Development of a Rapid Detection Device for Wind-Resistant and Anti-Skid Performance of Rail-Mounted Cranes

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Abstract: In order to improve the detection efficiency of the windproof and anti-skid performance of the port rail-mounted crane, a modularized wind-borne detection device is designed in this paper. The device realizes the windproof and anti-skid performance detection of the rail-mounted crane through PLC-controlled hydraulic system. Featuring ingenious structure and reasonable layout, this device converts the counter force of the crane on the detecting device into clamp force and friction of the detecting device on the guide rail, triggering it to enter into a self-lock state during work. Moreover, by adopting modular design, this structure facilitates disassembly and transportation. Furthermore, with high compatibility, it fits into all types of guide rails of various specifications, and all kinds of rail cranes.

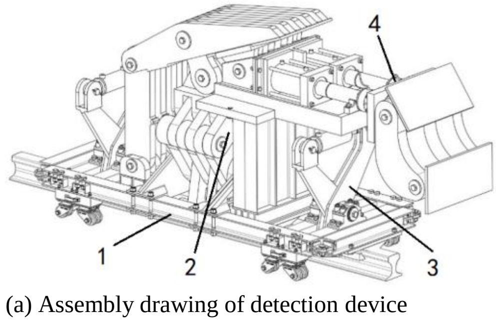
Keywords: rail-mounted crane; self-locking; wind-proof and anti-slip; building block design

1. Introduction

For a long time, due to the impact of typhoons in coastal areas, there have been many port crane overturning accidents, which not only seriously threatened the lives and safety of port operators, but also caused unnecessary economic and property losses to the port [1, 2]. Therefore, our country's quality supervision department implements a full range of inspection, testing, and supervision about ports to ensure that coastal port cranes can have sufficient wind-resistant and anti-skid capabilities [3]. The wind-resistant and anti-skid ability of port rail-mounted cranes depends on the braking performance of the crane itself and the reliability of the clamps, iron shoes, rail jacks and wind-proof cables. There are many reasons for the insufficient wind-proof ability of the wind-proof and anti-skid device, among which the common reasons are the anti-wind and anti-skid ability of rail-mounted cranes calculated by theories, which has a certain deviation from the actual situation and wear of anti-wind and anti-skid devices [4]. It is currently known that wind-resistant and anti-skid detection devices for rail-mounted loading and unloading apparatus all detect a kind or a certain type of rail-mounted loading and unloading apparatus, which have poor versatility and have various flaws. Therefore, this article proposes a rail-mounted crane anti-wind and anti-skid detection device that uses the clamping rail to fix and controls the hydraulic system through the embedded system of Atmel SAM3X8E as the core. This device can be adapted to test the anti-wind and anti-skid ability of rail-mounted cranes on different sizes and different rails [5].

2. The Structure and Working Principle of the Detection Device

The mechanical structure of the wind-resistant and anti-skid rapid detection device for rail-mounted cranes is shown in Figure 1. It mainly includes a fixed frame, a pre-tightening mechanism, a clamping mechanism and a butt joint. The clamping mechanism is a lever clamping mechanism. Since the wind-resistant and anti-skid performance detection of rail- mounted cranes requires two detection devices (symmetrically distributed), a set of hydraulic stations and supporting special control systems, the two detection devices are first transported to both sides of trajectories of the rail-mounted crane by crane or forklift. Then slowly place the detection device in a suitable position. The clever and reasonable layout makes it easy to adapt to the wind-resistant detection of different rail-mounted cranes by matching one end of the connector with the joint surfaces on both sides of the crane, The detection device exerts clamping force to the guide rail to generate enough friction to resist the deviation of the entire equipment, and uses the reaction force of the crane to make it into a self-locking state during operation to ensure the stability of the entire equipment.



(a) Assembly drawing of detection device

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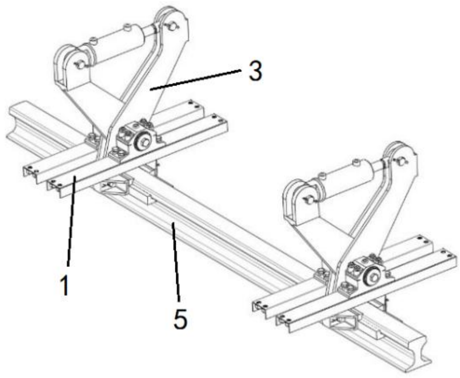
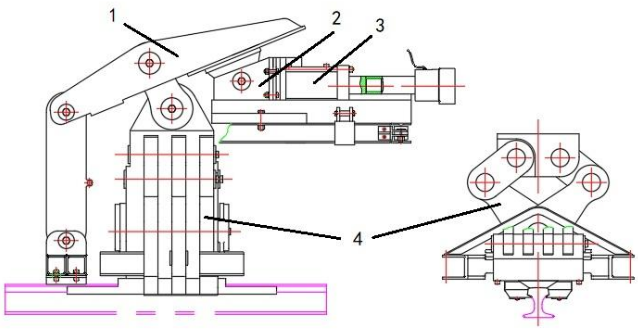


(b) Three-dimensional structure drawing of pre-tightening mechanism

1. Fixed frame 2. Clamping mechanism 3. Pre-tightening mechanism 4. Connector 5. Guide rail

Figure 1. Structure diagram of detection device

The self-locking clamp mechanism in the detection device is the most important component. Its function is to convert the reaction force of the crane to the detection device into the friction force of the clamp on the guide rail, making the equipment more reliable. Its structure is shown in Figure 2, mainly including main hydraulic cylinder, self-locking clamp mechanism, thrust wedge, lug plate type connecting rod, etc.



1. Lug plate type connecting rod 2. Thrust wedge 3. Main hydraulic cylinder 4. Clamping mechanism

Figure 2. The components of the self-locking clamp mechanism

The self-locking clamping mechanism converts the reaction force of the rail crane on the detection device into the clamping force and friction force of the detection device on the guide rail when the detection device is working, so that the detection device can reach a self-locking state. Due to the fact that clamping mechanism need to withstand greater load and friction, 50Cr alloy steel with a yield strength of 930Mpa is selected as the material of the clamp mechanism. The total loading load in this study is 100t. And the two detection devices are installed on the two rails of the crane and the crane is pushed at the same time, so the loading load of each detection device is 50t. The reaction force of the crane on the detection device is transmitted through the force, and will act on the thrust wedge of the clamping mechanism. The force analysis of the thrust wedge is shown in Figure 3. Among them Fx is the reaction force of the crane on the detection device 50t. F_N is the bearing force components' support force to the thrust wedge. F is the pushing force of the big lug connecting plate which influenced by the wedge.

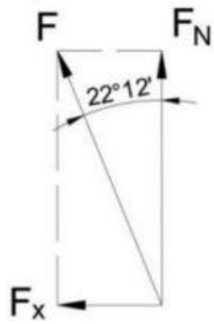


Figure 3. Force analysis diagram of thrust wedge

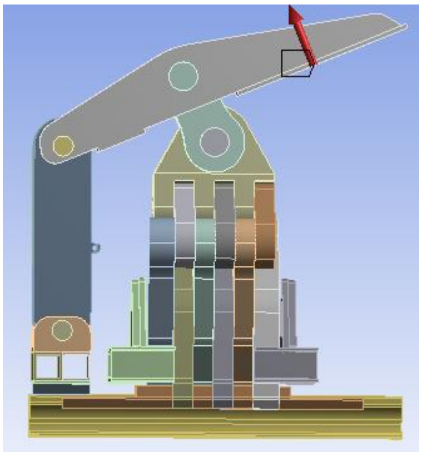
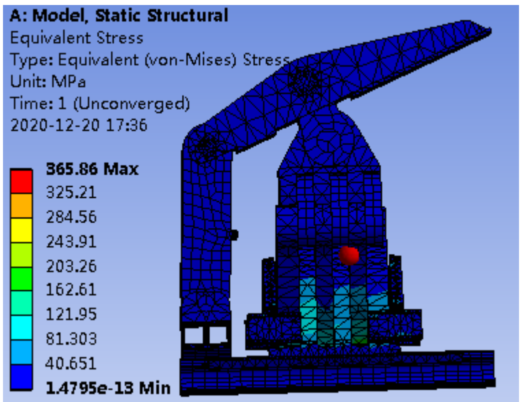


Figure 4. The force direction of the thrust wedge on the big ear connecting plate

The force direction of the thrust wedge on the big lug connecting plate is shown in Figure 4. In the emulation software, the contact relationship between the various components in the clamp mechanism is set according to the actual matching mode of the clamp mechanism, and then endue the load data and constraints related to the components and parts by the actual working load. In this way can we obtain the overall stress-strain cloud diagram of the clamping mechanism, as shown in Figure 5.



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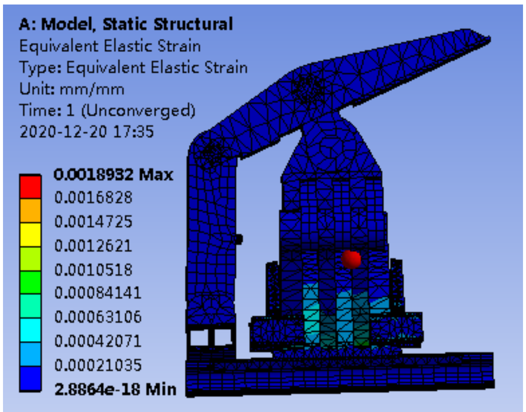

Figure 5. The stress-strain cloud diagram

It can be seen from the stress-strain cloud diagram that under the 50t reaction force of the crane, the maximum stress-strain generated by the clamping mechanism of a single detection device are located at the lower part of the connecting rod clamp, where the stress is 365.86Mpa, which is less than the 50Cr yield strength of 930Mpa, and the strain is very small and negligible.

The self-locking clamp mechanism is installed in the middle of the two pre-tightening mechanisms, and the main hydraulic cylinder is installed in the front of the detection device. Its working process is shown in Figure 6. The port gantry lifting equipment generally has a large span (≥20m), at the same time, we are considering the convenience of equipment operation and the safety of the operators. The electronic control system adopts remote control for sensor sampling and control. When the hydraulic system is started, the electromagnetic reversing valve of the auxiliary oil circuit on the hydraulic station is controlled by the 2.4G remote control to control the pre-tensioning mechanism to clamp the track, and the load is applied to the crane through the connector on the main hydraulic cylinder to simulate the influence of wind on the crane [6]. At the moment when the crane is pushed, the displacement sensor installed on the crane outputs a response, and transmits the signal to the main control system for data processing, and controls the electromagnetic overflow valve on the hydraulic system according to this signal to determine whether the pressure is relieved. At the moment when the displacement signal responds, the required pressure data is measured by the pressure sensor installed in the hydraulic system, and the data is converted into wind power and displayed on the host computer, which is convenient for human-computer interaction.

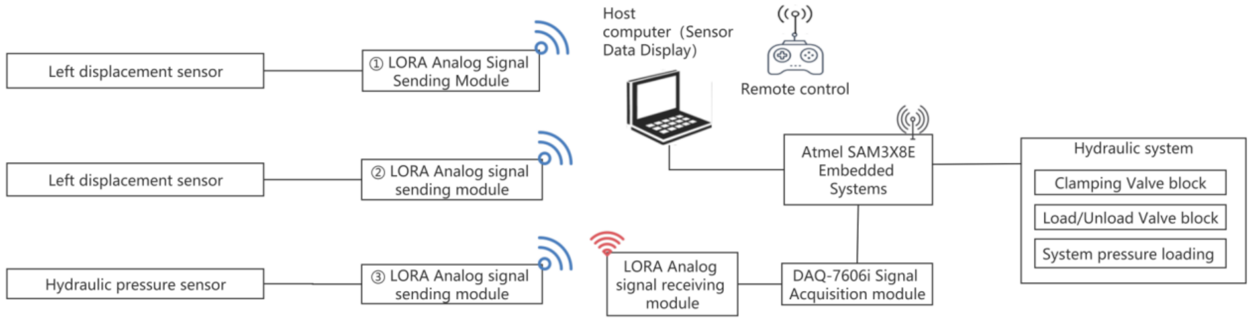

Figure 6. Schematic diagram of electrical control working process

3. Hydraulic System Design

All hydraulic cylinders in this study are in a horizontal layout. The main hydraulic cylinder and the auxiliary hydraulic cylinder adopt the rear-end flanged single piston rod double-acting hydraulic cylinder and the double ring-mounted single piston rod double-acting hydraulic cylinder. The main hydraulic cylinder drive the clamping mechanism to move, and the auxiliary hydraulic cylinder drives the pre-tensioning mechanism to move. Under the working conditions of pre-tensioning load of 12t and loading load of 100t, the pre-tensioning mechanism (action of auxiliary hydraulic cylinder) can be controlled to clamp the track, and then the loading mechanism (action of main hydraulic cylinder) can be controlled to push the crane. After obtaining the data, we are able to control the loading mechanism (action of the main hydraulic cylinder) to retreat and loosen the pretension mechanism (action of the auxiliary hydraulic cylinder).

According to the working principle of the detection device, considering that there may be differences in the conditions of the two tracks of the rail-mounted crane, in order to facilitate the adjustment of the detection device during the pre-tensioning process, the two auxiliary hydraulic cylinders on the same detection device are manually controlled in parallel [7]; During the loading process of the loading mechanism, the detection devices on the two tracks have a balance to the crane thrust. The four main hydraulic cylinders on the two detection devices are manually controlled in parallel. Combined with the actual situation, the hydraulic system in this study has the following characteristics:

(1) The hydraulic system adopts matching hoses and quick couplings closed with one-way valves, which can be quickly connected on site;

(2) Able to manually control the actions of the auxiliary hydraulic cylinders on the two detection devices;

(3) The main hydraulic cylinders on the two detection devices can be manually controlled to act at the same time;

(4) The oil inlet of the auxiliary hydraulic cylinder part has the function of maintaining pressure;

(5) The structure is compact, and the actuator can achieve intermittent work.

The hydraulic system is at the stage of loading in this study, the load pressure is higher in the loading phase, and the load pressure is lower in the retreat phase. In addition,

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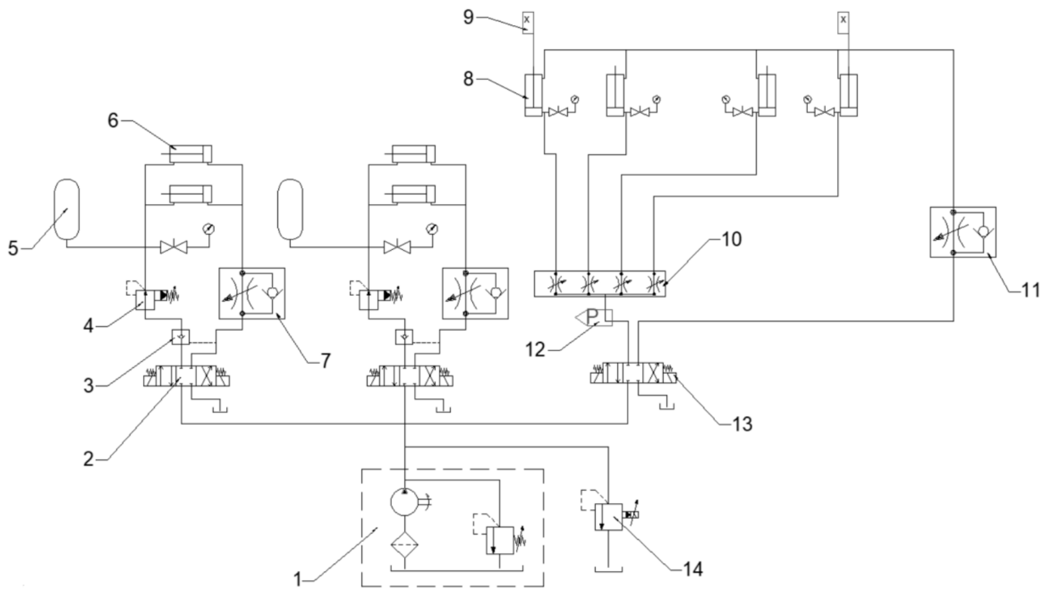
the four main hydraulic cylinders work at the same time, with the same load and the same speed. Therefore, the system needs to use hydraulic synchronizer and oil return throttle speed control circuit to ensure smooth movement during the loading phase [8]. Taking into account factors such as low requirements for automation of the detection device, medium system pressure, medium flow, and no hydraulic shock at the reversing transition position of the system, the main hydraulic system will use a single quantitative pump for oil supply. The three-position four-way "O"-type hand position spool valve with neutral function is selected as the main reversing valve of the system [9]. An electromagnetic overflow valve is connected in parallel at the outlet of the quantitative pump to realize the constant pressure overflow of the system. The principle of the hydraulic control system is shown in Figure 7 [10].



1. Hydraulic power station 2. Clamping mechanism hydraulic reversing valve 3. Hydraulic control check valve 4. Pressure reducing valve 5. Accumulator 6. Clamping (auxiliary) cylinder 7. Clamping oil circuit check valve 8. Main hydraulic cylinder 9. Displacement sensor 10. Hydraulic synchronizer 11. Load oil circuit one-way throttle valve 12. Hydraulic pressure sensor 13. Load oil circuit reversing valve 14. Electro-hydraulic proportional relief valve

Figure 7. Schematic diagram of hydraulic system

4. Circuit Control Part Design

The electronic control system mainly detects the pressure of the hydraulic system through the pressure sensor, thereby converting the loading data of the rail-mounted crane. We are using the displacement sensor to detect whether the crane is being pushed. The hydraulic detection system controlled by the microprocessor for the equipment's wind-resistant and anti-skid ability for digital monitoring. The schematic diagram of the control system is shown in Figure 8.

The central control system CPU uses SAM3X8E from Atmel, which is an ARM Cortex-M3 32- bit processor with 54 I/O pins (12 of which can be used as PWM outputs), 12 analog inputs, 512 KB Flash, 96 KB SRAM. The external clock selects 84 MHz crystal oscillator. The performance meets the requirements of professional small non-standard equipment electrical design programming.

After the motor of the hydraulic power station is started, the hydraulic valve electromagnet of the hydraulic system is remotely controlled by 2.4 universal remote control. 1YA, 2YA are the left auxiliary clamping hydraulic cylinder control valve solenoid, 3YA, 4YA are the right auxiliary clamping hydraulic cylinder control valve solenoid. To control 1YA, 2YA, 3YA, 4YA can realize the pre-tension or release of the two loading devices. 5YA and 6YA are the loading hydraulic cylinder control valves, which are responsible for realizing the forward and backward movement of the 4-way loading hydraulic cylinder. 7YA is an electro-hydraulic proportional electromagnet, which is responsible for the highest pressure control of the entire system. After the hydraulic station is started, the electric current through the electromagnet can be adjusted through the knob on the remote control, so as to realize the adjustment of the system pressure and the loading force of the loading hydraulic cylinder.

The wind-resistant ability of the port rail-mounted crane is converted from the hydraulic pressure of the system. Through sampling the maximum hydraulic pressure in the hydraulic system during the entire loading process to acquire the competence in the aspect of wind- resistant about rail-mounted crane. The sampling system uses a USB-DAQ-7606i module with an AD resolution of 16 bits and a maximum sampling speed of 80Ksps for three channels.

The analog LoRa transmission module uses Kejiexun's analog follower, with a maximum transmission distance of 100m. The pressure sensor uses MIK-P300 sensor, the maximum range is 31.5Mpa, and the accuracy is 0.1%. The displacement sensor adopts MIRAN's MPS- XS-MA, with a maximum range of 0.3m and an accuracy of 0.1mm.

During the test, the hydraulic system is slowly loaded with pressure, and the sampling system samples the values

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of each sensors. When any displacement sensor is greater than the set threshold, the hydraulic system stops loading and releases pressure. The central control system outputs the highest pressure of the hydraulic system during the entire loading process through the serial port.

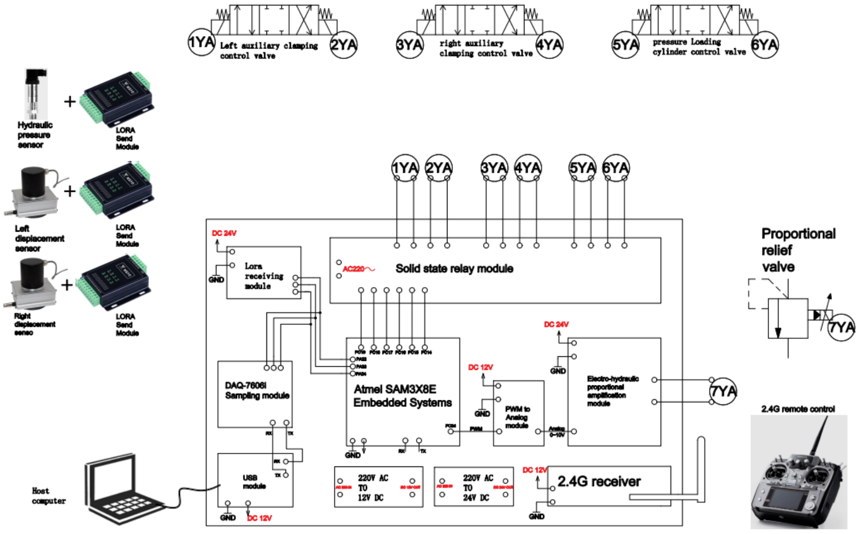

Figure 8: PLC controller wiring diagram

5. Conclusion

In summary, a rapid detection device for wind-resistant and anti-skid performance of rail-mounted cranes can realize the rapid and automatic detection of the wind and anti-skid ability of various cranes of different sizes, different gauges, and different detection weights. The device has many advantages such as light weight, small size, convenient transportation and hoisting, simple and fast on-site installation and adjustment, convenient connection between modules, hydraulic drive, mechanical wedge self-locking clamping, and automatic data collection, etc. The crane exerts a force along the track to simulate the wind-resistant and anti-skid performance of the crane under wind load, and then evaluate the wind-resistant and anti-skid effect of the crane. In addition, the device can be used as a typhoon- prevented crane device.

Acknowledgements

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