Research on Nuclear Channel Head CAD System

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Abstract
To enable the designers to design and modify model of nuclear channel head quickly and easily, we constructed the CAD system of the nuclear channel head. At first, we analyzed the geometric characteristics of nuclear channel, established feature control parameter set and the parametric model of nuclear channel head. Secondly, other parameters related to the solid modeling are described through the parameter control set. Thus, the feature solid modeling of head shell surface, nozzle and boss are programmed. Finally, it is proved that the method and development strategy of parametric CAD system is effective by using automatic design example of nuclear channel head which is developed through CAD system of nuclear channel head.

Keywords: Nuclear Channel Head, CAD system, Secondary development

1. Introduction
As one of the key components of nuclear channel equipment, the large nuclear channel head is pretty complex in its shape and requires high on its design and machining precision. Currently, the domestic design and manufacture of the key technologies in the research is relatively week and there is no any successful experience to learn [1].

As head of nuclear channel are series of products, if the work head in the design of various types of common modeling techniques, repetitive work and more modeling and low efficiency [2]. Series production of various types of head size and structure of nuclear channel, through not identical, but similar in its structure and process, you can use the parametric design of nuclear channel technology to the geometric head shape, head of nuclear channel is known about the conditions and as changes in head size using the corresponding variable instead of the basic parameters, and then calculated by the CAD software. Design of the Head and all the data required for the computer to automatically design a series of all types of nuclear channel head. Parametric modeling can be reduced by the nuclear channel head repeat and repeat the design drawings, designers reduce the labor intensity. CAD systems of the nuclear channel head design is based on UG software application environment for the system to UG / OPEN API, UG / OPEN MENUSCRIPT and UG / OPEN UISTYLER and VC for the high-level language development tools for the development and design.

2. Research Method
the geometry construction of the Nuclear Channel Head model and the parametric solid modeling and control parameters set will be introduced in this section.

2.1. Geometry Construction of the Nuclear Channel Head Model
Parametric design of the nuclear channel head is to establish the set of geometric constraint of graphs by means of predefined method. Firstly, to specify a group of parameters and associate the parameter with the set of geometric constraint. Then, to integrate all the correlations into the application program. Finally, to modify the parameter dimension by employing the interaction between people and computer. Meanwhile, the program will sequentially execute the expression to achieve implementation. The series of nuclear head...
have similarities with the universal, standardized products: the mathematical models and product structure are relatively fixed. The only differences lie on sizes of the structure due to the different product specifications. That is to say, the first thing to be done is to establish the parametric model for implementing the parametric CAD system of nuclear head.

The construction of parametric model of the nuclear can be divided into three steps: (a) analyzing the feature construction and its construction order of the nuclear head; (b) extracting the various features of the primary and secondary parameters of a set of controlled parameter group; (c) refining process of solid modeling of various features and describing parameters related to the solid modeling by using parameter controlled set according to its geometric properties to achieve parameter drive of final model.

2.1.1. Characteristics of the Nuclear Channel Head

Nuclear channel head is an important and indispensable component in the nuclear channel industry. It is not only the cover of the pressure vessel, but also is one of the main parts which are bearing pressure. The quality of nuclear channel head directly affects reliability and security of the pressure vessel. The nuclear channel head can be divided into three parts: the spherical shell, tube nozzles and boss, as shown in Figure 1. The spherical shell is composed of spherical surface, cone and cylindrical straight edge. The function of straight edge is to avoid of mutations of curvature radius on the weld connections and to improve the weld force conditions. Cylindrical straight edge is mainly affected by the size of the cylinder size. The cone is the transition section, which is to reduce the peak stress of the connection of sphere and cylinder. Nozzle is mainly connected with the pipes outside. And their sizes and shapes are affected by the connection pipes.

![Figure 1. The features of the Nuclear Channel Head](image)

Besides of the main features, there are some additional features: the number of boss and hole, the position of boss and hole, etc. Shown in Figure 2 is the feature relationship of the nuclear channel head.

2.1.2. Feature Set of Control Parameters and Geometric Constraints

Based on feature classification of the parts, we analyzed the feature parameter so that we can extract feature parameter and determine the design variables more easily [3-5]. As shown in Table 1, based on clearly expressing feature composition, classification and hierarchical relationships, the main parameters and secondary parameters can be determined. The main parameter of every feature determines main structure of part shape for enhancing

<table>
<thead>
<tr>
<th>Feature Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter of the Nozzle (Rt)</td>
<td></td>
</tr>
<tr>
<td>Outer Corner Radius</td>
<td></td>
</tr>
<tr>
<td>Included Angle (α)</td>
<td></td>
</tr>
<tr>
<td>Inner Corner Radius</td>
<td></td>
</tr>
<tr>
<td>Inner Diameter of the Nozzle (rt)</td>
<td></td>
</tr>
<tr>
<td>Neck Height (Hc)</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Inner Diameter (rc)</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Outer Diameter (Rc)</td>
<td></td>
</tr>
<tr>
<td>Cone Maximum Diameter (Rm)</td>
<td></td>
</tr>
<tr>
<td>Spherical Outer Diameter (Rb)</td>
<td></td>
</tr>
<tr>
<td>Spherical Inner Diameter (rb)</td>
<td></td>
</tr>
<tr>
<td>Radial Height of the Nozzle (Rt)</td>
<td></td>
</tr>
<tr>
<td>Outer Height of the Nozzle</td>
<td></td>
</tr>
<tr>
<td>Included Angle of the Nozzle (αt)</td>
<td></td>
</tr>
<tr>
<td>Outer Diameter of the Nozzle (Rt)</td>
<td></td>
</tr>
<tr>
<td>Outer Height of the Nozzle</td>
<td></td>
</tr>
<tr>
<td>Included Angle (α)</td>
<td></td>
</tr>
<tr>
<td>Inner Corner Radius</td>
<td></td>
</tr>
<tr>
<td>Inner Diameter of the Nozzle (rt)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Feature Set of Control Parameters

[Image: Figure 2. Feature relationship of the nuclear channel head]
flexibility and practicality of the system [6]. All the main parameters and secondary parameters are the input parameters and their values are determined by users or designers. They are both independent of each other, and also there is a corresponding constraint relations and uniquely describe geometry contracture of the nuclear channel head.

![Figure 2. Power head features hierarchy picture](image)

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Control Parameter Name</th>
<th>Constraints of the Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical Shell Features</td>
<td>Cylindrical Outer Diameter ($R_c$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spherical Outer Diameter ($R_b$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neck Height ($H_c$)</td>
<td>$H_c &gt;$ Minimum Permissive $N_c$</td>
</tr>
<tr>
<td></td>
<td>Spherical Inner Diameter ($r_b$)</td>
<td>$r_b &lt; R_b$ - Minimum Permissive Shell Thickness</td>
</tr>
<tr>
<td></td>
<td>Cylindrical Inner Diameter ($r_c$)</td>
<td>$r_c &lt; R_b$ - Minimum Permissive Shell Thickness</td>
</tr>
<tr>
<td></td>
<td>Maximum Cone Diameter ($R_m$)</td>
<td>$R_c &lt; R_m &lt; R_b$</td>
</tr>
<tr>
<td></td>
<td>Cone Height ($H_n$)</td>
<td>$H_n &gt;= 0$</td>
</tr>
<tr>
<td>Nozzle Features</td>
<td>Included Angle Between the Center Axis of Nozzle and X axis ($\beta$)</td>
<td>$\beta &lt; 90^\circ$</td>
</tr>
<tr>
<td></td>
<td>Included Angle Between the Center Axis of Nozzle and Z axis ($\alpha$)</td>
<td>$\alpha &lt; 90^\circ$</td>
</tr>
<tr>
<td></td>
<td>Radial Height of the Nozzle ($H_t$)</td>
<td>$H_t &gt; R_b$</td>
</tr>
<tr>
<td></td>
<td>Outer Diameter of the Nozzle ($R_t$)</td>
<td>$R_t &lt; 0.5 * R_b$</td>
</tr>
<tr>
<td></td>
<td>Nozzle Number ($N_t$)</td>
<td>$N_t &gt;= 1$</td>
</tr>
<tr>
<td></td>
<td>Nozzle Inner Diameter ($r_I$)</td>
<td>$R_t &lt; R_I$ - Minimum Permissive Shell Thickness</td>
</tr>
<tr>
<td></td>
<td>Interval Angle of Nozzles ($\psi$)</td>
<td>$\psi &lt; 360^\circ / \ N_t$</td>
</tr>
<tr>
<td></td>
<td>Bottom Outer Fillet Radius of Nozzle ($R_f$)</td>
<td>$0 &lt;= R_f &lt; H_t - R_b$</td>
</tr>
<tr>
<td></td>
<td>Bottom Inner Fillet Radius of Nozzle ($r_I$)</td>
<td>$r_I &gt;= 0$</td>
</tr>
<tr>
<td>Boss Features</td>
<td>Boss Width ($W_s$)</td>
<td>$W_s &gt;= 0$</td>
</tr>
<tr>
<td></td>
<td>Boss Height ($H_s$)</td>
<td>$H_s &gt;= 0$</td>
</tr>
<tr>
<td></td>
<td>Boss Number ($N_s$)</td>
<td>$N_s &gt;= 0$</td>
</tr>
</tbody>
</table>

Refer to the Parameter Name as shown in Table 1, after the feature parameter group has been determined, the constraints of corresponding parameters can be set according to the relationship of the structure, size, and some special requirements between each other. For example, if the users want to ensure the intensity of the nuclear channel head, they need to set the minimum permissible wall thickness. According to the size chain relationship of the outer surface of the nuclear channel head, the inner surface and the thickness of the nuclear channel
head, users can establish the constraint that the outer diameter of the spherical surface $R_b$ constrains the inner diameter $r_b$, and the outer diameter of the cylinder surface $R_c$ constrains the cylinder surface inner diameter $r_c$. Similarly, to ensure establishing reasonable parameter value and fatherly succeed in building the three-dimensional model of the head, we should set constraints as below: neck ($H_c$), the maximum cone radius ($R_m$), cone height ($H_n$), tube ($\psi$), radial nozzle height ($H_t$), the nozzle internal / external diameter ($r_t / R_t$), the number of nozzles ($N_t$), the nozzle interval angle ($\beta$) mouth angle between the axis and Z axis (mouth root of inner / outer radius ($R_f / r_f$), boss width / height ($W_s / H_s$), as shown on Table 1.

2.1.3. Workflow of the Nuclear Channel Head

Through the analysis and synthesis of the design process of the nuclear head, we present the CAD workflow of nuclear head based on the core of parametric modeling, shown as Figure 3. Refers to a group controlled parameter sets, the parametric modeling can express all the features of nuclear channel head completely and exclusively. To ensure the validity of the data input by users, every parameter to be input will be examined its suitability through the parametric model.

![Figure 3. Work flow for power head design](image-url)

2.2. Parametric Solid Modeling and Control Parameters Set

The purpose of solid modeling is to completely and unambiguously express objects. The accuracy of three-dimensional solid model of large nuclear channel head directly affects the reasonability of CAM NC code. The three main features of nuclear channel head has been described in the previous section. We can obtain the complete and accurate product model through the Boolean operation between the features, so-called feature modeling [7,8]. In terms of geometric operation, feature modeling is still based on solid modeling. The basic modeling elements—features, are similar to the system voxels of CSG (Constructive Solid Geometry). Part feature modeling is the process that the system tools construct part model through applying system voxels and its features. Usually, the biggest part or the main part is considered the basic feature and is first completed modeling. As the additional features, other parts’ solid models can be obtained through the Boolean operation, such as adding, moving, and intersection based on the basic features.
2.2.1. Surface of the Shell Features of Nuclear Channel Header Sealed the Solid Modeling

Shown in Figure 4, the basic characteristic feature of the nuclear spherical shell is a header surface of revolution. In order to simplify the process of its three-dimensional solid modeling can be used in one step rotation of the plane contour map built. Thus, modeling is the key to how to derive the exact and complete graphic outlines.

Shown in Figure 5, ABCDEFG header sealing surface of the shell is characteristic of nuclear channel plane contour sketches. Table 1 shows the meaning of the primary and secondary parameters. In order to accurately draw the outline sketch plane, you must derive the coordinates of all vertices. Figure 4 sketches the XOZ flat plane contour, Point O to the origin of coordinates. Assuming the coordinates of each point with an array that is where the key parameters need to include the indirect calculation of the Z coordinate of the center M, and Z coordinate of Point G. Geometry can be derived by the Equation (1) and Equation (2).

\[
M[2] = Hc + Hn - \sqrt{Rb^2 - Rm^2}
\]  

\[
G[2] = \sqrt{Rb^2 - rc^2}
\]

![Figure 4: Power head spherical shell feature of the Nuclear Channel Head](image)

![Figure 5: The planar contour sketch of the spherical shell feature of the Nuclear Channel Head](image)

2.2.2. Solid Modeling of the Nozzle

The axis line of the nozzle features and X axis form angle \(\beta\). The axis line and X axis form angle \(\alpha\). In order to facilitate the calculation, at first, we move the original O to M, which is the center of the sphere shell surface. Then we apply Boolean subtraction of the features of holes to form inner wall of nozzle. The feature solid modeling of nozzle can be got through creating outside cylinder by extruding circle. The reasonable height of outside cylinder can be set \(Ht-rb\). The draft circle contour of outside cylinder is perpendicular to the screen and on the plane which includes line AB lays. Its center is Point F, as shown in Figure 6. Figure 6 also shows the 3D solid model of the nozzle and identifies the characteristics of the outer contour of the nozzle frame of ABCD for easily to be understood.

![Figure 6: The solid model of the head nozzle features.](image)
To ensure the reasonable cylinder stretch size, the stretch height is \( H_{t-rb} \). Finally, the coordinate of outer cylinder’s center \( F \) can be got, shown as Equation (1), Equation (2) and Equation (3).

\[
F[0] = H_t \cdot \sin \beta \cdot \cos \alpha \tag{3}
\]
\[
F[1] = H_t \cdot \sin \beta \cdot \sin \alpha \tag{4}
\]
\[
F[2] = H_t \cdot \cos \beta \tag{5}
\]

For multiple nozzle features, their solid modeling can be completed by using Circular Array. In addition, the internal rounding and external rounding of nozzle roots can be added as the additional features.

### 2.2.3. Solid Modeling of Boss Feature

The feature solid modeling of outer surface boss of the nuclear channel head is achieved by stretching sketch profile contour. As shown in Figure 6, the sketch place is in \( XOZ \) plane. Cylindrical surface of the nuclear channel head features a number of convex sets is the use of solid modeling sketch profile of the stretch to achieve. Figure 7 shows the sketch plane is in \( XOZ \) plane. The sketch contour \( ABCD \) is stretched to both sides to form the thickness of boss. To ensure outer surface to form a complete intersection curve while keeping a smooth inner surface spherical shell, line \( CD \) should be between the outer and inner surface. In the \( XOZ \) plane, line \( CD \) is tangent cutting by inner ball the ball. As shown in Figure 7, Point \( N \) is the center of the intersection circles ob inner sphere and inner cylinder. \( \Theta \) is the angel between DN and DM. Coordinate origin point is moved from Point \( M \), center of sphere, back to Point \( O \), the center of install bottom place. It can be derived by geometry calculation.

\[
cos \theta = \frac{rc}{rb}
\tag{6}
\]
\[
CE = (Hc + Hn - ON + Hs) \cdot \tan \theta
\tag{7}
\]
\[
ON = rb \cdot \sin \theta + M[2]
\tag{8}
\]

Therefore, the X coordinate of Point \( C, C[0] \), is got from the Equations (1),(6),(7) and (8).

\[
C[0] = (Hs - rb \cdot \sin(\arccos(\frac{rc}{rb})) + \sqrt{Rb^2 - Rm^2}) \cdot \tan(\arccos(\frac{rc}{rb}))
\tag{9}
\]
3. Results and Analysis
In this section, the developed UG/OPEN API based software modules of the Nuclear Channel Head CAD system, programming examples and the running case are illustrated.

3.1. Software Modules of the Nuclear Channel Head CAD System
Based on the User Interface of the Nuclear Channel Head CAD system, four major tasks can be completed subsequently, the initialization file I/O (Input/Output), features solid modeling, design results screen printing as well as the storage of the design results, as shown in Figure 8.

3.2. Programming Examples of the Typical Features Construction
Considering data transmission and sharing, some global variables are defined in this system, which are shown as below:

```c++
// sketch plane of the spherical shell
tag_t tag_Sketch_Shell;
// outer cylindrical surface of the nozzle
tag_t tag_Tube_Outer_Cylinder;
// inner hole of the nozzle
tag_t tag_Tube_Inner_Cylinder;
// boss sketch plane
tag_t tag_Sketch_block;
// object list of the rotating angle of the spherical shell
uf_list_p_t list_of_obj_shell_revolved;
// rotating feature of the spherical shell
uf_list_p_t list_of_feat_shell;
// object list of the stretching feature of the boss on the spherical shell
uf_list_p_t list_of_obj_block_extruded;
// stretching feature of the boss on the spherical shell
uf_list_p_t list_of_feat_block;
double m_Rb;  // outer radius of the spherical shell
double m_rb; // inner radius of the spherical shell
```

Figure 8. Nuclear Channel Head CAD system software modules
double m_Rc;  // cylindrical outer radius of the spherical shell
double m_rc;  // cylindrical inner radius of the spherical shell
double m_Rm;  // maximum radius on the cone surface
double m_Hc;  // neck height
double m_Hn;  // cone height
......

For the Nozzle solid modeling of nuclear channel head, we only describe detailed the core part through Boolean addition and Boolean subtraction of outside the cylinder bore cylinder.

/***********************************************************************
 /* Description: Create the tube connector model of Power Head through cylinder add / subtract
 * Date:   02/10/2012
 ***********************************************************************/

void Create_TubeConnector()
{
    // outer diameter of the nozzle
double diam = 2.0 * m_Rt;
    // Cylinder axis center of nozzle on the upper surface
double Center[3];
    // stretching direction of the nozzle outer cylinder
double cylinder_direction[3];
    // stretching height of the nozzle outer cylinder
double cylinder_height = m_Ht-m_rb;

    // referring to the equations of (3) and (5)
    Center[0] = m_Ht * sin(m_Beta) * cos(m_Alpha);
    Center[1] = m_Ht * sin(m_Beta) * sin(m_Alpha);
    Center[2] = m_Ht * cos(m_Beta);

    cylinder_direction[0] = - sin(m_Beta) * cos(m_Alpha);
    cylinder_direction[1] = - sin(m_Beta) * sin(m_Alpha);
    cylinder_direction[2] = - m_Ht * cos(m_Beta);

    // create the outer cylinder of the nozzle
    UF_CALL (UF_MODL_create_cyl1(UF_POSITIVE, //cylinder_sign, add to the solid of power head shell
                                  Center, cylinder_height, diam, cylinder_direction, &Tube_Outer_Cylinder));

    ......;

    // inner diameter of the nozzle
diam = 2.0 * m_rt;
    // the nozzle hole (>extruding height of outer cylinder)
cylinder_height = m_Ht - 0.5*m_rb;
    // create the cylindrical hole of the nozzle
    // UF_NEGATIV means the cylinder_sign, the inner hole is subtracted from the solid of power head shell
    UF_CALL (UF_MODL_create_cyl1(UF_NEGATIV, //cylinder_sign, add to the solid of power head shell
                                  Center, cylinder_height, diam, cylinder_direction, &Tube_Outer_Cylinder));

    ......;
}
3.3. Running Case

Figure 9 shows that the users apply CAD system to design two typical series of products for the Nuclear Channel Head. Through changing the size and shape geometry parameters of the nuclear head, the user will be able to modify the size and shape of the head entity. By re-setting the geometry parameters of the outer diameter of the header surface, the tube nozzle number and other parameters, the system will be able to make the user's design thought come true.

![Figure 9. The comparison of the geometric modeling chart of the Nuclear Channel Head](image)

4. Conclusion

Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

To enable the designers to design and modify the shape of the nuclear channel head quickly and easily, this paper constructed a dedicated CAD system of nuclear channel head. Firstly, we analyzed the geometric characteristics of nuclear channel, established feature control parameter set and its geometric constraints, and the parametric model of nuclear channel head on the basis of the previous work. Secondly, parameters related to solid modeling process were expressed through control parameter set. Thus, solid modeling of characteristics of head shell
surface, nozzle, and boss can be completed. Finally, based on the core of parametric model, we complete nuclear channel head development of CAD system by applying UG/Open API functions.

Acknowledgments
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