Design of control and hydraulic drive system for high-altitude live working vehicle

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Abstract: This article mainly introduces the motion control system of high-altitude live working vehicle and the design of the hydraulic drive system of the trolley. Motion control system is the nerve centre of auxiliary robot for power distribution without interruption. It plays a key role. The hydraulic drive system with trolley provides power support for the insulated bucket of the trolley car. The experimental results show that the design scheme of the control system and the hydraulic drive system can meet the actual operation requirements of the electric car.

1 Introduction

The motion control system of the high-altitude live working vehicle plays a vital role in the function and performance of the tram. The main task of the control system is to control the position, attitude, trajectory, operation sequence, and time of movement of the tram in the working space. At present, there are three types of motion control: a robot control system with a single-chip microcomputer as a core, a robot control system with a PLC as a core, and an industrial robot control system based on an IPC+ motion controller.

The robot control system with the single-chip microcomputer as the core is embedded in the motion controller with a single-chip microcomputer (MCU), which can run independently and have a universal interface to facilitate communication with other devices. Single-chip microcomputer is a single-chip integrated central processor, dynamic memory, read-only memory, input and output interfaces etc. The motion controller circuit designed using it is simple in principle and has good running performance and low system cost [1, 2].

The second is a robot control system with PLC as the core. PLC can be programmed logic controller, a digital logic controller for automatic real-time control, designed specifically for industrial control of the computer, in line with industrial environmental requirements. It is a combination of automatic control technology and computer technology into automatic control products. Widely used in all areas of current industrial control. The robot control system with PLC as its core technology is mature and easy to program. It has obvious advantages in reliability, expandability, and adaptability to the environment. It also has the advantages of small size, convenient installation, and maintenance, and strong interchangeability; it has a complete set of technical solutions. For reference, shorten the development cycle. However, like a robot control system with a single-chip microcomputer as the core, it does not support advanced and complex algorithms and cannot perform complex data processing. Although general environment reliability is good but it is unstable under high-frequency environment, it cannot satisfy the multi-axis of the robot system [3, 4].

The third type is a motion controller-based robot control system. The IPC+ motion controller is the mainstream and development trend of industrial robot system applications. The IPC robot control system has low cost of software development, good system compatibility, strong system reliability, and obvious advantages in computing power. Therefore, the use of computer platforms and embedded real-time systems provides hardware control for dynamic control algorithms and complex trajectory planning [5–7].

Although the above motion control methods have many advantages, there are problems such as closed structure, fixed functions, poor system flexibility, poor reconfigurability, lack of runtime reconfiguration mechanisms, and development and integration of components limited to certain languages. Now it tends to be more accurate, more functional, more stable, and gradually develops towards standardisation, modularisation, and intelligence [8–10].

The main components of the hydraulic system are the hydraulic drive system, the hydraulic pump station, and the hydraulic device. It supplies fuel according to the drive (mainframe) and controls the direction, pressure, and flow of the oil. It is suitable for various hydraulic machinery which separating the main engine from the hydraulic device. It is only necessary to connect the hydraulic station to the actuator (hydraulic cylinder and oil motor) on the main engine with tubing, and the hydraulic machine can realise various specified actions and work cycles. The hydraulic station is composed of a pump unit, a manifold or valve unit, a fuel tank, and an electrical box. The function of each component is as follows: the pump device is the power source of the hydraulic station and converts the mechanical energy into the hydraulic energy of the hydraulic oil. It is equipped with a motor and an oil pump. The integrated block is composed of a hydraulic valve and a channel body, and it implements the direction, pressure, and flow regulation of the hydraulic oil. Valve assembly is a plate valve mounted on the vertical plate, plate rear tube connection, it has the same function with the integrated block; fuel tank is a steel plate welded semi-closed container, also equipped with oil filter, air filter etc. It is used to store oil, oil cooling, and filtration; electrical box is divided into two forms: one is to set the external lead terminal board and the other is equipped with a full set of control appliances.

The working principle of the hydraulic station is as follows: the motor drives the oil pump to rotate, the pump draws oil from the oil pump and then the oil converts the mechanical energy into the hydraulic energy of the hydraulic oil, and the hydraulic oil achieves direction, pressure, and flow through the manifold (or valve assembly) by the hydraulic valve. After adjustment, it is transferred to hydraulic cylinder or oil motor through external pipelines to control the direction of the hydraulic motor, the strength, and speed of the hydraulic motor, and promote the performance of various hydraulic machinery [11].
2 Motion control system

The motion control system is the ‘neurocentricity’ of the tram and plays a very key role [12, 13]. Fig. 1 shows the block diagram of the motion control system of the assisted robot.

2.1 Walking: forward, reverse, turn left, turn right

The walking operation process has a certain degree of danger, and the requirement for the centre of gravity of the vehicle cannot exceed the warning height. Therefore, this system uses a robot position feedback sensor as a safety identification mark for the walking license of the vehicle body. Therefore, the body controller detects the state of each sensor of the robot arm in real time and displays it on the display after analysis. When the robot arm is not homed, the controller marks the inner arm’s non-homing marker symbol. In addition, the leg also has a safety discriminating mark status respectively, and only these two mark symbols show the requirement for the centre of gravity of the vehicle cannot exceed the warning height. Therefore, this system uses a robot position feedback sensor as a safety identification mark for the walking license of the vehicle body. Therefore, the body controller detects the state of each sensor of the robot arm in real time and displays it on the display after analysis. When the robot arm is not homed, the controller marks the inner arm’s non-homing marker symbol. In addition, the leg also has a safety discriminating mark for permitting walking. When the leg is not homed, the controller also marks the internal leg's non-homing mark.

When the operator wants to operate the body, the operator moves the corresponding button or joystick in the remote controller, and after the controller recognizes that the remote controller operates, a corresponding software system control flow (walking flow) is generated, and the flow judgment mechanism is changed. The arm and the leg can return a mark symbol and a mark symbol status respectively, and only these two mark symbols show that they have been reset, the controller system software executes the operation flow and generates the corresponding control command, which is then transmitted to the motor control through the communication line. After receiving the command, the motor controller generates a corresponding motor control signal and drives the high-power motor to rotate through the bridge circuit inside the controller.

2.2 Robot lifting operation

Robotic lift is a very dangerous and complicated operation process. It has certain requirements for the stability of the chassis and the hardness of the foundation. Therefore, this process has several conditions that must be met, that is, the body is at the level (the body's inclination should not be >3 degrees) and the legs should be fully extended. At the same time, the operator must pay attention to the operation during the operation to prevent danger. The entire process is: adjust the level→outriggers→reach→adjust the work cloak to work position→job is completed→drop robot arm to return→cloak to return→outriggers to return. Manipulators, capes, and legs are hydraulically actuated. Hybrid control technology is used. The controller reads the status of each hydraulic button switch, and the state of the hydraulic sensor and other sensors, and performs a comprehensive judgment to calculate whether an action is a danger, if not, a corresponding electric signal is generated to drive the corresponding solenoid valve, so that the action process of the corresponding mechanism is realised by the hydraulically driven hydraulic cylinder (Fig. 2).

3 Hydraulic drive system

Work devices such as the lifting and lowering of the legs, the lifting and lowering of the lifting mechanism, the rotation of the turntable etc. are all achieved through the hydraulic transmission system. The automobile engine transmits power to the hydraulic pump through the power take-off device. The hydraulic oil is drawn into the gear pump through the strainer in the oil tank. The pressure oil output from the gear pump enters the working circuit through the fine filter. Each working device is controlled by a solenoid reversing valve and a speed control valve. When it is not working, the hydraulic oil directly returns to the tank through the unloading circuit. When the leg is not working, 1YA is powered on. When the legs work, 2YA is powered on. The bidirectional hydraulic lock guarantees that the vertical cylinder can stop at any position and will not be displaced under the action of external force after stopping. When the upper arm is raised, 3YA is energised, and when the upper arm is lowered, 4YA is energised. When 5YA is powered on, the lower arm goes up. When 6YA is powered on, the lower arm goes down. The counterbalance valve prevents the working arm from falling freely under the action of gravity after stopping. When 7YA is energised, the swing mechanism operates. When the 8YA is powered on, the swing mechanism does not work. Fig. 3 shows the hydraulic system schematic. Lifting arms and basic arm are hydraulically driven. The hydraulic drive method drives the high-pressure pump through the battery to the DC motor, converts the energy of the battery into high-pressure hydraulic energy of the hydraulic oil, controls the movement of the hydraulic cylinder using the solenoid valve, converts the high-pressure hydraulic energy into mechanical energy, and drives the movement of the parallel four-bar linkage mechanism. Thus, the lifting platform completes various actions.
such as up and down translation and up and down rotation. Hydraulically driven lifting mechanism is mainly composed of oil source control device, controller, hydraulic cylinder, lifting arm, square tube, platform etc. It has the characteristics of compact structure, wide operating range, high work efficiency, safety, and reliability etc. It can be widely used in transportation work on the vehicle. The hydraulic principle of the lower folding arm is shown in Fig. 4.

The rod cavity of the lower arm of the folding arm is connected with the rodless cavity of the cylinder of the folding arm to form a serial connection. When the lower arm of the folding arm changes amplitude, the lower folding arm rises; at the same time, the hydraulic oil with the rod cavity is discharged into the rodless cavity of the cylinder on the folding arm, and the cylinder on the folding arm also changes with the upper amplitude and the upper folding arm rises, vice versa. Thus, the upper folding arm and the lower folding arm synchronously move up and down, and the vertical edges of the upper connecting frame and the lower connecting frame are always kept vertically. The hydraulic principle of the upper folding arm is shown in Fig. 5.

3.1 Cylinder selection

Hydraulic cylinders are the actuators in the hydraulic system. They can be divided into piston type, plunger type, and oscillating type according to their structural characteristics. They can be divided into single acting and double acting according to the mode of action [14]. Among them, double-acting piston type hydraulic cylinders are most widely used. The piston-type hydraulic cylinder is characterised by its light weight, simple structure, reliable operation, convenient assembly, and easy maintenance. It is widely used in hydraulic transmission systems of vehicles, engineering machinery, crane transportation machinery, mining machinery, and other machinery industries. Piston hydraulic cylinders are suitable
3.1 Cylinder diameter: The selection of the hydraulic cylinder is mainly based on the maximum force required for the lifting and lowering of the street light installation vehicle and the actual working stroke of the hydraulic cylinder. The former is used to determine the diameter of the cylinder and the latter is used to determine the working stroke of the cylinder (see Table 1).

\[ D^2 = \frac{4(F + F_{fr})}{\pi P_1} + \frac{(D^2 - d^2)P_1}{\pi P_1} \]  

(1)

In the formula:
- \( P_1 \) – hydraulic cylinder working pressure, the system work pressure can be selected when the initial calculation, take 16 MPa; \( P_2 \) – back pressure of hydraulic cylinder return chamber; \( d/D \) – the ratio of the diameter of the piston rod to the internal diameter of the cylinder; \( F \) – Maximum external load at work; \( F_{fr} \) – the friction at the seal of the hydraulic cylinder, its exact value is not easy to obtain, and the mechanical efficiency of the commonly used hydraulic cylinder \( \eta_{cm} \) is estimated.

\[ F + F_{fr} = \frac{F}{\eta_{cm}} \]  

(2)

In the formula:
- \( \eta_{cm} \) – The mechanical efficiency of the hydraulic cylinder, generally \( \eta_{cm} = 0.9–0.97 \), which is taken as 0.9, is substituted into the above formula:

\[ F + F_{fr} = 1.1F \]  

(3)

Therefore, the final cylinder diameter \( D \) can be obtained as:

\[ D = \sqrt{\frac{4 \times 1.1F}{\pi P_1}} = \sqrt{\frac{4.4F}{\pi P_1}} \]  

(4)

3.1.2 Calculate hydraulic cylinder working stroke:

\[ S = l_{max} - l_{min} \]  

(5)

In the formula:
- \( l_{max} \) – the longest distance between the two articulation points of the hydraulic cylinder during operation; \( l_{min} \) – the shortest distance between the two hinges of the hydraulic cylinder when working.

3.2 Hydraulic pump selection

Common hydraulic pumps are gear pumps, piston pumps, and vane pumps. The gear pump has the advantages of simple structure, good craftsmanship, small size, light weight, convenient maintenance, and long service life. The structure of the vane pump and the plunger pump is relatively complex and the price is high. The use of gear pumps in the hydraulic system of high-altitude trucks can meet the needs of work. Commonly used series include CB, CBX, CG, and CN.

3.2.1 Hydraulic pump theoretical flow \( Q_r \): The theoretical flow of the hydraulic pump of a folding boom type aerial working platform shall be determined by pressing the arm cylinder rise time.

\[ Q_r = \frac{60 \times \Delta V}{\eta \times t} \]  

(6)

among them:
- \( \Delta V \) – The maximum working volume of the cylinder; \( S, D \) – Lower arm hydraulic cylinder parameters; \( t \) – Lift time;

3.2.2 Oil pump displacement \( q \):

\[ q = \frac{Q_r}{n} \times 10^3 \text{ mL/r} \]  

(7)

In the formula:
- \( Q_r \) – oil pump flow; \( n \) – the rated speed of the pump;

3.2.3 Oil pump function \( N \):

\[ N = \frac{pQ_r}{\eta} \]  

(8)

In the formula:
- \( p \) – the maximum working pressure of the pump; \( Q_r \) – oil pump rated flow; \( \eta \) – The total efficiency of the oil pump;

4 Simulation

The human–computer interface (HCI) usually becomes a user interface. As shown in Fig. 6, The interface design mainly includes three aspects: (i) designing the interface between software components; (ii) design modules and other non-human information producer and consumer interface; and (iii) interface between user and computer.

On the one hand, starting from the user's situation, decide on the level of support and complexity that the dialogue should provide, select one or several suitable interface types, and on the other hand, match interface tasks and system requirements, and classify interaction patterns. Fig. 7 shows the main interface of the auxiliary robot for power network operation.

The interface displays the status parameters of the car, including the angles \( x, y \) of the horizontal, temperature, humidity, and battery voltage. The alarm, turntable, chassis, and other windows are also reserved. As shown in Table 2, the main functions of the human–machine interface are listed (see Fig. 8).
This paper designs and introduces the control system and the hydraulic driving system of the tram. The motion control system is the core part of the tram line, and the hydraulic drive system with trams provides the power source for the tramway insulation hopper. By designing the human–computer interaction interface to carry out the motion control and driving of the tram, all can achieve the desired effect.

### 5 Conclusion

This paper designs and introduces the control system and the hydraulic driving system of the tram. The motion control system is the core part of the tram line, and the hydraulic drive system with trams provides the power source for the tramway insulation hopper. By designing the human–computer interaction interface to carry out the motion control and driving of the tram, all can achieve the desired effect.

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### Table 2: Human-machine interface main function

| Features          | Function                                      |
|-------------------|-----------------------------------------------|
| initialisation    | void TFT_Init(void)                          |
| receive           | void TFT_Receive(UINT8 ubData)                |
| write             | void TFT_WriteCanData()                      |
|                   | void TFT_WriteCanData_CANFault(void)         |
|                   | void TFT_WriteCanData_CANOk(void)            |
| copy              | void copydata()                              |
| send              | void NullFunction(void)                      |
| key               | void KeyService(void)                        |

### Fig. 8: The interface of different functions and the trouble shooting

(a) Functional interface, (b) Troubleshooting interface