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Identification of Friction Parameters in Pneumatic Cylinders using a Combined Real-Time and Simulation Environment

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Abstract

This paper presents a method to identify the friction parameters for servo-pneumatic systems using a combined-reality environment. To acquire system friction parameters accurately can be extremely difficult once the servo-system has been assembled because of its highly nonlinear nature, which causes a great difficulty in servo-pneumatic system modelling and control. In this paper, a combined-reality environment has been used to determine the friction parameters easily and efficiently through online identification technique. The advantages of this method are simplicity, speed and high accuracy in the estimated parameters. Using this method the frictional parameters of two different sized cylinders are identified.

Keywords: servo pneumatics, pneumatic actuaor, friction, idetification, combined reality

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INTRODUCTION

Pneumatic actuators are widely used in the automation systems industries and robots. Traditionally, the pneumatic actuators are used for motion between two determined hard stops. The pneumatic systems are very useful for the manipulation and rapid motion of mechanical objects in assembly, monitoring, packing, stacking, clamping, and fixing of various products.

The pneumatic drives can attain high speeds in linear motion without additional mechanical transmissions with considerable force development and prolonged intense operation without risk of overheating. The advantages of these drives include high ceiling, high mechanical efficiency, long working life, broad working temperature range, low operating costs, simple storage of the compressed air energy, and compatibility with portable power sources. The practical advantage of the pneumatic drives is the ability to operate in wet, dusty, and chemically aggressive atmospheres which poses the risk of fire or explosion. These drives can be used in the presence of radiation and electromagnetic fields, as well as mechanical vibrations.

Servo pneumatics is the technology of using a feedback system which enables the pneumatic cylinders to be positioned in any position within its stroke length. This servo pneumatic system has potential to replace electromechanical and costly hydraulic system in many applications. The main problem is that these drives are nonlinear in nature. The pressure within the pneumatic cylinder, the frictional force, and the compressed air flow rates through the chokes of the pneumatic drive, all vary in nonlinear fashion. The dead zone and time delay characteristics of the servo valve also adds to the complexity for designing controller for the system.

Friction is one of the most common nonlinearities present in pneumatic systems. The knowledge of frictional behavior and parameters; play vital role in the accurate position control of pneumatic actuator. Friction is a very complex phenomenon which has various forms such as stiction, stribeck effect, stick-slip, and Coulomb friction. Thus, obtaining a frictional model that would represent the characteristics of the friction forces is not an easy task. Therefore, many research efforts have been directed to address this problem.

Andrighetto *et al.* have presented a comparative study among friction behavior of several double-acting pneumatic actuators available to industrial use. [1] Tran and Yanada presented an experimental investigation and modeling of dynamic friction behaviors in the sliding regime of pneumatic cylinders. [2] Belforte *et al.* presented an experimental apparatus to measure the friction force in pneumatic cylinders is described. [3] Chang *et al.* described friction force measurement tests to measure the friction force of pneumatic cylinder, under both dry and lubricated conditions. [4] Experimental equipment has been designed to assess the effect of seals and lubrications in pneumatic cylinder. But instead of direct measurement of frictional forces, system identification methods are used for identification of frictional parameters from experimental values. Liu *et al.* presented a method of identifying parameters of the LuGre model, which is a nice friction model that can describe the friction phenomenon of pneumatic cylinders comprehensively. [5]

Carducci *et al.* have analyzed the procedure for the experimental identification of viscous force with regard to a mathematical model. [6] Saleem *et al.* have presented a method to identify the friction parameters for servo-pneumatic systems using a mixed-reality environment. [7] This method involves manual tuning of the parameters by visualizing the response of the system. In this paper a new methodology has been presented for identification of frictional parameters using automatic iterative method using mixed reality environment. This mixed reality environment consists of both real-time and simulation environments simultaneously. Using this method, frictional coefficients of two different size cylinders are obtained.

SYSTEM DESCRIPTION

System Overview

The closed loop schematic diagram of servo pneumatic position control system is shown in Figure 1. The main components in the system are pneumatic cylinder, proportional directional control valve, position transducer and a fuzzy controller. The position of the pneumatic cylinder is controlled by the proportional valve which regulates the flow rate of the compressed air.

The position transducer is used to sense the present position which is used by the controller to manipulate the spool movement in the proportional DCV. This spool movement manipulates the air flow rate to the cylinder chambers and hence controlling the position and velocity of the cylinder movement.

Mathematical Model of the System

The following assumptions are normally made in modelling of the servo pneumatic positioning system.

1. The air used is assumed to be a perfect gas.
2. The pressures and temperature within each chamber are homogeneous.
3. The supply and exhaust pressures are assumed to be constant. Normally exhaust pressure is taken as atmospheric pressure.
4. Kinetic and potential energy terms are neglected in energy equations.

5. The air leakages between the chambers and between chambers and external environment are neglected.
6. The effects due to connecting tubes are normally neglected. Tube length can be ignored when air supply is very close to valve and cylinder.

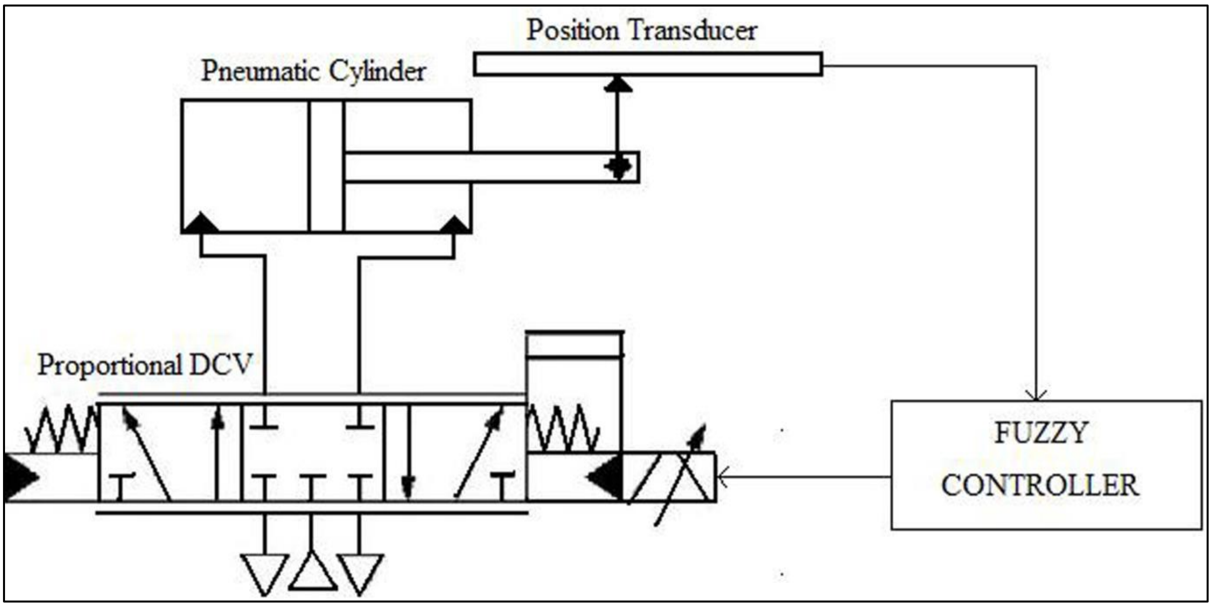

Fig. 1: *Schematic Representation of Servo Pneumatic Positioning System.*

According to Newton's second law of motion, the dynamics of the piston-rod-load assembly can be expressed by Eq. (1).

$$(\mathrm{M_L} + \mathrm{M_P})\ddot{x} = F_P - F_{fric} - \mathrm{F_{ext}} + \mathrm{M_L g} \sin\theta \quad \text{Eq. (1)}$$

where x, $\dot{x}$(or v), $\ddot{x}$ are the displacement, velocity and acceleration of the cylinder respectively, M_L is mass of the external load, M_P is mass of the piston-rod assembly of the cylinder, g is acceleration due to gravity (9.8 ms^{-1}) and θ is tilting angle of the cylinder.

The resultant pneumatic force (F_P) is given by Eq. (2).

$$F_p = \mathrm{A_1} P_2 - \mathrm{A_2} P_2 - \mathrm{A_{rod}} \mathrm{P_a} \quad \text{Eq. (2)}$$

Where; A_1 and A_2 are cross sectional areas of two cylinder chambers, A_{rod} is cross sectional area of the piston rod, P_1 and P_2 are absolute pressure in two cylinder chambers and P_a is the ambient or atmospheric pressure.

The equation of pressure dynamics of compressed air in the cylinder chambers is given by Eq. (3).

$$\dot{P_l} = \frac{\kappa}{V_{0i} + A_i\left(\frac{1}{2}l \pm x\right)}(\mathrm{R}T_i\dot{m_l} - P_i A_i \dot{x}) \quad \text{Eq. (3)}$$

where i = 1, 2; is the cylinder chambers index, V_{0i} is the inactive volume at the end of stroke and admission ports, κ is adiabatic exponent, l is the stroke length of the cylinder, R is specific gas constant, T_1 and T_2 are temperatures in two cylinder chambers, $\dot{m}_1$ and $\dot{m}_2$ are mass flow rates to the cylinder chambers.

Friction Model in Cylinder

The friction force in the pneumatic cylinder is the most complex non-linearity in pneumatic position servo system.

The frictional nonlinearity causes many control difficulties such as position steady state and position trajectory tracking errors. The limit cycles around the desired position (hunting) and stick-slip movements are caused by frictional force variations. The behaviour of frictional forces with velocity is shown in Figure 2.

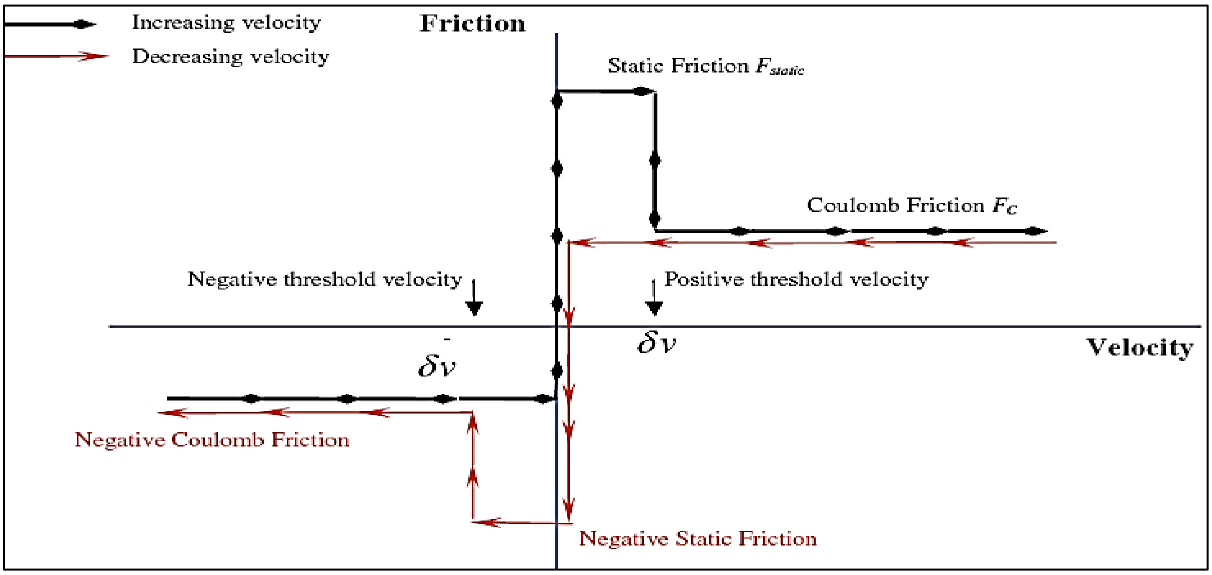

Fig. 2: *Frctional Behaviour with Velocity.*

The frictional force inside the pneumatic cylinder is given by Eq. (4).

$F_{fric} = F_c + F_v\dot{x} + k_p(P_1 - P_2)$ Eq. (4)

Where; F_c is the static or Coulomb frictional coefficient, F_v is the viscous coefficient of friction and k_p is the coefficient of friction due to cylinder seals.

COMBINED REALITY ENVIRONMENT

To achieve an accurate model for a pneumatic system, it is crucial to determine the frictional parameters of the system. However, it is extremely difficult to measure the nonlinear friction parameters directly once the pneumatic actuator has been assembled to form an actuation system. A combined reality environment has been developed, in which a real system is run in conjunction with a simulation environment as shown in Figure 3. The main concept of such structure is to use real signals acquired from the system's sensors to calculate the piston's speed and position. These calculations depend on three variables: (1) static friction F_c, (2) viscous friction F_v, and (3) coefficient of friction due to cylinder seals k_p. Therefore, by comparing the position that resulted from these calculations and the real position of the system on the same plot, the three variables can be identified. All the responses are obtained using open loop response of the system. The automatic tuning of these parameters is done following the least square algorithm. The parameters which possess less error between simulation and real-time response will be used for identification of best fit frictional parameters.

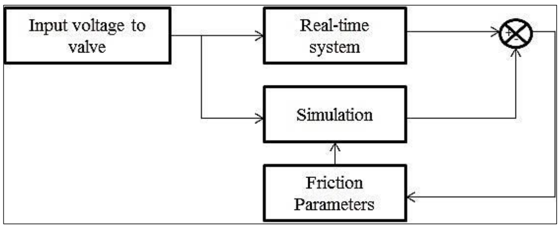

Fig. 3: *Block Digram for Combined Reality Environrment.*

RESULTS AND DISCUSSION

The combined reality method is used to identify the parameters for two cylinders. The size parameters of the two cylinders used are given in the Table 1. Using the combined reality environment the frictional parameters in simulation are automatically varied using least square algorithm to match the real-time response. Figure 4 shows the plot between real-time response and simulation with F_c=5 N, F_v=0 N and k_p=0 N/Pa for cylinder A. It shows a very large deviation between the signals.

Figure 5 shows the plot between real-time response and simulation with F_c=24.8 N, F_v=12 N and k_p=2 N/Pa for cylinder A. In this plot the deviation is minimized, and further the both real-time and simulation signals follows similar trajectory. Figure 6 shows the plot between real-time response and simulation with F_c=24.8 N, F_v=13.49 N and k_p= 2.89 N/Pa for cylinder A. This response has least deviation between the two responses, so the parameters are fixed to these values.

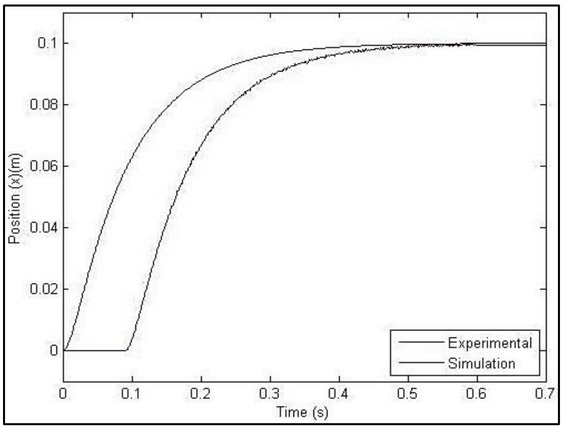

Fig. 4: *Realtime and Simulation Response of Cylinder A with F_c=5 N, F_v=0 N and k_p=0 N/Pa.*

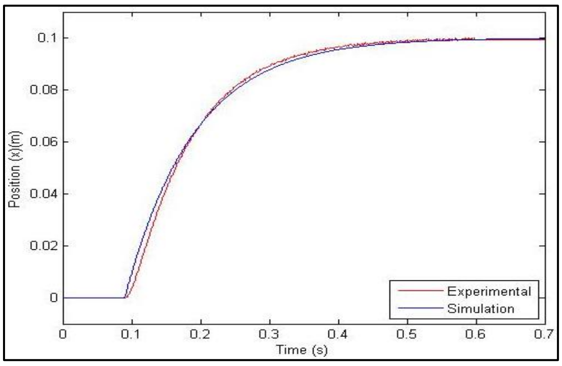

Fig. 5: *Realtime and Simulation Response of Cylinder A with F_c=24.8 N, F_v=12 N and k_p=2 N/Pa.*

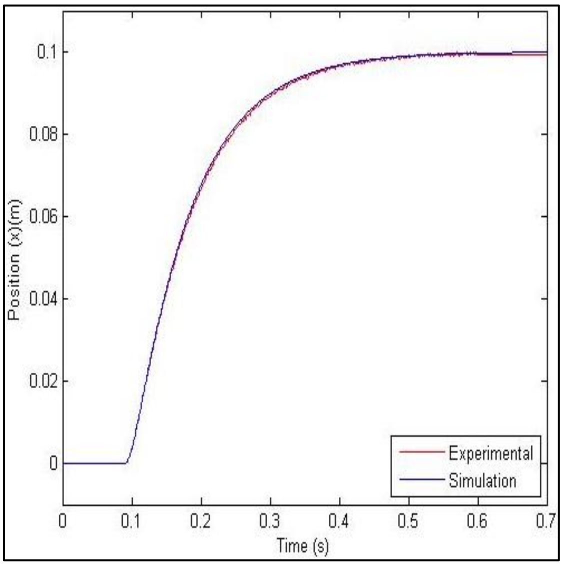

Fig. 6: *Realtime and Simulation Response of Cylinder A with F_c=24.8 N, F_v=13.45 N and k_p=2.89 N/Pa.*

Table 1: *Parameters of Cylinders Used.*

Parameter	Inner Diameter (m)	Stroke Length (m)
Cylinder A	0.032	0.1
Cylinder B	0.016	0.04

Figure 7 shows the plot between real-time response and simulation with F_c=1.5 N, F_v=0 N and k_p=0 N/Pa for cylinder B. It shows a very large deviation between the signals.

Figure 8 shows the plot between real-time response and simulation with F_c=5.2 N, F_v=2 N and k_p=0.7 N/Pa for cylinder B. In this plot the deviation is minimized, and further the both real-time and simulation signals follows similar trajectory.

Figure 9 shows the plot between real-time response and simulation with F_c=5.2 N, F_v=2.24 N and k_p=0.79 N/Pa for cylinder B.

This response has least deviation between the two responses, so the parameters are fixed to these values.

The identified parameters are shown in Table 2.

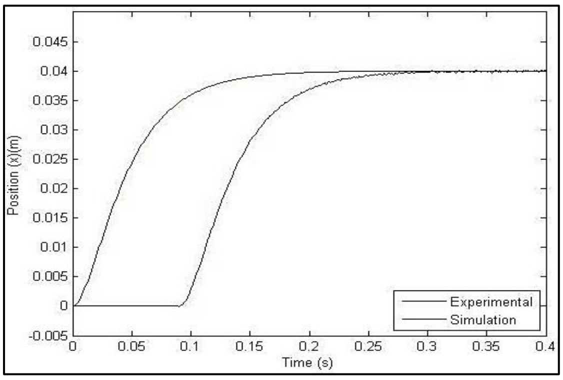

Fig. 7: *Realtime and Simulation Response of Cylinder B with F_c=1.5 N, F_v=0 N and k_p=0 N/Pa.*

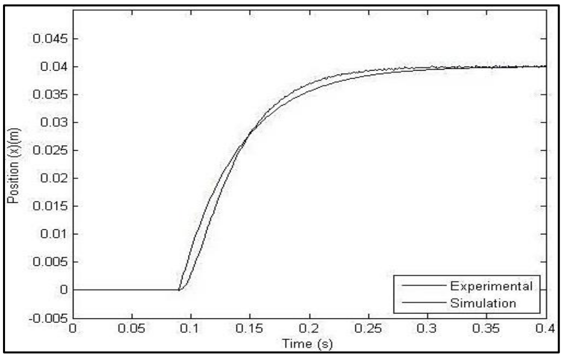

Fig. 8: *Realtime and Simulation Response of Cylinder B with F_c=5.2 N, F_v=2 N and k_p=0.7 N/Pa.*

Table 2: *Frictional Parameters Identified.*

Parameter	F_c (N)	F_v (N)	k_p (N/Pa)
Cylinder A	24.8	13.45	2.89
Cylinder B	5.2	2.24	0.79

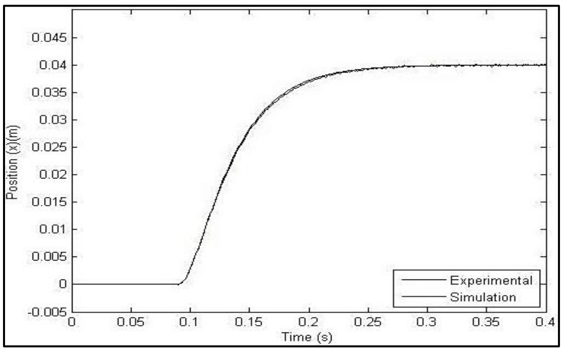

Fig. 9: *Realtime and Simulation Response of Cylinder B with F_c=5.2 N, F_v=2.24 N and k_p=0.79 N/Pa.*

CONCLUSION

The experimental and simulation results reveal that combined-reality environment is an easy, accurate and robust way to measure and estimate the nonlinear frictional parameters for the pneumatic system. Most of nonlinear behaviours have been considered by determining the frictional parameters for the whole system online. The friction parameters are two cylinders are identified easily using the combined reality method. It enables to produce the accurate model of the system.

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