process of parts [2]. In 2011, Jiang Bin of Harbin Engineering University conducted a study on feature-based part design methods [3]. In 2012, Lin Yangqiao of Sichuan University established a rapid design platform based on the secondary development of SolidWorks, reducing the repetitive work of designers [4]. In 2013, Lu Yongchun of...
Shandong University researched and developed a feature-based part intelligent design system based on feature-based CAD technology and artificial intelligence technology [5]. In the same year, Li Yuefeng of Harbin Institute of Technology studied the design process of disposable mechanical parts based on the design criteria of conventional mechanical parts [6]. In 2014, You Hongliang of AVIC Shenfei Civil Aircraft Co., Ltd. carried out a study on the part design of end mill machining [7]. In 2016, Li Lu of Guangxi University designed a non-standard parts design knowledge service platform to realize the knowledge sharing and management of the non-standard parts design process [8]. Although some progress has been made in the research of parts design, it has not formed the universal and efficient part design standard and part design software. Therefore, the innovation of parts design method and theory still has great research value and development space.

2. Related concept of feature elements

2.1. The definition and classification of feature elements

The essence of the product from the design to the finished product is that producers use single or combined processing technology to process raw materials until they meet design requirements after matching the design requirements with the manufacturing capacity of the manufacturing resources [3]. Visibly, as the basis of the entire mechanical product, the structural appearance of the part is the combination of geometric features which is formed by a series of processing technology in accordance with a certain process sequence. Based on this, we propose the concept of feature elements, and define the three-dimensional geometric structures with process information that are formed by machining the raw materials or semi-finished products in the manufacturing process as feature elements.

The feature elements are essentially different from the traditional processing features. Feature elements refer to the three-dimensional geometric structure with process information that is formed by machining processing when the design requirements are matched with manufacturing resources, which corresponds with the 3D model of the geometric structure formed by the machining. Machining features are processes that use certain machining behaviors or multiple combinations of machining behaviors to process part to form certain geometric shapes and process attributes under the constraints of processing technology and manufacturing resources, which corresponds with the machining process of parts.

Machining process is the basis for the formation of feature elements. Different machining processes can form feature elements of different shapes. Therefore, according to different machining processes, the feature elements are roughly classified into turning type feature elements, milling type feature elements, drilling/reaming type feature elements, boring type feature elements, grinding type feature elements, and planning type feature elements [9], which is shown in figure 1.

The turning type feature elements include outer circle, chamfer, fillet, groove, thread, and end face. The outer circle is divided into straight circle, cone and special-shaped circle. Slot is divided into outer slot, inner slot, and end slot.

Milling type feature elements include cavity, groove, keyway, face, spiral surface, step surface, forming surface, etc. The cavity is divided into open cavity, closed cavity. The slot is divided into T-slot, V-slot, dovetail slot, straight slot, and spiral slot. Faces are divided into planes and surfaces.

Drilling/reaming type feature elements are processing holes and threads, which mainly include drilling hole, reaming hole, and tapping. Holes and blind holes are the main types of holes.

The boring type feature elements is mainly used for boring holes, such as boring blind holes, boring taper holes, etc. It can also be used for boring face, boring thread, etc.

Grinding type feature elements are mainly used for semi-finishing and finishing, and are classified into cylindrical grinding, internal grinding, surface grinding, thread grinding, gear grinding, and spline grinding.
Planning type feature elements are mainly used to process planes, all kinds of grooves and forming surfaces, can be divided into planning plane, planning surface, planning steps, planning right angle groove, planning T-slot, planning rack, etc.

2.2. The feature element drawing function
Machining process is the basis of feature elements. Conversely, feature elements are the result of machining and manufacturing. It can be seen that feature elements and processing technology have a certain mapping relationship, and this mapping relationship is embodied as a feature element mapping function. Therefore, the feature element drawing function refers to the specific implementation process of the three-dimensional model corresponding to the geometry formed by machining.

The feature element drawing function has uniqueness and drawing function. The uniqueness means that the mapping function between the feature elements and the feature element drawing function has a one-to-one correspondence, and each feature element corresponds to only one feature element drawing function. The drawing function refers to that the feature element drawing function can realize the three-dimensional model expression of the corresponding feature element. The feature drawing function proposed in the paper is based on the Open GL [10] drawing function. Taking the outer circle of the car as an example, the corresponding three-dimensional model of the outer circle of the car is a segment of a cylinder. Therefore, the feature drawing function of the outer circle of the car is as follows:

```c
bool T_CyDr(T_Cy t_cy)
{
    GLUquadricObj *quadricObj = gluNewQuadric();
    gluQuadricDrawStyle(quadricObj, GLU_FILL);
    gluCylinder(quadricObj, t_cy.Diameter/2.0, t_cy.Diameter/2.0, t_cy.Length, 60, 60);
    gluDisk(quadricObj, 0.0, t_cy.Diameter/2.0, 60, 60);
    glTranslatef(0.0f, 0.0f, t_cy.Length);
    gluDisk(quadricObj, 0.0, t_cy.Diameter/2.0, 60, 60);
    glTranslatef(0.0f,0.0f,-t_cy.Length);
    gluDeleteQuadric(quadricObj);
    return true;
}
```
2.3. The feature elements graphic library

The feature elements graphic library refers to a collection of three-dimensional models corresponding to all feature elements, namely, a collection of all feature elements drawing functions, which is shown in figure 2. In the process of designing mechanical parts, according to the specific design requirements, the feature element drawing function module is directly invoked from the feature element graphic library to design, which can greatly improve the design efficiency of the parts.

![The feature elements graphic library](image)

**Figure 2.** The feature elements graphic library.

3. The combination relationship of feature elements

All the parts are combined by certain geometric structures formed by machining process according to certain technological sequence. Therefore, all parts can be decomposed into different feature elements. Conversely, different feature elements can also form the final shape of parts through different combinations.

$F^1$, $F^2$ and $F^n$ represent two feature elements and multiple feature elements respectively. $R$ represents their combination way, $R \in (A,Q,C,Z)$, Among them, $A$ represents Adjacent relation, $Q$ means embedded relation, $C$ represents subordinate relation, and $Z$ represents array relationship. The combination types of the feature elements are as follows:

1. **Adjacent relationship.** The two feature elements $F^1$ and $F^2$ that are expressed independently are adjacent to each other and can be expressed as $F^i \leftarrow A \rightarrow F^j$. The adjacent relationship can be established either by using a coordinate system alone or by locating the feature surface. The life cycle of the feature elements of the adjacent relationship is independent of each other. Namely, one feature element is deleted, another feature element still exists.

2. **Embedding relationship.** The embedding relationship expresses a feature element $F^1$ embedded in another feature element $F^2$, which can be expressed as $F^i \leftarrow Q \rightarrow F^j$. The embedding relationship has priority, the embedded feature element is the next-level feature element, the embed feature element is the former-level feature element, and the former-level feature element is the basis for the establishment of the later-level feature element. Therefore, it must be preceded by former-level feature element.

3. **Subordination relationship.** The subordination relationship expresses the relationship between a secondary feature element $F^i$ and a main feature element $F^2$, which can be expressed as $F^i \leftarrow C \rightarrow F^2$. In subordination relationship, the main feature elements include the secondary feature elements. When the main feature elements are deleted for some reason, the secondary feature elements are also deleted. The secondary feature elements cannot exist without the main characteristic elements.

4. **Array relationship.** The array relationship expresses the relationship of multiple identical feature elements to one feature element, which can be expressed as $F^i \leftarrow Z \rightarrow F^2$. A plurality of feature elements is evenly arranged around a certain feature element, and the array feature elements are dependent on the center feature element.
4. The part design based on feature elements

As a three-dimensional model unit with geometric structure, feature elements not only include design information that meets functional requirements, but also cover the process information required for processing and manufacturing. It can be seen that design information and manufacturing information must be implemented collaboration in the process of constructing feature elements. The feature element information model is a combination of information requirements in different application areas. In order to be able to reasonably express the design intent and manufacturing information of parts, the geometric information, process information, transaction information, combination relationship information and supplementary information of parts are digitized and symbolized, and a parts information system is established, which is shown in figure 3.

![Figure 3. Division of part system.](image)

Geometry information includes basic dimensions, deviations, shape types, shape tolerance values. The basic size information has different size information according to different feature elements. Manufacturing information includes surface roughness, materials, and heat treatment information. The surface roughness, material, and heat treatment information may be determined by the designer himself or determined in consultation with the manufacturer. Positioning information is an interface that provides positioning coordinates and positioning vectors for subsequent parts to be combined into one product. Ancillary information is used to add additional information that is not displayed directly in the geometry or callouts.

Parts are composed of a combination of multiple feature elements in a certain process sequence. The mathematical model can be expressed as:

$$\sum_{i=1}^{n} M_i = M_1 + M_2 + M_3 + M_4 + \cdots + M_n$$

$$\sum_{i=1}^{n} F_i = F_1 + F_2 + F_3 + F_4 + \cdots + F_n$$

$$\sum_{i=1}^{n} Z_i = Z_1 + Z_2 + Z_3 + Z_4 + \cdots + Z_n$$

$$\sum_{i=1}^{n} S_{FZ} = \sum_{i=1}^{n} S_F + \sum_{i=1}^{n} S_Z$$

(1)

Here, $P$ denotes a part, $M$ denotes a machining process, $F$ denotes a feature element, $Z$ denotes a combination of feature elements, and $\sum S_{FZ}$ denotes a final form of a part in which the different feature elements are formed in a certain combination relationship.

The basis of parts modeling is feature elements. The key to the establishment of feature elements is the coordination of design information and manufacturing information. The part modeling process is essentially the process of constructing feature elements, invoking the feature drawing functions, and combining feature elements. Therefore, the flow chart of innovative design of parts is shown in figure 4.

From figure 4, we know that the part modeling process is as follows: First, analyze the parts for design intent, and try to coordinate design information and manufacturing information, and achieve synergy. After successful collaboration, the feature element drawing function is developed and a feature element graphic library is constructed. Finally, the feature elements are called from the graphics library and feature elements are combined. After the combination of multiple feature elements, the part modeling process is realized.
5. The part innovation design example based on feature elements

Based on the VC++2010 development environment and OpenGL graphics software, this article has developed a part-innovation design platform ManuPower. Now take the shaft part in figure 5 as an example to illustrate the parts design.

According to the analysis of the shaft part in figure 5, it can be seen that the part includes three kinds of feature elements, such as turning outer circle, turning chamfer, and turning groove. And the combination relationship of each feature element is the adjacent relationship. Therefore, the feature element combination relationship model of the shaft is shown in figure 6.

**Figure 4.** The flow chart of innovative design of part.

**Figure 5.** Shaft part diagram.

**Figure 6.** The feature element combination relationship model of the shaft.
Visibly, the main innovative design process of the shaft part is: First, coordinate the design requirements and manufacturing resources. After successful coordination, call the chamfer and the outer circle of the car from the feature element graphic library and combine them together according to the adjacent relationship. Afterwards, according to the combined relationship model of the shaft part, feature elements such as the groove of the car, the outer circle of the car, and the chamfer of the car are sequentially called to realize the innovative and efficient design of the shaft parts. The specific design process is as follows:

1. Click the design-manufacturing coordination menu to coordinate the design requirements and manufacturing resources until the collaboration is successful;
2. Click the New submenu under the File menu to create a new project file, and fill in the project information, which is shown in figure 7.
3. Click the Create Feature Elements submenu under the Feature Elements Design menu to pop up the Feature Design dialog box, which is shown in figure 8. Then click the turning chamfer feature element, the turning Chamfer dialog box will pop up, then set the parameters as shown in figure 9, and click OK.
4. Click on the Feature Elements Design menu. In the dialog box that pops up, click on the feature elements of the turning outer circle. In the pop-up turning outer circle dialog box, set the size parameter and the combination relationship parameter, and then click OK to realize the combination of turning chamfer and outer circle feature elements, which is shown in figure 10.
5. Afterwards, according to the adjacency relationship, the feature elements such as the turning outer circle, the turning groove and the turning chamfer are sequentially designed to realize the innovative design of the shaft part, which is shown in figure 11.

![Figure 7. New project.](image-url)
Figure 8. The design of feature elements.

Figure 9. The parameter setting of turning chamfer.
6. Conclusions
Based on the characteristics of the machining process, the paper defines and classifies the feature elements of the mechanical parts. According to the mapping relationship between the feature elements and the geometric structure, the drawing function of the feature elements is developed and the graphic library of the characteristic elements is constructed, which realizes the effective management and effective invocation of the drawing function of the feature elements of the mechanical parts. By studying the combination mode of various processing techniques of mechanical parts, the combinations of the four mechanical parts feature elements such as adjacent relationship, embedding relationship, subordination relationship, and array relations are defined, and the combination relation model of part feature elements is established. Therefore, the virtual construction of the three-dimensional view of the mechanical parts is realized through the modular call of the feature drawing function and the combination model of the feature elements. Finally, the efficiency and functionality of the part innovation design platform are verified by taking the shaft as an example.
References

[1] Qiu J 2013 Design method and strategy of mechanical parts Electronic Production 02: 154
[2] Wang L 2009 Study on serialized part design based on SolidWorks Electrical and Mechanical Product Development and Innovation 22(02):96-97
[3] Jiang B 2011 Research on part design method based on processing features Harbin Engineering University
[4] Lin Y 2012 Parts rapid design platform based on SolidWorks Silicon Valley 5(13): 53-57
[5] Lv Y 2013 Research on intelligent design of parts based on feature Shandong University
[6] Li Y 2013 Research on Design and Application of Typical Disposable Mechanical Parts Harbin Institute of Technology
[7] You H 2014 Three-dimensional design method of machined parts Equipment Manufacturing Technology 03:276-277
[8] Li L, Mao H, Wu Z and Mao H 2016 Knowledge Service Method and System Implementation of Mechanical Parts Design Computer Applications and Software 33(06): 68-72
[9] Fan Q, Cao Y and Wang B 2012 Feature Classification and Feature Information Model for Shaft Parts Journal of Xi'an Polytechnic University 26(5): 643-647
[10] Schrener 2008 OpenGL Programming Guide Beijing: Mechanical Industry Press 20-149