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Fuzzy Adaptive PID Control of a New Hydraulic Erecting Mechanism

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Abstrak

Mekanisme ereksi konvensional adalah rumit dan kecepatan ereksi adalah lambat, sehingga mekanisme ereksi hidrolik baru diperkenalkan pada makalah ini. Tetapi mekanisme ereksi ini memiliki dua masalah. Pertama adalah masalah kerja sama antara silinder tegak dan silinder horizontal. Kedua, nonlinier dan ketidakpastian yang ada dalam sistem yang membuat presisi kendali yang buruk. Karenanya dikembangkan model simulasi gabungan dibangun berdasarkan pada perangkat lunak AMESim dan Simulink. Dan dari model ini, waktu terbaik kerjasama dikonfirmasi. Selanjutnya, pengendali PID adaptif fuzi diperkenalkan untuk meningkatkan kinerja pengendalian yang ditujukan untuk masalah nonlinier dan ketidakpastian. Aturan inferensi fuzi dan parameter pengendali juga disajikan pada makalah ini. Hasil eksperimen menunjukkan bahwa waktu kerja sama yang diterima dari simulasi sudah benar, dan pengendali PID adaptif fuzi memiliki kinerja pelacakan lebih baik dibandingkan dengan pengendali PID dan pengendali fuzi konvensional.

Keywords: *Hydraulic erecting mechanism; Simulation; Fuzzy adaptive PID control; Nonlinearity*

Abstract

Conventional erecting mechanism is cumbersome and the erecting velocity is slow, so a new hydraulic erecting mechanism is introduced in this paper. But it has two problems. First is the cooperation problem between the erect cylinder and the horizontal cylinder. Second, the nonlinearities and uncertainties exist in the system make the control precision poor. So the combined simulation model is built based on the software AMESim and Simulink. And from this model, the best cooperation time is confirmed. Further, the fuzzy adaptive PID controller is introduced to improve the control performance aiming to the nonlinearities and uncertainties. The fuzzy inference rules and parameters of the controller are also presented in this paper. Experiment results show that the cooperation time which received from the simulation is correct, and the fuzzy adaptive PID controller has nice tracking performance compared to the conventional PID controller and fuzzy controller.

Keywords: *Hydraulic erecting mechanism; Simulation; Fuzzy adaptive PID control; Nonlinearity*

1. Introduction

Electro-hydraulic proportional systems are widely used in erecting mechanism of large machineries, equipments and armaments for their high power capability, mechanical efficiency, good positioning capability and fast response characteristics. The commonly erecting mechanism is mainly composed of erect arm, erect cylinder, vehicle frame, and so on. And its back hinge pivot is fixed. This make the erecting mechanism is cumbersome and the erecting velocity is slow [1-2]. So a new hydraulic erecting mechanism with removable back hinge pivot is presented in this paper. The working principle of the new erecting mechanism is illustrated in Figure 1.

Compared with the conventional erecting mechanism, the new one adds two horizontal cylinders (left and right horizontal cylinder), a tramroad and a slide block. The back hinge pivot is not fixed on the vehicle frame, but linked to the horizontal cylinder by slide block. In the process of erecting, the erect cylinder drives the erect arm and load turn around the pivot O_3, and the horizontal cylinder draw back to pull the erect arm glide along the tramroad.

However, this new erecting mechanism has two problems: first, the two cylinders cooperation problem that is at what time the horizontal cylinder starts and stops is the best,

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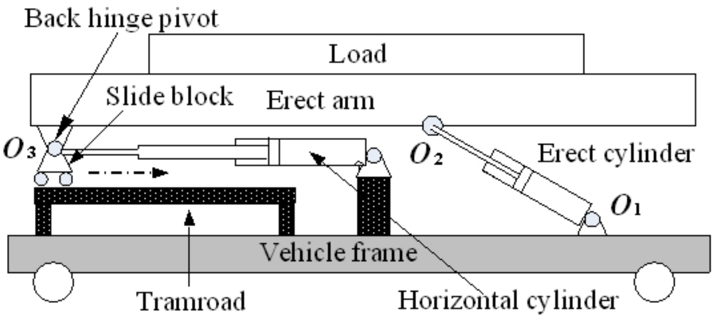


Figure 1. Erecting mechanism with removable back hinge pivot

second, the mechanism has many uncertainties, time varying and highly nonlinear characteristics due to the flow-pressure relationship, oil leakage, dead zone of valve, volume flow unbalance of asymmetrical cylinder and so on, so the conventional linear control methods cannot guarantee our request for the large erecting mechanism. In recent years many research efforts on erecting mechanism control have been made. For example, an intelligent integration control method is used to velocity tracking [3]. Furthermore, a nonlinear predictive controller based on the BP neural network is proposed in the same year [4]. These control methods provide satisfactory results from the simulations. But they need to know the accurate mathematic model. And the authors did not give the experiment validation. Fuzzy logic-based controller is an intelligent control method and needn't to know the accurate mathematical model of the controlled object. So in recent years, more and more research using fuzzy controller in hydraulic proportional system have appeared, especially the fuzzy adaptive PID controller which combined the fuzzy controller and PID controller has good control performance [6-12].

In order to solve the above two problems, the simulation model is built to get the best cooperation time of the two cylinders, and applying fuzzy adaptive PID controller to overcome the nonlinearities exist in the erecting mechanism. The experiments have been down to prove the validity of the simulation results.

2. Simulation model and fuzzy adaptive PID control

The software AMESim can effectively simulated the mechanical and hydraulic system, but it is hard to realize a complicated control method. However, the software Simulink has good ability to model a control method. So in order to simulate the actual system farthest, the software AMESim and Simulink are combined by the interface to establish the simulation model of the erecting mechanism.

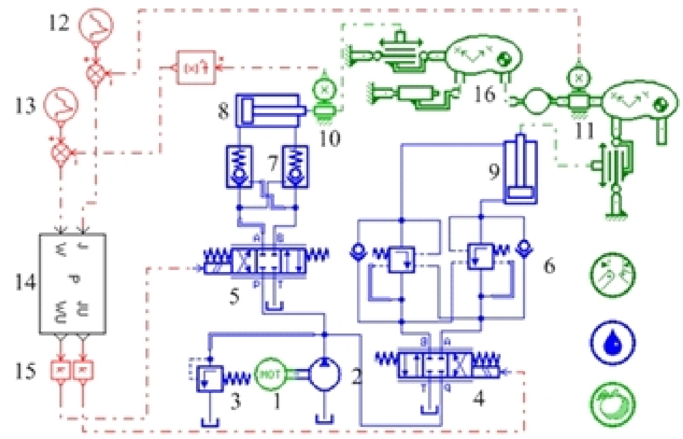
2.1 Combined simulation model based on the software AMESim

Build simulation model in the software AMESim under the sketch mode as shown in Figure 2. In actual modeling, for the two horizontal cylinders are linked by a pin and the software AMESim cannot establish three-dimensional model, so we applying one cylinder equivalent to the two cylinders. And the software AMESim and Simulink are communicated by the interface module 14.

2.2 Fuzzy adaptive PID controller design

The erecting mechanism is a complicated nonlinear system as introduced in section 1. Applying conventional linear controller is difficult to achieve high control performance due to the influences of the uncertain factors exist in the system. So the fuzzy adaptive PID controller is introduced to overcome the above problems.

The fuzzy adaptive PID controller is combined the PID controller with the fuzzy logic algorithm and its principle is shown in Figure 3. It has two inputs error e and change in error ec, and three outputs ΔK_p, ΔK_i and ΔK_d which are the change in parameters K_p, K_i and K_d of the PID controller.



1-electrical motor; 2-hydraulic pump; 3-relef valve; 4, 5-electrically operated 3 position 4 port hydraulic servo-valve; 6-counterbalance valve; 7-hydraulic check valve; 8-horizontal cylinder; 9-erect cylinder; 10, 11-linear displacement transducer 12-reference angle signal; 13-reference displacement signal; 14-interface module 15-gain; 16-mechanical system

Figure 2. Combined simulation model in the AMESim

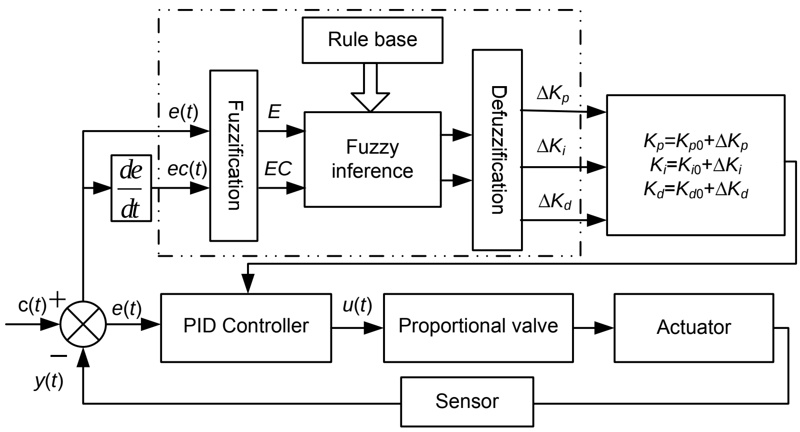


Figure 3. Structure of the fuzzy adaptive PID controller

The core of fuzzy adaptive PID controller is the fuzzy algorithm and it composed of three main elements: fuzzification, fuzzy inference, and defuzzification. The first step is fuzzification of the input and output variables, which transforms the input and output data into semantic value. The fuzzy range of all the variables *e*, *ec*, ΔK_p, ΔK_i , ΔK_d are uniform fuzzy range [-1 1], and the fuzzy subsets of the semantic value is [*NB, NM, NS, ZO, PS, PM, PB*] where *NB* is negative big; *NM* is negative middle; *NS* is negative small; *ZO* is zero; *PS* is positive small; *PM* is positive middle; *PB* is positive big. And all membership function is triangular membership function *'trimf'*. The most important step is establishment of fuzzy inference rule between the input variables *e*, *ec* and the output variables ΔK_p, ΔK_i , ΔK_d based on the experience of experts or input-output data. From the simulations and experiments, the fuzzy inference rules are summarized in Table 1. There are 49 rules in Table 1, and the implication used in the rules is as follows:

If *e* is A_i and *ec* is B_j, then ΔK_p /ΔK_i /ΔK_d is C_{ij} /D_{ij} /E_{ij} where A_i, B_j, C_{ij}, D_{ij}, E_{ij} are corresponding to the fuzzy subsets of *e*, *ec*, ΔK_p, ΔK_i, ΔK_d.

The third step is defuzzification which is converting the fuzzy value into the numeric value. The center of gravity method is applied to obtain the numeric value. After defuzzification, the three parameters K_p, K_i and K_d can be obtained as follows:

$$K_p=K_{p0}+\Delta K_p;\ K_i=K_{i0}+\Delta K_i;\ K_d=K_{d0}+\Delta K_d$$

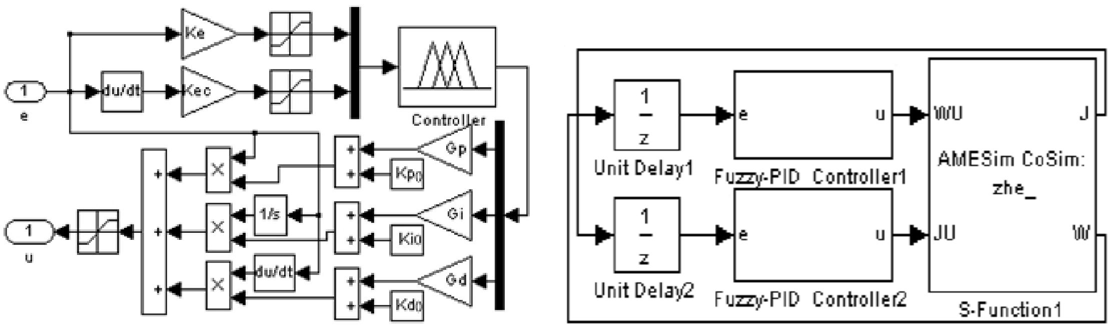
where K_{p0}, K_{i0} and K_{d0} are the original parameters of the PID controller.

Table 1. Fuzzy inference rules of ΔK_p, ΔK_i and ΔK_d

$\Delta K_p/\Delta K_i/\Delta K_d$ (e \ ec)	NB	NM	NS	ZO	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/NS/NB	ZO/ZO/NM	ZO/ZO/PS
NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/ZO/ZO
NS	PM/NB/ZO	PM/NM/NS	PM/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/PS/NS	NS/PS/ZO
ZO	PM/NM/ZO	PM/NM/NS	PS/NS/NS	ZO/ZO/NS	NS/PS/NS	NM/PM/NS	NM/PM/ZO
PS	PS/NM/ZO	PS/NS/ZO	ZO/ZO/ZO	NS/PS/ZO	NS/PS/ZO	NM/PM/ZO	NM/PB/ZO
PM	PS/ZO/PB	ZO/ZO/NS	NS/PS/PS	NM/PS/PS	NM/PM/PS	NM/PB/PS	NB/PB/PB
PB	ZO/ZO/PB	ZO/ZO/PM	NM/PM/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

2.3 Simulink model of the Fuzzy adaptive PID controller

Fuzzy Logic Toolbox of the Simulink is an important toolbox which is mainly used to design fuzzy controller. Based on the principle of fuzzy adaptive PID controller, the Simulink model is established as shown in Figure 4 (a) after designing the fuzzy controller by the Fuzzy Logic Toolbox. K_{p0}, K_{i0} and K_{d0} are the original parameters of the PID controller, and G_p, G_i, G_d, K_e, K_{ec} are proportional coefficients. Then the combined model in the Simulink is shown in Figure 4 (b) where Fuzzy-PID Controller1 is applied to control horizontal cylinder and Fuzzy-PID Controller2 is applied to control erect cylinder. And Table 2 gives the best parameters of the fuzzy adaptive PID controller.



(a) Fuzzy adaptive PID controller (b) Combined simulation model in the Simulink

Figure 4. Fuzzy adaptive PID controller model

Table 2. Parameters of the fuzzy adaptive PID controller

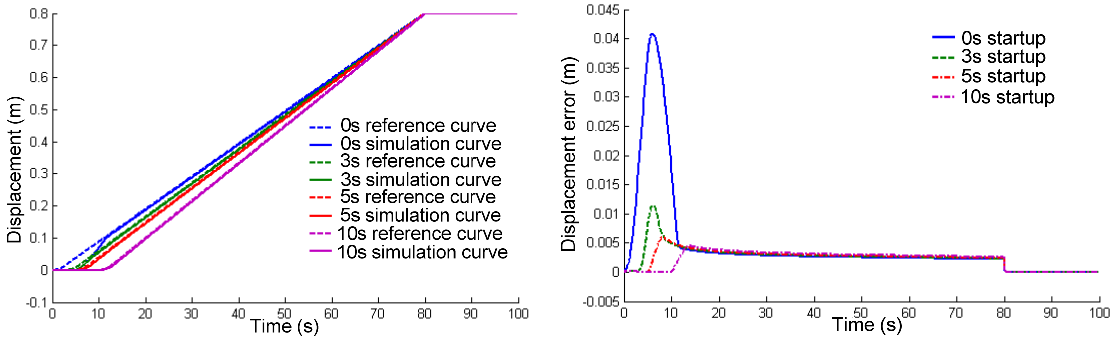
Parameters		Horizontal cylinder	Erect cylinder
PID parameters	K_{p0}	2.5	450
	K_{i0}	0.04	0.1
	K_{d0}	0.7	8
Proportional coefficients	K_e	0.2	5
	K_{ec}	0.2	5
	G_p	2	400
	G_i	0.02	0.08
	G_d	0.5	2

3. Simulation results

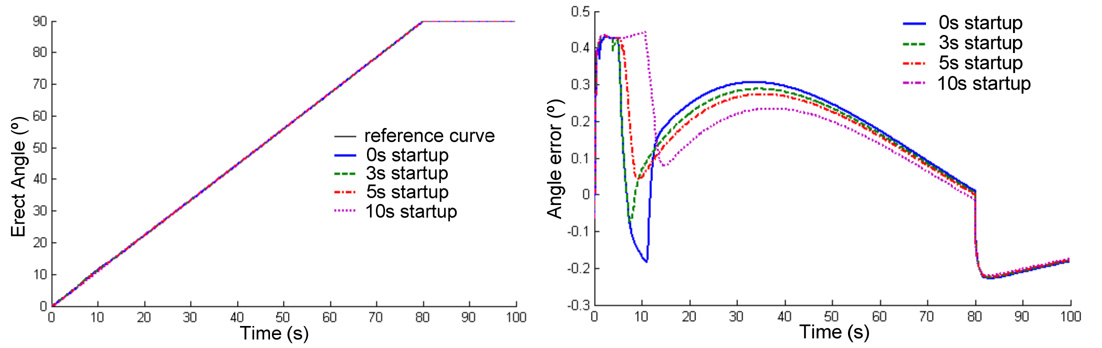
Due to the new erecting mechanism has two cylinders, the cooperation problem exists in the process of erecting. The experiment studies show that for the horizontal cylinder stressed great force at the beginning, the piston rod cannot extend out. So the horizontal cylinder should start acting between 15° and 20°. Then the two cylinders acting together and the horizontal cylinder stop acting at a certain angle. The start and stop point have great impact on the erecting process, so it needs further study. Meanwhile, the performance of fuzzy adaptive PID controller is also needs to validate.

3.1 Startup time of the horizontal cylinder

In order to confirm the start point of the horizontal cylinder, set the horizontal cylinder start acting at the time 0s, 3s, 5s, 10s respectively and stop acting with the erect cylinder at the time 80s. And applying the fuzzy adaptive PID controller introduced in section 2 to tracking the reference curve. The simulation results are shown in Figure 5.



(a) Displacement of the horizontal cylinder (b) Tracking error of the horizontal cylinder



(c) Erect angle curve (d) Tracking error of the erect arm

Figure 5. Simulation results of the startup time

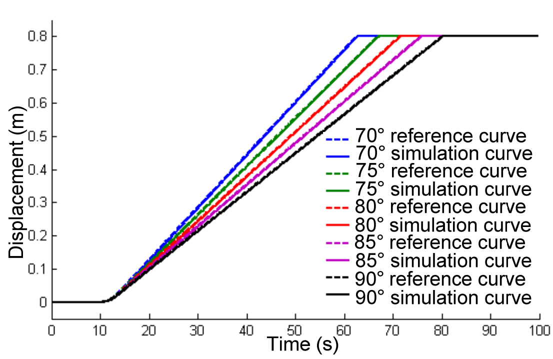
From Figure 5(a), it can be seen that at the beginning the displacement of horizontal cylinder is zero, because the stress force acted on the horizontal cylinder is too big to pull the erect arm, after 5 second, the horizontal cylinder starts working and the displacement has increased with the erect angle. Meanwhile, the tracking error has become decrease as shown in Figure 5(b), after 12 second, the tracking error has become stable. And the response time and tracking error have decreased with the startup time increasing. For example, the max error is 0.041m when the startup time is 0 second, but 0.0047m when the startup time is 10 second. Figure 5(c) and (d) exhibit the erect angle curve and tracking error of the erect arm under different startup time. It can be seen that the startup of horizontal cylinder has great effect on the erect arm and erect cylinder, and it has the minimum effect when the startup time is 10 second.

The simulations results show that there is a critical startup point for the horizontal cylinder. If the horizontal cylinder starts working before this critical point, the tracking error is too big, so the horizontal cylinder should act after this critical point. For this system, the best startup time is 10 second.

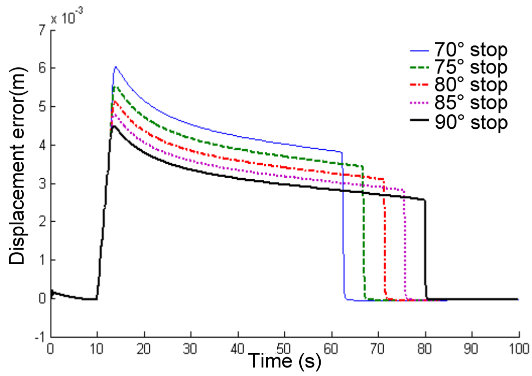
3.2 Stop time of the horizontal cylinder

Set the horizontal cylinder start working at 10 second, and stop at the erect angle is 70°, 75°, 80°, 85°and 90°. The simulation results are shown in Figure 6.

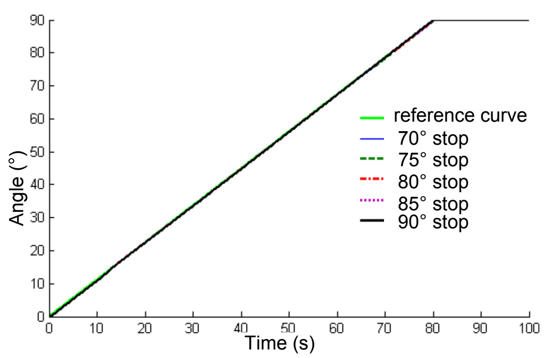
In Figure 6(b), we can see that the higher erect angle the smaller tracking error of the horizontal cylinder. And the minimum is at the angle 90 degree and the max error is 4.5mm. Figure 6(d) presents the tracking error of erect arm. We can see that before the horizontal cylinder acting the tracking error is much big, but it decreased sharply when the horizontal cylinder starts working. And it will increase if the erect angle is less than 90 degree. So the best stop angle is 90 degree, and the max tracking error of the erect cylinder is 0.45 degree.



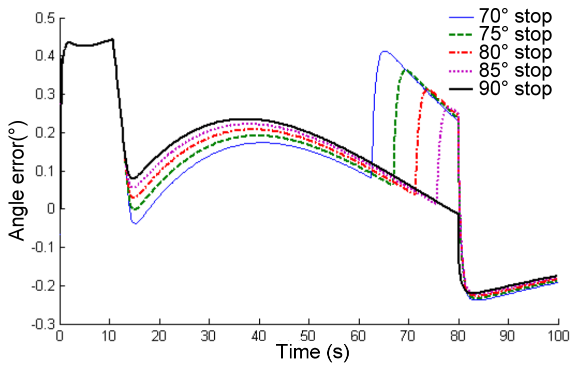
(a) Displacement of the horizontal cylinder



(b) Tracking error of the horizontal cylinder



(c) Erect angle curve



(d) Tracking error of the erect arm

Figure 6. Simulation results of the stop time

4. Experiment results

The best cooperation time between horizontal cylinder and erect cylinder is derived in section 3, this section we will do experiments to validate the simulation results and actual performance of the fuzzy adaptive PID controller. The experiment flat of the erecting system is contructed in our Lab. And the main equipments are shown in Figure 7.

The pressure sensor, angle sensor, angle velocity sensor and displacement sensor are applied to measure the pressure, erect angle, erect angle velocity, and displacement of the horizontal cylinder, respectively. The software Labwindows/CVI of the NI Company is used for controlling flat, and it has interface with the software Matlab, so it can use Fuzzy Logic Toolbox of the Matlab to realize fuzzy inference calculate. Then the calculate output import to the proportional valve to control the hydraulic cylinders. The hydraulic system pressure is 8MPa and the reference curves are the same as in the simulation.

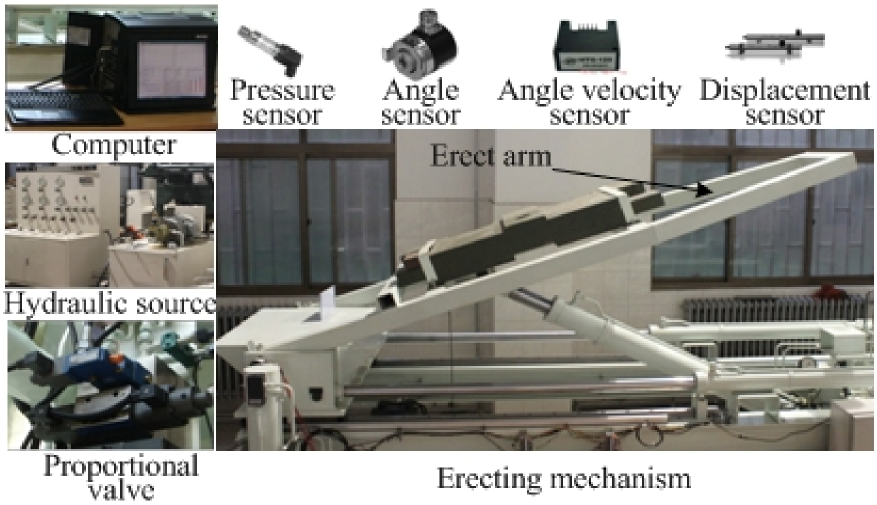


Figure 7. Experiment flat of the erecting system

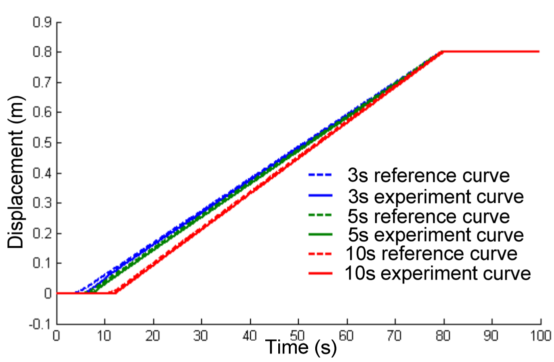
The hydraulic source is the power take-off that drives the mechanism to erect. And the computer is used to handle all the I/O data operation for the whole system and to calculate the control law based on the software. The erect angle and the displacement of the horizontal cylinder are controller as follows: Once the voltage inputs corresponding to the desired angle θ_d or displacement x_d and the actual angle θ or displacement x are transmitted to the fuzzy adaptive PID controller, the input current is generated in proportion to the output from the fuzzy controller. Then, the proportional valve spool position and direction are controlled according to the input current. Depending on the spool position, the flows as well as the direction supplied to each cylinder chamber is determined. The motion of the erect arm and the displacement of the horizontal cylinder are then controlled by these flows.

First, we do experiments to valdate the startup time and stop time of the horizontal cylinder. Then the performance of the fuzzy adaptive PID controller is compared to the fuzzy controller and PID controller. The experiment results are shown in Figure 8-10.

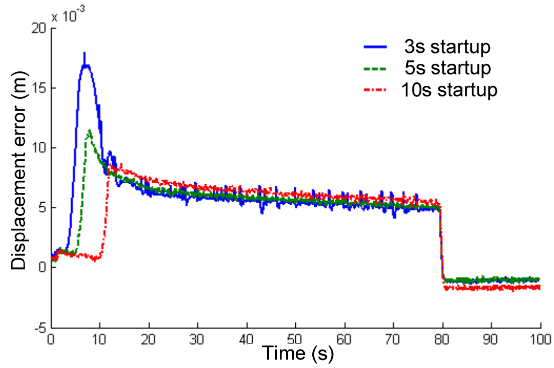
Figure 8 shows the experiment results of the startup time. We can see that the experiment results are similar to the simulation results in general, and the best startup time is also at 10 second. Compared with the simulation, the experiment curves are not smooth, and the tracking error is much bigger, for example, at 10 second startup the max error of horizontal cylinder is 8.82×10^{-3}m for the experiment, but just 4.78×10^{-3}m for the simulation. Similarly, the max error of erect cylinder is about 1.45° for the experiment, but 0.425° for the simulation. And in Figure 8(d), after the horizontal cylinder startup, the error is much steadier than that of the simulation.

The experiment results of stop time are shown in Figure 9. It can be seen that the experiment results are similar to the simulation too, but noises exist in the experiment curves as shown in (b) and (d). And the max error is also different, for example, the max tracking error of the horizontal cylinder and erect cylinder is 8.7×10^{-3}m and 1.43° for the experiment, but just 4.5×10^{-3}m and 0.45° for the simulation.

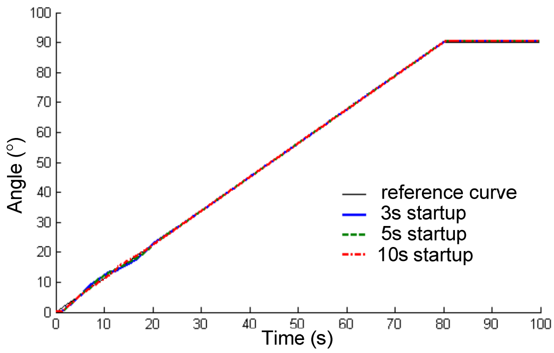
In order to demonstrate the tracking ability of fuzzy adaptive PID controller, the tracking experiment is designed. Applying the fixed fuzzy controller, PID controller and fuzzy adaptive PID controller to track the erect angle curve, the experiment results are shown in Figure 10. And the parameters of PID controller 1 is K_{p1}=250, K_{i1}=0.08, K_{d1}=5, and PID controller 2 is K_{p2}=450, K_{i2}=0.1, K_{d2}=8.



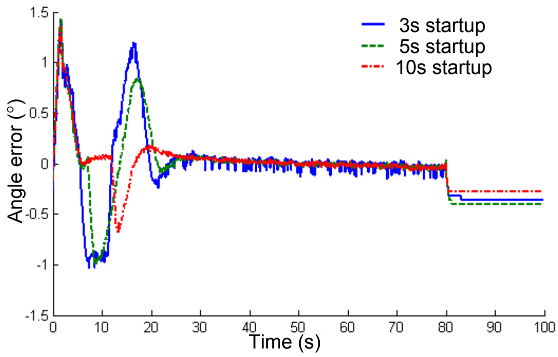
(a) Displacement of the horizontal cylinder



(b) Tracking error of the horizontal cylinder

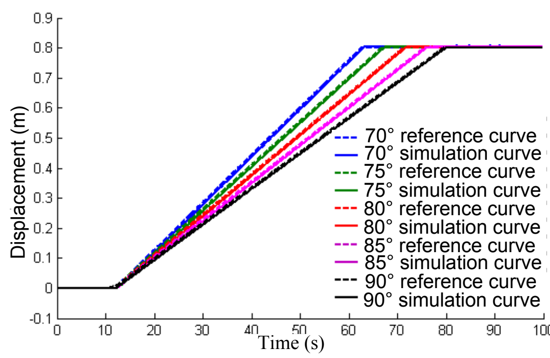


(c) Erect angle curve

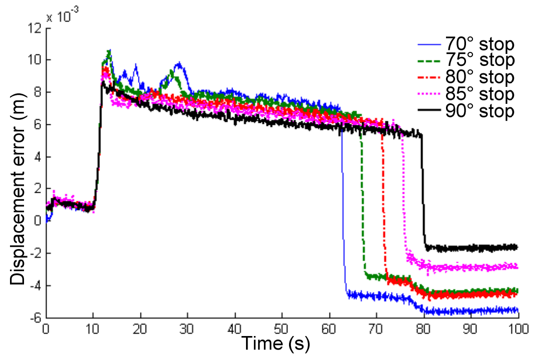


(d) Tracking error of the erect arm

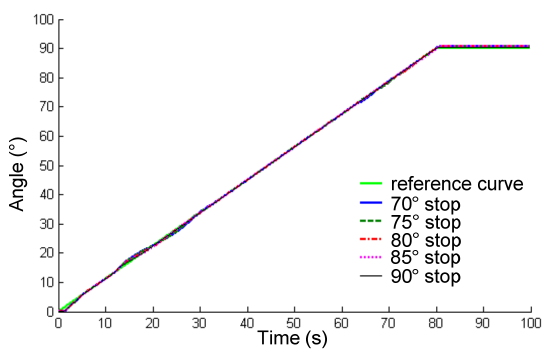
Figure 8. Experiment results of the startup time



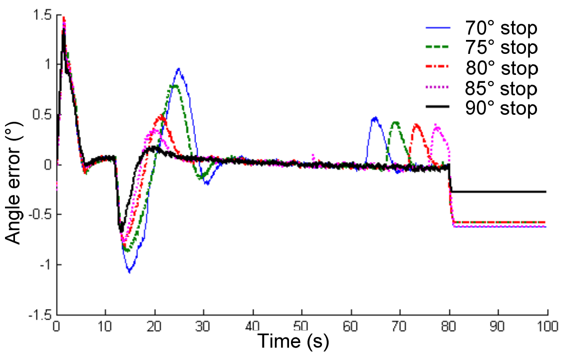
(a) Displacement curve of the horizontal cylinder



(b) Tracking error of the horizontal cylinder



(c) Erect angle curve



(d) Tracking error of the erect arm

Figure 9. Experiment results of the stop time

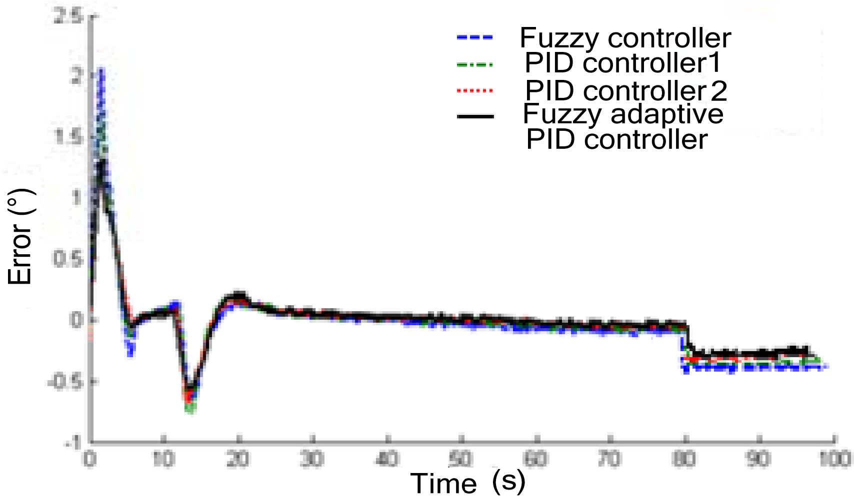


Figure 10. Experiment results of different controllers

Figure 10 shows the tracking error. We can see that the fuzzy adaptive PID controller has the best tracking precision, and the max error is 1.38°, but 2.07° for fixed fuzzy controller, 1.71° for PID controller 1 and 1.42° for PID controller 2.

5. Conclusion

In this paper, a new hydraulic erecting mechanism with removable back hinge pivot is presented. However, it has a cooperation problem between horizontal cylinder and erect cylinder for this erecting mechanism. So the simulation model is built using the software AMESim and Simulink. From the simulations, the cooperation time is confirmed. And the best startup time of the horizontal cylinder is 10s and stop time is at the erect angle 90°. The other problem is the nonlinearities and uncertainties exist in the system make the conventional linear control hard to satisfy our request. Therefore, a fuzzy adaptive PID controller is introduced to overcome the nonlinearities and uncertainties. Experiments have been down to shown that the cooperation time is correct and the fuzzy adaptive PID controller performs more accurate tracking ability compared with the fixed fuzzy controller and conventional PID controller.

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