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RESEARCH ON MODELING METHOD FOR COMPLEX-STRUCTURED MECHANICAL COMPONENTS BASED ON THREE-DIMENSIONAL DISCRETE ELEMENT METHOD

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Abstract. *Based on secondary development of three-dimensional Pro/ENGINEER, certain issues in Pro/ENGINEER solid model of boundaries of complex-structured mechanical components, including recognition and reading of curved surfaces contacting granular material, binding of motion attributes and material attributes as well as data storage are researched, and discrete element-based analytical models for regular curved surfaces such as plane, sphere, cylindrical surface, circular conical surface, spherical crown surface, circular truncated cone surface and spherical segment surface are established in this paper, based on which an analytical model based on three-dimensional discrete element method for combination inner-cell precision seed metering device is established through three-dimensional Pro/ENGINEER solid model, which lays a foundation for general modeling method for complex-structured mechanical components in the next step.*
Keywords: Mechanical components, Pro/ENGINEER, Modeling method, Precision seed metering device

1. **Introduction.** During analysis of interaction between granular material and mechanical components based on discrete element method, although mechanical components generally have relatively complex structures, what contact and interact directly with granular material are surfaces of some parts in mechanical components. Therefore, only information about these surfaces should be taken into consideration. However, such surfaces include regular curved surfaces which can be expressed with elementary analytic functions and irregular curved surfaces which cannot be expressed with the said functions. It is feasible and generally applicable to build discrete element method-based analytical model for mechanical components through reading regular and irregular curved surfaces contacting granular material (which should be read after being discretized into regular curved surfaces) [1] in Pro/ENGINEER solid models. At present, there are mainly four discrete element method-based modeling methods for boundaries described in literature.

The first method is function modeling method [2], namely building discrete element method-based analytical models for relatively simple boundaries through curved surface equations corresponding to them. The second method is grain arranging method applicable to modeling for simple boundaries, in which spherical grains (in certain sizes) are arranged based on shape of boundary. Therefore, contact detection algorithm for spherical grains can be used as contact detection algorithm for contact between grains and boundaries. However, three-dimensional simulation for such algorithm will consume excessive time. The third method is Finite Wall Method [3], which is generally used in modeling for boundaries of complex-structured mechanical components such as seed metering device. Kremmer and Favier [3] put forward a boundary modeling method called Finite Wall Method, in which any three-dimensional curved surface in space can be divided into several small triangular planes and such planes are called finite wall. The fourth modeling method based on CAD is generally used in modeling for boundaries of complex-structured mechanical components such as seed metering device. Based on the AutoCAD software, though the secondary development, the discrete Element analysis model was established by the CAD model of the boundary (CAD design drawing), which is the organic combination of discrete element analysis of the of performance and CAD design of mechanical parts contacted with the granular material [4].

In the corn seed molding practice the writer researched before, manual and automatic spherical filling are used to build 3D analysis models filled by drawing spheres manually according to the outline and size determined by the shape of the corn seed. The complete the modeling proceeds through spherical combination according to the scanned outline obtained by a 3D scanner [5,6].

With an increasing demand on modeling for complex boundaries in actual production, it is extremely urgent to establish an efficient, precise and adaptive discrete element method-based boundary modeling method. As for the modeling method based on Pro/ENGINEER described in this paper, modeling of mechanical components should firstly be realized through Pro/ENGINEER software, and then a discrete element method-based analytical model can be established through reading regular and irregular curved surfaces contacting grains in Pro/ENGINEER boundary models.

The rest of this paper is organized as follows. Section 2 states the method for extracting geometric information based on Pro/ENGINEER solid model. Section 3 proposes the 3D discrete element method based analytical boundaries model. And Section 4 describes the realization detail for complex-structured mechanical components. And this paper is concluded in Section 5.

2. **Method for Extracting Geometric Information Based on Pro/ENGINEER Solid Model.** From the perspective of geometric modeling, extraction of geometric information can be divided into recognition and extraction of three-dimensional curves, three-dimensional fundamental curved surfaces, three-dimensional combined curved surfaces, other complicated irregular curved surfaces, etc. Three-dimensional curves are the most fundamental primitives forming boundaries of mechanical components, which commonly include straight line, circular arc and elliptic arc and serve as the basis for extracting information about three-dimensional fundamental curved surfaces. Solid model of a mechanical component is mainly composed of fundamental curved surfaces. Combined curved surfaces are composed of fundamental regular curved surfaces. As for other irregular curved surfaces which cannot be expressed with elementary analytic functions, extraction of geometric information can be realized through using grid generation method for curved surfaces. With fundamental curved surfaces, combined curved surfaces and irregular curved surfaces, extraction of geometric information about more complex mechanical components can be realized, based on which subsequent modeling can be more effective.

2.1. **Extraction of geometric information about circular conical surface.** In Pro/ENGINEER database, type name of circular conical surface is PRO_SRF_CONE, which refers to a curved surface formed by a straight line rotating around the rotation axis, in which the straight line forms an included angle (α) with rotation axis and intersects the rotation axis. Topological structure diagram of circular conical surface is indicated in Figure 1. Corresponding data structure definition is as follows.

```
typedef struct ptc_cone
{
    ProVector e1, e2, e3;
    Pro3dPnt   origin;
    double     alpha;
} ProConedata;
```

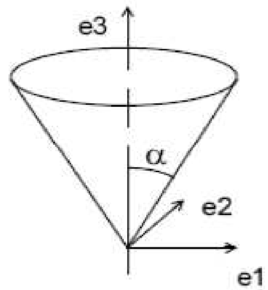


Figure 1. Topological structure of circular conical surface

2.2. **Extraction of geometric information about sphere (toroidal surface).** In Pro/ENGINEER, type name of toroidal surface is PRO_SRF_TORUS and its topological structure is indicated in Figure 2. When $R1 = 0$, toroidal surface is a sphere, so sphere is a special case of toroidal surface.

Firstly, matched comparison of types of curved surface and toroidal surface should be conducted. When matching is successful, geometric information about sphere/toroidal surface can be acquired through data structure of toroidal surface. In Pro/TOOLKIT, definition on data structure of sphere/toroidal surface is as follows.

```
typedef struct ptc_torus
{
    ProVector   e1, e2, e3;
    Pro3dPnt    origin;
    double      radius1;
    double      radius2;
} ProTorusdata;
```

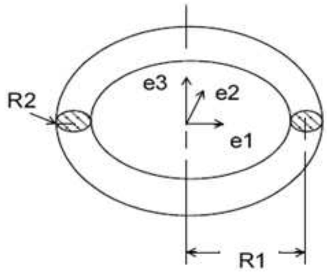


Figure 2. Topological structure of toroidal surface

2.3. **Extraction of geometric information about circular truncated cone surface.** A circular truncated cone is composed of a circular cone truncated by two circular planes, so its side belongs to object type of conical surface while its top surface and undersurface belong to circular planes. Topological structure of circular truncated cone is indicated in Figure 3.

Thus, modeling for circular truncated cone includes two steps. Firstly, geometric information about circular conical surface should be extracted. Then, radiuses of top surface and undersurface and coordinates of centers of circles should be extracted through UserCirclePlaneInfoDisp(), and height of circular truncated cone can be calculated, based on which modeling of circular truncated cone surface can be completed.

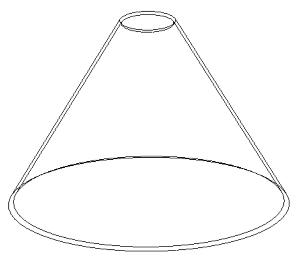


Figure 3. Topological structure of circular truncated cone

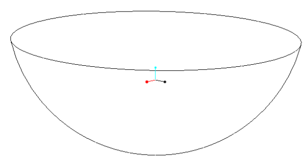


Figure 4. Topological structure of spherical crown

2.4. **Extraction of geometric information about spherical crown surface.** Similarly, modeling for spherical crown includes two steps. Firstly, geometric information about sphere should be extracted, namely coordinates of center of sphere and radius should be extracted. Then coordinates of center of undersurface and radius should be read by relevant function used for reading circles, and spherical sector can be read finally. Its topological structure is indicated in Figure 4.

As for extraction of geometric information about complex-structured mechanical components, they should firstly be broken down into fundamental curved surfaces and combined curved surfaces existing in the database through geometric primitive method. Secondly, geometric information about remaining boundaries should be extracted through grid generation method.

3. **Establishment of Analytical Model of Boundaries Based on Three-Dimensional Discrete Element Method.** In addition to extraction of geometric information about boundaries, motion attributes of boundaries should be set. In discrete element method-based modeling process, modes of motion mainly include translational motion and rotation. When mode of motion is set as translational motion, velocity and mode are two important factors. It can be seen from function that three components of velocity vector for boundaries are required to be set. In other words, when translational motion of boundary reaches the maximum distance, mode of its further motion should be set in order to control whether it should stop or continue to conduct reciprocating motion. When boundary is rotating, velocities of its rotation axis and rotation angle should be determined. In addition to the above setting of motion attributes for boundary, material characteristics of boundaries of mechanical components should also be set based on requirements, as different materials of mechanical components lead to different physical and mechanical attributes, which can be differentiated by different numbers for different boundaries. Generally, such attributes should be assigned to discrete element method-based boundary model through human-computer interaction, which are stored in corresponding data table in the database [7].

4. **Realization of Boundary Modeling for Complex-Structured Mechanical Components.**

4.1. **Example verification of boundary modeling for fundamental curved surfaces and combined curved surfaces.** Modeling verification on fundamental regular curved surfaces is conducted through the above method. Comparison of Pro/ENGINEER models and discrete element method-based analytical models of circular conical surface, sphere, circular truncated cone surface and spherical crown surface is indicated in Figure 5.

4.2. **Modeling of analytical model based on three-dimensional discrete element method for combination inner-cell corn seed precision metering device.** Combination inner-cell corn seed precision metering device is a complex-structured mechanical component, for which modeling of analytical model based on three-dimensional discrete element method is mainly composed of extraction of geometric information about three parts including housing, seed protecting plate and seed metering wheel and modeling of analytical model. Housing is broken down into boundary primitives contacting seeds and geometric information should be extracted through geometric primitive method, which is broken down into 6 boundaries, including 3 incomplete right circular cylinders, 2 circular planes and 1 cylindrical surface. Internal and external surfaces of seed protecting plate contact seeds, which are incomplete right circular cylinder surfaces. However, internal and external surfaces share the same shape and are close to each other, so geometric information about only one surface is extracted. Seed metering wheel is the most complex

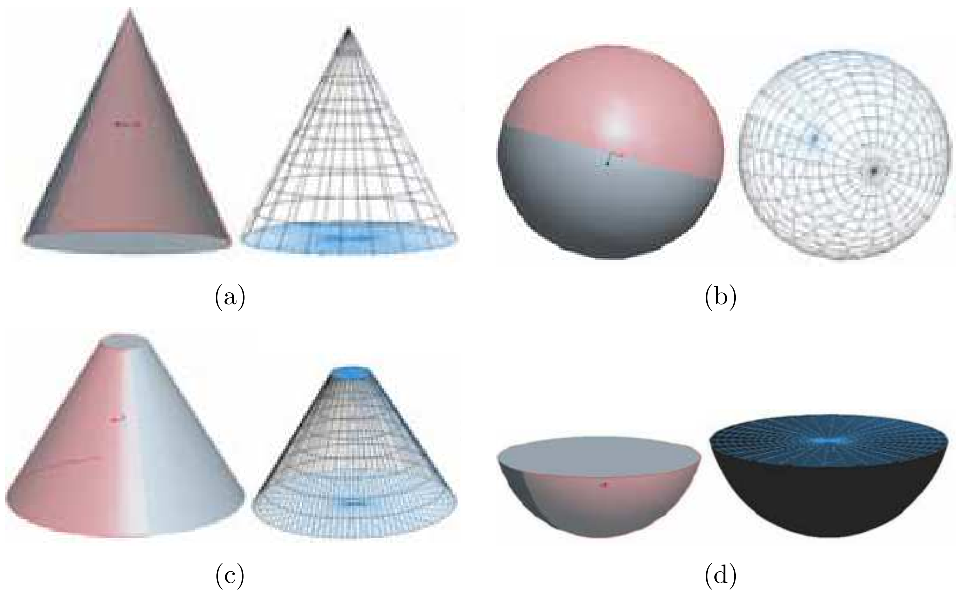


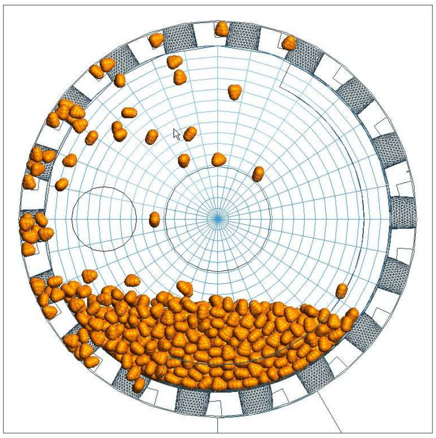
Figure 5. Pro/ENGINEER model and discrete element method-based analytical model for circular conical surface, sphere, circular truncated cone surface, and spherical crown surface, respectively

Table 1. Extraction of geometric information about boundaries of complex-structured mechanical component – seed metering device

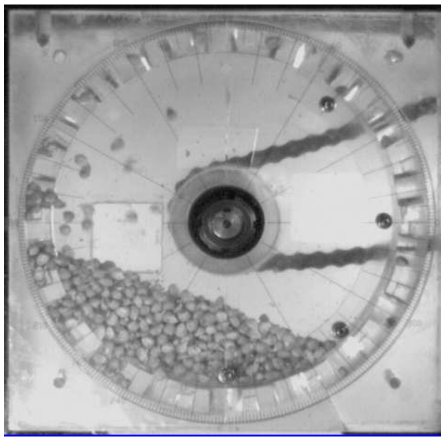
Name of Mechanical Component	Extracted Boundary	Quantity	Method of Extraction
Outer Shell Body	Incomplete Right Circular Cylinder	3	Geometric Primitive Method
	Circular Plane	2	
	Cylindrical Surface	1	
Seed Protecting Plate	Incomplete Right Circular Cylinder	1	Geometric Primitive Method
Seed Metering Wheel	Polygonal Plane	4	Geometric Primitive Method
	Circular Plane	1	
	Curved Surface (Including Inner Side Surface of Seed Metering Wheel)	3	Grid Generation Method

part among the three parts, which is broken down into 8 boundaries including 4 polygonal planes and one circular plane and geometric information is extracted through geometric primitive method. Geometric information of three curved surfaces (including internal side of seed metering device) should be extracted through grid generation method. Seed metering device is a moving part, so motion attributes should be set and material attributes should be added through human-computer interaction in addition to extraction of geometric information.

With the above method, analytical model based on complex-structured mechanical component – three-dimensional discrete element method for combination inner-cell corn seed precision metering device is realized through Pro/ENGINEER solid model for such device. Comparison of simulation experiment and bench test is indicated in Figure 6, which indicates a high degree of similarity between them. Effectiveness of such modeling method is verified in a preliminary way, which lays a foundation for further general modeling method for complex-structured mechanical components.



(a) Simulation experiment diagram



(b) Bench test diagram

Figure 6. Diagram of comparison between simulation experiment and bench test of working process of combination inner-cell corn seed precision metering device

5. **Conclusions.** Based on secondary development of Pro/ENGINEER software, in-depth research on certain issues in Pro/ENGINEER solid model of boundaries of complex-structured mechanical components, is conducted in this paper. With combination inner-cell corn seed precision metering device as an example, modeling of analytical model based on three-dimensional discrete element method is realized through three-dimensional Pro/ENGINEER model of complex-structured mechanical component, which lays a foundation for subsequent simulation analysis.

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