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Co-simulation and Experiment Research on a Novel Erection Mechanism

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Abstract

The erection mechanism with movable back hinged bearing is a novel erection mechanism and the form of its moving process is complicated. The novel erection mechanism needs to be extensively tested to prove its value and to ensure it works properly. Kinematic analysis was accomplished and mathematical model of the hydraulic system was acquired. Fuzzy adaptive PID control was adopted for the erection mechanism taking advantage of fuzzy control and PID control. The novel erection mechanism was validated by virtual prototype technology realized by co-simulation method. The mechanical, hydraulic and control models were respectively established in ADAMS, AMESim and Simulink. Experiment was completed on a platform. The results of simulation and experiment indicated that the novel erection mechanism could move based on designed scheme and the control effect of fuzzy adaptive PID control was excellent. The novel erection mechanism had great practical value.

Keywords*: Erection mechanism, Co-simulation, Virtual prototype technology, Fuzzy control*

1. Introduction

The erection mechanism with movable back hinged bearing is a novel erection mechanism. Compared with traditional erection mechanism it adds horizontal cylinder, therefore back hinged bearing can move in horizontal direction driven by hydraulic cylinder. The novel mechanism can fulfill the erection requirements in strictured space. The erection mechanism needs to be extensively tested to prove its value and to ensure it works properly.

Experiments normally require expensive equipment and long process of part design and system integration. Comprehensive simulations are often necessary and helpful. The erection mechanism contains mechanical and hydraulic system, therefore alone software cannot completely achieve its feature. The dynamic behavior of hydraulic system is highly non-linear due to the phenomena such as nonlinearities of valve cylinder combination, friction, fluid compressibility and associated stiffness, which cause difficulties in the control of such systems.

Virtual prototype technology provides an effective approach for investigating the novel erection mechanism. One widely used simulation software is Simulink, which is a diagram programming method and provides a general environment. ADAMS is a powerful mechanical design and simulation software, which provides tools to build mechanical structures and 3D visual simulation. AMESim offers a graphical modeling approach and many libraries of components particularly in hydraulics. Co-simulation method has been extensively adopted in research and simulation of hydraulic steel-belt overwind buffer device [1], braking performance of a vehicle [2], a two-axis tracking system [3], four-wheel-drive hybrid electric vehicle [4], a turbojet fuel system [5], parallel hybrid loader [6], an electric bus with motorized wheels [7], the composite ABS control of vehicles [8], and so on. The co-simulation platform exploits the advantages of different software. The simulation results illustrate that virtual prototype technology has a good application in many scopes and is an effective approach for investigating behaviors of complex systems. It can also save time and cost. Fuzzy logic control is an alternative approach to achieve desired goals. Chen C. Y. [9] proposed an integrated fuzzy controller to achieve a synchronous positioning objective for a dual-cylinder electro-hydraulic lifting system with unbalanced loadings, system uncertainties and disturbances. The experimental results showed that the controller can effectively achieve the objective of position synchronization. Li L [10] proposed a fuzzy adaptive sliding mode control scheme which

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combined fuzzy control with sliding mode control to achieve nonlinear control of the ercting mechanism. Chiang M. H. [11] combined fuzzy logic and sliding mode control to develop an electro-hydraulic velocity controller that was robust to external load disturbances. Zheng J. M. [12] used fuzzy control to an electro-hydraulic position servo and provided good tracking performance even subjected to external disturbances. Otto Cerman [13] introduced a method for design of a fuzzy sliding mode controller for electro-hydraulic servo mechanism. The results from above research showed that fuzzy control has been successfully used in the complex process with good performance. It has a short rise time and a small overshoot.

We introduced co-simulation method to simulate the erection mechanism. The erection system was modeled in ADAMS, AMESim and Matlab/Simulink. The advantages of ADAMS in mechanical system, AMESim in hydraulic system and Simulink in advanced controller design were exploited and combined to offer an integrated simulation for the erection mechanism. Fuzzy adaptive PID control was adopted to control the novel erection mechansim. It was able of adaptation to parameter changes and deal with nonlinear dynamic behavior associated with hydraulic motion system. The aim of this research is to investigate the novel erection mechanism and prove its value.

2. Composition of the Novel Erection Mechanism

The erection mechanism with movable back hinged bearing is mainly composed of erection arm, lock device, rail, slider, erection and horizontal cylinders, as shown in Figure 1. Erection arm is used to support and erect load from horizontal state to vertical state or back to flat. Lock device is applied to fixing and limiting load against vertical and lateral movement on erection arm. Erection cylinder pushes load and erection arm rotating round back hinged bearing. Horizontal cylinder pulls back hinge bearing moving along the rail, realizing load moving in horizontal direction. Two horizontal cylinders are symmetrically arranged to ensure stability.

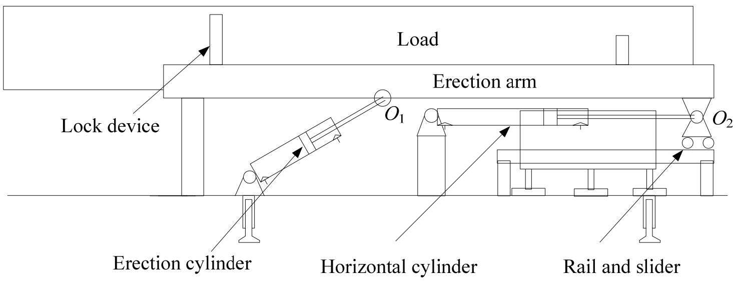


Figure 1. Composition of the novel erection mechanism

Compared with traditional erection mechanism, the erection mechanism with movable back hinged bearing adds rail, slider and horizontal cylinder. It adopts erection and horizontal cylinders to realize erection process. Erection cylinder is used to alter amplitude and horizontal cylinder to transfer horizontal position. The novel erection mechanism expands the moving form of erection mechanism.

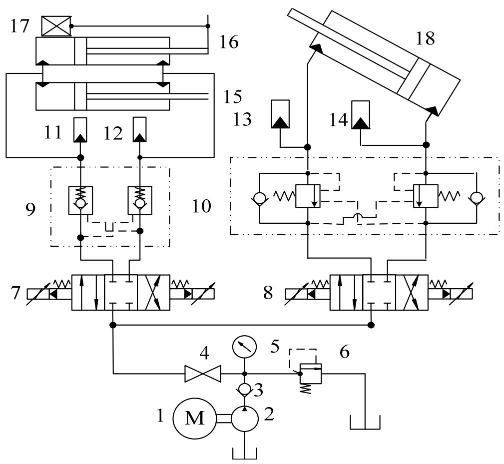
The erection process can be divided into three stages:

(1) Early erection stage. Horizontal cylinder is locked. Erection cylinder pushes the load and erection arm rotating round back hinged bearing to a certain angle.

(2) Cooperation stage. Horizontal cylinder starts to move. Erection and horizontal cylinders move together. The load and erection arm rotate round back hinged bearing as well as move in horizontal direction.

(3) Vertical adjustment stage. Horizontal cylinder ceases when erection angle attains about 80°~85°. The load is erected to vertical state by erection cylinder alone.

Hydraulic principle of the erection system is shown in Figure 2. Hydraulic system includes hydraulic pump, overflow valve, bidirectional balance valve, hydraulic lock, hydraulic cylinder, electro-hydraulic proportional valve and other components. From electro-hydraulic proportional 7 and 8 which control the speeds of hydraulic cylinders, pressure oil flow in the forward chambers of erection cylinder 18 and horizontal cylinder 15 and 16. This actualizes the load rotating round back hinged bearing which moves in horizontal direction.



1-Motor; 2-Pump ; 3-Check valve; 4-Throttle valve; 5-Pressure gage; 6-Relief valve; 7,8-Electro-hydraulic proportional valve; 9-Bilateral pilot-controlled valve; 10-Bilateral balance valve; 11,12,13,14-Pressure sensor; 15,16-Horizontal cylinder; 17-Displacement sensor; 18-Erection cylinder

Figure 2. Hydraulic principle of the erection system

3. Mathematical Model of the Erection Mechanism
3.1. Kinematic Analysis of the Mechanism

In order to acquire kinematic feature of the novel erection mechanism, kinematic analysis is accomplished firstly. In erection process the load and erection arm rotates around back hinged bearing and also moves in horizontal direction. Kinematic model is shown in Figure 3.

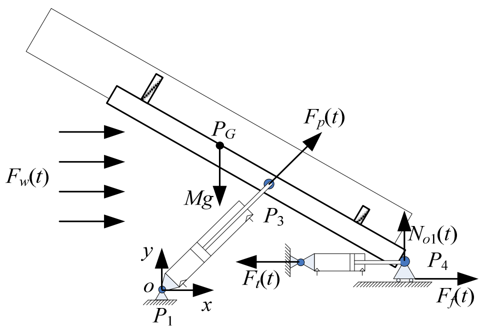


Figure 3. Kinematic model of the mechanism

In plane coordinate system *oxy*, P_1 is the origin of coordinate system. Supposes coordinate of P_3 is ($x_2(t)$, $y_2(t)$) and coordinate of P_4 is ($x_1(t)$, $y_1(t)$). The following equations can be acquired based on geometric relationship.

$$\sqrt{x_2^2(t)+y_2^2(t)}-l_{ei}=\int_0^t v_2(\tau)d\tau \quad (1)$$

$$\sqrt{[x_1(t)-x_2(t)]^2+[y_1(t)-y_2(t)]^2}=l_{em} \quad (2)$$

$$\theta(t) = \arctan\frac{y_2(t) - y_1(t)}{x_1(t) - x_2(t)} \quad (3)$$

Where $\overline{P_1P_3} = l_{ei}$ is the initial length of erection cylinder and $\overline{P_3P_4} = l_{em}$ represents the distance between two junctions. $\theta(t)$ refers to the erection angle. $v_1(t)$ and $v_2(t)$ are the speeds of two hydraulic cylinder piston rods.

Kinematic balance equations of the load and erection arm are as follows:

$$F_p(t)\cos\gamma(t) + F_f(t) - F_t(t) + F_w(t) = M\ddot{x}_1(t) \quad (4)$$

$$F_p(t)\sin\gamma(t) + N_{o1}(t) - Mg = M\ddot{y}_1(t) \quad (5)$$

$$F_p(t)l_p(t) - Mgl_G(t) + M_w(t) = J_P\ddot{\theta}(t) \quad (6)$$

Where $F_p(t)$ is thrust force of erection cylinder. $\gamma(t)$ represents the angle between thrust force and positive x axis. $F_f(t)$ is friction force between rail and slider. $F_t(t)$ is pull force of horizontal cylinder. $F_w(t)$ is calculated wind load. M represents mass of the load and erection arm. $N_{o1}(t)$ is support force of rail to slider. $l_p(t)$ is thrust force arm of erection cylinder to point P_4. $l_G(t)$ is load gravity arm to point P_4. $M_w(t)$ is the moment of calculated wind load. J_P is the moment of inertia of the load and erection arm to point P_4. $l_p(t)$ and $l_G(t)$ are defined as:

$$l_p(t) = \frac{l_{em}\sqrt{x_1^2(t) + y_1^2(t)}}{\sqrt{x_2^2(t) + y_2^2(t)}}\left[\sin\theta(t) + \arctan\frac{y_1(t)}{x_1(t)}\right] \quad (7)$$

$$l_G(t) = \overline{P_GP_4}\cos[\theta(t) + \alpha_0] \quad (8)$$

Wind load is given by:

$$F_w(t) = \sum q_i S_i \quad (9)$$

Where S_i is calculated windward area and q_i represents wind pressure corresponding calculated windward area.

3.2. Mathematical Model of the Hydraulic System

Servo valve and hydraulic cylinder are two important parts in the electro-hydraulic actuator system as shown in Figure 4. The cylinder ports are connected to a proportional valve, and piston motion is obtained by modulating the oil flow into and out of the cylinder chambers. P_s is the hydraulic supply pressure and P_0 is the return pressure. x_v is the spool valve displacement. q_1 and q_2 are fluid flow from and to cylinder. P_1 and P_2 are the fluid pressure in the forward and return cylinder chambers of the actuator, respectively. A_1 is the piston side area and A_2 is the rod side area. When differences between P_1 and P_2 exist, the hydraulic cylinder extends or compresses.

The flow through a restriction is generally turbulent and proportional to the squared root of the pressure drop. Equations of flow through the valve orifices come from orifice flow equations explained in the following equations.

$$q_1 = C_d w x_v\sqrt{\frac{2g}{\gamma}(p_s - p_1)} \quad (10)$$

$$q_2 = C_d w x_v\sqrt{\frac{2g}{\gamma}(p_2 - p_0)} \quad (11)$$

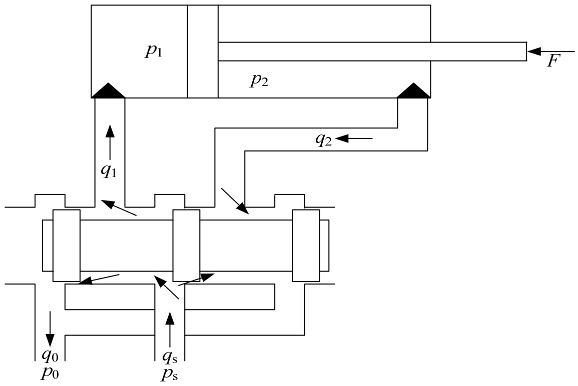


Figure 4. Schematic diagram of the hydraulic system

Where C_d is discharge coefficient, w is the spool area gradient and ρ is the fluid density.

In order to obtain a mathematical description of instantaneous pressure insider the forward and return cylinder chambers, the fluid flow balance equations are considered for two control volumes at each side of the cylinder.

The derivative of the load pressure is given by the total load flow through the actuator. It divided by the fluid capacitance and also taking leakage and compressibility into consideration. We can obtain the flow continuity equations:

$$q_1 = \frac{dV_1}{dt} + \frac{V_1}{\beta_e}\frac{dp_1}{dt} + C_{ec}p_1 + C_{ic}(p_1 - p_2) \tag{12}$$

$$q_1 = A_1\frac{dy}{dt} + \frac{(V_{01} + A_1 y)}{\beta_e}\frac{dp_1}{dt} + (C_{ec} + C_{ic})p_1 - C_{ic}p_2 \tag{13}$$

$$q_2 = -\frac{dV_2}{dt} - \frac{V_2}{\beta_e}\frac{dp_2}{dt} - C_{ec}p_2 + C_{ic}(p_1 - p_2) \tag{14}$$

$$q_2 = A_2\frac{dy}{dt} + \frac{(V_{02} - A_2 y)}{\beta_e}\frac{dp_2}{dt} - (C_{ec} + C_{ic})p_2 + C_{ic}p_1 \tag{15}$$

Where V_1 and V_2 are the total fluid volumes in the two cylinder chambers, V_{01} and V_{02} are the original total fluid volumes of the two cylinder chambers (including the volume of pipelines and initial cylinder chambers), A_1y and A_2y represent the flow rates as a function of volume change due to piston motion, β_e is the bulk modulus of hydraulic fluid.C_{ic} and C_{ec} are the internal and external leakage coefficient.

The dynamic equation of the hydraulic system with mass m is described by Second Newton Law:

$$m\frac{d^2y}{dt^2} = A_1p_1 - A_2p_2 - F \tag{16}$$

Where m is the equivalent mass, y is the piston displacement, and F is the friction force and external force on the cylinder.

3.3. Control System Design

PID control has been widely used in industry because of its simplicity. However, PID control is not suitable for system with a large amount of lag, parameter variations and uncertainty in the model. Fuzzy control has found many applications in a variety of fields,. It has the advantage that it does not require an accurate mathematical model of the system [14, 15]. Hence, fuzzy adaptive PID control was developed to utilize the advantages of both PID control and fuzzy logic control. Figure 5 represents the structure of fuzzy adaptive PID controller. By using the reference signal and the feedback signal that comes from the sensors, the controller transmits the control signals that are calculated by the control algorithm to operate the proportional valve. The aim of control action is to minimize the tracking error.

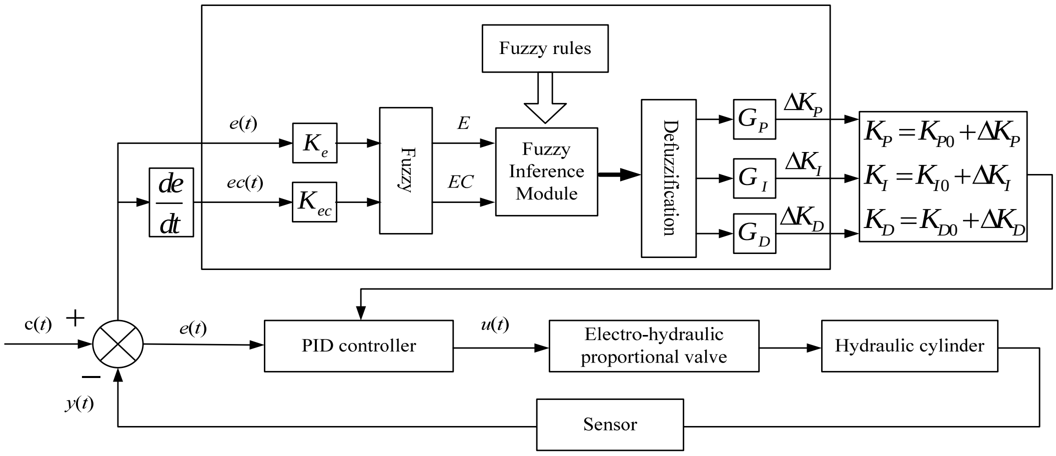


Figure 5. The structure of fuzzy adaptive PID controller

The purpose of fuzzy logic controller is to adjust three parameters of PID controller. Fuzzy logic controller consists of two input variables and three output variables. The inputs are the error *e* and the change in error *ec*, which are blurred and exported to fuzzy inference module with fuzzy rules. The outputs are ΔK_P, $\Delta K_I$and ΔK_D, which are respectively added to initial variable K_{P0}, K_{I0} and K_{D0} [16, 17].

Fuzzy controller consists of input fuzzification, fuzzy control rules, fuzzy inference and output defuzzification. It works according to a set of linguistic rules and calculates output variables. Input values go through fuzzification interface and are converted to fuzzy linguistic values. Then, fuzzy control rules are used to infer the output variables. Finally, defuzzification method converts the fuzzy output values into signals to be sent out. The inference process consists of a set of rules driven by the linguistic values of the error and the error in change [18]. Table 1 shows the fuzzy control rules to determine the proper control actions that are feasible for the current condition.

Table 1. Fuzzy control rules

e \ ec (ΔK_P ΔK_I ΔK_D)	*NB*	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*
NB	*PB/NB/NS*	*PB/NB/PS*	*PM/NM/PB*	*PM/NM/PB*	*PS/NS/PB*	*ZO/ZO/PM*	*ZO/ZO/NS*
NM	*PB/NB/NS*	*PB/NB/PS*	*PM/NM/PB*	*PS/NS/PM*	*PS/NS/PM*	*ZO/ZO/PS*	*NS/ZO/ZO*
NS	*PM/NB/ZO*	*PM/NM/PS*	*PM/NS/PM*	*PS/NS/PM*	*ZO/ZO/PS*	*NS/PS/PS*	*NS/PS/ZO*
ZO	*PM/NM/ZO*	*PM/NM/PS*	*PS/NS/PS*	*ZO/ZO/PS*	*NS/PS/PS*	*NM/PM/PS*	*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/NB*	*ZO/ZO/PS*	*NS/PS/NS*	*NM/PS/NS*	*NM/PM/NS*	*NM/PB/NS*	*NB/PB/NB*
PB	*ZO/ZO/NB*	*ZO/ZO/NM*	*NM/PS/NM*	*NM/PM/NM*	*NM/PM/NS*	*NB/PB/NS*	*NB/PB/NB*

The inputs and outputs are defined by using seven verbal values such as: *NB*-negative big, *NM*-negative medium, *NS*-negative small, *ZO*-zero, *PS*-positive small, *PM*-positive medium, *PB*-

positive big. The control laws consist of 49 control rules defined as'if *e* is *NB* and *ec* is *NB*, thenΔK_P, $\Delta K_I$and ΔK_D is *PB*, *NB* and *NS*'. The fuzzy rules have been designed and adjusted based on the simulation and expert knowledge of hydraulic cylinder feature and PID control algorithm. It is reasonable to present these linguistic terms by triangular-shape membership functions which are used to determine the degree of inputs in the fuzzification process. The decision-making output can be obtained using a max-min fuzzy inference where the output is calculated by the Center of Area method.

The structure of control system is shown in Figure 6. The sensors acquire erection angle and displacement of horizontal cylinder piston rod. The error signal is obtained by comparing acquired signal with desired signal. The control signal is obtained by calculation of fuzzy adaptive PID controller. The control electrical current is obtained through proportional magnifier. The electrical current input electro-hydraulic proportional valve to adjust opening which adjusts the flow and hydraulic cylinder piston rod speed, therefore mechanism can move based on expectation.

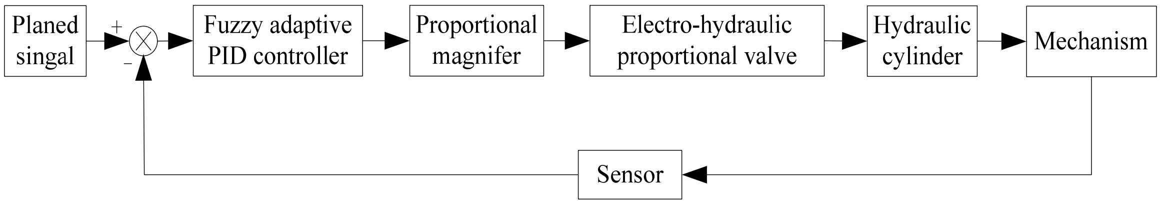


Figure 6. Structure of control system

Erection process generally uses the uniform acceleration and deceleration planning method. Due to the acceleration curve is not continuous, there is flexible impact in erecting process. Acceleration selection is quite conservative and erection time is long. We adopt composite sine function to plan erection angle to solve the problem. θ_0 is initial value of erecting angle and θ_1 is final value. Erecting time is *T*, $\tau=t/T$. $\theta(t)$ is determined by the following expressions:

$$\theta(t) = (\theta_1 - \theta_0)s(\tau) \tag{17}$$

$$s(\tau) = \begin{cases} \frac{k}{4\pi}\left[\tau - \frac{\sin(4\pi\tau)}{4\pi}\right] & 0 \le \tau < \frac{1}{8} \\ \frac{k}{4\pi}\left[\tau + \frac{2}{\pi} - 9\cos(\frac{4\pi\tau}{3} - \frac{\pi}{6})/4\pi\right] & \frac{1}{8} \le \tau < \frac{7}{8} \\ \frac{k}{4\pi}\left[\tau + \frac{4}{\pi} - \frac{\sin(4\pi\tau - 2\pi)}{4\pi}\right] & \frac{7}{8} \le \tau \le 1 \end{cases} \tag{18}$$

Constant $k = 4\pi^2/\pi + 4$.

Horizontal cylinders pull back hinged bearing moving along horizontal direction, completing erection process together with erection cylinder. Requirement of horizontal cylinder is moving smoothly. Displacement, velocity, acceleration and impact curves change smoothly and avoid mutation. We adopt polynomial interpolation method to plan erection angle. S_0 is initial value of horizontal cylinder displacement and S_1 is final value. Movement time is *T*. $S(t)$ is given by:

$$S(t) = (S_1 - S_0)s(\tau) \tag{19}$$

$$s(\tau) = -20\tau^7 + 70\tau^6 - 84\tau^5 + 35\tau^4 \tag{20}$$

4. Co-simulation of the Erection Mechanism

Mechanical model is established in Pro/E and ADAMS. Hydraulic model is established in AMESim. Control model is established in Simulink. The models established in AMESim and ADAMS are transmitted to Simulink which is the main simulation environment. AMESim and ADAMS are assistant simulation environment. Information is exchanged through software interface.

4.1. Mechanical model

ADAMS is used to analyze virtual mechanical system and it adopts Lagrange equations to establish kinematic model. ADAMS/View is a prototyping module that allows users to build a complex mechanical system. Users can define various properties such as: material, density, stiffness and so on. Three-dimensional model capability of ADAMS is limited, however, it can exchange files with other advanced CAD software to ensure data consistency. Mechanism/Pro adopts seamless connection with Pro/E and transmits model to ADAMS/View to conduct comprehensive kinematic analysis. Mechanical model of the erection mechanism established in ADAMS is shown in Figure 7. Three-dimensional model was established in Pro/E, and it was transmitted to ADAMS/View using Mechanism/Pro. The model is composed of seven rigid bodies which are linked with others by revolute pair, prismatic pair and fixed pair.

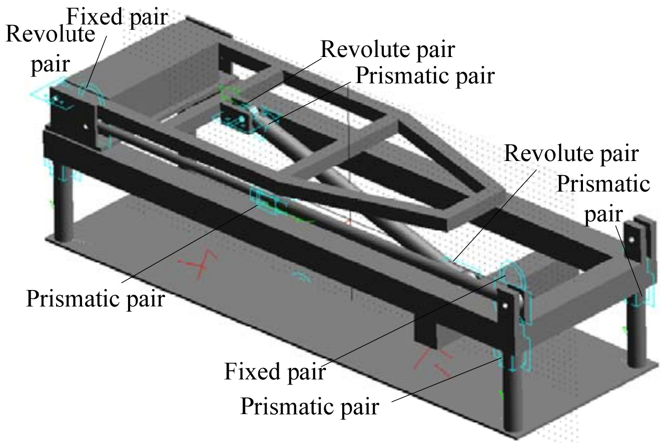


Figure 7. Mechanical model in ADAMS

As the model in ADAMS must interact with the control model in Simulink, it should define suitable “state variables” which are used to exchange information. The input state variables are piston rod speed signals of hydraulic cylinders. The output state variables are erection angle, piston rod displacement of horizontal cylinder, and loads of hydraulic cylinder.

4.2. Hydraulic Model

AMESim uses graphical model approach that each component contains a set of equations and is linked with others through a system of ports. Firstly select hydraulic pump, relief valve, bilateral balance valve, hydraulic lock, hydraulic cylinder, and electro-hydraulic proportional valve from hydraulic library, then establish model in accordance with the sequence of sketch mode, sub-model mode, parameter mode, and run mode. Hydraulic model established in AMESim is shown in Figure 8. The co-simulation interface of AMESim and Simulink is achieved by connecting the menu icon in AMESim to the S-function in Simulink. The model in AMESim is compiled in S-function which can be used in Simulink.

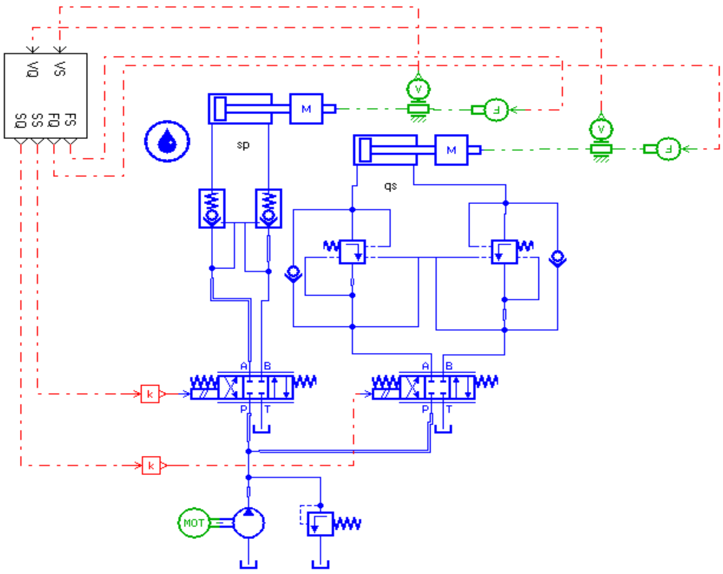


Figure 8. Hydraulic model in AMESim

4.3. Co-simulation Results and Analysis

Simulink block of the erection mechanism is shown in Figure 9. It is mainly composed of four parts: planed curve, fuzzy adaptive PID controller, hydraulic model, and mechanical model. Planned curves are desired erection angle and displacement of horizontal cylinder piston rod. There are two fuzzy adaptive controllers which separately control erection and horizontal cylinders. Hydraulic model is established in AMESim and compiled in S-function that can be used in Simulink. Mechanical model is established in ADAMS and transmitted to Simulink by software interface. The input variables of fuzzy adaptive controllers are the errors of planned erection angle and displacement of horizontal cylinder piston rod with actual erection angle and displacement in simulation process. The output variables are control signals of electro-hydraulic proportional valves. The input variables of hydraulic model are control signals of electro-hydraulic proportional valve and hydraulic cylinder loads. The output variables are piston rod speed signals. The input variables of mechanical model are piston rod speed signals. The output variables are erection angle, displacement of horizontal cylinder piston rod and hydraulic cylinder loads.

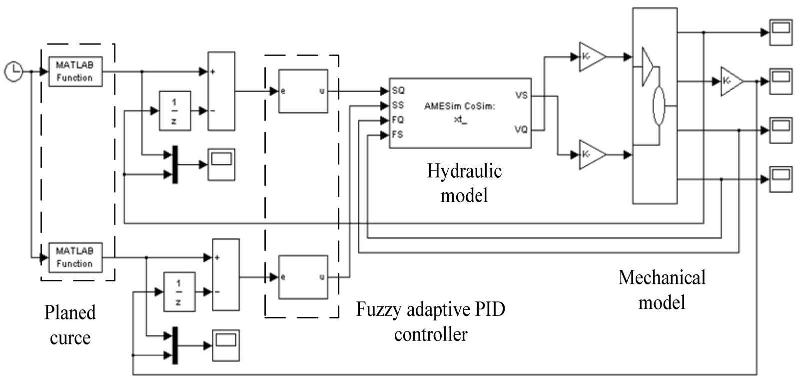
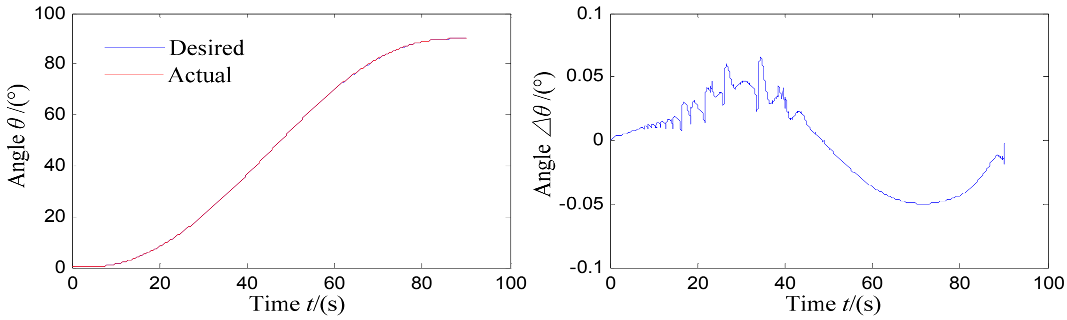


Figure 9. Simulink block of the erection system

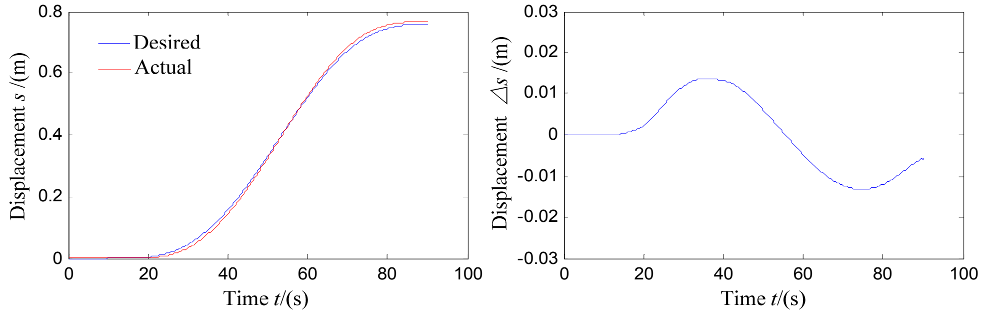
Simulation results of erection angle are shown in Figure 10. Figure 10(a) is desired and actual erection angle in simulation process. Figure 10(b) is the error of desired and actual erection angle. Displacement simulation results of horizontal cylinder piston rod are shown in

Figure 11. Figure 11(a) is desired and actual displacement in simulation process. Figure 11(b) is the error of desired and actual displacement. By the simulation results we can obtain that erection angle and displacement of horizontal cylinder piston rod change smoothly. The error of erection angle is controlled in 0.06°.The displacement error of horizontal cylinder piston rod is controlled in 0.014 m. The control precision is great and satisfies the control target of erection process. Compared erection angle with displacement of horizontal cylinder piston rod we can acquire that erection angle doesn't change greatly at the start and end of horizontal cylinder movement. It indicates that the impact of two hydraulic cylinders is little.



(*a*) Desired and autual erection angle (*b*) Angle error

Figure 10. Simulation erection angle



(*a*) Displacement of horizontal cylinder piston rod (*b*) Displacement error

Figure 11. Simulation displacement of horizontal cylinder piston rod

5. Experimental Verification

We designed an experimental apparatus that can realize desired movement to prove the effectiveness of the novel erection mechanism. Mechanical constitution is shown in Figure 12. Measurement and control system of experimental apparatus are established using virtual instrument technology. We choose the hardware of PXI-1044 case and PXI-6259 multifunction data acquisition card and software of LabVIEW to program.

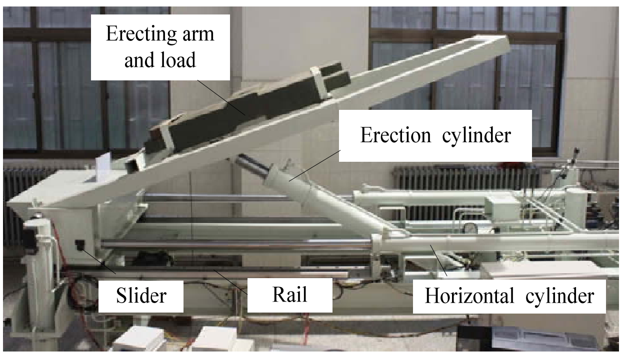
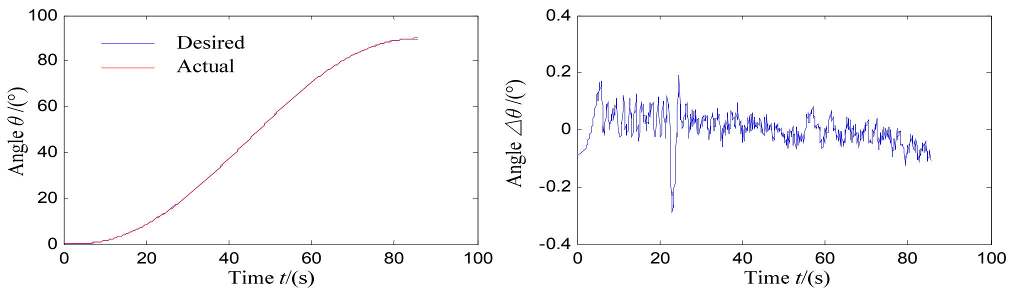


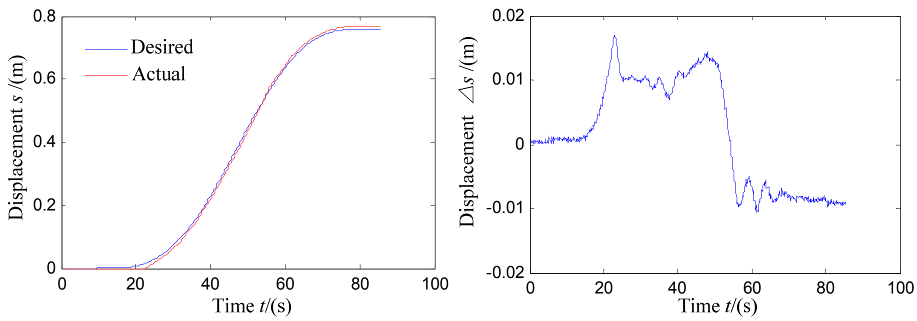
Figure 12. Mechanical constitution of the platform

Experimental erection angle results are shown in Figure 13. Figure 13(a) is desired and actual erection angle in experiment process. Figure 13(b) is error of desired and actual erection angle. Experimental displacement results of horizontal cylinder piston rod are shown in Figure 14. Figure 14(a) is desired and actual displacement in experiment process. Figure 14(b) is the error of desired and actual displacement. By the experimental results, we can obtain that the angle error gradually becomes larger at erection cylinder start stage (0s~5s). The displacement error also gradually becomes larger at horizontal cylinder start stage (10s~22s). The erection angle error is controlled in 0.1° in erection process. The displacement error is controlled in 0.015m. The control precision satisfies the control target of erection process. The experimental error of angle and displacement is a little larger than the simulation error as shown in Figure 10(b) and Figure 11(b). It is aroused by the hardware precision, program execution time and other factors.



(a) Desired and actual erection angle (b) Angle error

Figure 13. Experimental erection angle



(a) Displacement of horizontal cylinder piston rod (b) Displacement error

Figure 14. Experimental displacement of horizontal cylinder piston rod

6. Conclusion

The research accomplished co-simulation and experiment research on the erection mechanism with movable back hinged bearing. Mathematical models of the mechanism and hydraulic system were acquired. The mechanical, hydraulic and control models were respectively established in ADAMS, AMESim and Simulink. Fuzzy adaptive PID controller was designed for the erection mechanism by combining fuzzy control with PID control. Experimental verification was completed on a platform. The results demonstrated that the novel erection mechanism could move based on designed scheme. It satisfied designed requirement. The precision of fuzzy adaptive PID controller was great. The research indicated that the novel erection mechanism could be applied in practical engineering.

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