PNEUMATIC CYLINDER CONTROL PID FOR MANIPULATOR ROBOT

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This work shows a controller development for cylinder penumatic, that due to compressibility air characteristics, present a non linear behavior. Is including the develop of PID, discreete PID and Fuzzy Logic approximation, as solution to the problem. The work is part of a major project of Flexible Manipulator Robot, with dielectrics characteristics, for cleaning of porcelain isolators of high voltage transmission lines, with one freedom degree. A Simplified Thermo-Mechanics model has been developed for manipulator control simulation. This paper shows an alternative control proposal, and results to implement it.

1. Introduction

The pneumatic cylinders are very useful for it clean, economy and low weight, however, they have a behavior highly non linear, due to the air compressibility and internal friction [1]. Because of this conditions, exist certain difficulties in pneumatics cylinder control design.

Several works developed around this kind of controllers, like Reference Model, MRAC, used in Adaptive Control [2], however, in this work they consider an actuator with lineal behavior valve, without damping system at the sides, ideal gas, adiabatics state changes, constant viscous friction and equal volumes in both sides of the chamber. Finally, all this take us to design of lineal model, limited by citated limitations.

Several works have been focus to friction parameters identification techniques of cylinder pneumatic [3], dynamic modelation and simulation [4], analytics and experimental research [5] in development of robotic hand using cylinder pneumatics.

The flexible manipulators are ligth, cheap, have a higher power-weight relation robot. This kind of robot must be used only under two conditions: When must be minimized the robot weight, and when must prevent a colisions in the work space.

The modelation of flexible manipulators have been realized almost 35 years ago [7] [8], where, almost in all cases, are using electric or hydraulic actuators, and the pneumatic cylinder are few used, because of their non linear behavior.

The pneumatic control started in 1968, with Burrows [9], and present works have relation with adaptive control methods [2] [10]. Other works have been working in mechanical systems modelation with pneumatic actuators, from these kind of works, has been developed the Flexible Manipulator Model with pneumatic cylinder, called Thermo-Mechanical model, where are involved the mechanical system to give the movement for the flexible arm [11].

In flexible manipulators development are using electric actuators [12], where the motor speed is considered, for the control law implementatios, where the motor effects are considered, joint to the system structure. However, the flexible manipulator robot of us application, the kind of actuator used is pneumatic, with damping systemin the both sides, and we must to use the both mechanical and pneumatic systems in the modelo to control. For that, the use of Thermo-Mechanical model is desired.

The integral Termo-Mechanical modelation of pneumatic actuators, let us to predict it behavior, considering the air compresibility effects, internal friction forces, damping effects in the both extreme of cylinder, massic flow and energy conservation; let us too to know the instant pressure, that depend of rod position.

From the control ingeniering point of view, this modelo let us to predict the variables behavior, envolved in the fisical process, and can be used to control proposal.

2. Actuator Modelling

The Termo-Mechanical model equations are showing in the set of Eq. (1) to (10), developed in [13].

For the interval 0 ≤ X ≤ L:

$$\dot{X} = \frac{d}{dt} X \tag{1}$$

$$D\dot{X} = \frac{d^2}{dt^2} X \tag{2}$$

For the interval 0 ≤ X ≤ L_{alp}

$$\dot{P}_{a1} = g_{21}(X)\left(\dot{m}_{a1} - \dot{m}_{c1} - 9.176\times10^{-10} P_{a1}DX\right)\times10^{8} \tag{3}$$

$$\dot{P}_{c1} = g_{31}(X)\left(\dot{m}_{c1} - 3.608\times10^{-8} P_{c1}DX\right)\times10^{6} \tag{4}$$

For the interval L_{alp} < X ≤ L

$$\dot{P}_{a1} = g_{22}(X)\left(\dot{m}_{a1} - 3.7\times10^{-8} P_{a1}DX\right)\times10^{11} \tag{5}$$

$$\dot{P}_{c1} = g_{32}(X)\left(\dot{m}_{c1} - 3.7\times10^{-8} P_{c1}DX\right)\times10^{11} \tag{6}$$

For the interval 0 ≤ X ≤ (L-L_{alv})

$$\dot{P}_{c2} = g_{41}(X)\left(\dot{m}_{c2} + 3.469\times10^{-8} P_{c2}DX\right)\times10^{11} \tag{7}$$

$$\dot{P}_{a2} = g_{51}(X)\left(\dot{m}_{a2} + 3.469\times10^{-8} P_{a2}DX\right)\times10^{11} \tag{8}$$

For the interval (L - L_{alv}) < X ≤ L

$$\dot{P}_{c2} = g_{42}(X)\left(\dot{m}_{c2} + 3.352\times10^{-8} X_4 X_6\right)\times10^{13} \tag{9}$$

$$\dot{P}_{a2} = g_{52}(X)\begin{bmatrix} 9.983\times10^{3}\left(\dot{m}_{a2} - \dot{m}_{c2}\right) + \\ 1.168\times10^{-5} X_5 X_6 \end{bmatrix}\times10^{4} \tag{10}$$

The pneumatic cylinder is installed on mechanical system [11], as show in Figure 1, to generate the movement to the arm manipulator. The output of the mechanic-pneumatic system, is the arm elevation angle, θ, generated for the impulse mechanism.

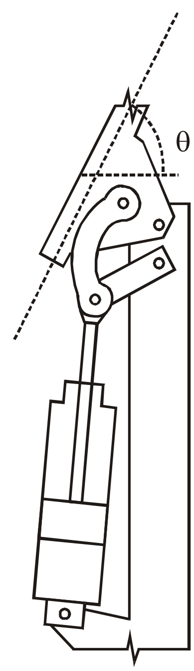

Figure 1. Mechanical-Pneumatic system for the flexible manipulator.

3. Controller Modelling

The Thermo-Mechanical Model have as control entries, the air flow valve effective area. The Eq. (11) shows us it.

$$u = \left[A_1, A_2, A_r\right] \tag{11}$$

Where A1, A2 y A3 are the valve area of cylinder side, rod side, and air return, respectively.

3.1. *Controller PID Proposal*

Figure 2 shows the control block diagram used to the pneumatic actuator system, taking as out the rod position.

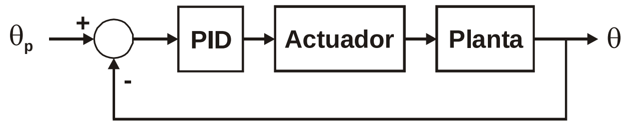

Figure 2. Flexible arm position control used with the movement mechanism.

3.2. *Control Proposal Using Speed Change*

A speed change feedback is added to the system control, as shown in Figure 3.

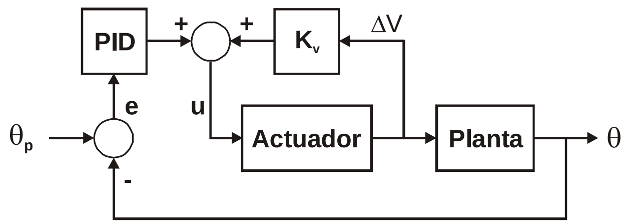

Figure 3. Position controller of flexible arm impulse mechanism with speed change feddback.

The equations controller are showed in Eq. (12) to (13).

$$V_d = V_{nT} - V_{(n-1)T} \quad (12)$$

$$A_i = A_{i0} + Kp_{Ai}e + Ki_{Ai}\sum_{j=1}^{3} e_i + Kd_{Ai}\Delta e + V_e Kv \quad (13)$$

Where ΔV is the speed changes between nT and (n-1)T instants of time; A_i is the valve aperture corresponding of *i* value; Kp, Ki, Kd and Kv, are constants of proportional, integral and derivative control, and speed change, respectively.

4. Results

4.1. *PID Control*

The constants values for the PID control are showing in the Table 1.

Table 1. Control values applied to Pneumatic-Mechanical system.

Valve	Kp	Ki	Kd
A1	4.00	0.0	100.0
A2	-4.00	0.0	100.0
A3	0.45	0.0	0.0

Figure 4 shows the result of position controller of pneumatic actuator, using differents values of reference.

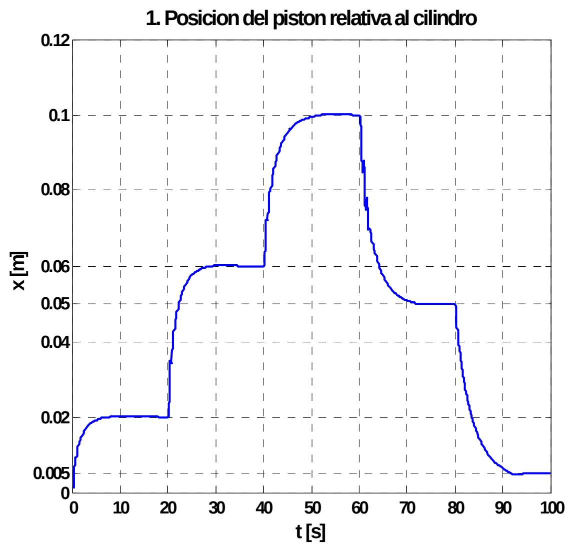

Figure 4. PID Controller result for the pneumatic system.

4.2. *Discrete PID Controller Proposal*

The values used are: Tc=0.5, Ti=10.0, Td= 12.5; the proportional control constants for A1, A2 y A3, are 1.5, -1.5 and 9.5, respectively.

Figure 5 shows the results of this kind of controller.

4.3. *Control Proposal Using Speed Change*

Figure 6 shows the result of use speed change feedback control, and the Table 2 give the values for the control constants.

Table 2. Values used to the discrete PID control for Mechanic-Pneumatic system.

i	Kp, $\times 10^{-4}$		Ki $\times 10^{-4}$	Kd $\times 10^{-4}$	Kv
	$S_p > -40$	$S_p \leq -40$			
1	6.6	1.3	1	10	0.3
2	6.6	1.3	1	10	0.3
3	6.6	1.3	1	10	0.3

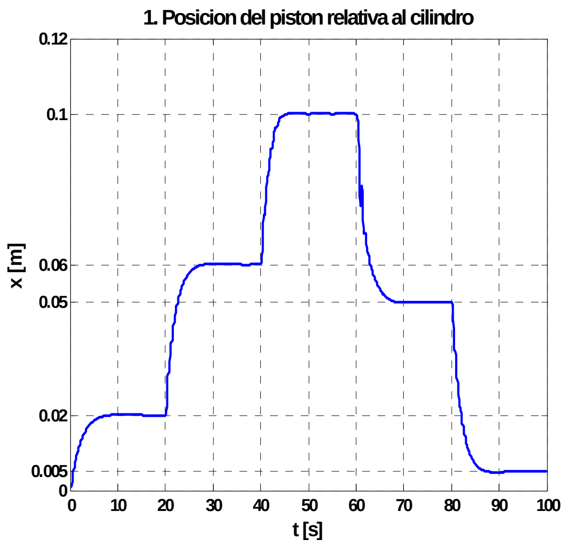

Figure 5. Pneumatic system with discrete PID controller.

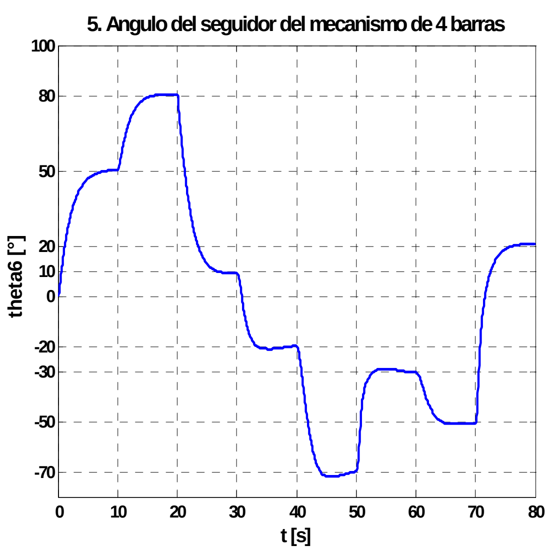

Figure 6. PID control position, to the output angle θ, for the pneumatic-mechanical system.

5. Conclusions

In this work has been presented two control proposal for mechanism of a flexible manipulator arm, with pneumatic actuator using the complete and simplify Thermo-Mechanic model. Both options are good to implement.

The results has been presented until this moment, consider only simulation tools, however, we are working for the application of this methodology in an electronic-mechanic prototype , as solution representative of this problem.

As future work, is considering the use of reference frame, fuzzy logic, neuronal networks and maybe a combination of those controllers.

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