RESEARCH ON THE INFLUENCE OF HULL DEFORMATION ON SHAFTING ALIGNMENT UNDER DIFFERENT SUBMERGED DEPTHS

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The hull deformation is a significant factor affecting the quality of the shafting alignment. The deep-water submersible vehicle is taken as the research object, by establishing the 3D finite element model of the submersible vehicle, and the hull deformation under the action of gravity, buoyancy and hydrostatic pressure is analyzed when submersible vehicle is in upright floating attitude, and the displacement data of each bearing of the submersible vehicle shaft system is obtained, which offers a reference for shafting alignment of submersible vehicle considering hull deformations. A method of adjusting the balance of gravity and buoyancy of submersible vehicle by spring constraint is proposed, and the displacement scatter plot of the bearing is fitted by the least squares method. The straight line is used as the relative displacement reference line of the bearings, and the displacement of each bearing of shafting system relative to the reference line is obtained. The analysis results show that the bearing displacement inside pressure hull is smaller than that outside. The difference of support structure of the bearing will result in different bearing displacements. The asymmetric arrangement of the liquid tank inside the submersible vehicle will lead to a lateral displacement of the bearing located on the liquid tank.

Keywords: submersible vehicle; finite element model; the hull deformation; shafting alignment
1. **Introduction**

In recent years, the development of deep-water submersible vehicle is developing towards greater depth. The increase of diving depth will lead to the increase of hydrostatic pressure on the wet surface of its pressure hull and the increase of structural deformation. Because the stiffness of the shafting is stronger than that of the hull, the deformation of the hull will cause changes in the support structure of the submersible vehicle's shafting, which will cause the displacement of the shafting and change the original alignment state of the shafting [1]. The submersible vehicles spend most of their time underwater, and the external forces acting on the hull are hydrostatic pressure and gravity, buoyancy, and shear force and bending moment caused by uneven distribution of gravity and buoyancy along the length, among which hydrostatic pressure played a major role [2]. It is very important for engineering practice to calculate hull deformation and analyse its influence on submersible vehicle shafting.

At present, many scholars have studied the influence of ship hull deformation on shafting alignment [3-5], but there are few publicly available information on deep-water submersible vehicle. There are two main methods for calculating the displacement of submersible vehicle bearing: ①Simplifying the hull into a cylinder and a cone to estimate the relative displacement of the bearings simply; ② Establishing the finite element model of the whole ship and calculating the deformation of the hull under the combined action of gravity and hydrostatic pressure when it is in the upright floating attitude, and then obtaining the bearings’ displacement [6-7].

This paper takes the deep-water submersible vehicle as the research object, establishes the finite element model of the whole boat, comprehensively considers the effects of gravity, buoyancy and hydrostatic pressure, calculates the deformation of the submersible vehicle under different submerged depths, and analyses its influence on the shafting system.

2. **Finite element calculation of submersible vehicle hull**

2.1 **Shafting model of submersible vehicle**

Fig. 1 is a sketch of the shafting arrangement of the submersible vehicle. The shafting consists of seven bearings.

![Fig. 1 Shafting Arrangement](image)

2.2 **Finite element model of hull**

The hull of submersible vehicle is mainly composed of pressure hull, internal platform, internal bulkhead, equipment base and non-pressure hull, etc. The whole structure can be divided into shell,
plate, longitudinal girder, ribs, reinforcing ribs and so on. With the help of finite element software, the 3D model of the submarine is established. The pressure hull, platform plate, bulkhead, rib plate and web of girder of the boat body are simulated by shell element and plate element. Beam element simulation is used for longitudinal girder, stiffeners and ribs. The internal equipment adopts simplified model modeling and mass point simulation, and the model density or mass point quality is adjusted to make it as close as possible to the actual equipment quality. Bonded-connection is used to connect the equipment base to the equipment and the boat body structure. Meshing, then the model for all plate element and shell element is given priority to with quadrilateral grid meshing, beam element uses the automatic meshing, simplified equipment model is given priority to hexahedron meshing. The key parts such as bearing base and the hull structure nearby are refined.

![Finite Element Model of Submersible Vehicle](image)

**Fig. 1** Finite Element Model of Submersible Vehicle

### 2.3 Boundary condition

The calculation assumes that the submersible vehicle is in an upright floating attitude, considering the combined effects of hydrostatic pressure, self-gravity and seawater buoyancy, ignoring the effects of ambient temperature, waves, and the like.

Generally, the hull is divided into 20 theoretical stations along the ship's length. The ship's loads are distributed according to the theoretical stations, keeping the distribution range and action point of each load basically unchanged. The mass in each theoretical station can be regarded as uniform distribution, and the stepped mass curve distribution is used instead of the real mass distribution. Although the load distribution obtained by this method is different from the actual situation, it will not bring obvious error to the calculation [8].

1. **Loads**

   According to the mass distribution curve, the hull structure quality of each theoretical station is subtracted. For the cabin without shafting, the internal equipment quality is simulated by mass points. For the cabin with shafting, the equipment in the cabin is modeled appropriately, and the quality of the real equipment is consistent by adjusting the density of the model. Then the vertical acceleration of $-9.8 \text{m/s}^2$ is applied to the whole ship model to simulate the effect of gravity. A gradient pressure load varying with water depth is applied to the wet surface of the submersible vehicle to simulate the effects of pressure and buoyancy.

2. **Constraints**

   The submersible vehicle is a free body in underwater navigation. When doing static analysis, it is necessary to ensure that the structure of the submersible vehicle has no rigid body displacement, otherwise the program cannot be solved. Nine springs are installed on the horizontal bow surface of the submersible vehicle to prevent rigid body displacement (one in the axial direction and two in the horizontal direction, and six in the vertical direction due to the imbalance between gravity and buoyancy), as shown in Fig. 3.
(3) Static Balance Adjustment

In order to simulate the real force of the submersible vehicle when it is upright floating attitude, the static balance of the submersible vehicle is adjusted. After applying the loads and constraints to the submersible vehicle, the initial calculation results of gravity and buoyancy must be unbalanced. Observe the constraint reaction of the spring, and then adjust the mass of each station (similar to the submersible vehicle adjusting the balance water tank to achieve the submersible vehicle’s upstream and downward) until the whole submersible vehicle is in a upright floating attitude and the vertical force is balanced. The force of each spring after balance is shown in Table 1. Except for the large supporting force of the axial spring, the support force of the other springs is less than 0.05% of the total gravity of the submersible vehicle, resulting in a rigid body displacement of less than 0.0005mm, which meets the calculation error requirement [9].

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3. Calculation and Analysis of Hull Deformation

3.1 Absolute displacement of bearings

Three bearings (1~3) of the seven bearings supporting the shafting are located outside the pressure hull, while the other four (4~7) are located inside the pressure hull, and their base seats are on the inner liquid tank of the submersible vehicle. The vertical and horizontal displacements of seven bearings at different diving depths (depth 1 < depth 2 < depth 3 < depth 4) vary with the distance from the propeller as shown in figs. 4 and 5.
Fig. 4 Vertical Absolute Displacement of Bearings Under Different Submerged Depths

From Fig. 4, it can be seen that the bearing inside the pressure hull body shifted upward and the bearing outside drooped with the depth increasing, but the displacement of the bearing inside the pressure boat changed more obviously with the depth increasing, and the displacement of the bearing outside the pressure hull was larger.

Fig. 5 Horizontal Absolute Displacement of Bearings Under Different Submerged Depths

As can be seen from Fig. 5, the lateral displacement of the bearing is smaller as a whole and increases with the increase of the depth of the submersible vehicle, but the displacement of the bearing6 is much larger than that of other bearings. The cause of this phenomenon is the lateral asymmetry of the structure of the liquid tank inside the submersible vehicle.

By comparing the two figures, it can be found that the displacement of each bearing is different in different depth, and the vertical displacement is much larger than the horizontal displacement, and both increase with the increase of the depth.

3.2 Relative displacement of bearing

The simulation results above are the absolute displacement of each bearing in the shafting, and the relative displacement of each bearing in the shafting alignment is the focus of the shafting alignment. In order to obtain the relative displacement of the bearings, the reference point or line should be selected, and the distance between the bearings of the shafting and the reference line should be taken as the
relative displacement of the bearings. Previous studies mostly choose a bearing displacement as reference zero or absolute displacement connection of two bearings as reference line [1, 3, 7]. In this paper, the least square method is used to fit the scatter points of each bearing displacement of the shafting to get a straight line, as shown in Figure 6. Based on this reference line, the vertical and horizontal relative displacements of each bearing in the shafting under different submerged depths are obtained.

![Fitting Scatter Plot of Support Displacements of Shafting by Least Square Method to Get Reference Line](image)

**Fig. 6** Fitting Scatter Plot of Support Displacements of Shafting by Least Square Method to Get Reference Line

In shafting alignment, the position of bearings is generally adjusted so that the loads on the bearings and the stresses of each shaft section are within the allowable range, so as to ensure that the shafting can still operate continuously, normally and safely under dynamic working conditions. Compared with other reference lines with two points as the reference line to measure the relative displacement of shafting, the line fitted by least square method as the reference line can better reflect the distribution of bearing displacement, reduce the bearing adjustment displacement in the subsequent shafting alignment process to a certain extent, and reduce the influence of hull deformation on the shafting alignment.

### 4. Conclusion

In this paper, according to the structural characteristics and working environment of the submersible vehicle, the 3D finite element model of the submersible vehicle is established, and the spring constraint is used to adjust the balance of gravity and buoyancy of the submersible vehicle, and the displacement of each bearing in the shafting system is calculated. The simulation results show that:

1. The vertical displacement of bearings is larger than the horizontal displacement, which indicates that the displacement of bearings is mainly vertical; the displacement of shafting increases with the increase of submerged depth, and the displacement of bearing in pressure hull changes more obviously with the increase of submerged depth. It proves that hydrostatic pressure is the main factor leading to bearing displacement, which has greater impact on bearing displacement in pressure hull.

2. The displacement of each bearing varies with the depth of submergence, and the trend is also different. Adjusting the stiffness of bearing support to make the displacement of each bearing in shafting consistent is a better way to reduce the influence of hull deformation on shafting.

3. The horizontal asymmetric arrangement of the inner tank structure supporting the bearing base will cause the horizontal displacement of the bearing inside the pressure hull, and it will increase with the increase of the depth of submergence. Therefore, in order to reduce the lateral displacement of the bearing, it is better to symmetrically arrange the hull structure supporting the bearing base.
(4) In this paper, the least squares method is proposed to fit the displacement of each bearing in the shafting system to get the reference line of the shafting displacement. On this basis, the relative displacement data of the bearing can be obtained, which can better serve the follow-up shafting alignment work.

REFERENCES


