ISSN: 2688-8645

Research on Synchronous Steering Control of Three-Track Paver based on PID in Manual Mode

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Abstract

A method for realizing synchronous steering in manual mode of a three-track paver based on PID algorithm is proposed, a structured language control program is given, and experimental research is carried out on the three-track paver. Experimental research shows that compared to simply directly controlling the opening of the proportional solenoid valve to achieve synchronous steering, the accuracy of synchronous steering using this method has been significantly improved.

Keywords

PID algorithm; Three-track paver; Manual mode; Synchronous steering.

1. Introduction

The electro-hydraulic proportional valve is based on the traditional industrial hydraulic control valve. It adopts a reliable and cheap analog electro-mechanical conversion device (proportional electromagnet, etc.) to convert the electrical signal into a displacement signal to continuously control the working medium in the hydraulic system. It is a hydraulic component of pressure, direction or flow. When this kind of valve works, the electrical-mechanical conversion device in the valve produces corresponding actions according to the input voltage signal, so that the spool of the working valve is displaced, and the valve port size is changed, thereby completing the pressure and flow output proportional to the input voltage. However, the proportional control system itself is an open-loop control system, and is susceptible to machining errors, use environment, and equipment wear. The oil pressure output by the hydraulic cylinder and the loss of oil pressure in the pipeline will also affect the control accuracy of the system. It is difficult to meet the requirements of high-precision synchronous operation of the cylinder. The method of computer control can be used to realize the closed-loop control of position parameters in the proportional control system through software programming. This paper proposes a method of using the PLC controller to realize the position PID closed-loop control of the proportional valve-controlled hydraulic cylinder to realize the synchronous steering in the manual mode of the three-track paver, that is, to keep the steering angles of the latter two tracks consistent at all times. The experiment was verified on the paver. Experiments show that this method significantly improves the accuracy of the synchronous steering of the three-track paver.

2. Motion Model Analysis

The position of the steering column of the frame structure of the three-track paver is shown in Figure 1.

ISSN: 2688-8645

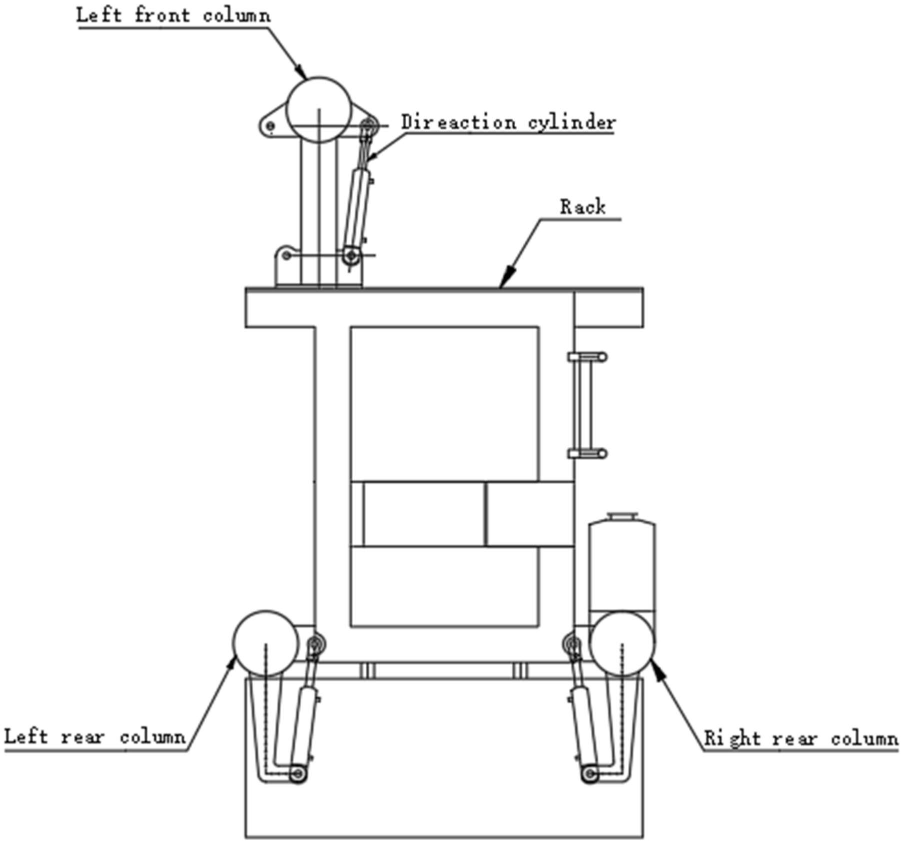

Figure 1. Three-track paver frame structure

When the three-track paver turns manually [1], the left rear track rotates through an angle, and the right rear track turns at the same angle at the same time, which is synchronous steering. In order to enable synchronous steering of the paver, the left and rear steering cylinder of the paver is used as the master cylinder and the right rear cylinder as the slave cylinder. When steering, the left rear cylinder expands and contracts, the steering angle of the left rear crawler can be calculated, which is the steering angle of the right rear crawler, and then the target extension length of the right cylinder is calculated, so you only need to control the extension of the right rear cylinder. It can guarantee the synchronous steering of the three-track paver.

When the paver turns to the right, the simplified geometric motion model is shown in Figure 2.

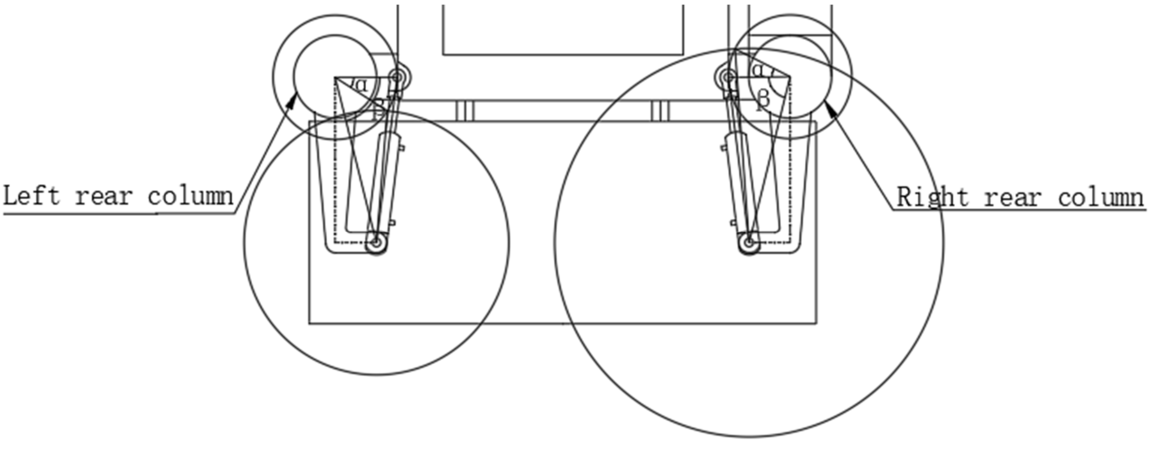

Figure 2. Sketch of the geometric motion model of the right turning of the paver

The specific geometric operation diagram is shown in Figure 3.

Figure 3. Schematic diagram of the right turn geometric operation

From the trigonometric function formula:

$$\beta = \arccos\frac{a^2+b^2-c^2}{2ab}$$

$$\alpha = \arccos\frac{a^2+b^2-S_1^2}{2ab}-\beta \tag{1}$$

$$S_2 = \sqrt{a^2+b^2-2ab\cos(\beta-\alpha)}$$

$$S_2 = \sqrt{a^2+b^2-2ab\cos(2\arccos\frac{a^2+b^2-c^2}{2ab}-\arccos\frac{a^2+b^2-S_1^2}{2ab})} \tag{2}$$

In the above formula:

$$a = \sqrt{800^2+200^2}mm;$$

$$b = 300mm;$$

$$c = \sqrt{800^2+100^2}mm;$$

S_1 is the length of the left cylinder;

S_2 is the target length of the right cylinder.

When the paver turns, the left cylinder extends first, and the extension length of the left cylinder is obtained from the feedback signal of the displacement sensor, plus the initial length of the cylinder is the left cylinder length S_1. Calculate the rotation angle of the left steering column according to formula (1), which is the rotation angle of the right steering column, and calculate the target length S_2 of the right cylinder according to formula (2).

When the paver turns to the left, S_2 can be obtained in the same way as formula (2).

3. Synchronous Steering Control Principle

The overall framework of the control system is as follows: First, install displacement sensors on the left rear oil cylinder and the right rear oil cylinder to feed back the changing length of the oil cylinder in real time. Secondly, according to the left oil cylinder length combined formula (2), the target length of the right oil cylinder is calculated by the controller and used as the input of the closed loop system, and the right oil cylinder length fed back by the displacement sensor on the right oil cylinder is set as the comparison value. After PID calculation [2], the output PWM value is provided to the right cylinder proportional directional valve for execution.

The PLC's PID control algorithm design is based on the continuous PID control law, and computer control is a kind of sampling control. It can only calculate the control value based on the deviation value at the sampling time, so it is digitized and written into a discrete form of

PID equation , And then design the control program according to the discrete equation. In a continuous system, a typical PID closed-loop control system is shown in Figure 4.

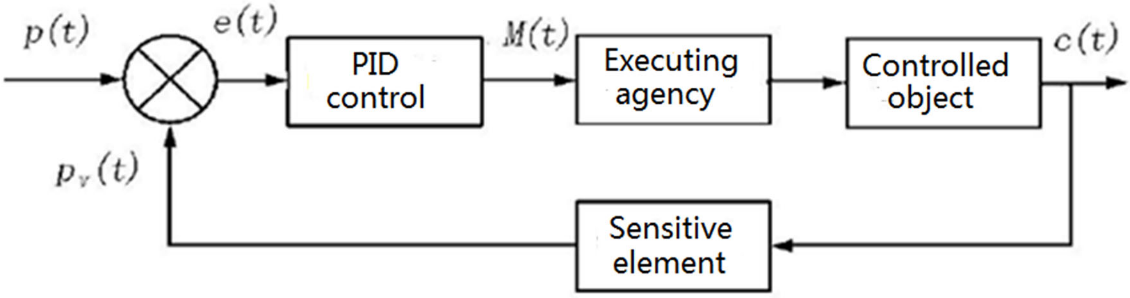

Figure 4. Block diagram of continuous closed loop control system

In Figure 4 , $p(t)$ is the given value, which is the target length signal of the right rear cylinder, $p_v(t)$ is the feedback quantity, which is the real-time length feedback signal of the right rear cylinder, and $c(t)$ is the output of the system, that is, the signal that controls the expansion and contraction of the right rear cylinder.

As the most widely used control method in process control, PID control is widely used in industrial control and experimental control due to its convenient, effective and reliable characteristics. This article uses positional PID algorithm for controller design. The PID formula is:

$$M(t) = K_c[e(t) + \frac{1}{T_t}\int_0^t e(t)dt + \frac{1}{T_d} de(t)/dt] + M_0 \tag{3}$$

Among them: $M(t)$ is the controller output; M_0 is the initial value of the output; $e(t) = p(t) - p_v(t)$ is the error signal; K_c is the proportional coefficient; T_i is the integral time constant; T_d is the derivative time constant.

4. Synchronous Steering Control Program based on CoDeSys

CoDeSys [3] is a powerful PLC software programming tool, it supports IEC61131-3 standard IL, ST, FBD, LD, CFC, SFC six PLC programming languages, users can choose different languages in the same project to edit subroutines, functions Modules etc. Select EPEC controller, use ST language in CoDeSys software to program the synchronous steering control program. The calculation process and PID module are written into the program together, and the realization of the synchronous steering control program of the three-track paver in manual mode is as follows:

```
lengthhz:=REAL_TO_WORD(300*(WORD_TO_REAL(AI_X3_7_H_Z_STEER_I)-178)/(863-178));
lengthhz_s:=WORD_TO_REAL(lengthhz)+640;
alpha:=ACOS((770625-lengthhz_s*lengthhz_s)/495000);
length_hy_goal:=SQRT(770625-495000*COS(144.92/57.296-alpha))-640;
IF DI_X2_8_STEER_SERVO=1 AND (HZ_A_M=0 OR HY_A_M=0) THEN
    IF (HZ_Z=1 OR HY_Z=1) THEN
        PWM_RATIO_X1_22_HZ_CYL_E:=REAL_TO_WORD(ratioU*hz_steer_ratio);
        Steer_goal_hy_U:=length_hy_goal+4;
        Steer_goal_hy_D:=length_hy_goal-4;
```

ISSN: 2688-8645

```
        steer_hy(
                PID_out_pos_min:=770 ,
                PID_out_pos_max:=900 ,
                offset_pos:=Steer_goal_hy_U ,
                Fast_calculation_Add:=420 ,
                Fast_calculation_Sub:=420 ,
                PID_out_max:=900 ,
                PID_out_min:=-900 ,
                D_parameter:=0.1 ,
                PID_out_neg_min:=-900 ,
                PID_out_neg_max:=-770 ,
                I_parameter:=0.1,
                P_parameter:= 2.5,
                offset_neg:=Steer_goal_hy_D ,
                PID_goal:=length_hy_goal ,
                Actual_input:=lengthhy,
                PWM_RATIO_CYL_E=> CYL_E,
                PWM_RATIO_CYL_R=> CYL_R);
        PWM_RATIO_X2_6_HY_CYL_E:=CYL_E;
        PWM_RATIO_X2_7_HY_CYL_R:=CYL_R;
END_IF
END_IF
```

5. Experimental Verification and Conclusion

Pour the written program into the EPEC controller and start the machine for testing. It is found that the actual effect is good. The steering angle of the latter two tracks is basically the same, as shown in Figure 5. It has been proved that the method of synchronous steering control based on PID-based three-track paver in manual mode is feasible.

Figure 5. Real machine test effect diagram

ISSN: 2688-8645

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