PLC-based Lifting Device for Shore Power Cable

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Abstract: Due to the different sizes and heights of ships docked at the port and the rise and fall of water at the harbor, there are many problems in providing electricity to ships berthing at the port [1]. The shore power cable lifting device is adaptable to the cable connection under different environments, mainly consisting of a multi-stage telescopic hydraulic arm [2], a cable drum, a luffing mechanism, and a slewing mechanism. In the process of cable lifting, the cooperative control of multiple working mechanisms is related to the cable connection precision, as well as the safety. Compared with the traditional control of the circuit, PLC control can ensure higher accuracy and safety, and improve the automation level and convenience of shore power connection.

1. Introduction
The size and height of ships docked at the port are different, which are affected by the rise and fall of wharf water; thus, it is difficult to connect cables directly from the ship to the electric pile at the port, together with great potential hazards in safety. At present, lifting devices for shore power cable are commonly used in ports along the Yangtze River Basin. The 360° rotation of the slewing platform, the pitch motion of luffing cylinder [3], the extension and contraction of the multi-stage telescopic arm, and the rotation of the cable winch motor are all controlled by the remote-control unit. A single person can operate the remote-control device at the port or on the ship.

2. Cooperative control of shore power cable and hydraulic arm
In the lifting and transmission of shore power cable, the precision of cooperative control is closely related to system feedback. In the cooperative control of shore power cable transmission, it is necessary to obtain the lengths of multi-stage hydraulic telescopic arm and cable in real time for the system feedback of the PID control algorithm.

To obtain the accurate displacement of the multi-stage hydraulic telescopic arm, a built-in displacement sensor is installed in the hydraulic cylinder to obtain information regarding the displacement.
2.1 Control of multi-stage hydraulic arm

![Flowchart of the built-in displacement sensor](image)

Figure 1 shows the control procedure of the involved built-in displacement sensor in the hydraulic cylinder, through which the measured real-time signal can be transformed into the current extension length $X$ of the hydraulic arm, sequentially, the difference $\delta_X$ between the current length $X$ and the expected length $X'$ can be used as the input of the PID control algorithm. After amplification, the output signal treated as the current signal is transmitted to the proportional valve electromagnet, so as to drive the hydraulic cylinder. Compared to the traditional control method, PID control can improve the operation stability and dynamic adaptability of the hydraulic system [4].

In cooperative control, to realize the synchronization of the cable retracting speed and the hydraulic arm, it is essential to obtain the length of the cable in real time. In the measurement of cable length, an encoder is adopted to convert the angular displacement of the measuring wheel into the linear displacement of the cable. However, in the initial working state, the length of the cable in a static state cannot be measured directly through the encoder. To overcome this problem to obtain a more accurate length of the cable, a pressure sensor is installed on the guide wheel at the end of the cable. The pressure sensor adopts a resistance strain gauge to obtain the pressure signal of the guide wheel through the strain gauge installed on the guide wheel; therefore, the mass and length of the cable can be calculated accordingly. Through the combined measurement of the encoder and pressure sensor, the cable length can be obtained to meet the accuracy requirements.

2.2 Control of retraction and release for shore power cable

(1) Encoder design

The shore power cable winding out from the drum passes through the guide and measuring wheels in sequence, and an encoder is installed on the expansion shaft of the measuring wheel. The encoder can read the angular displacement of the measuring wheel in the cable lifting, and after signal processing, the angular displacement $\varphi$ of the measuring wheel can be obtained, with the known diameter $d$ of the measuring wheel; thus, the displacement $x$ of the cable can be calculated as:

$$x = \frac{\varphi d}{2}$$

(1)
(2) Pressure sensor

The measuring wheel, installed at the proximal end of the multi-stage hydraulic arm, is used to guide the cable, as displayed in Figure 2, and the cable extends through the measuring wheel. Assuming that the ideal tensions applied to both ends of the cables on the measuring wheel are both equal to $F$, the tension is expressed as:

$$ F = G_d + G_t \quad (2) $$

Where $G_d$ is the gravity of the dripped cable on the right side and $G_t$ is the gravity of the connecting end at the head of the cable.

Force analysis of measuring wheel leads to

$$ T = F + G_t + F \cdot \cos \theta \quad (3) $$

Where the angle $\theta$ between the cable and support frame can be measured through a gyroscope, as shown in the figure, and the gyroscope is installed on the multi-stage hydraulic arm to measure the three pose angles of the hydraulic arm in operation. The cable in tension is parallel to the hydraulic arm; therefore, the angle $\theta$ is the angle $\theta$ between the hydraulic arm and the proximal end of the support frame.

The signal measured by the pressure sensor is analyzed to calculate the force $T$ expressed as:

$$ T = f(\varepsilon) \quad (4) $$

Where $\varepsilon$ is the measured data from the pressure sensor.

The pulling force $F$ of the cable can be calculated from Eq. (2-2) below:

$$ F = \frac{T - G_L}{1 + \cos \theta} \quad (5) $$

As a consequence, the gravity $G_d$ of extended cable is obtained as

$$ G_d = F - G_t \quad (6) $$

$$ G_d = \frac{T - G_L}{1 + \cos \theta} - G_t \quad (7) $$

While in the actual docking of shore power, due to the influence of the torque of the measuring wheel and the tightness of the cable as well as the poor dynamic measurement effect of the pressure sensor, the extended length of the cable calculated from the measurement by the pressure sensor is not always accurate. It can only be used to assist in measuring the static extended length $l$ when starting to lift the cable, where the length is expressed as

$$ l = \frac{G_d}{g \cdot \rho} \quad (8) $$

$$ l = \frac{T - G_L - G_t(1 + \cos \theta)}{g \cdot \rho(1 + \cos \theta)} \quad (9) $$
\[ l = f(\varepsilon) - G_L G_T (1 + \cos \theta) g \cdot \rho (1 + \cos \theta) \] (10)

It is noted that in the actual docking test of shore power, the cable length \( l \) is not accurate enough because of the various influence factors. Hence, the length of the extended cable can only be estimated before the cable is lifted by the lifting device, in which multiple groups of data can be used according to experience. The length measurement of the shore power cable is shown in Figure 3.

The total length of the shore power cable is equal to

\[ L = X + l \] (11)

Since the estimated cable length from the measurement of the pressure sensor is not always accurate, the estimation of the extended length \( l_0 \) of the cable is limited to the initial release of the cable, and the length \( l_0 \) can be given by experimental data according to experience.

Thus, the initial length \( l_0 \) of the cable is:

\[ L_0 = X_0 + l_0 \] (12)

Where \( X_0 \) is the initial length of the multi-stage hydraulic arm.

And the length \( L \) of the cable in transmission can be calculated as:

\[ L = L_0 + x \] (13)

With the known length \( X \) of the hydraulic arm, the multi-stage hydraulic telescopic arm extends with a prescribed speed. The displacement \( X \) is calculated according to the data from the displacement sensor.

Assuming that the expected length of the cable from the winch drum is to be \( L' \):

\[ L' = X + l' \] (14)

Where the \( l' \) is the expected tolerance. A suitable cable length can prevent the port facilities or ships from the collision due to the extended length over the expected and the cable damage by the guide wheel of the hydraulic arm due to that the cable is not long enough.

The error \( \delta \) between the current extended cable length \( L \) and the expected \( L' \) is

\[ \delta = L' - L = X + l' - X_0 - l_0 - x \] (15)

The feedback error \( \delta \) can be integrated into the PID control algorithm as:

\[ Y = K_P \left\{ \delta + \frac{1}{T_i} \int \delta \, dt + K_D \frac{d\delta}{dt} \right\} \] (16)

Equation (2-16) stands for the general expression of the PID control algorithm, including proportional, integral, and derivative, where \( K_P \) represents the proportional tuning parameter, and
\[ \frac{1}{T_I} \int \delta dt \] stands for integral with tuning parameter \( T_I \), and \( K_D T_D \frac{d\delta}{dt} \) stands for derivative with tuning parameter \( K_D T_D \).

Figure 4 shows the PID control for the cooperative control of the cable and hydraulic arm. The deviation of the expected and actual value obtained through the previous calculation is used as the input of the PID control algorithm, and the output is processed and converted into the voltage signal required by the motor to drive the drum to accomplish the corresponding action.

**Conclusion**

In response to the drawbacks of the lifting and delivering device for inland shore power cables in inland ports of the Yangtze River, this paper carries out the analysis of the shore power cable lifting device, and a new control scheme is proposed. The cooperative control of the lifting and telescopic mechanisms of the shore power cable lifting device is realized based on the PID control algorithm. To this end, an innovative scheme to measure the cable length is proposed, and the effectiveness is proved by modeling analysis. Finally, the whole control system of the lifting and delivering device for inland shore power cables in inland ports is simulated by MATLAB/Simulink. Compared to the traditional control method, the PID cooperative control can ensure faster-lifting speed and higher accuracy.

**Reference**

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