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Analysis of Dynamic Pendulum Dynamics of Amusement Facilities Based on ADAMS

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Abstract: In order to improve the safety performance and comfort of amusement facilities, reduce research and development costs and shorten the development cycle, simulation analysis can be performed using the mechanical system dynamics analysis software ADAMS. In this paper, through the analysis of the principle of the large pendulum movement, the physical object is rationally simplified. The three-dimensional CAD software is used to model the key components of the pendulum, and then the three-dimensional model is imported into the dynamic simulation software. After setting the technical parameters and motion functions of the components in the model, the simulation analysis can be performed to obtain the movement and force conditions of each component during the operation of the device. The simulation analysis results are compared with the theoretical calculation results. The research shows that the output of simulation analysis is consistent with the theoretical calculation result. Using virtual prototype instead of physical prototype is an effective method to improve equipment safety and reduce costs.

1. Introduction
The amusement facility pendulum is one of the important entertainment items in amusement facilities. It is a large-scale amusement equipment and is commonly found in major amusement parks. Tourists sit in a circular cockpit and face outwards. Usually, a large pendulum is used as a safety restraint with a pressure shoulder, and a safety belt is used as a secondary insurance. While the cockpit rotates, the main shaft of the suspended cockpit is driven by the motor. Movement, the operation of the big pendulum can thrill the tourists sitting on it[1]. Figure 1 shows the physical map of the pendulum. The pendulum is a stimulating amusement device. Its safety problem is the focus of attention of people from all walks of life. Because of its high-speed operation, the impact caused by an accident is very bad.

On April 21, 2018, in Xuchang City, Henan Province, China, the “big pendulum” in high-altitude rides in the West Lake Park fell off due to a seat belt buckle, causing a man to fall from a height, and died after being rescued by the hospital[2].

On July 26, 2017, a carnival amusement park in Columbus, Ohio, took place in the evening and a terror accident took place in the evening. A game similar to the pirate ship “big pendulum”, one of the hammers suddenly broke, causing passenger seats to fly off and passengers to dumped out of the seat. The passengers in the seat were immediately thrown into the air and flew directly to the ground, killing 1 person and injuring 7 people. Among them, 5 people were in danger at the scene[3].

Due to the complexity of the movement, a lot of simplified calculations are required in the design process, resulting in inaccurate speeds, accelerations, and movement history. In traditional designs, a
large number of repeated calculations and modifications are required, and physical prototypes are then manufactured. Repeatedly, the production cost is greatly increased, and the design cycle is extended. In order to shorten the development cycle and improve the design quality, it is a good solution to use virtual prototypes for simulation research and analysis and R&D.

ADAMS, or Automatic Dynamic Analysis of Mechanical Systems, is a virtual prototype analysis software developed by Mechanical Dynamics Inc[4]. ADAMS software uses an interactive graphical environment and parts library, constraint library, and force library to create a fully parametric mechanical system geometry model.

The solver uses the Lagrangian equation method of multi-rigid system dynamics theory to establish system dynamics. Equations, static, kinematic and dynamic analysis of virtual mechanical systems, output displacement, velocity, acceleration and reaction force curves[5]. The simulation of ADAMS software can be used to predict the performance of mechanical systems, range of motion, collision detection, peak load, and input loads for finite element calculations[6]. In this paper, a 3D solid simple model of a large pendulum is established by using 3D CAD software and imported into a dynamic simulation software. The kinematics of a large pendulum is analyzed by kinematics, and different types of loads are applied to adjust the different swing angles. The effect of component motion parameters. It provides important reference value for the design, operation and safety of the pendulum.

2. Material and Methods

2.1. The establishment of a model

The virtual prototype established in this paper is based on the model of the fourth-generation challenger tour made by Wenzhou South Amusement Equipment Engineering Co.Ltd. Specific technical parameters are shown in Table 1. The big pendulum is fixed on the concrete platform by four bolts and the ground through the bolt connection. The main movement is through the gear drive to make the boom oscillate back and forth around the axis of rotation. The swing angle is between 0-110°, the second movement. For the rotation of the cockpit around the central axis of the boom, the speed of the turntable is 11.3 rpm, and the tourists sit in the cockpit consolidating around the circumference of the turntable. During the model building process, only the components involved in the movement are modeled in three dimensions. Save the established three-dimensional model as an output of type .x_t to exchange data. After importing into ADAMS, the materials of each component are set. The material set is low-carbon steel. The specific technical parameters are shown in Table 2.

| Equipment height (m) | Rotary diameter (m) | Reciprocal tangent angle (°) | Turntable speed (rpm) | Rated member (people) | Driving power (kw) | Total power (kw) | Total floor area (m²) |
|----------------------|---------------------|-----------------------------|-----------------------|-----------------------|-------------------|-----------------|----------------------|
| 18.8                 | 36.04               | ±110                        | 11.3                  | 42                    | 297               | 315             | 25±19                |
Table 2. Technical parameters of the material.

| name      | Density (kg/m³) | Elastic Modulus (N/m²) | Poisson’s ratio | Anti-reducing modulus (N/m²) |
|-----------|-----------------|------------------------|-----------------|-------------------------------|
| Q235B     | 7850            | 2.05×10¹¹              | 0.285           | 8.0×10¹⁰                      |

2.2. Theoretical Calculation of Validation Parameters

As shown in Figure 2 is a schematic diagram of the establishment of the SolidWorks 3D CAD modeling software. The names, masses, and distances of the various components from the centroid are as follows:

- \( G_1 \): Swing arm 13000kg; \( G_2 \): Rotary turntable 2000kg; \( G_3 \): Cockpit, seat, passenger and other parts of 10000kg; \( G_4 \): Leg, frame and other fixed part of 40,000kg; \( L_1 \): Swing arm distance from the swing center distance 12000mm; \( L_2 \): Turn the distance from the turntable to the swing center is 16000mm; \( L_3 \): The distance from the swing center to the cockpit is 17000mm.

By considering the active components as a whole, by substituting the above data into the formula, we can calculate the center of gravity \( I \) of the device in the static state:

\[
I = \frac{G_1 L_1 + G_2 L_2 + G_3 L_3}{G_1 + G_2 + G_3} = \frac{13000 \times 12000 + 2000 \times 16000 + 10000 \times 17000}{13000 + 2000 + 10000} = 14.32 \text{ (m)}
\]  

(1)

By simplifying the structure of the pendulum to a single pendulum motion, the maximum linear velocity and the maximum angular velocity of the pendulum during the motion can be obtained.

\[
h = I + I \sin 20° = 14.32 + 14.32 \sin 20° = 19.22 \text{ (m)}
\]  

(2)

\[v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 19.22} = 19.41 \text{ (m/s)}\]

(3)

Where: \( h \) is the maximum height of the swing arm; \( g \) is the acceleration of gravity; \( v \) is the maximum line speed.

Maximum angular speed:

\[
w = \frac{v}{I} = \frac{19.41}{14.32} = 1.36 \text{ (r/s)} = 489.6 \text{ (rad/s)}
\]  

(4)
Where: $w$ is the maximum angular velocity. When the speed is maximum, the centrifugal force at this position is also the greatest. For the calculation of the acceleration of the big pendulum, the centroidal acceleration of the cabin as a whole is:

$$a = w^2 R = 1.36^2 \times 17 = 31.44 \text{ (m/s}^2)$$

(5)

Where: $R$ is the distance from the bottom of the cockpit to the center of rotation.

Cockpit overall centrifugal force $F$:

$$F = G3(a + g) = 10000 \times (31.44 + 9.8) = 412400 \text{ (N)}$$

(6)

3. Results

The connection mode between the model setting components to be imported into the ADAMS/View module, the rotation pair between the foot seat and the swing arm, the swing arm and the cockpit, and then the foot and the swing arm rotation pair as the active member to add the swing arm Coupling between the pair of turns with the cockpit. After adding power, set the drive function.

3.1. Linear Velocity and Acceleration Analysis

Using the ADAMS/Post Processor post-processing module, simulation analysis shows that the cockpit data is shown in Figure 3.

![Figure 3. Cockpit Speed and Acceleration Data.](image)

3.2. Analysis of angular velocity and angular acceleration

The data obtained from the simulation analysis is shown in Figure 4. We can see that the angular velocity of the cabin is about 500 rad/s.

![Figure 4. Cockpit angular velocity and angular acceleration data.](image)

The power consumption of the swing arm motor can also be obtained from the system dynamics.
simulation, as shown in Figure 5; and the element stress and element twist force at the contact point of the swing arm rotation center are shown in Figure 6.

![Figure 5. Motor power consumption.](image1)

![Figure 6. Element Stress and Unit Torque](image2)

3.3. Offset influence on the equipment

In order to study the effect of partial load on the equipment, different stress conditions were set in ADAMS. From the results of the simulation, as shown in Figure 7 and 8, Figure 7 is the tension and shear force under uniform load setting. JOINT_5 is the contact force at the swing arm, and JOINT_6 is the contact force at the cockpit.

![Figure 7. Forced map under uniform load.](image3)
4. Discussion

From Figure 3, we can see that the maximum speed is about 22.5 m/s and the maximum acceleration is about 32.5 m/s\(^2\). The results calculated by equations (1) and (5) are not much different from each other, and are within the acceptable range[7].

From Figure 4, we can see that the angular velocity of the cabin is about 500 rad/s, which is not much different from the theoretical calculation result of equation (4), 489.6 rad/s, within the allowable error range. From Figure 4 we can also get the angular acceleration of the cabin is 780 rad/s\(^2\), which can provide us with data validation and reference value in the design process.

From Figure 5 and Figure 6 it can be clearly seen that the motor power consumption, element stress and unit torque and other parameters of the course of change.

It can be seen from Figure 7 that the tension at the cockpit is different from the result obtained by equation (6). Figure 8 shows the changes of the tension and shear force at the two contacts under the same load and partial load conditions. From the comparison of the two figures, it is not difficult to find that under partial load conditions, the forces at the two contacts are greater. From the above data, it is not difficult to recognize the adverse effects of partial loading. When the staff guides the tourists, they must ensure that the passengers are evenly seated. After everything is ready, they can start the equipment and must not place the tourists in one place. It will not only affect the service life of the equipment, but also cause unnecessary accidents.

5. Conclusion

(1) Simplifying the solid model by studying the movement mechanism and structure of the large pendulum is an important step in further simulation analysis and a key step in whether the simulation analysis is reasonable.

(2) The results of theoretical calculation and simulation analysis are compared and analyzed. The results show that the simulation results are consistent with the theoretical calculations. Through the virtual prototype simulation analysis, the movement conditions and stress conditions of the equipment can be easily obtained, and the equipment can be greatly shortened. The research and development cycle saves a lot of manpower and material resources, reduces research and development costs, and improves the safety performance of the equipment.

(3) It can be seen from the ADAMS simulation data that the eccentric load will increase the tension and shear force at the contact between the two components, which will affect the life of the equipment and increase the accident rate. This phenomenon should be eliminated during the operation of the equipment.

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