IeCAT 2020

sciforum

Active Disturbance Rejection Control for Double Pump Direct Driven Hydraulics

Author: Shuzhong Zhang , Angen Wu
Fuquan Dai

Reporter: Angen Wu

Fujian University of Technology

Abbreviations

DDH	Double-pump direct driven hydraulics
ADRC	Active disturbance rejection control
TD	Tracking-differentiator
ESO	Extended state observer
NFCL	Nonlinear feedback control law
PID	Proportional-Integral-Differential

Content

1. Introduction

2. Modelling

3. Method

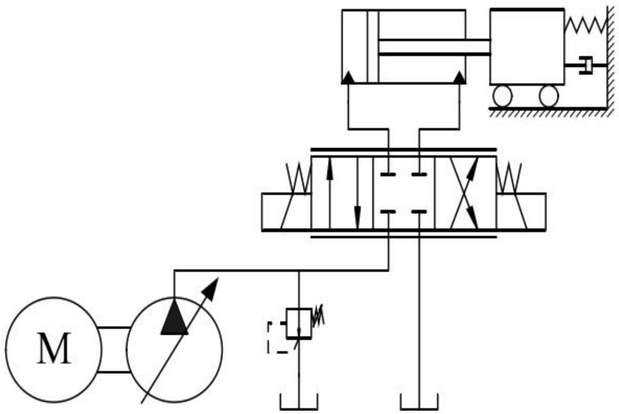
4. Results and analysis

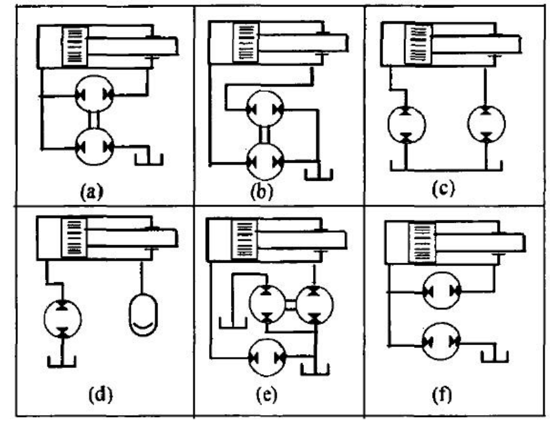
5. Conclusions

1 Introduction

1. 1 Background

Electro-hydraulic servo system





valve-controlled

- Fast dynamic response
- High control accuracy
- Large throttling loss
- Low system efficiency
- etc.

pump-controlled

- Eliminates the throttling loss
- Improves system efficiency
- etc.

Pump-controlled system has become the centre of the focus

1. 1 Background

Unbalanced flow

1.Time-varying
2.Nonlinearity

Double-pump compensation circuit

Multi-pump compensation circuit

Asymmetric flow distribution pump

Pilot-operated check valve

Adaptive fuzzy control

Control based on disturbance observer

Adaptive backstepping

etc.

1. 2 Research content

This paper proposed a control method adopting ADRC for the time-varying and nonlinear problems of DDH.

1 > Use ADRC method in DDH

2 > Build a model, including the DDH, mechanism of the crane, and ADRC controller

3 > Simulations were performed using two types of reference signal with or without disturbances

2 Modelling

2.1 Working principle of DDH

The schematic diagram of DDH as shown in Figure 1,and the list of the components as shown in Table 1.

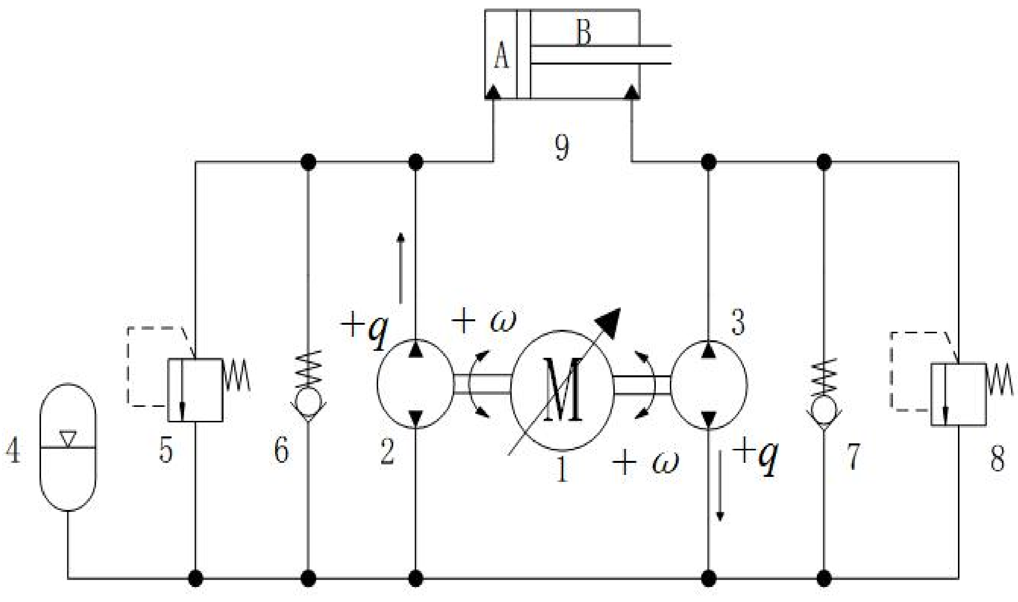


Figure 1. Schematic diagram of DDH [8]

Table 1. List of the components (see Figure 1)

No.	Component
1	Permanent magnet synchronous motor
2	A-side pump
3	B-side pump
4	Hydraulic accumulator
5，8	Pressure relief valve
6，7	Check valve
9	Hydraulic cylinder

2.2 Model

In the model, the following assumptions are given: the hydraulic cylinder leakage is zero; the hydraulic cylinder load is an inertial load, and there is no elastic load.

1) Pump Model: $Q_{A} = \eta\omega D_{pA}$ $Q_{B} = -\eta\omega D_{pB}$

2) Cylinder Model: $q_{A} = A_{A}\dot{x} + \frac{V_1}{\beta_e}\dot{p}_{A}$ $-q_{B} = A_{B}\dot{x} + \frac{V_2}{\beta_e}\dot{p}_{B}$

$$p_{A}A_1 - p_{B}A_2 = M\ddot{x} + B_c\dot{x} + F$$

3) State-space equations:

Defining the state variables: $[x_1, x_2, x_3] = [x, \dot{x}, \ddot{x}]$

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = x_3 \\ \dot{x}_3 = a_1 x_2 + a_2 x_3 + a_3\omega + f \end{cases}$$

$$a_1 = -\left(\frac{A_1^2\beta_e}{V_1 m} - \frac{A_2^2\beta_e}{V_2 m}\right); a_2 = -\frac{B_c}{m}; a_3 = \frac{A_1\eta D_{pA}\beta_e}{V_1 m} - \frac{A_2\eta D_{pB}\beta_e}{V_2 m}; f = -\frac{\dot{F}_L}{m}$$

2.2 Model

4) Mathematical model of crane

The schematic diagram of the crane structure is shown in Figure 2. the hydraulic cylinder velocity can be expressed by:

$$\frac{dx_t}{dt} = \frac{d_1 d_2 \frac{d\gamma}{dt} \sin(\gamma)}{\sqrt{d_1{}^2 + d_2{}^2 - 2d_1 d_2 \cos(\gamma)}}$$

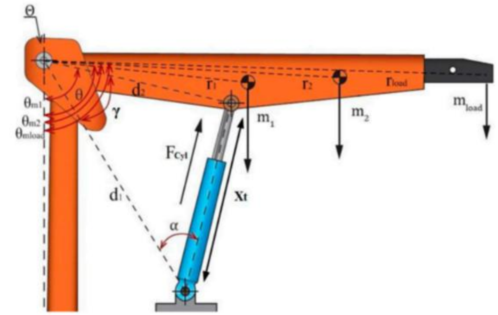


Figure 2. Crane structure diagram [8]

5) State-space equations Model validation:

This verifies the feasibility of the deduced state-space equation of the DDH.

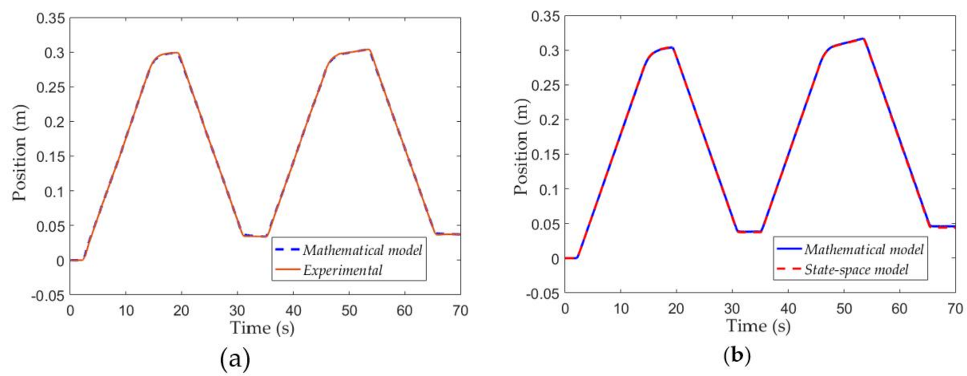


Figure 3. Validation: (a) experimental and mathematical model; (b) mathematical model and state-space model.

3 Method

3.1 Structure of ADRC

ADRC is a control algorithm without dependence on the system model. Its basic idea is to consider unmodelled dynamics and unknown external disturbance as "total disturbance" of the system.

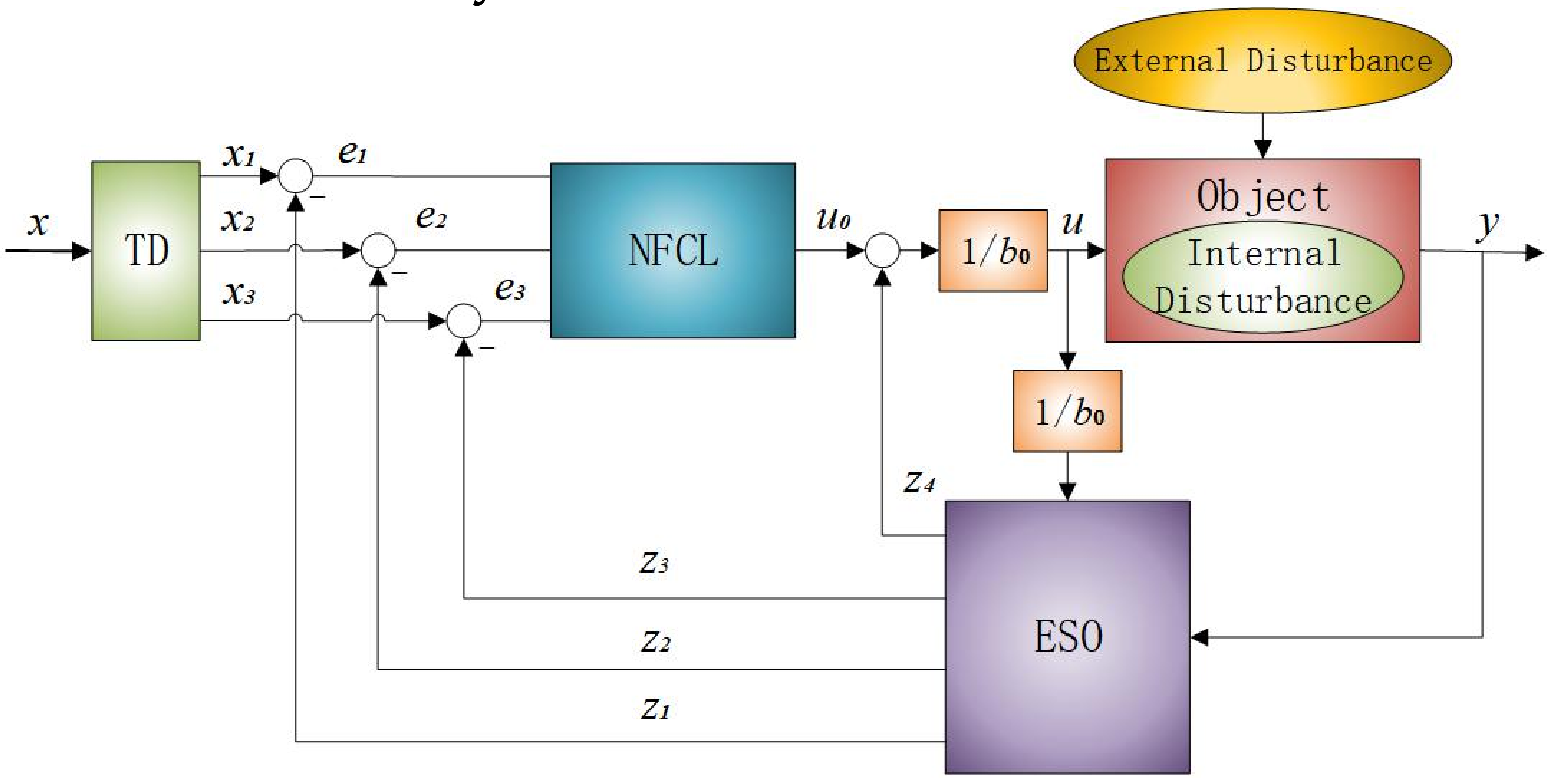


Figure 4. Structure of ADRC

3.2 Design of ESO

The ESO is the core part of ADRC, which can track the state variables and estimate the internal and external disturbance of the system.

Actual value

$$k_1 = -\left(\frac{A_1{}^2\beta_e}{V_1 m} - \frac{A_2{}^2\beta_e}{V_2 m}\right) \qquad k_2 = -\frac{B_c}{m}$$

$$k_3 = \frac{A_1\eta D_{pA}\beta_e}{V_1 m} - \frac{A_2\eta D_{pB}\beta_e}{V_2 m}$$

Define nominal value

$$k_{1n} = -\left(\frac{A_1{}^2\beta_{en}}{V_1 m_n} - \frac{A_2{}^2\beta_{en}}{V_2 m_n}\right) \qquad k_{2n} = -\frac{B_{cn}}{m_n}$$

$$k_{3n} = \frac{A_1\eta D_{pA}\beta_{en}}{V_1 m_n} - \frac{A_2\eta D_{pB}\beta_{en}}{V_2 m_n}$$

$$\tilde{k} = k_n - k$$

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = x_3 \\ \dot{x}_3 = k_{1n}x_2 + k_{2n}x_3 + k_{3n}\omega + \sigma \end{cases}$$

$$\sigma = \tilde{k}_1 x_2 - \tilde{k}_2 x_3 - \tilde{k}_3\omega + f$$

Internal disturbance

External disturbance

3.3 Design of ADRC

The overall mathematical equation of ADRC is as follows:

$f(x_1(k), x_2(k), r, h)$

the fast optimal control function

$$\begin{cases} fh = fhan(x_1(k), x_2(k), r, h); \\ x_1(k+1) = x_1(k) + Tx_2(k); \\ x_2(k+1) = x_2(k) + Tfh; \\ x_3(k+1) = fh \end{cases}$$

TD

TD discrete form

Transition

$$\begin{cases} e_1 = z_1 - y \\ \dot{z}_1 = z_2 - \beta_{01} e_1 \\ \dot{z}_2 = z_3 - \beta_{02} e_1 \\ \dot{z}_3 = a_{1n} z_2 + a_{2n} z_3 + z_4 - \beta_{03} |e_1|^{\frac{1}{4}} sign(e_1) + a_{3n} \omega \\ \dot{z}_4 = -\beta_{04} |e_1|^{\frac{1}{8}} sign(e_1) \end{cases}$$

$\beta_{01} = 4\omega, \beta_{02} = 6\omega^2, \beta_{03} = 4\omega^3, \beta_{04} = \omega^4$

ESO

ESO algorithm expression

Estimate

Error

$$\begin{cases} e_1 = x_1 - z_1 \\ e_2 = x_2 - z_2 \\ e_3 = v_3 - z_3 \\ u_0 = \beta_1 fal(e_1, \alpha, \delta) + \beta_2 fal(e_2, \alpha, \delta) + \beta_3 fal(e_3, \alpha, \delta) \\ u = u_0 - \frac{z_4}{b_0}. \end{cases}$$

NFCL

NFCL algorithm expression

Compensate

4 Results and analysis

4.1 Simulation parameters of DDH

Uses sine signal and actual working position signal as inputs to the system, compares the position tracking performance with P and PI controller. The simulation parameters of DDH are shown in Table 2

Table 2. Simulation parameters of DDH

Parameters	Value	Unit	Parameters	Value	Unit
Pump A Volumetric Displacement (D_{pA})	13.03	ml/rev	Effective bulk modulus (β_e)	7e8	Pa
Pump B Volumetric Displacement (D_{pB})	9.35	ml/rev	Cylinder stroke (L)	400	mm
Piston diameter of hydraulic cylinder (d_d)	60	mm	Damping coefficient (B_c)	500	N·s/m
Piston rod diameter of hydraulic cylinder (d_r)	30	mm	Dead volume of chamber A (V_{01})	2e-6	m^3
Load mass (m)	50	kg	Dead volume of chamber B (V_{02})	2e-6	m^3

4.2 sine position signal

The sine position signal was set as: $x_r = 0.15\sin(\frac{2}{10}\pi t - \frac{\pi}{2}) + 0.15$

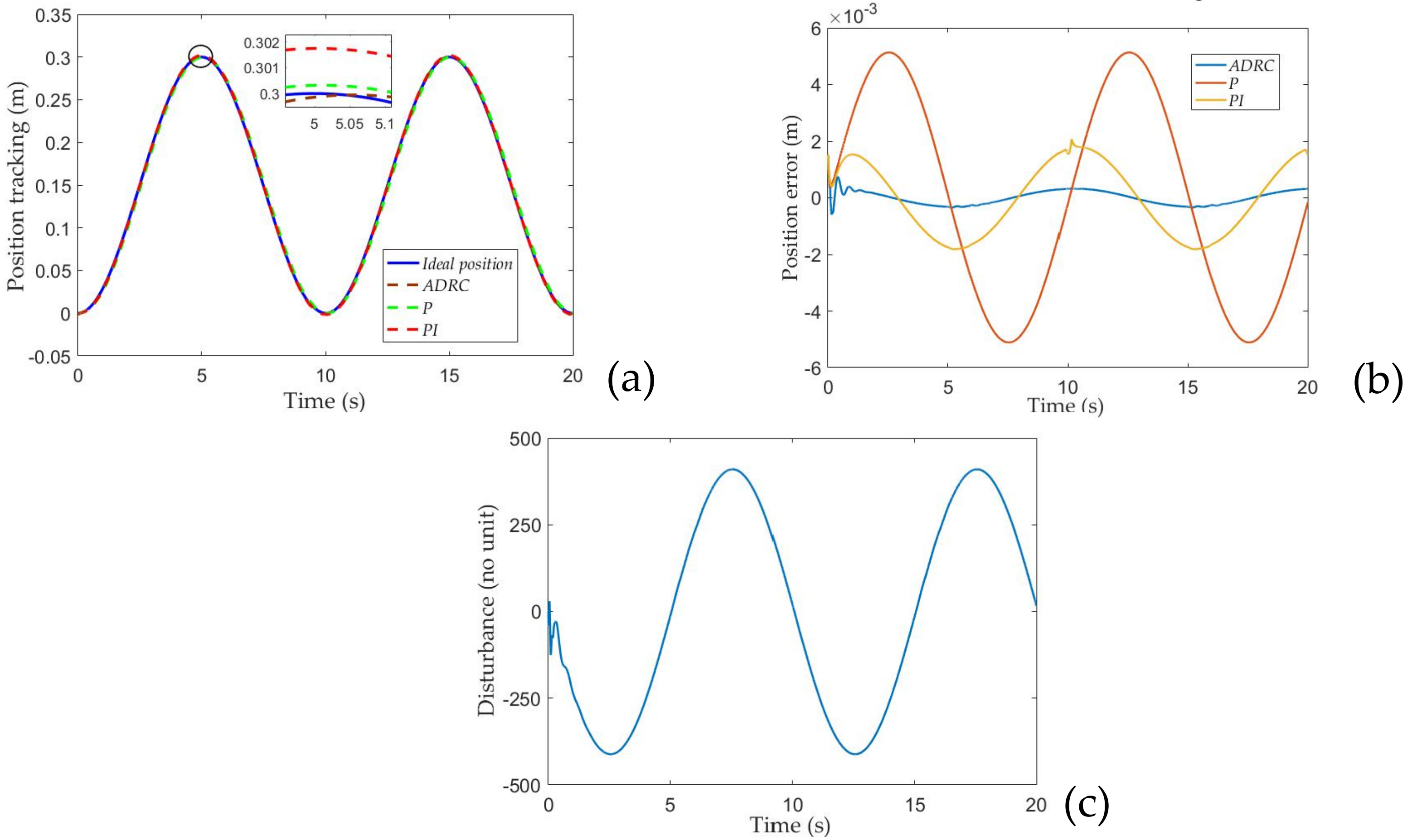


Figure 5. The sine position signal tracking without disturbance: (a) position tracking ; (b) position tracking error ; (c) total disturbance observation.

4.2 sine position signal

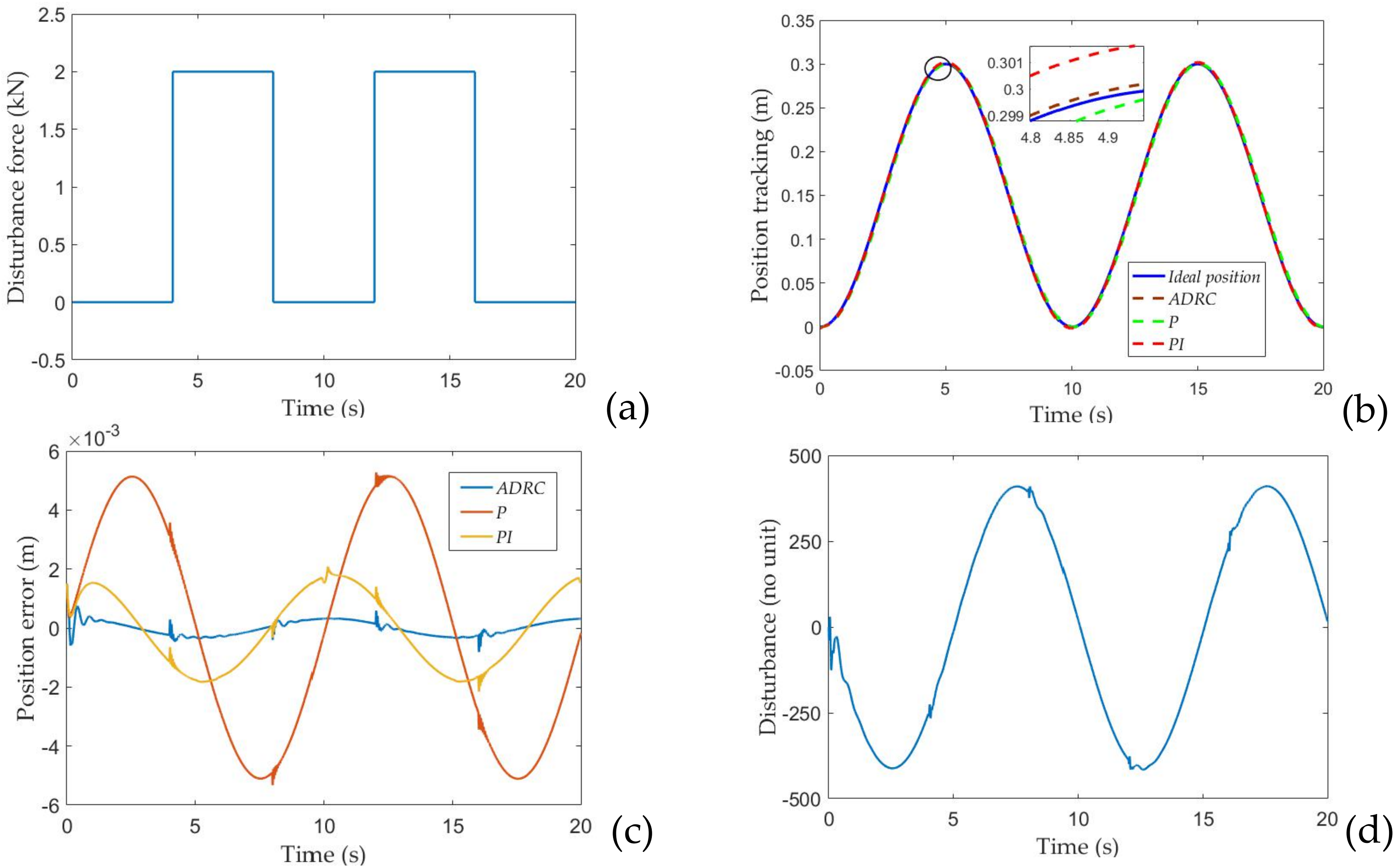


Figure 6. The sine position signal tracking with disturbance: (a) disturbance force ; (b) position tracking ; (c) position tracking error ; (d) total disturbance observation.

4.2 sine position signal

Table 4. Comparison of tracking error of sine position signal

Control method	Without disturbance position error/m		With disturbance position error/m	
	Root mean square	Maximum	Root mean square	Maximum
P	2.985e-3	5.132e-3	3.472e-3	5.275e-3
PI	1.262e-3	2.080e-3	1.223e-3	2.081e-3
ADRC	4.276e-4	1.514e-3	3.833e-4	1.514e-3

	ADRC reduce			
Compare with P	86%	70%	89%	71%
Compare with PI	66%	27%	69%	27%

4.3 Actual working position signal

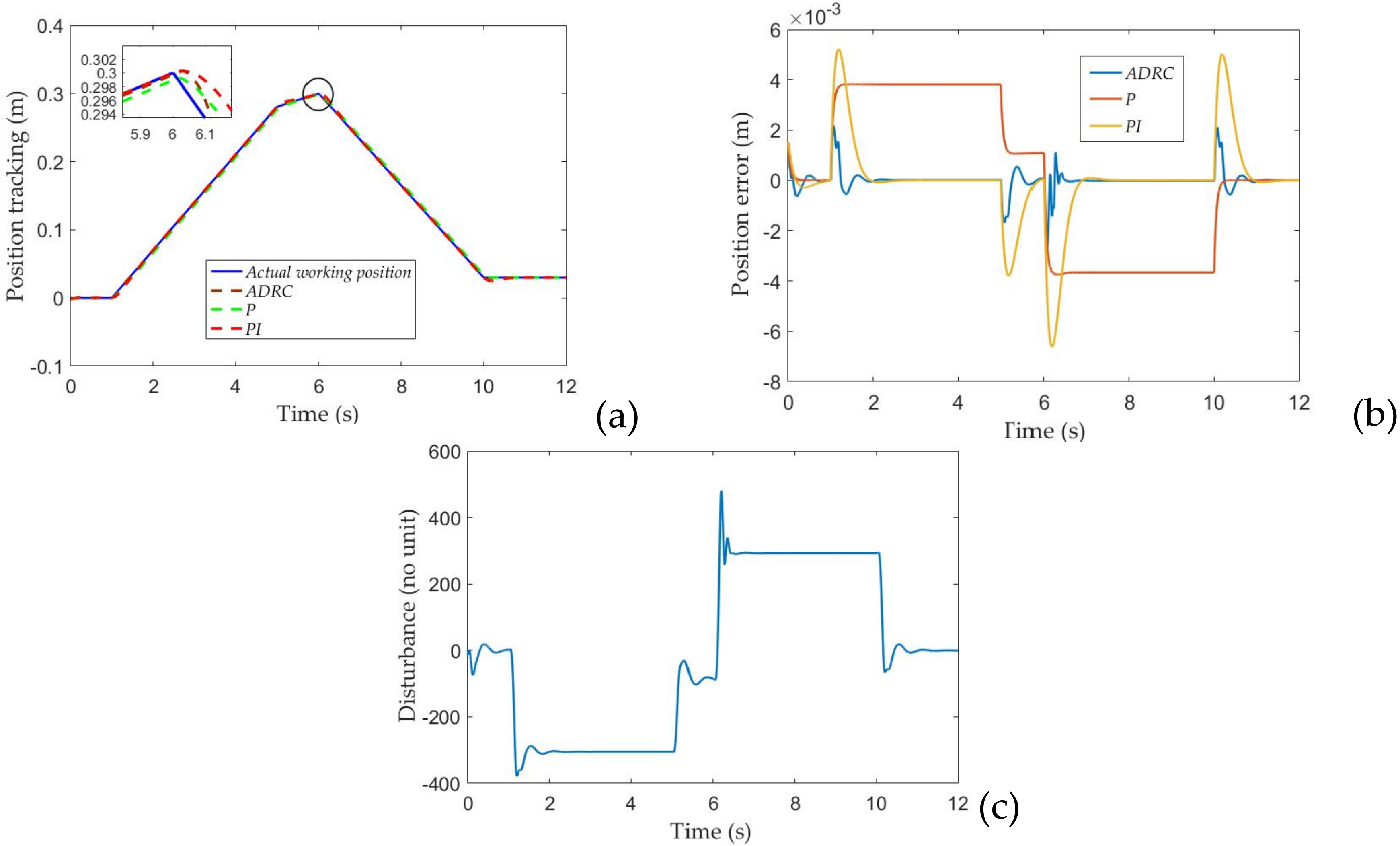


Figure 7. The actual working position signal tracking without disturbance: (a) position tracking ; (b) position tracking error ; (c) total disturbance observation.

4.3 Actual working position signal

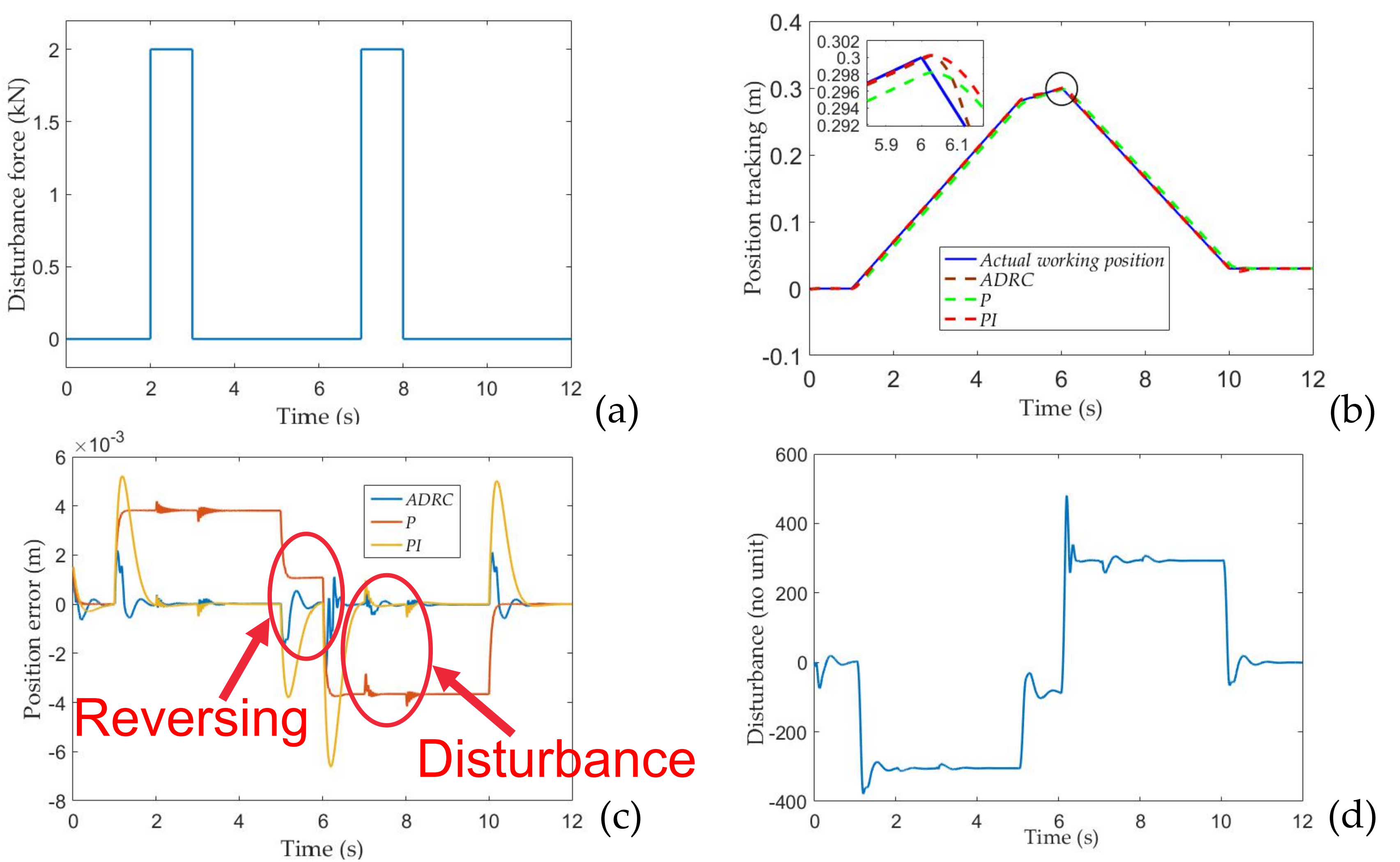


Figure 8. With disturbance: (a) disturbance force ; (b) position tracking ; (c) position tracking error ; (d) total disturbance observation.

4.3 Actual working position signal

Table 5. Comparison of tracking error of actual working position signal

Control method	Without disturbance position error/m		With disturbance position error/m	
	Root mean square	Maximum	Root mean square	Maximum
P	2.415e-3	3.829e-3	2.642e-3	4.189e-3
PI	1.955e-3	5.221e-3	1.873e-3	5.221e-3
ADRC	5.268e-4	2.183e-3	5.003e-4	2.183e-3

	ADRC reduce			
Compare with P	78%	43%	81%	48%
Compare with PI	73%	58%	73%	58%

5 Conclusions

5 Conclusions

Compared with PID control, ADRC can suppress internal and external disturbances effectively, having high position tracking precision and strong robustness.

Although the control method ADRC can improve control accuracy on the DDH based on the simulation results, it should be compared with experimental data for validation. Hence, in the near future, a test bench needs to be set up, and experiments should be performed with the proposed control method.

Thank You !