Proceedings of the 2002 IEEE
International Conference on Robotics & Automation
Washington, DC • May 2002

High Steady-State Accuracy Pneumatic Servo Positioning System with PVA/PV Control and Friction Compensation

Shu Ning and Gary M. Bone*

Department of Mechanical Engineering,
McMaster University,
Hamilton, Ontario, Canada, L8S 4L7.
*Corresponding author. E-mail: gary@mcmaster.ca

Abstract

Pneumatic servo actuators have the benefits of low-cost, cleanliness and a high power-to-weight ratio. However, their relatively poor accuracy prevents them from competing with electro-mechanical systems when higher accuracy is needed. The cause of the steady-state error for a pneumatic servo system with an open-center servo valve is investigated. Full nonlinear and linearized plant models are presented. An effective friction compensation method is introduced which can be added to any control strategy. When combined with a novel PVA/PV control approach, a steady-state accuracy of ±0.01mm has been verified in experiments. This is a tenfold improvement over previously reported experimental results for such systems. This performance is achieved for both vertical and horizontal movements with payloads ranging from 0.3 to 11.3 kg, without re-tuning the controller.

1. Introduction

In recent years many researchers have investigated pneumatic servo systems due to their potential as a low-cost, clean, high power-to-weight ratio actuator. The compressibility of the working media, air, and the large static and Coulomb friction have made achieving accurate position control a challenging problem.

Various approaches including: adaptive control [6,9] fuzzy control [3,5], neural networks [2,4,7] and extended PID control [1,8] have been investigated recently with varying degrees of success. (Please see [8] for a review of earlier pneumatic servo research). The best steady-state accuracy achieved in previous work is on the order of ±0.2mm (see [6,8] for example). This prevents pneumatic servos from competing with electro-mechanical systems when higher accuracy is needed. Most of these systems were tested only for horizontal movement, avoiding the difficulty introduced by gravity loading.

In this paper we describe the development of a novel pneumatic servo system. Full nonlinear and linearized plant models are presented. A controller is developed incorporating friction compensation and a modified form of proportional plus velocity plus acceleration (PVA) control. Simulation and experimental results are reported.

2. The Pneumatic Servo Positioning System and Its Model

The pneumatic system used in this research is shown in Figure 1. A rodless cylinder and an open-center servo valve both made by Festo are utilized. The orientation of the system can be adjusted to 0°, 45° and 90° with the horizontal plane. The nonlinear mathematical model of the plant can be expressed by following equations:

$$\dot{m}_a = f_a(x, p_a, p_s, p_0) \tag{1}$$

$$\dot{m}_b = f_b(x, p_b, p_s, p_0) \tag{2}$$

$$KRT\dot{m}_a = p_a A_a K\dot{y} + A_a(y_{a0} + y)\dot{p}_a \tag{3}$$

$$KRT\dot{m}_b = p_b A_b K\dot{y} + A_b(y_{b0} + y)\dot{p}_b \tag{4}$$

$$M\ddot{y} = \begin{cases} p_a A_a - p_b A_b - c_{vf}\dot{y} - F_{cf} - F_l, & \dot{y} \neq 0 \\ 0, & \dot{y} = 0 \ and \ (p_a A_a - p_b A_b) < F_{sf} \end{cases} \tag{5}$$

Where:

A_a, A_b	Piston area in chamber A and B
c_{vf}	Coefficient of viscous friction
$\dot{m}_a$, $\dot{m}_b$	Mass flow rate into chamber A & B
f_a, f_b	Flow rate function
F_{cf}	Coulomb friction force
F_{sf}	Static friction force
F_l	External load force
K	Ratio of specific heat c_p/c_v
M	Payload mass
p_a, p_b	Air pressure in chamber A and B
p_s	Supply pressure
p_0	Atmosphere pressure
R	Ideal gas constant
T	System temperature

0-7803-7272-7/02/$17.00 © 2002 IEEE