氣壓伺服控制於高科技產業製程之應用

以 Air Bearing Conveyor Systems 應用於 TFT-LCD製程為例

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Outline

- Introduction
- Test Rig Layout
- Modeling of Air Bearing Conveyor System
- Controller Design
- Simulations and Experiments
- Conclusions

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Introduction

- Flat Panel displays (FPD) have become one of the most significant industries in the world. The manufacturers of FPD concentrate especially on the countries in east-Asia, including Taiwan, Japan and Korea.
- In order to satisfy the fast development of the request of the market that trends toward larger and larger sizes for TV and monitor, the new generations of the glass substrates have been developed almost every 3 years.
- However, the weights and the dimensions of the glass substrates also increase such that the manufacturing equipments have to face new process challenge.

Generation of Glass Substrates

Generation	Size (mm^2)	Weight (kgf)
2nd Gen	400×500	0.4
3rd Gen	550×670	0.7
3.5th Gen	600×720	0.8
4th Gen	680×880	1.1
5th Gen	1100×1250	2.5
5.5th Gen	1300×1500	3.5
6th Gen	1500×1850	5
7th Gen	1800×2000	6.5
7.5th Gen	1950×2250	7.5
8th Gen	2160×2400	8.5

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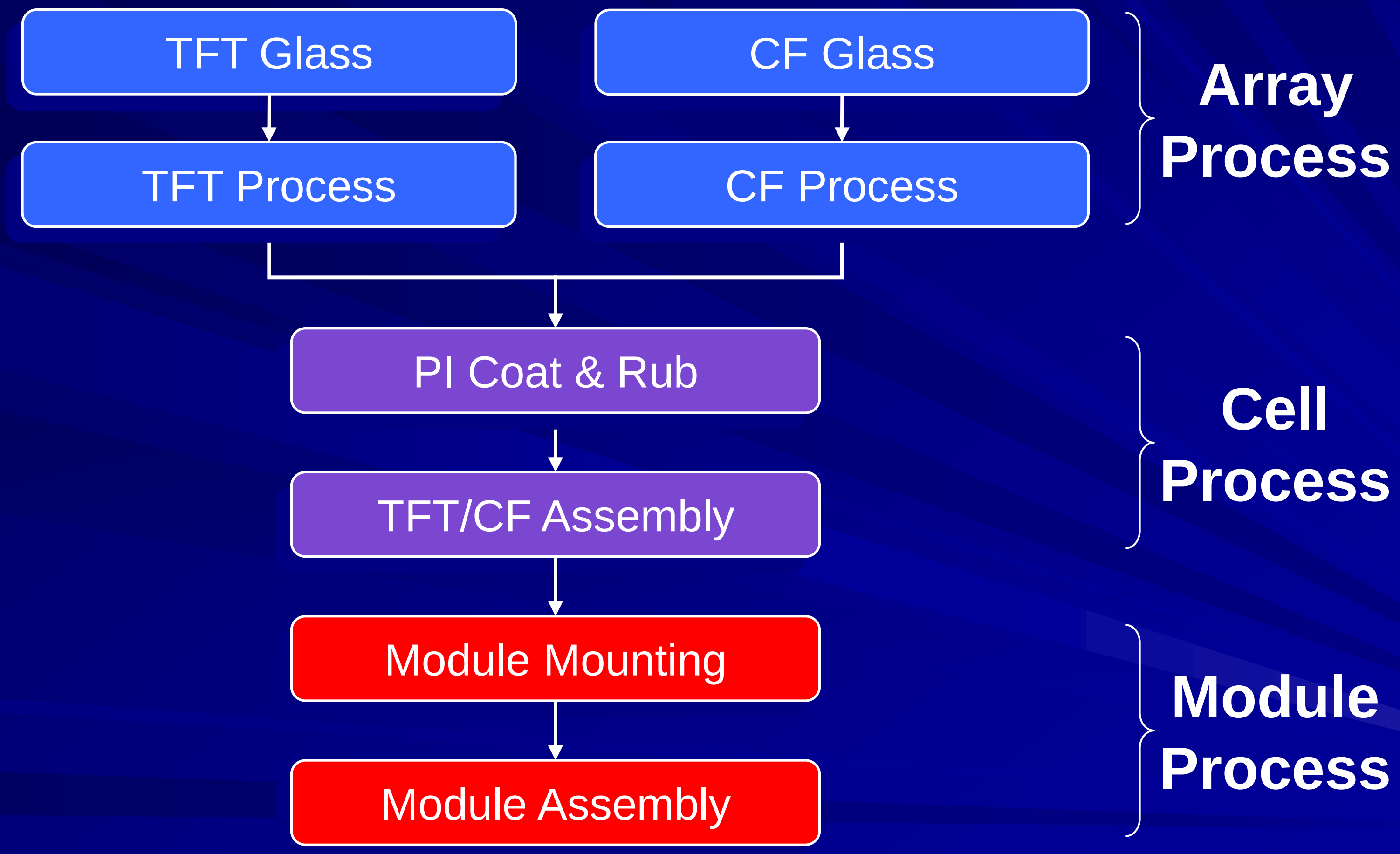
Process of TFT-LCD



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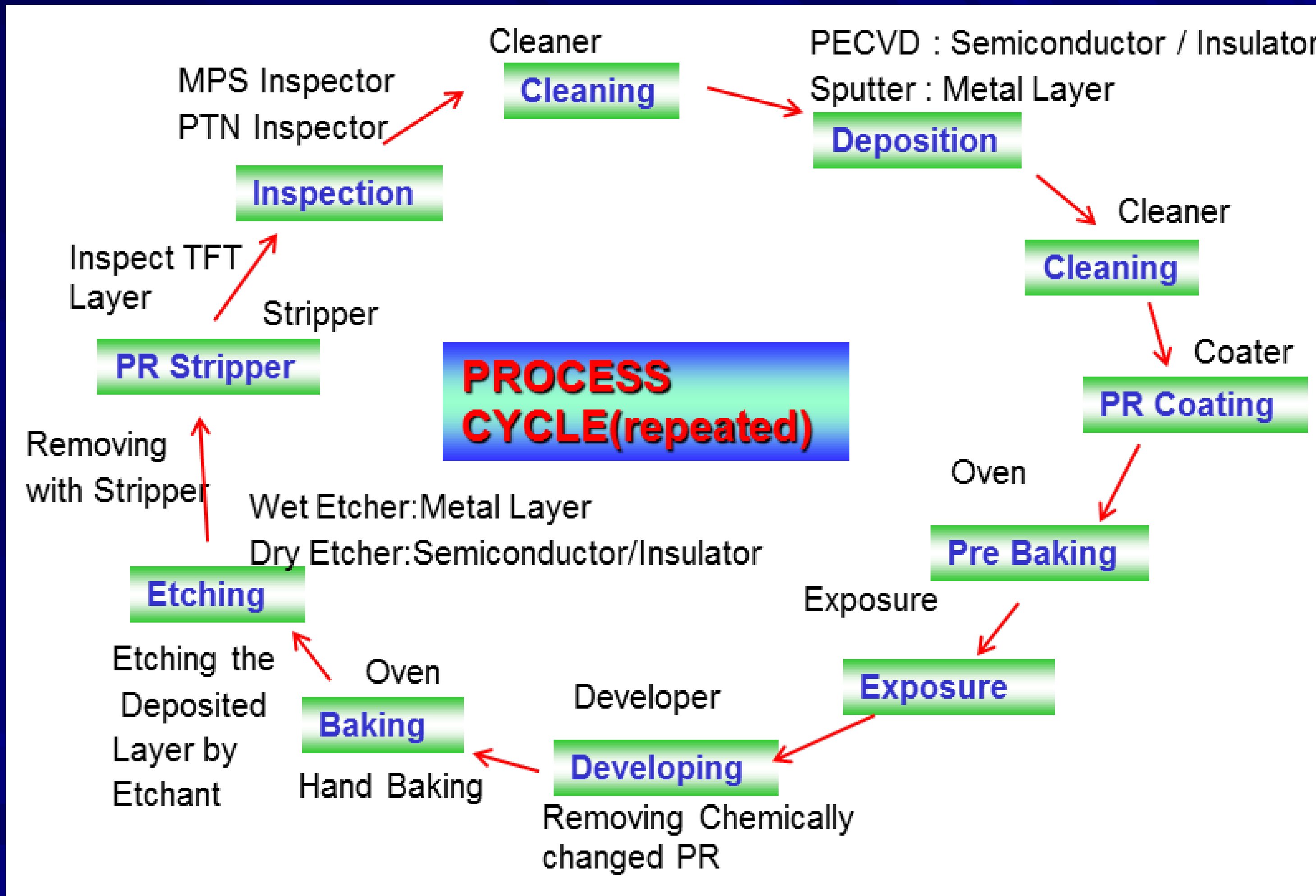
Array Process of TFT-LCD



CHIANG, M.-H.

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Introduction

- The conveyor systems of the glass substrate become more and more complex due to the increase of the dimension and weight of the glass substrate.
- The conveyor systems of the glass substrate contain horizontal linear conveyor, horizontal rotational conveyor and vertical lifting system.
- The horizontal linear conveyors are driven by rollers in the conventional conveyor system by means of the friction force between the glass substrates and the driving rollers.
- However, it will result in abrasion and streaks on the contact surfaces of the glass substrates owing to the increasing of the weight.

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Conventional Roller Conveyor Systems for TFT LCD

Introduction

- **Air-bearing system** can be used to form an **air cushion between the glass substrates and the air-bearing plates** such that the glass substrates can be supported by **pressured air without contact**.
- Although **the air-bearing** can tackle the **friction force, the unstable leveling position** of the glass substrates occur due to **unstable air pressure** between the air bearing plates and the glass substrates.
- However, some applications in the process of TFT-LCD, such as **inspection**, request the glass substrates for **keeping stable in the vertical direction**.

Air-Bearing Conveyor Systems for TFT-LCD

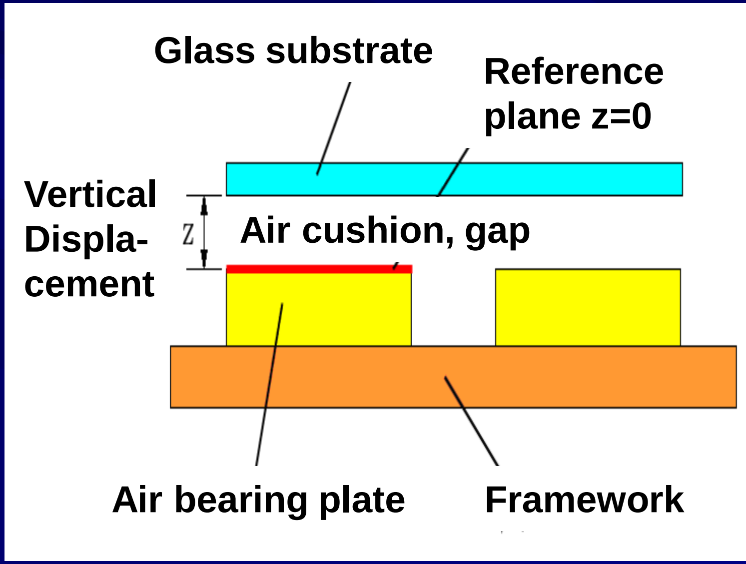
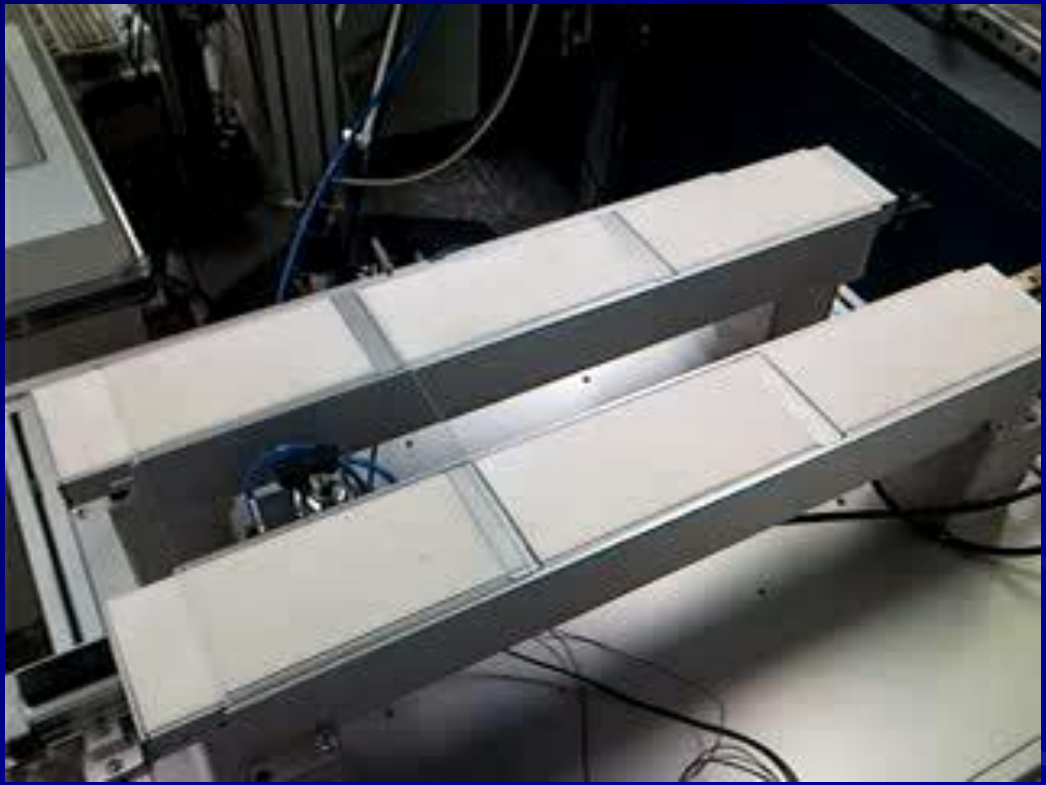


Illustration of structure of air-bearing plates



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Objective of the Research

- Active leveling control of an air bearing conveyor system for glass substrates of TFT-LCD or solar cell.
- Improvement of the damage due to friction or shaking on the surface of glass substrates
- Development of an active leveling control for an air bearing conveyor system
- Control of the floating altitude of the glass substrates for verifying the control performance, stability and robustness experimentally
- Setup of test rig for 3.5th gen. of glass substrates

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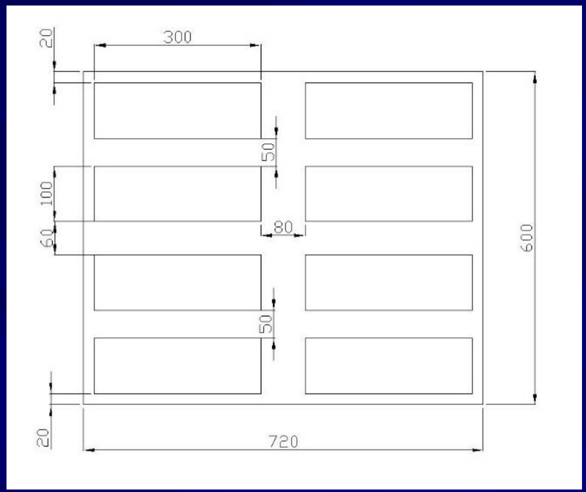
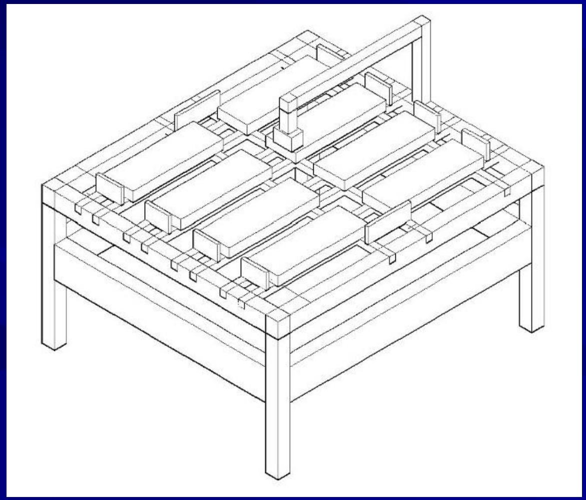
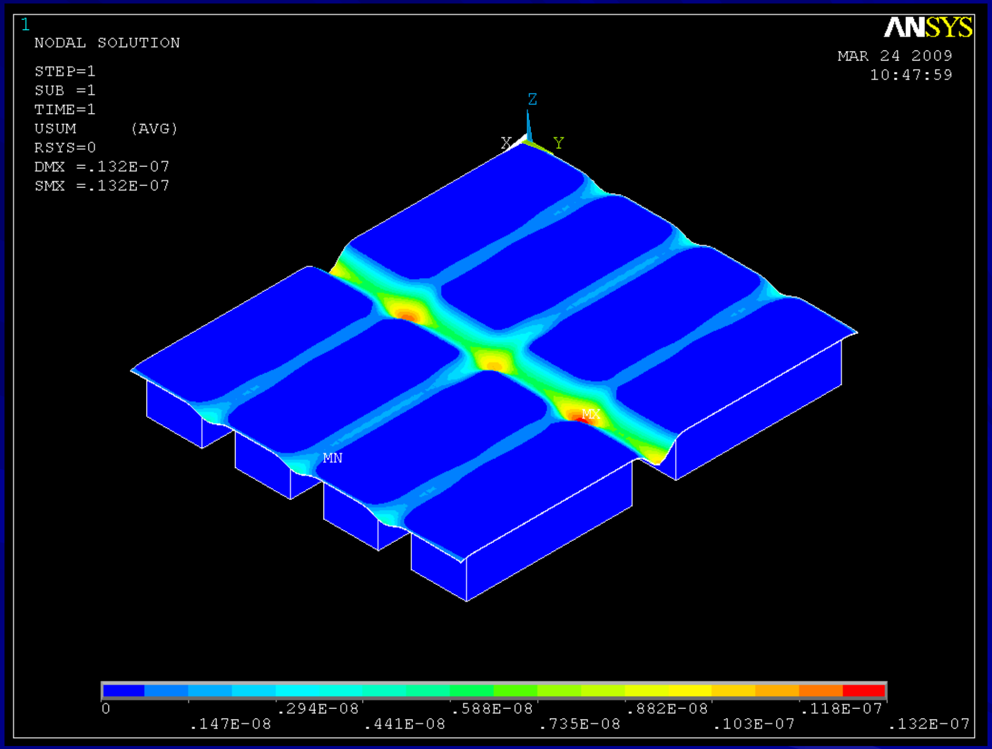
Deformation Analysis of Glass Substrate by ANSYS







Max. deformation $1.32 \times 10^{-8} m$

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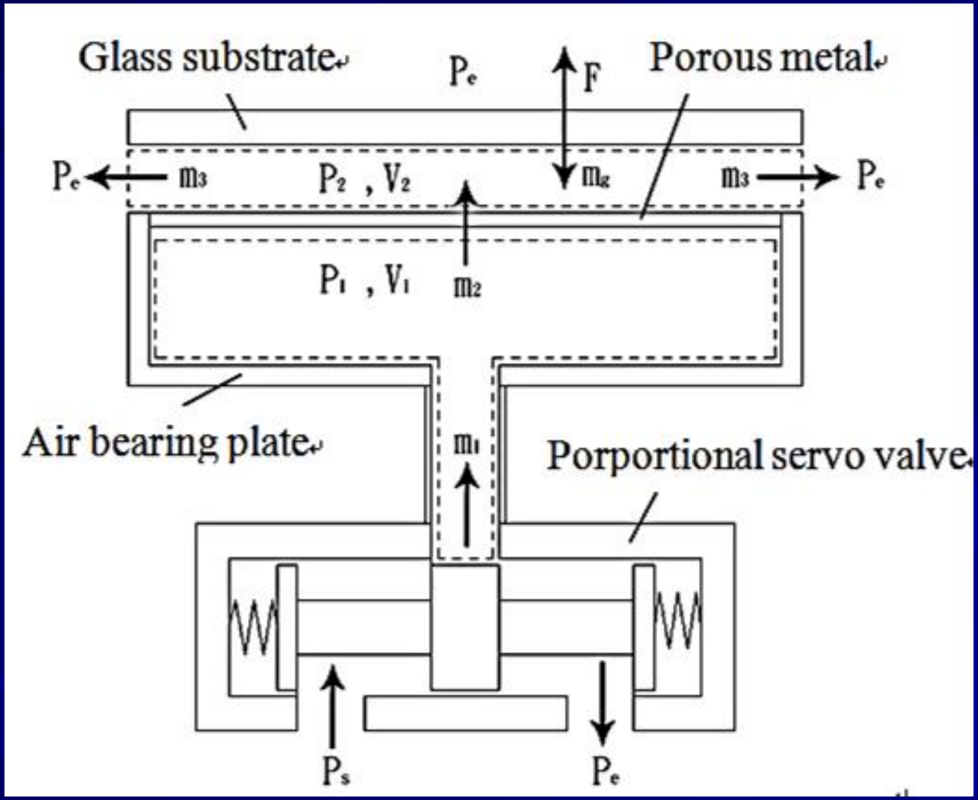
Illustration of Air bearing Conveyor System



P_e : atmosphere pressure (1 bar)

P_s : supplied pressure (5 bar)

P_1 : pressure in the air bearing plate

P_2 : pressure in the gap

m_1 : air mass flow (valve → air bearing plate)

m_2 : air mass flow (air bearing → gap)

m_3 : air mass flow (gap → atmosphere)

M_g : weight of glass substrate (N)

V_1 : internal volume of the air bearing plate

V_2 : volume of the gap

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Dynamic Model of the System

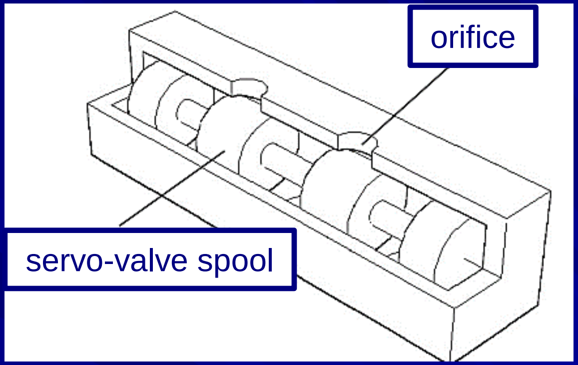
1. Proportional Servo Valve:

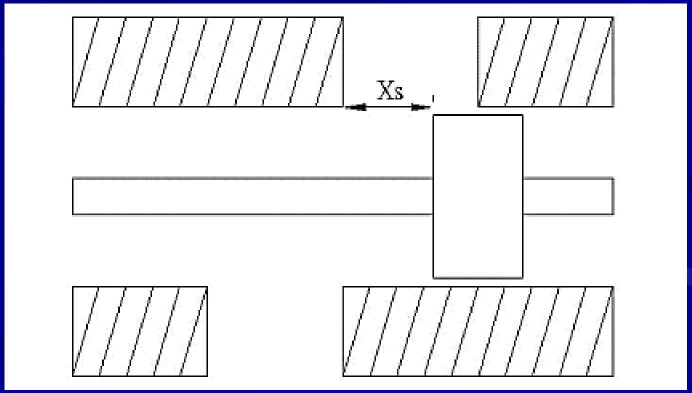
$$x_s = \frac{K_s}{T_s s + 1} \cdot u_s$$

X_s : spool displacement
K_s : constant gain of input to output
T_s : time constant of servo valve
u_s : voltage input

$$A_s = \begin{cases} L_s \cdot X_s & 0 \le X_s \le X_{max} \\ 0 & X_{max} \le X_s \le 0 \end{cases}$$

A_s : area of orifice
L_s : outside dimension of spool
X_s : displacement of spool
X_{max} : maximum displacement of spool





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Dynamic Model of the System

■ 2. Mass Flow Rate of Orifice:

Equilibrium equation by Mc Cloy

$$\dot{m} = C_d C_m \frac{P_{up}}{\sqrt{T_u}} A_h$$

$\dot{m}$: mass flow rate of orifice

C_d : output/displacement flow rate

C_m : parameter of mass flow rate

P_{up} : Stagnation pressure of upstream

T_{up} : Stagnation temperature of upstream

Dynamic Model of the System

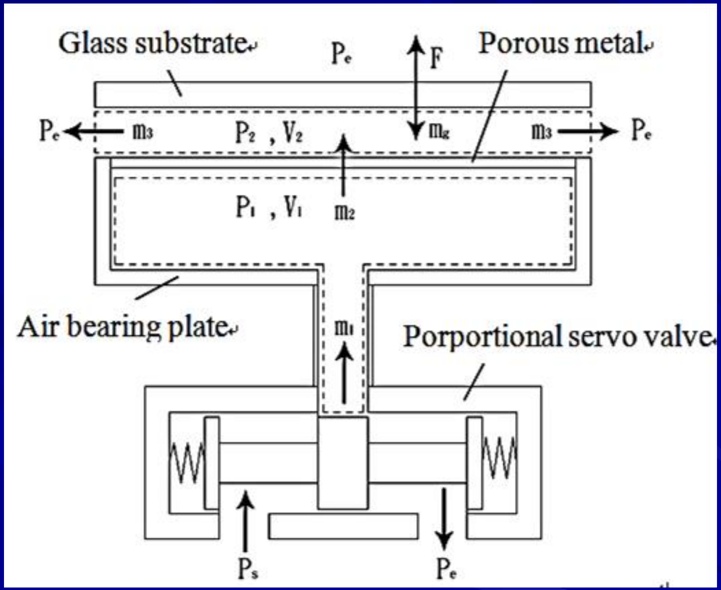
■ 3. Continuous equation

pressure rate in the air bearing plate

$$\dot{P}_1 = \frac{\gamma}{V_1} \cdot \left(R T_1 (\dot{m}_1 - \dot{m}_2) \right)$$

pressure rate in the gap

$$\dot{P}_2 = \frac{\gamma}{V_{2D} + A_a \cdot Y} \cdot \left(R T_2 (\dot{m}_2 - \dot{m}_3) + A_a P_2 \dot{Y} \right)$$



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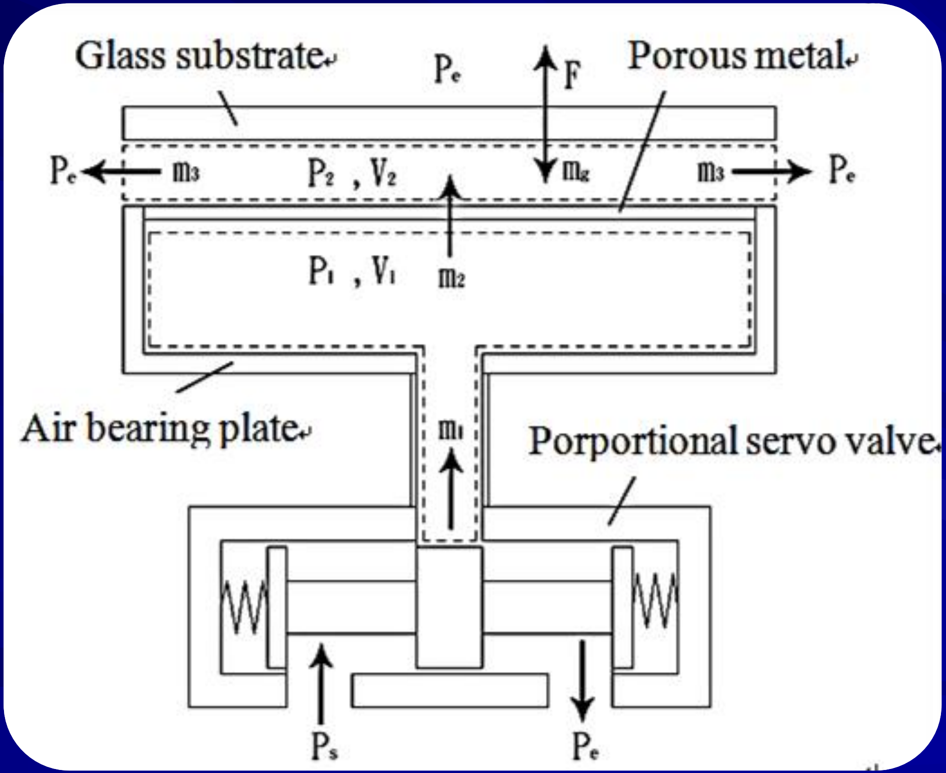
Dynamic Model of the System

- 4. Motion equation

$$M \cdot \ddot{Y} = (P_2 - P_e) \cdot A_a - M_g - F_r$$



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Controller Design

- Pneumatic system is a nonlinear time-varying system, so It's difficult to build up an accurate mathematical model and get the accurate parameters.
- In this research, we use functional approximation with Fourier series based to build up an adaptive sliding mode control, Fourier series-based adaptive sliding mode controller (FSB-ASMC).
- FSB-ASMC with H_∞ tracking performance is using to handle the function approximation errors, un-modeled dynamics and disturbances.

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Controller Design

Functional Approximation with Fourier Series

+

Sliding Mode Controller

+

H∞ Tracking Performance

FSB-ASMC+H∞ Controller

Model-Free, Robustness

Controller Design

In order to develop the controller for the pneumatic air-bearing servo system, FSB-ASMC+H∞ controller is used in this study to solve the high non-linearity and time-varying problems.

STEP1: A general nonlinear system is shown as

$$y^{(n)}(t) = f(\mathbf{x},t) + g(t)u(t) + d(t) = F(t) + g(t)u(t)$$

STEP2: Define the output error as

$$e(t) = y(t) - y_m(t)$$

STEP3: Define the sliding surface

$$s = a_1 e(t) + a_2 \dot{e}(t) + \ldots + e^{(n-1)}(t)$$

STEP4: Choose the controller input

$$u(t) = \frac{-\hat{\mathbf{W}}_F^T \mathbf{q}_F(t) - a_1 \dot{e} - a_2 \ddot{e} - p_{21} e - p_{22} \dot{e} + y_m^{(3)}(t) - \frac{s}{2\rho^2}}{\hat{\mathbf{W}}_g^T \mathbf{q}_g(t)}$$

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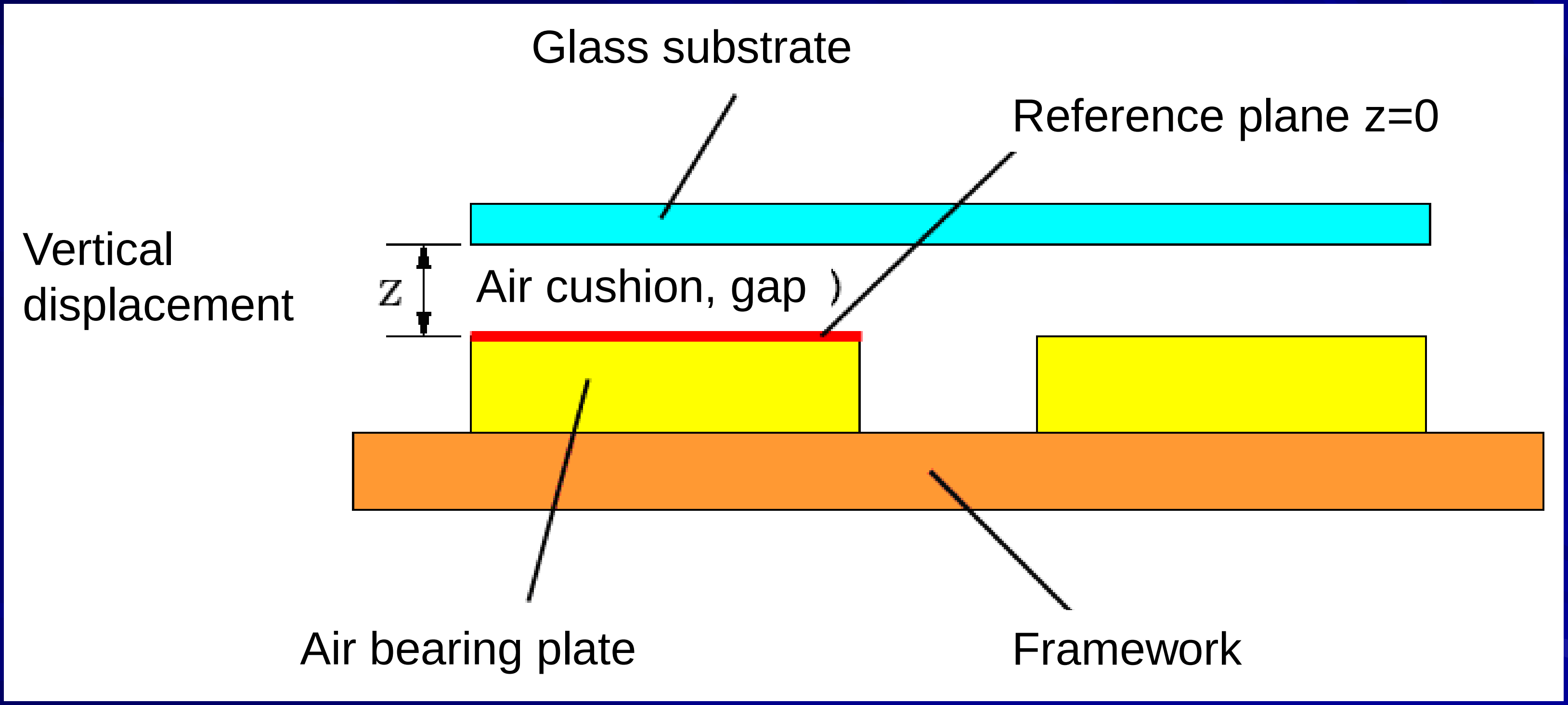
Simulation of Vertical Displacement of Glass Substrate



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Simulation of Displacement of Glass Substrate in Open-Loop

- Comparison between simulation and experiment in open loop
- Oscillation occurs without controller
- Step response in closed loop
- 5th order position tracking in closed loop
- 5th order tracking control + position control in closed loop
- Sinusoid position tracking in closed loop

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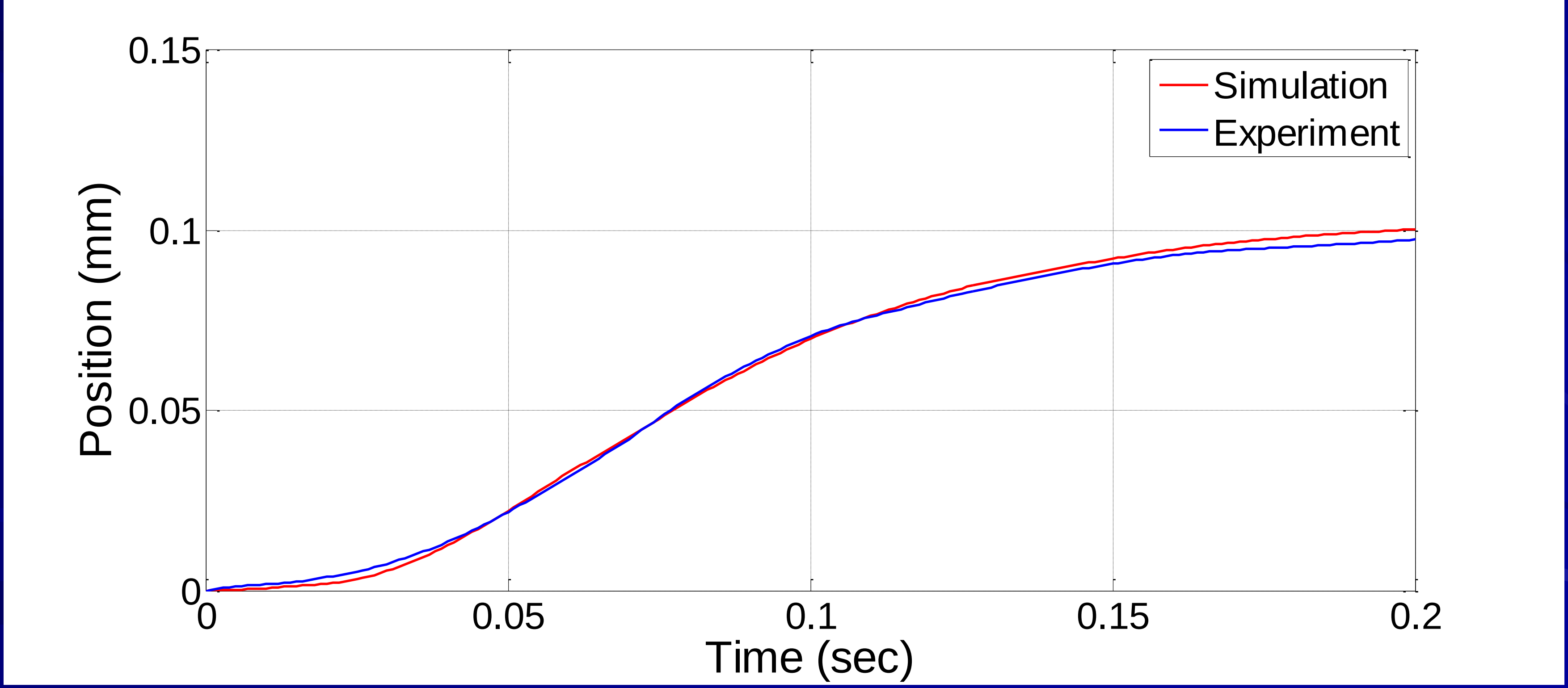
Simulation of Displacement of Glass Substrate in Open-Loop

- **Comparison between simulation and experiment in open loop system**



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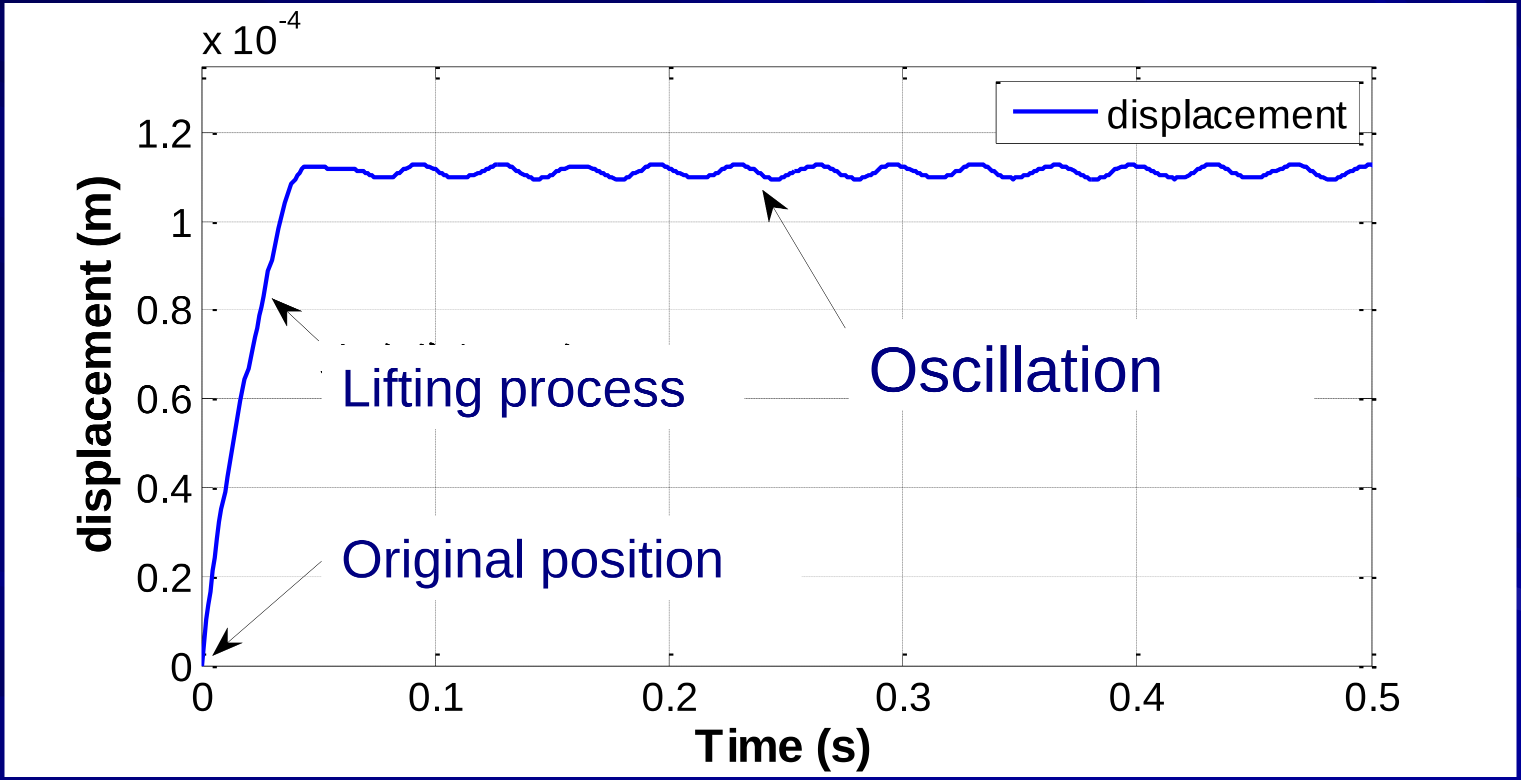
Simulation of Displacement of Glass Substrate in Open-Loop

- **Oscillation occurs when the glass substrate reaches the stable height without controller.**



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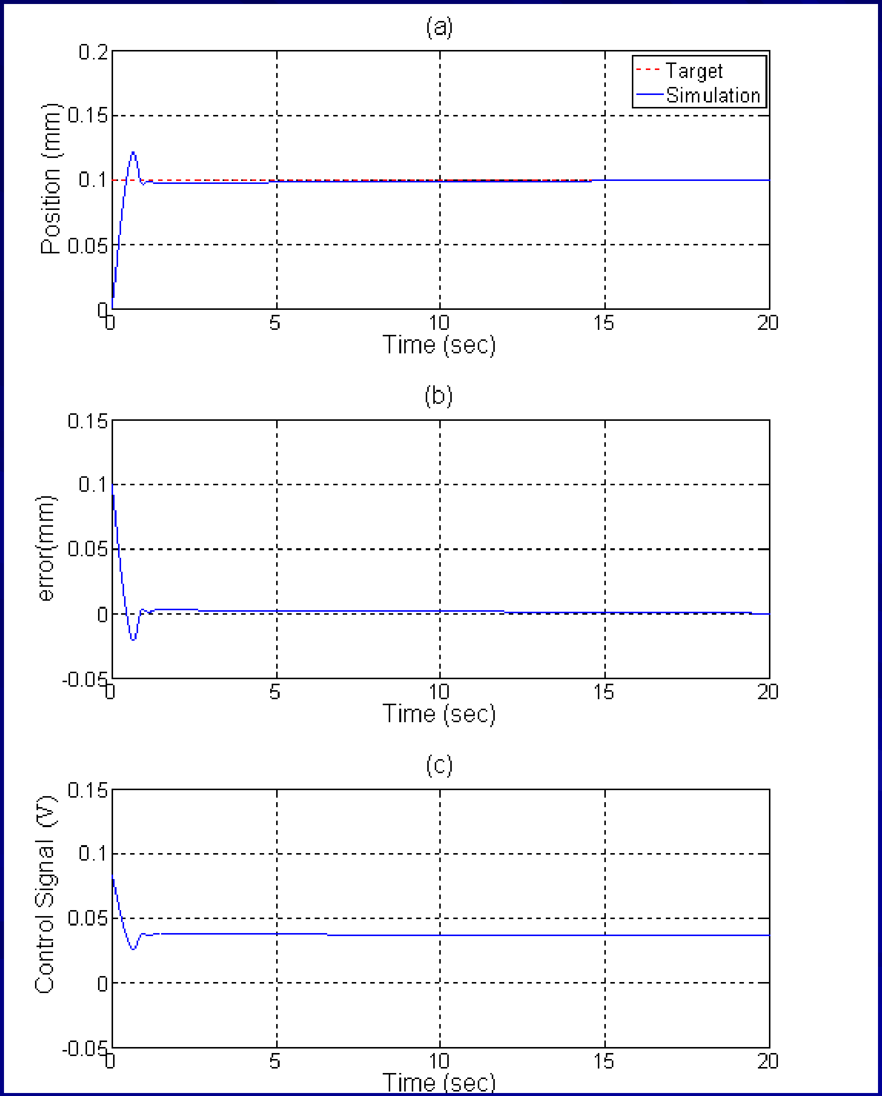
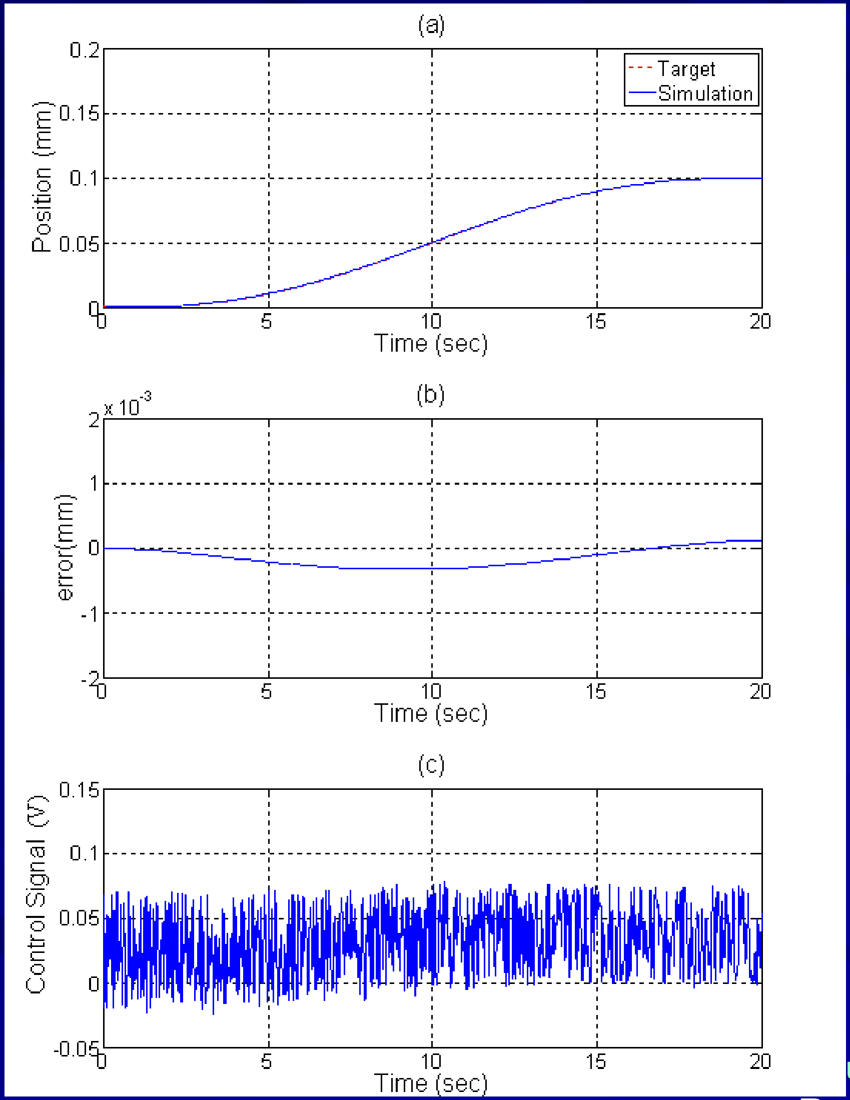
Simulation of step response in closed loop (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

Simulation of 5th order position tracking in closed loop (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

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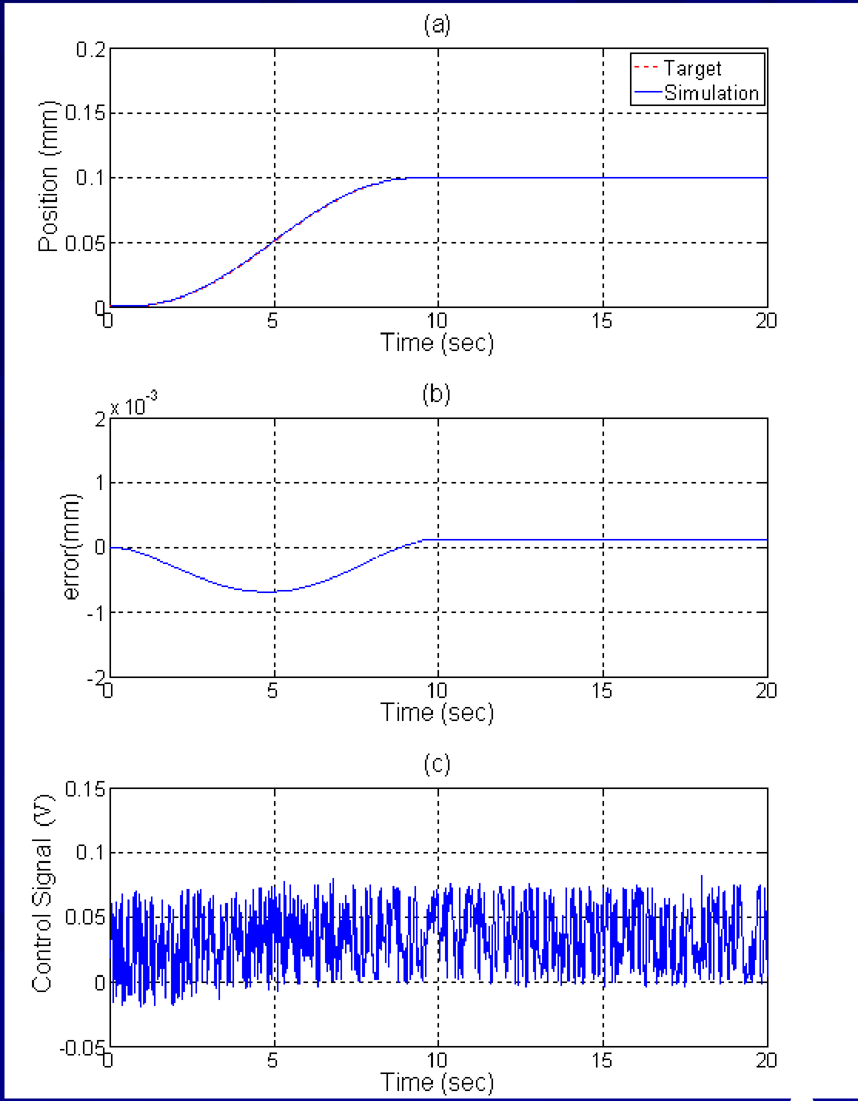
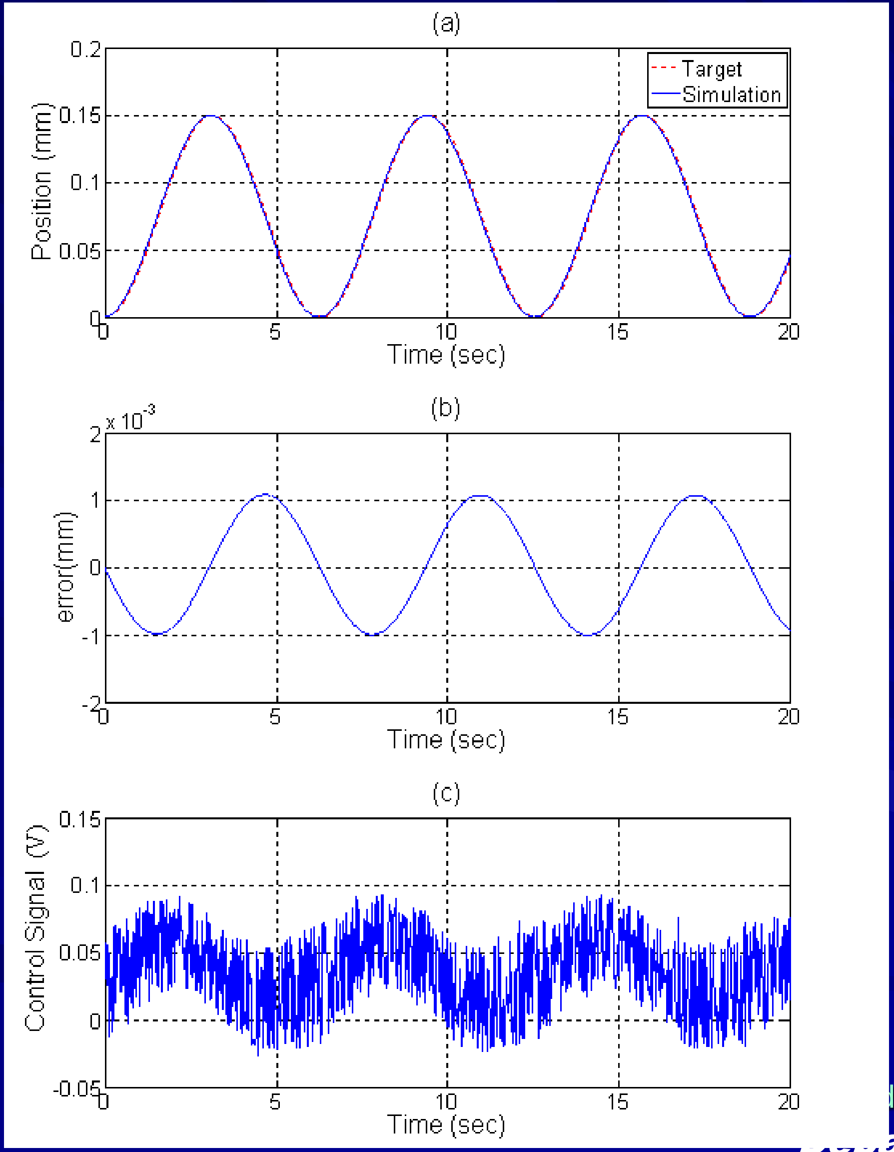
Simulation of 5th order tracking control + position control in closed loop (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

Simulation of sine position tracking in closed loop (stroke: 0. 075 mm, 2π sec/period, 20 sec)



(a) trajectory response
(b) error
(c) control signal

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Experiment of Displacement of Glass Substrate in Open-Loop

- Experiment in open loop
- Open loop with disturbance
- Step response in closed loop
- 5^{th} order position tracking in closed loop
- 5^{th} order tracking control + position control in closed loop
- Sinusoid position tracking in closed loop

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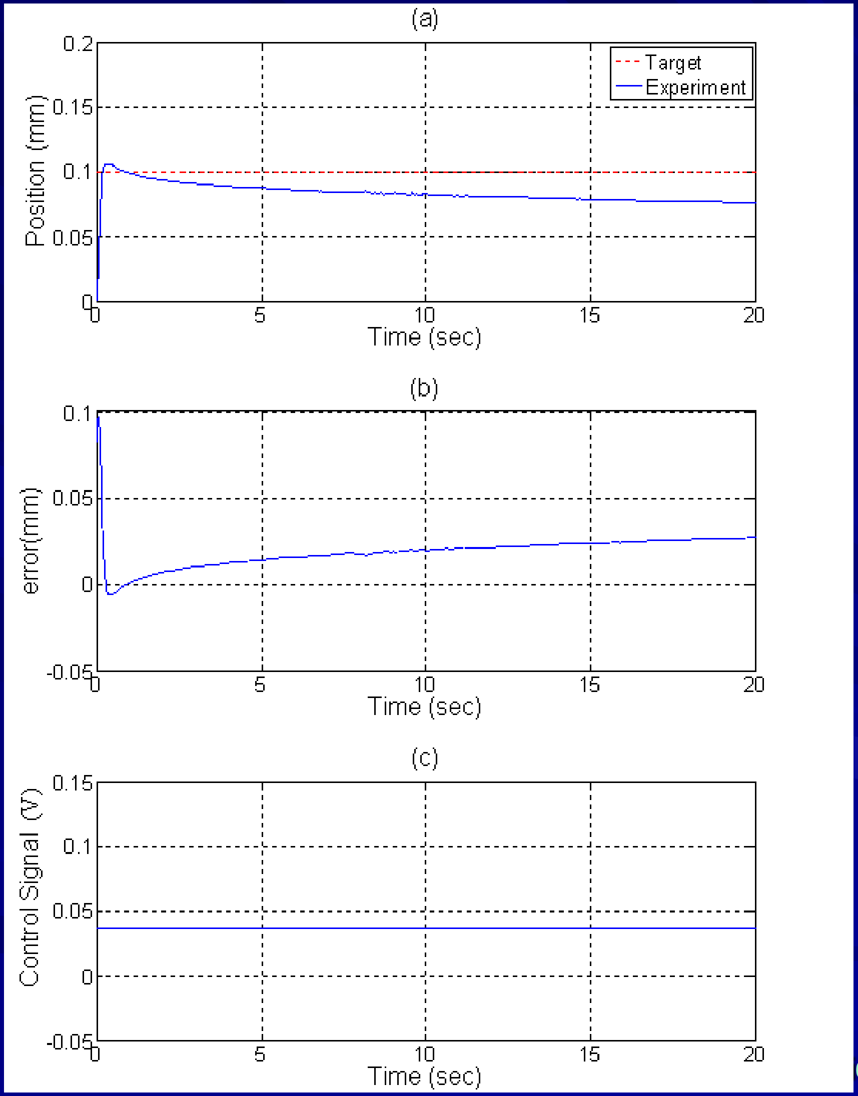
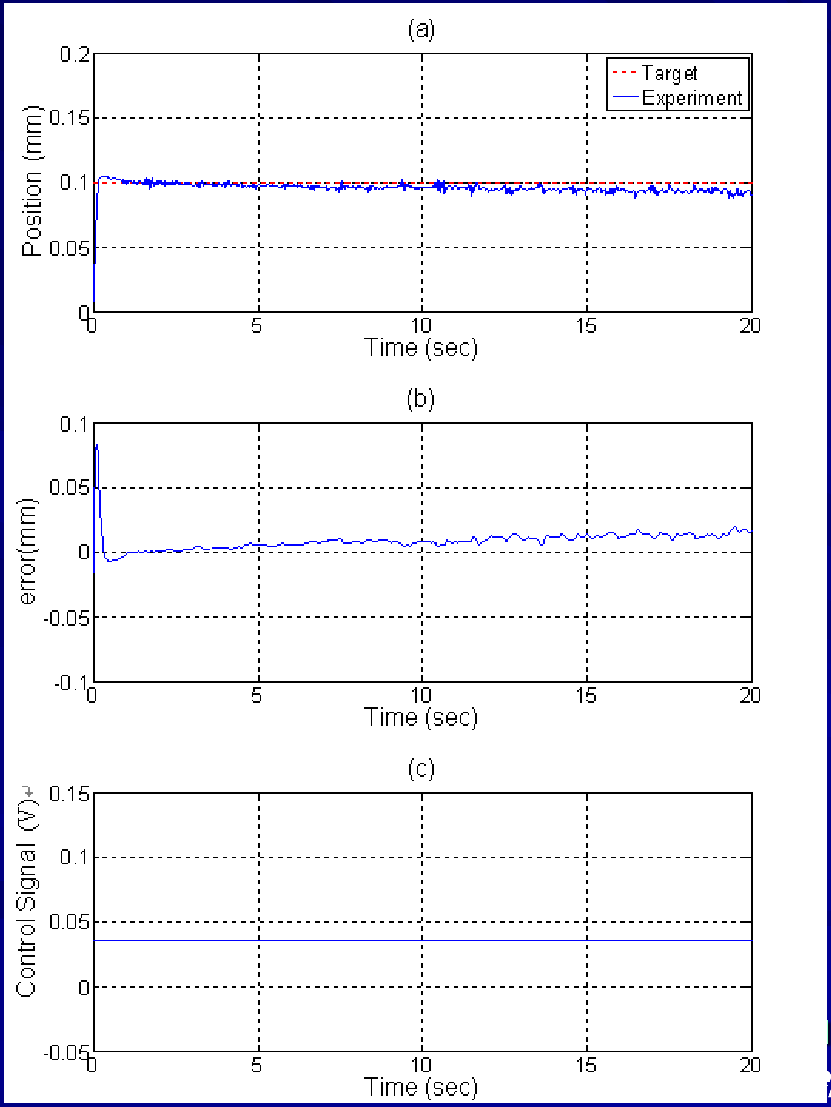
Experiment of displacement of glass substrate in open loop (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

Experiment of displacement variation of glass substrate in open loop with disturbance (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

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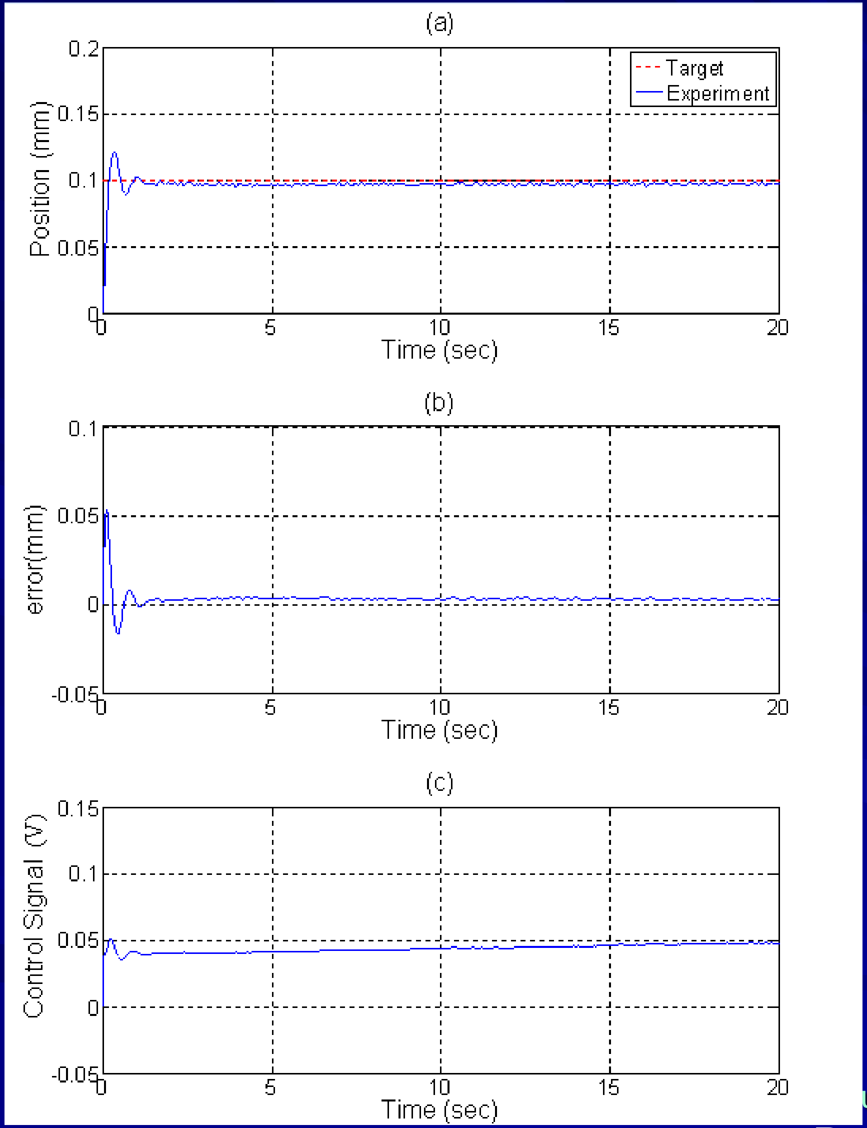
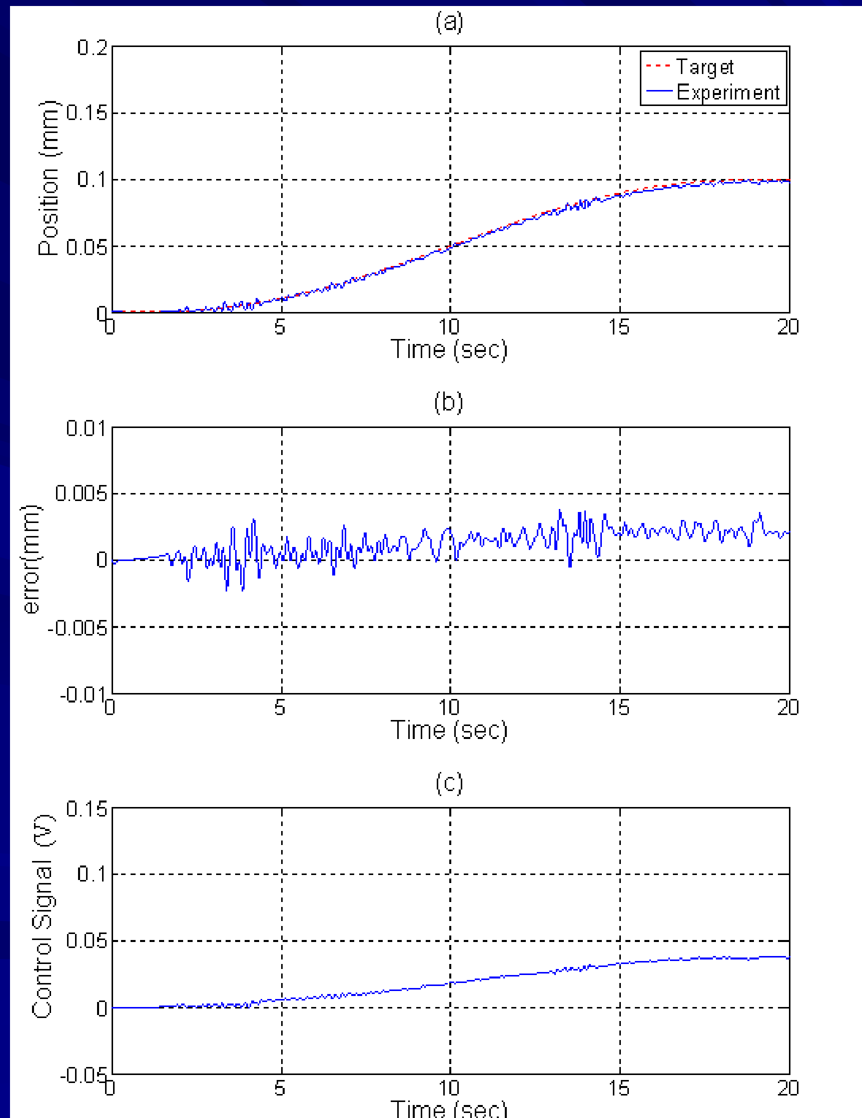
Experiment of step response in closed loop (stroke: 0.1 mm, 20 sec)



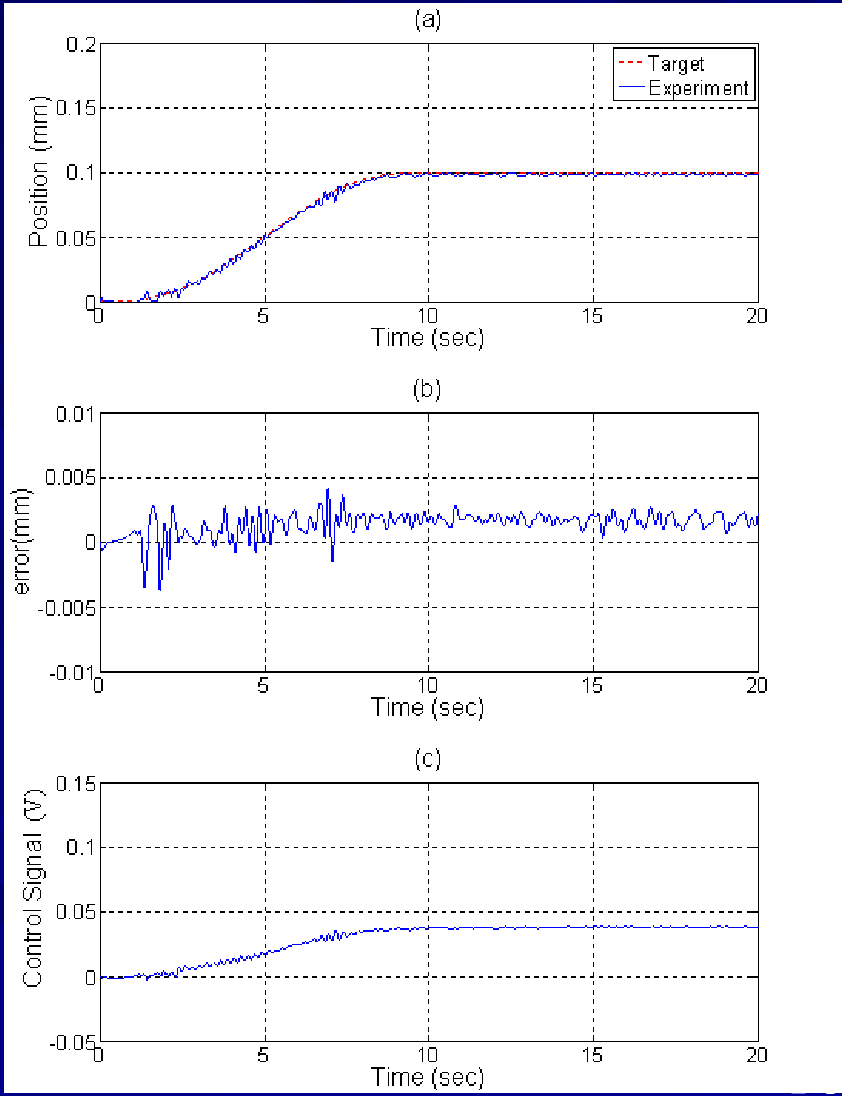
(a) trajectory response
(b) error
(c) control signal

Experiment of 5th order tracking control in closed loop (stroke: 0.1 mm, 20 sec)



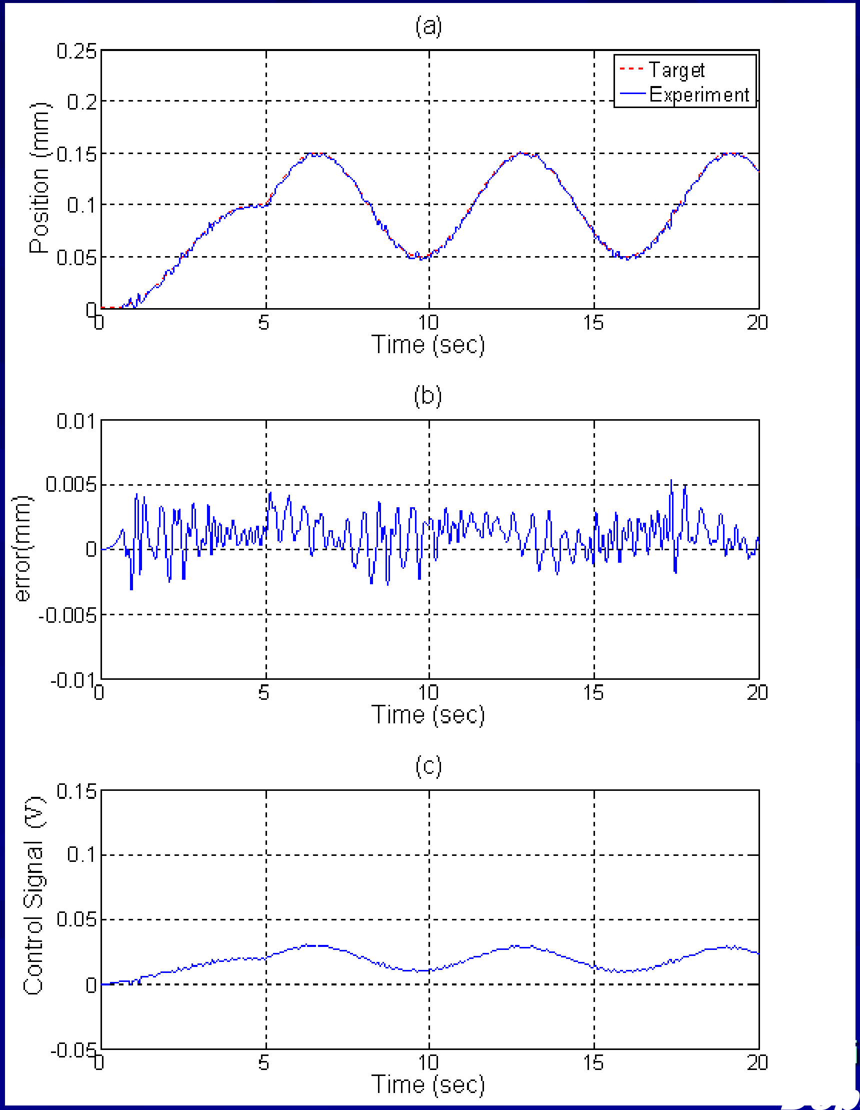
(a) trajectory response
(b) error
(c) control signal

Experiment of 5th order tracking control + position control in closed loop (stroke: 0.1 mm, 20 sec)



(a) trajectory response
(b) error
(c) control signal

Experiment of sine tracking control in closed loop (stroke: 0. 05 mm, 2π sec/period, 20 sec)



(a) trajectory response
(b) error
(c) control signal

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Comparison and Discussion of Experiment Results

- Comparison of open-loop and closed-loop control
- Comparison of different controllers
- Comparison of different strokes
- Comparison of different loads
- Comparison of sine path tracking control
- Robust test

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Experimental comparison of open loop and closed loop

Case (1)

stroke : 0.1 mm

time : 20 sec

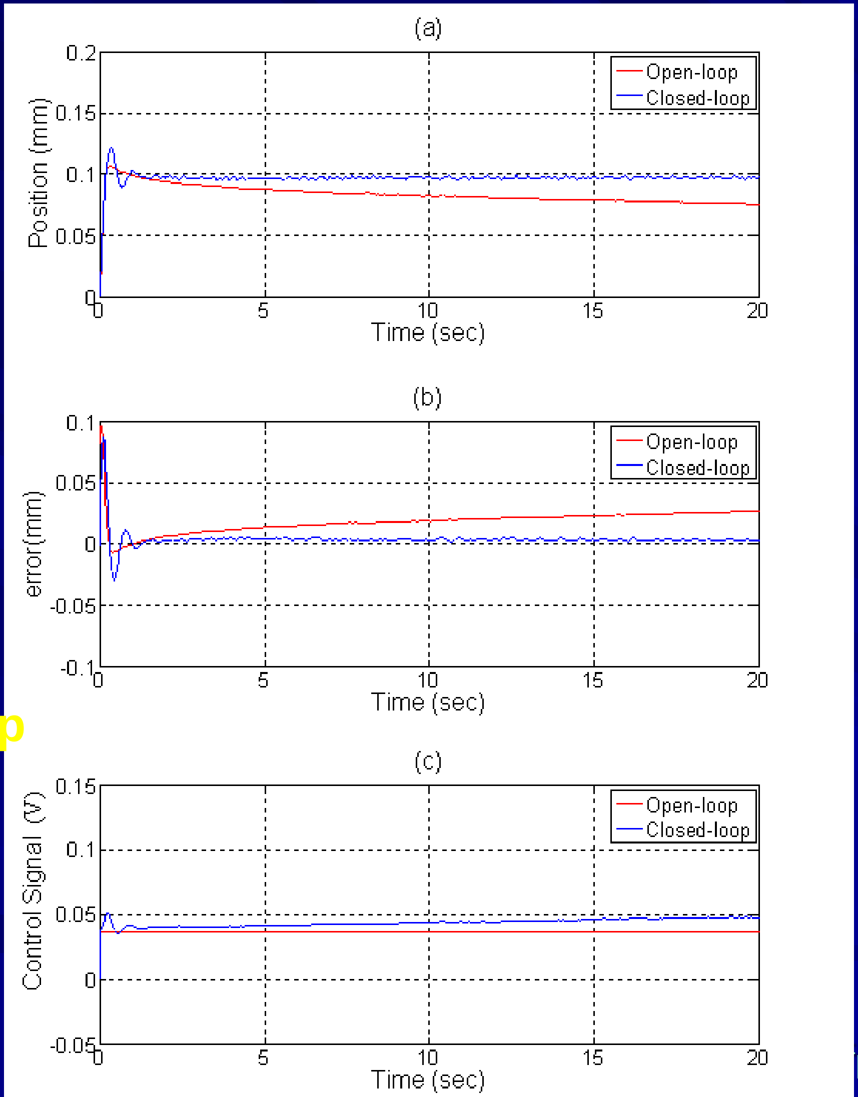
system: open loop

Case (2)

stroke : 0.1 mm

time : 20 sec

system: closed loop



(a) trajectory response
(b) error
(c) control signal

Experimental comparison of different controllers

Case (1)

stroke : 0.1mm

5^{th} order : 20sec

Time : 20sec

System : without H_∞

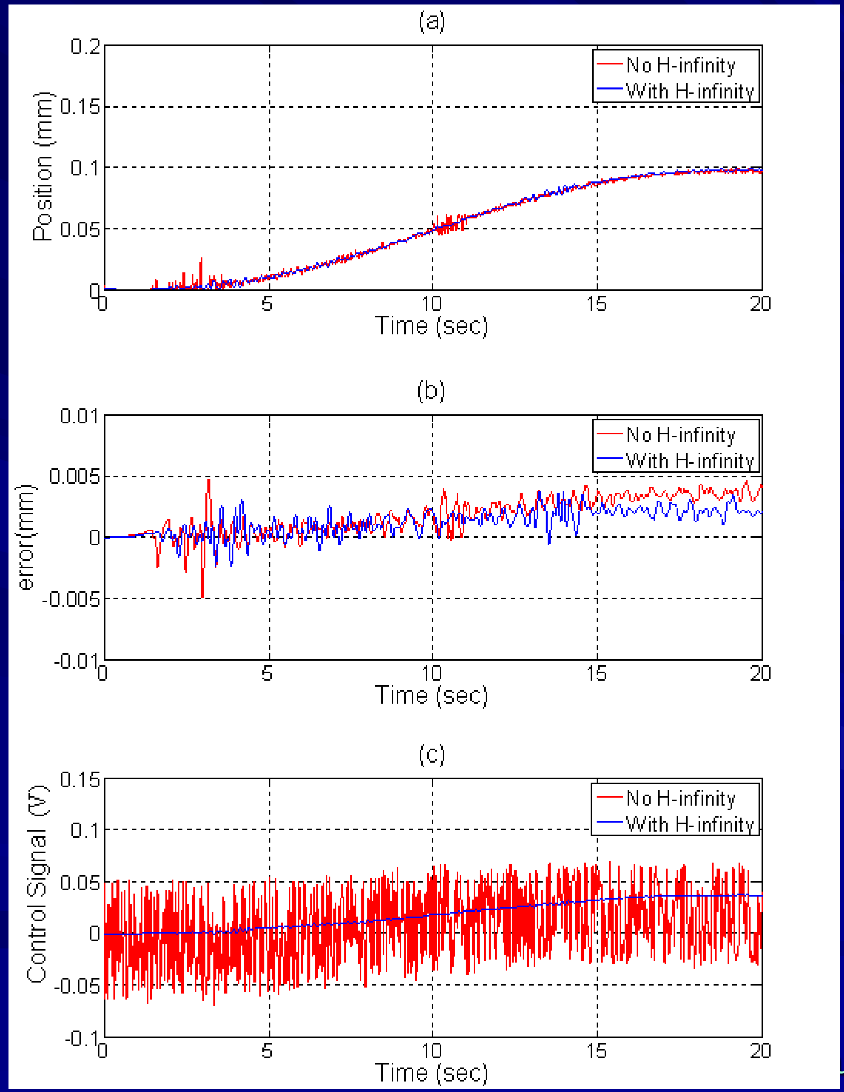
Case (2)

stroke : 0.1mm

5^{th} order : 20sec

Time : 20sec

System : With H_∞



(a) trajectory response
(b) error
(c) control signal

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Experimental comparison of different strokes

Case (1)

stroke ： 0.1mm

5th order ： 20sec

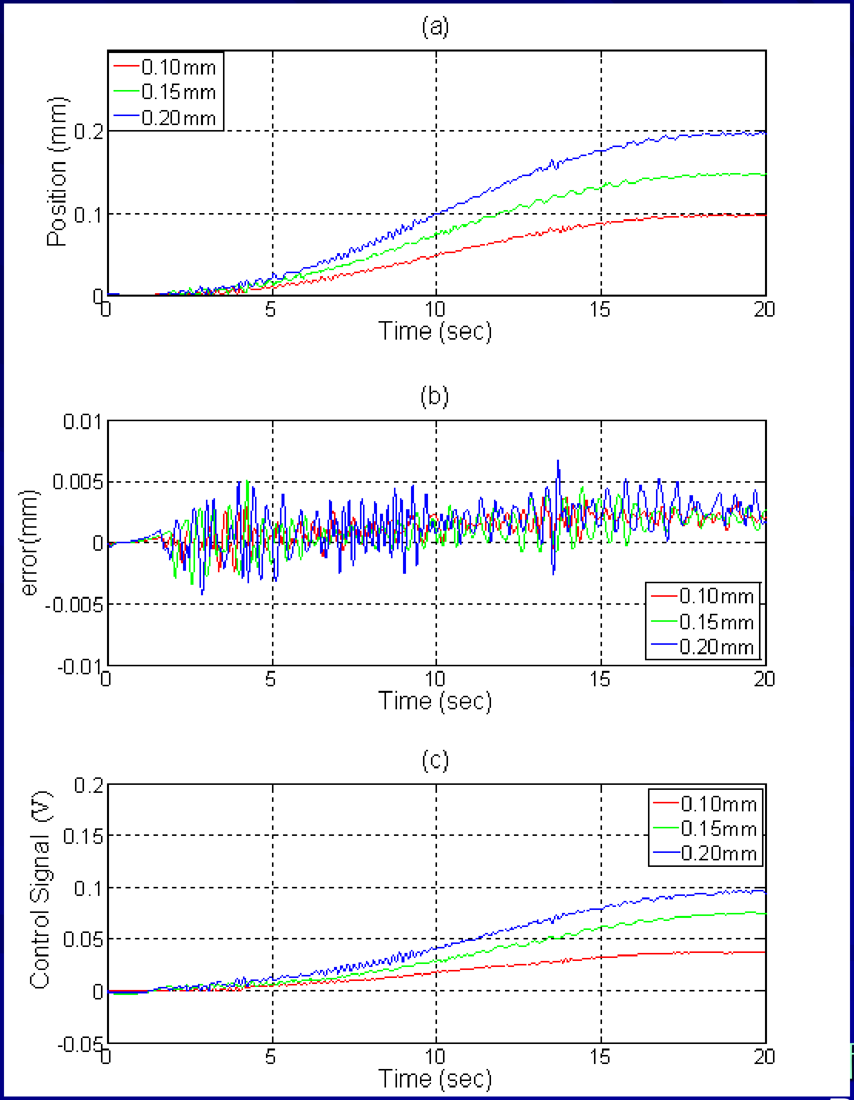
time ： 20sec

Case (2)

stroke ： 0.15mm

5th order ： 20sec

time ： 20sec



Case (3)

stroke ： 0.2mm

5th order ： 20sec

time ： 20sec

(a) trajectory response
(b) error
(c) control signal

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Experimental comparison of different loading

Case (1)

Stroke: 0.1mm

5th order：20sec

Time：20sec

Thickness: 1mm

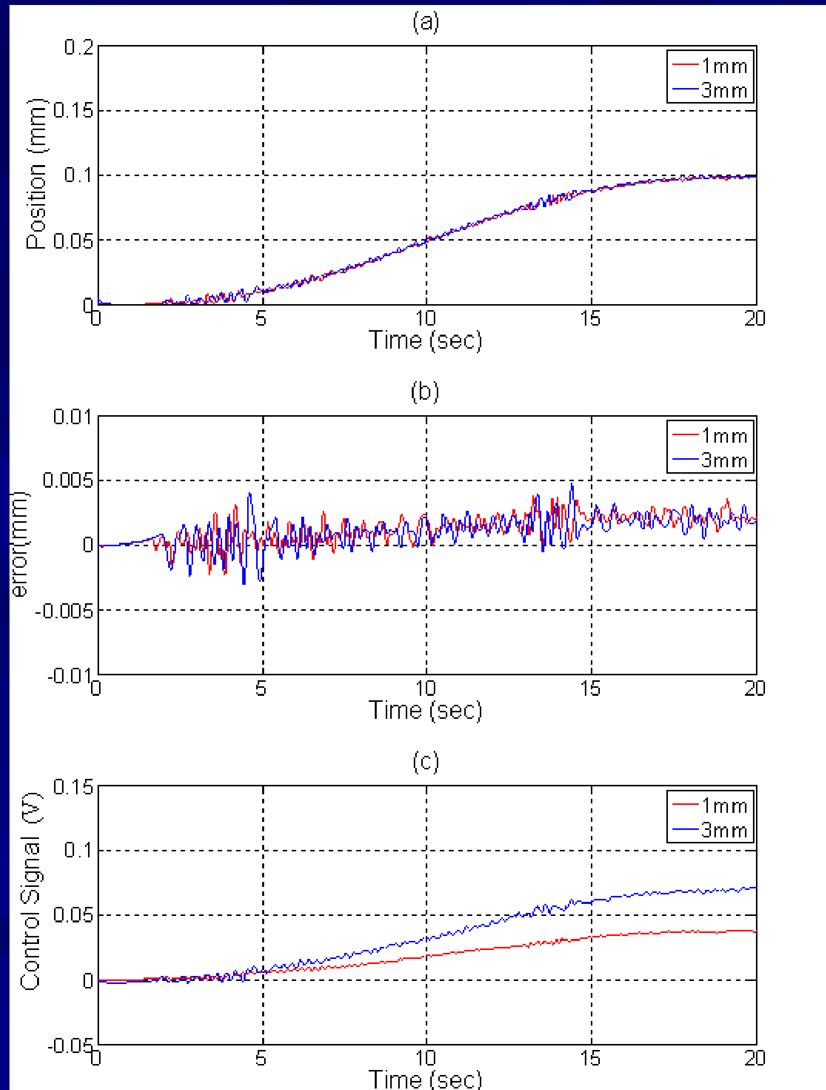
Case (2)

Stroke: 0.1mm

5th order：20sec

Time：20sec

Thickness: 3mm



(a) trajectory response
(b) error
(c) control signal

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Experimental comparison of different sinusoid tracking control

Case (1)

stroke：0.05mm

period：2πsec

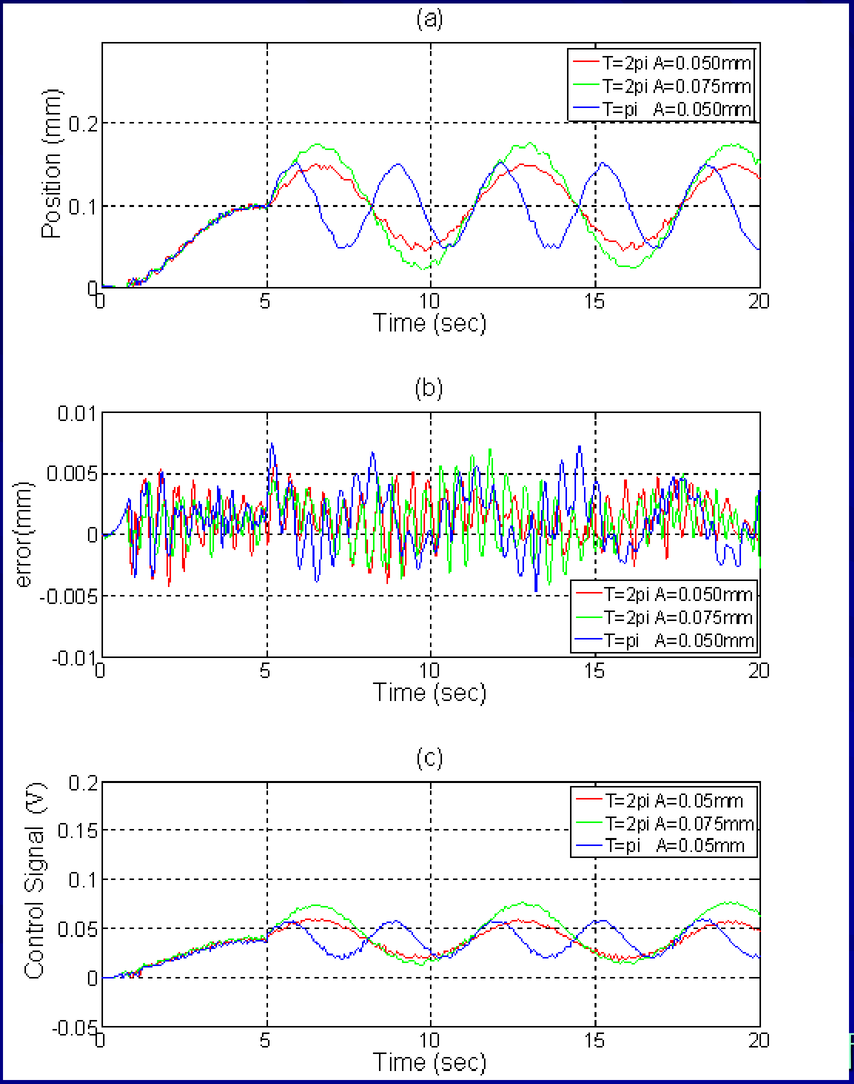
time　：20sec

Case (2)

stroke：0.075mm

period：2πsec

time　：20sec



Case (3)

stroke：0.05mm

period：2πsec

time　：20sec

(a) trajectory response
(b) error
(c) control signal

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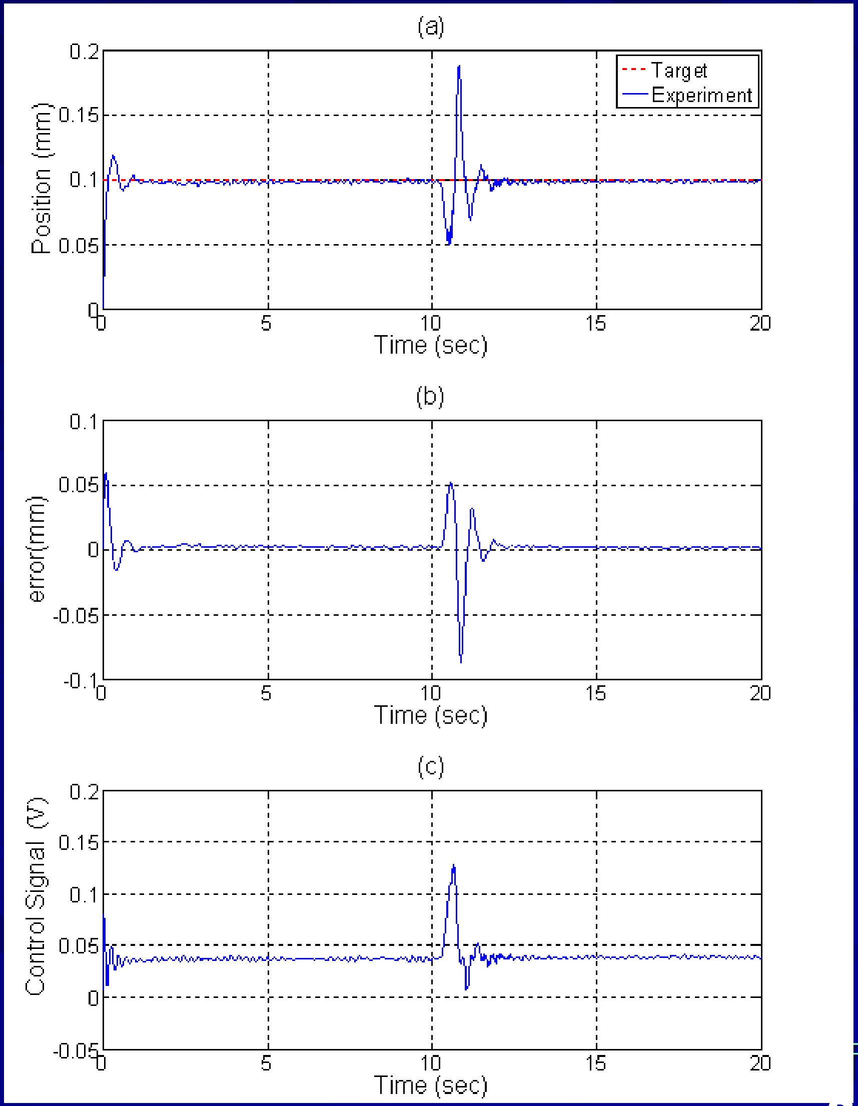
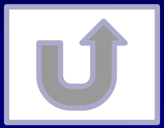
Robust test of air bearing conveyor system by adding disturbance (stroke：0.1mm, 20sec)



(a) trajectory response
(b) error
(c) control signal



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Conclusions

- This paper developed an **active leveling control** for an air bearing conveyor system for glass substrates of TFT-LCD or solar cell.
- The proposed concept of active leveling control for an **air bearing conveyor system** is to input high pressure air to the air bearing plates such as to form an **air cushion** between the air bearing plates and the glass substrates.

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Conclusions

- Hence, the friction between the glass substrates and the air bearing plates can be avoided, and the damage of the friction or shaking on the surface of glass substrates can be diminished.
- Through simulation and experiments, the unstable leveling position of the glass substrates occurring due to unstable air pressure between the air bearing plates and the glass substrates can be improved be means of the closed-loop leveling position control.

Thanks for Your Attention!

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