A Sea Wave Surge Base Alignment Test Device Based on the EtherCAT Fieldbus

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Abstract. A sea wave surge base alignment test device consisting of a linear motion guide rail, a stewart platform, a rotating mechanism, a cantilever beam and an electronic control system based on an EtherCAT fieldbus is designed. The linear motion guide and the stewart platform provide the seven movement dimensions for the whole device, the rotating mechanism, the cantilever beam and the linear motion guide widen the movement dimension and amplitude of the device, the EtherCAT fieldbus effectively satisfies the real-time, synchronization and accuracy of the whole device, the whole system effectively satisfies the requirements of multi-degree, large amplitude, low frequency, large acceleration combined superimposed rocking motion and simulation motion in the sea wave surge simulation motion.

1. Introduction
In the traditional control system, the analog signal has attenuation and noise interference during transmission. It is difficult to develop to the multi-degree-of-freedom control system due to the cable and volume limitation. With the continuous development of industrial technology, the demand of various simulation simulators for motion freedom, amplitude, synchronization, etc. is also increasing, and the application of the EtherCAT fieldbus is more and more extensive [1-5]; W. You et al. use the EtherCAT fieldbus to control multi-degree-of-freedom robots, and the following error is reduced by nearly 3 times [6]; K. Jyotsna et al. use the EtherCAT fieldbus to obtain data from various channels and sources of wind turbines to ensure the real-time and synchronization of data [7]; B. Allouche et al. use the EtherCAT fieldbus to build an auxiliary standing system for disabled people to make the disabled movement more coordinated [8]; Therefore, this paper applies the EtherCAT fieldbus to the wave simulation movement, improving the real-time, synchronization and accuracy of the entire system.

2. The sea wave surge base alignment test device
It is mainly composed of the mechanical platform, a console, a control cabinet and cables. The mechanical platform includes the six-degree-of-freedom platform, the horizontal linear motion platform, the cantilever beam and the interval rotating mechanism. The six-degree-of-freedom platform uses servo motors which is equipped with absolute coders to drive a high-precision electric cylinder to control the platform motion attitude; the linear motion platform uses dual servo motors to drive high-precision roller rack to motion and uses a high-precision linear laser scale to achieve closed-loop control; The interval rotating mechanism is composed of bearings and guide wheel mechanisms. The device is controlled by the EtherCAT fieldbus which improves the reliability, real-time and accuracy of control and realizes the automatic monitoring and system security protection functions of overspeed and overload by the computer; The Ethernet port and the RS422 interface are
added for the remote control communication. In the aspect of measurement and control software, the man-machine interface is built by the Visual C++ for controlling and displaying the real-time state of equipment movement.

3. The mechanical structure
The length and width of the platform are about 10345mm × 9000mm × 4000mm (zero state), and the weight of the platform is about 20,000kg. The overall structure of the platform is shown in Figure 1.

![Figure 1. Structure diagram of the platform of the sea wave surge base alignment test device.](image)

3.1. The horizontal linear motion component
The horizontal linear motion component is composed of a horizontal motion platform, two linear guide motion pairs, a splicing base, a linear motion driving device and a laser feedback component. The platform structure is shown in Figure 2.

- The linear guide rail has a length of 10m, and the rotation mechanism of the 15° interval makes the horizontal linear motion range of each degree of freedom of the device expand from 1m to about 7m;
- The high-precision roller rack (double drive) is selected as the driving pair of the horizontal linear motion, and the servo motor drives the roller to rotate through the reducer. In order to improve the rigidity of the output shaft of the reducer, a pair of back-to-back mounting is added.
- The GDLE-10 laser encoder is installed in the middle of two linear guides as a linear motion feedback device, which has the advantages of long distance measurement, high precision and high speed, improving its positional accuracy;

![Figure 2. The horizontal linear motion platform.](image)

3.2. The six-degree-of-freedom platform
The six-degree-of-freedom platform in the test device realizes the angular motion of the pitch, roll and azimuth axes and the linear motion in three directions, which is used to expand the dimension of the sea wave simulation motion, as shown in Figure 3. It consists of the upper platform, the lower
platform, six electric cylinders, ball joints and universal joints. The outer dimensions are about Φ2295mm, the height is about 2197mm (height at zero position), the lifting height is ±500mm, and the weight is about 1300kg. The lower platform is connected to the electric cylinder by installing six universal joints with a certain angle. The upper platform is connected with the electric cylinder through the ball joint, and is driven by the linear motion of the electric cylinder through the rotation of the universal joint and the ball joint to the rotation and linear motion of the platform.

![Image of platform components](image)

**Figure 3.** The six-degree-of-freedom platform.

3.3. The Rotating mechanism

As shown in Figure 4, the center of the table body is designed with a certain mandrel system (a pair of deep groove ball bearings). Three guide wheels are installed circumferentially. After manually turning to the desired position, the mounting screws are fastened, that is, the six-degree-of-freedom platform is locked in the required position. The scale of -90~+90 on the mounting plate of the six-degree-of-freedom platform is designed to determine the angular position during the rotation process. So that the angles of six degrees of freedom can be rotated at a certain angle, further broadening the dimension and magnitude of the wave simulation.

![Image of rotation mechanism](image)

**Figure 4.** The Rotation Mechanism.

3.4. Load installation

The device is designed in two installation modes, one is that the load is directly mounted on the upper platform of the six-degree-of-freedom platform, as shown in Figure 5. The other is the load is installed on one side of the cantilever bracket by means of a cantilever beam, such as As shown in Figure 6, the total length of the cantilever is more than 6 m, and the length from the work surface to the load is less than 3 m. This structural design is matched with the rotating mechanism and the heave, make the test range of the tested product expand to ±3.35m.
4. The electronic control system
The electronic control system is an important part of the final realization of the function and technical performance of the wave surge base aligning test device. Its main components are:

- The three-level control structure is combined with the industrial control computer, the EtherCAT fieldbus, the motion controller and drivers.
- Using precision servo motors and matched intelligent drivers directly drive;
- A high-precision, high-resolution laser encoder is used as feedback components of a linear motion platform;
- Precision servo motors and absolute multi-turn German HEIDENHAIN absolute encoders is used as the motion feedback components of each electric cylinder of the six-degree-of-freedom platform;
- Software and hardware are combined to realize the multi-level fault detection and the real-time recording of status data to realize system safety operation protection and analysis and diagnosis functions;
- The computer software is based on the Windows 10 operating system and is modular in design and has the capability to expand.

The basic structure of the electronic control system of the sea wave surge base alignment test device is shown in Figure 7.
Figure 7. The basic structure of the electronic control system.

The EtherCAT fieldbus motion controller realizes the synchronous motion of the six-degree-of-freedom platform and the synchronous motion of the double-side motor of the linear motion platform with its high real-time and synchronization, and completes the solution between the attitude and the motor, the trajectory planning, the synchronous drive, and the Closed-loop control of the linear platform, the command transmission, the device status monitoring and protection; intelligent drivers complete the closed-loop control and status input of each motion axis of the six-degree-of-freedom platform. Each drive rod uses HEIDENHAIN absolute angle encoder as angular position and angular rate feedback. The component forms a three closed loop control system in the drive. The linear motion mechanism uses the laser distance sensor as the motion feedback component, and cooperates with the zero position and limit sensor to form a three-closed loop control system and motion protection function in the fieldbus motion controller.

5. Test site
The sea wave surge base alignment test device has been put into use in a research institute. The schematic diagram of the site is shown in Figure 8.

Figure 8. The schematic diagram of the equipment site.

The longitudinal movement of the device is -18°, the input command position is 18°, the command speed is 50°/s, and the command acceleration is 1000°/s². The motion curve is tested as shown in Figures 9, 10.
6. Conclusion

The six-degree-of-freedom platform, the linear motion guide and the rotating mechanism are combined to increase the horizontal linear amplitude of the seven degrees of freedom to 7m, and the angular swing amplitude is extended to 3.35m. The use of the EtherCAT fieldbus makes the entire system angular positioning accuracy From 5° to 1°, the dynamic following error is reduced from 0.6° of the original system to 0.2° at maximum speed and maximum acceleration; Combined with its high speed, high acceleration, composite superimposed rocking function, file simulation and file simulation and the composite superimposed rocking superposition function, the device can fully realize the real simulation motion of advanced sea conditions.

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