Application and Realization of Fully Automatic Portal Crane

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Abstract. Among all kinds of lifting machinery and port machinery, the grab portal crane is the most widely used, while its automatic control is the most difficult. By solving the key technical problems such as high-precision positioning, intelligent anti-swing and multi-crane cooperative operation, the fully automation of the grab portal crane is realized, which greatly promotes the automation process of general bulk terminal.

Keywords: Automation, portal crane, intelligent anti-swing, cooperative operation.

1. Introduction

With the continuous development of smart port construction, more and more automated container terminals are put into use, while the automation level of traditional bulk terminals is still relatively backward. As the port operation equipment with the most widely used and largest quantity in bulk terminal, the portal cranes have the characteristics of mobility, flexibility, versatility and play an irreplaceable role[1]. The current application of the portal cranes is mainly divided into three types: grab portal cranes, hook portal cranes and container spreader portal cranes [2]. Among the three, grab portal cranes are the most representative and the most important ones, as shown in Figure 1.



a) grab b) hook c) container spreader

Fig. 1 Three types of portal cranes

At present, the automation process of the portal crane is still in its infancy. The research in this field at home and abroad mainly focuses on remote control and semi-automatic operation [3-6]. Some domestic port enterprise have begun to try to put the transformed fully automatic portal crane into production, mainly aiming at key technical problems such as high-precision positioning, intelligent anti-swing and multi-crane cooperative operation.

2. Positioning system and intelligent anti-swing

The automatic portal crane is positioned by means of mutual verification of redundant control between GPS and encoder. The encoder has the characteristics of high resolution and fast data feedback, which is suitable for the dynamic positioning of each mechanism. GPS has the opposite characteristics to encoder, so it is used as position compensation of each mechanism in static state.

Automatic gantry crane includes lifting mechanism, luffing mechanism, slewing mechanism and traveling mechanism. The specific positioning mode of each mechanism is shown in Table 1.

Table 1. Positioning mode of each operating mechanism

Mechanism Name	Positioning mode		
	Absolute encoder	Incremental encoder	GPS
Lifting mechanism	●	○	○
Luffing mechanism	●	○	●
Slewing mechanism	●	○	●
Traveling mechanism	●	●	○
Note: ● indicates that this mode is applied, ○ indicates that this mode is not applied.			

In practice, the running track of the grab is formed under the joint action of lifting mechanism, luffing mechanism, slewing mechanism and traveling mechanism. Grab shaking refers to the shaking of the grab in the track plane due to inertia at a certain time. From the causes, it can be divided into two types: shaking caused by slewing and shaking caused by luffing. When the slewing motion accelerates to start or decelerates to stop, the centripetal force changes due to the change of the original angular velocity of the grab, resulting in shaking. At this time, the influence of centripetal force changes should be balanced by decreasing or increasing the amplitude accordingly. When the luffing motion accelerates or decelerates, the real-time speed of the grab is inconsistent due to the soft connection between the grab and the main structure through the steel wire rope. At this time, the speed change mode needs to be controlled and adjusted to wait for the synchronous action of the grab.

According to the overall mechanical structure of the gantry crane, the grab specifications, wire rope winding mode and other factors, an accurate anti-swing mathematical model is established to interact with PLC in real time. In the process of automatic operation, the anti-swing intelligent control system is carried out for the grab to realized the coordinated operation of slewing motion and luffing motion, so that the luffing motion can automatically offset the swing component generated by the slewing motion in its direction. At the same time, the synchronous calculation of lifting motion is taken into account, and the anti-swing effect will not be affected under the condition of full speed operation of the grab.

3. Multi-crane cooperative operation

When two adjacent cranes operate at the same time, if they are divided according to whether the rotation direction of the boom system is consistent, they can be divided into two types: operation in the same direction and operation in the opposite direction. Among them, the operation in the opposite direction can be specifically divided into face-to-face operation and back-to-back operation, as shown in Figure 2 and Figure 3.

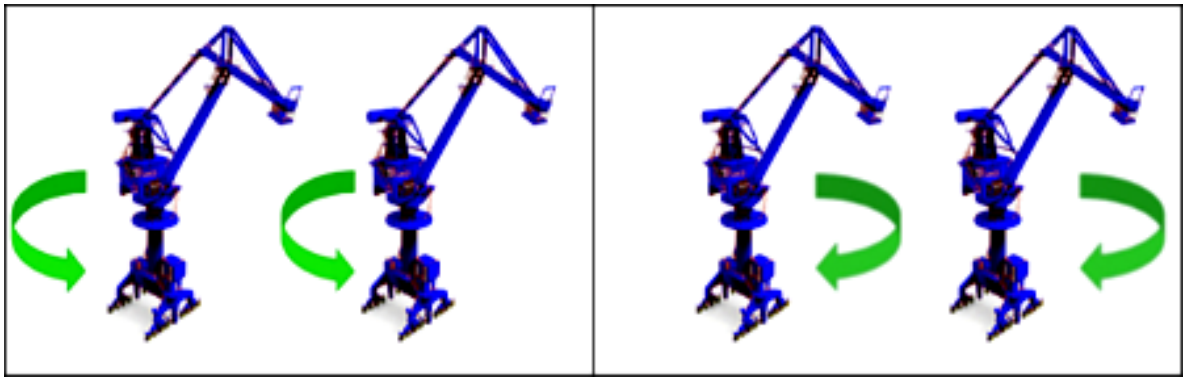
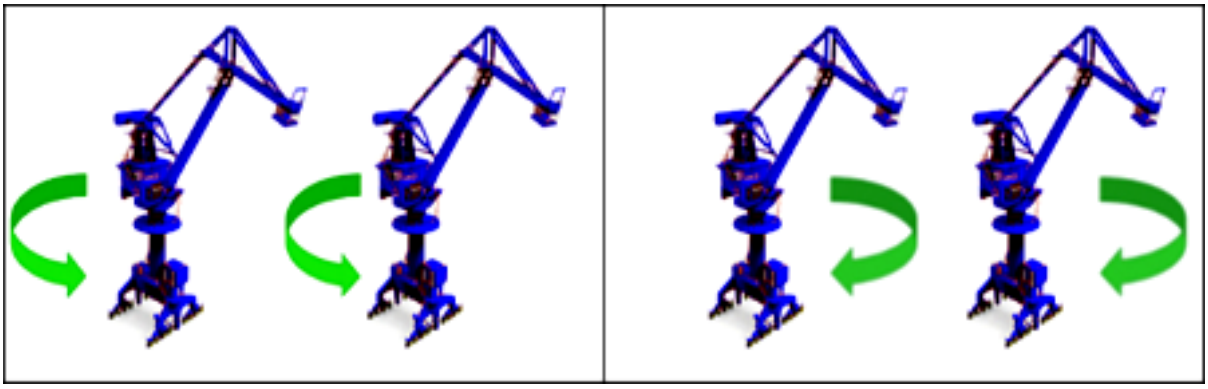


Fig. 2 Operation in the same direction



a) back to back b) face to face

Fig. 3 Operation in the opposite direction

In the above operation states, according to the mechanical structure characteristics and operation mode of the gantry cranes, the face to face operation in the opposite direction is the most likely to occur collision. In view of this operation state, radar sensors are installed on the trunk beam of two adjacent crane boom systems. The two adjacent cranes are set as one master and one slave, and the priority of the action performed by the master is higher than that of the slave. It is preset that the left crane is master A and the right crane is slave B. They conduct face-to-face reclaiming operation at the same time. The path of boom system in the reclaiming process is defined as Reclaiming Area (referred to as R-A), Common Area (referred to as C-A) and Discharging Area (referred to as D-A), as shown in Table 2.

Table 2. Area division of cooperative operation of adjacent portal cranes

Area Category	Area Content	Area Property
Reclaiming Area (R-A)	A1、B1	Opening
Common Area (C-A)	A2、A3、B2、B3	Locking
Discharging Area (D-A)	A4、B4	Opening

R-A includes A1 area and B1 area, C-A includes A2 area, A3 area, B2 area and B3 area, and D-A includes A4 area and B4 area. R-A and D-A are in the open state and can pass freely, while C-A is in the locked state. The locking area can be released only after the traffic application is successful. After the crane passes through the area, the area is restored to the locked state again.

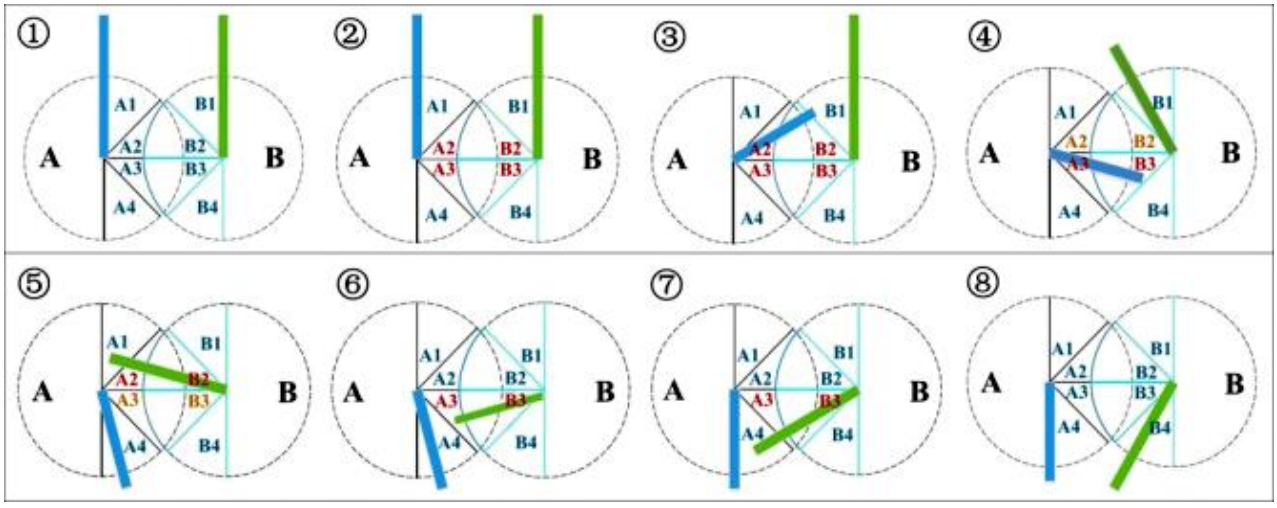


Fig. 4 Cooperative operation process of adjacent portal crane

The collaborative operation process of two adjacent cranes is shown in Figure 4, with specific instructions as follows: crane A and crane B are both in the initial position of A1 and B1 in R-A. Crane A first applies for regional access to all areas of C-A. After the application is successful, A2,

A3, B2 and B3 of C-A are all unlocked. Crane A rotates clockwise to A2 and B2 of C-A and locks the areas at the same time. At this time, crane B is still waiting in B1 of R-A and starts to apply to access the common area. Crane A accesses A3 and B3 through A2 and B2 of C-A, locks A3 and B3 and removes A2 and B2 lock at the same time. As A2 and B2 of C-A are unlocked, the regional access for crane B passes successfully and starts to turn counterclockwise to A2 and B2 of C-A. Crane A enters A4 of D-A through A3 and B3 of C-A, and removes A3 and B3 lock at the same time. Since A3 and B3 are unlocked, crane B continues to turn to A3 and B3 after passing A2 and B2 of C-A, and locks A2 and B2 at the same time. Next, crane A reaches the positive circle -90°, that is, the discharging point position of D-A to unload and completes the discharging process of this road. However, crane B enters B4 of D-A through A3 and B3 of C-A, at the same time releases A3 and B3, and continues to rotate until it arrives at the discharging point of -90° in the positive circle.

It should be noted that if crane A has completed the discharging process of this road, while A3 and B3 of C-A are still not unlocked. This indicates that crane B has not passed through the corresponding area. At this time, crane A should wait in A4 of D-A and apply for access in the common area until the relevant area is unlocked, then turn counterclockwise to return to the initial position through A3 and B3 of C-A, A2 and B2 of C-A and A1 of R-A to prepare for the next round of reclaiming process. The same applies to crane B.

4. Conclusions

After the portal crane realizes automation, it fills the gap in the industry and greatly promotes the automation process of the traditional bulk terminals. As the most widely used and highest quantity port machinery equipment, it has strong promotion value. It also responds to the construction concept of smart green port, conforms to the development trend of port automation and port intelligence, and is of great significance to the construction of smart port.

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