ENHANCEMENT OF TRANSIENT RESPONSE PROPERTIES OF A SERVO PNEUMATIC ACTUATOR VIA PROPORTIONAL-INTEGRAL (PI) CONTROLLER EMBEDDED WITH POLE PLACEMENT

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ABSTRACT: Transient response attributes are one of the important aspects of designing a controller. Many controllers have been introduced by scholars. The problem is the controller that has been proposed are complex and usually involve a highly mathematical algorithm, thus requires a highly equipped machine and processing to support the system. Owing to this reason, a Proportional-Integrator (PI) controller, embedded with a zero-pole compensator using pole placement method, is implemented to cater to this issue. The controller is relatively simple, functional, and practical compared to other controllers. Based on the simulation, it is concluded that the implemented controller shows a significant improvement in the servo pneumatic systems response. Rise time, improve by 89%, percent overshoot, %OS by 0.6%, and settling time, by 97%. A few other parameters were validated to add to the analysis. The research suggests the designed controller be tested experimentally to the fully equipped pneumatic system. The basic zero-pole compensator presented, is fundamental to designing an advance adaptive controller of the same type for future research.

Keywords: *Servo Pneumatic Actuator; Proportional-Integral Controller; Pole Placement Method*

1. INTRODUCTION

This research presents an application of a method to improve a current Proportional-Integral (PI) controller for the positioning and tracking control of a pneumatic actuator. Pole placement is the theoretical method applied. In theory, the pole placement method is usually applied to a non-compensated, any order system (commonly exampled as a second-order system) [1] [2]. Actual research has been performed on an uncompensated system and in a different configuration (pole placement as a feedback compensator) [3]. In a system available for this research, a compensated fourth-order system is applied to and analyzed. The simulated results are promising, for transient system response. Steady-state may require improvement in the design. Based on these results, it is suggested, the improved controller be implemented experimentally and analyzed.

2. METHODOLOGY

The mathematical representation stated as a transfer function, of the servo pneumatic plant, is obtained by performing the system identification method [4]. An acceptable PI controller with suitable gains has been tuned for the simulated transfer function using the Ziegler-Nichols method [5] is tabulated in Table 1.

$$G(s) = \frac{1.478s^2+1.122s+0.05463}{s^3+0.7467s^2+0.1132s+0.06178} \quad (1)$$

Table 1 Gain Values for the PI Controller

Parameter	Gain Value
Proportional Gain, K_P	9.3144
Integral gain, K_I	3.6541

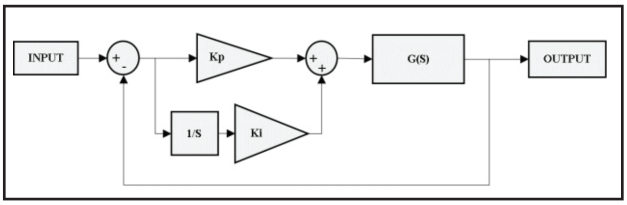

Figure 1 Block diagram of a PI controller for the servo pneumatic actuator

The additional pole placement steps are as presented [1][2]:

a. The zeros and poles are attained for the whole system using MATLAB.
b. The transient response of the system is generated using MATLAB.
c. Percent overshoot (%OS) is attained from the transient response. The damping ratio, ζ is calculated from %OS parameter, using the formula in Equation 2.

$$\zeta = \frac{-\ln(\%\frac{OS}{100})}{\sqrt{\pi^2 - ln^2(\%\frac{OS}{100})}} \quad (2)$$

d. The root-locus diagram and ζ line is generated using MATLAB.
e. The 'dominant pole' is attained from intersection of the root-locus of with the ζ. The 'dominant pole' coordinate is -*0.563+j0.469*.

f. A zero compensator Z_C is positioned in the root-locus. Z_C must be located on the real axis, near origin and in the stable region. In this case, Z_C is located at *-0.1+j0.0*.

g. A pole compensator, P_C is to be calculated based on all of the zero-poles and new Z_C. The angle between the 'dominant pole' to all the zero-poles is summed and equal to $(2K+1)\times 180°$

$$\sum \theta_{Zeros} + \sum \theta_{Poles} + \theta_{ZC} + \theta_{PC} = (2K+1)\times 180° \quad (3)$$

h. Once θ_{Pc} has been calculated from Equation 3, the location of the new pole compensator can be defined.

i. The new zero and pole compensators coordinates are tabulated in Table 2.

Table 2 Compensators value

Compensators	Value	Location
Zero, Z_C	-0.1	*-0.1 + j0.0*
Pole, P_C	-5.3068	*-5.3068 + j0.0*

3. RESULTS AND DISCUSSION

Figure 2 shows the block diagram of the PI controller with the compensator. The compensator block is highlighted in the red-box. A new transient response of the system is generated using MATLAB to analyze the parameters. Figure 3 shows a slight close up of the transient response comparison between Input, PI controller, and PI with zero and pole compensators.

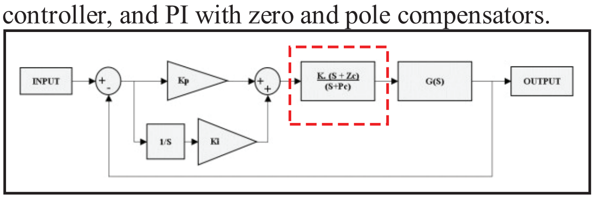

Figure 2 PI controller with additional Zero and Pole compensator

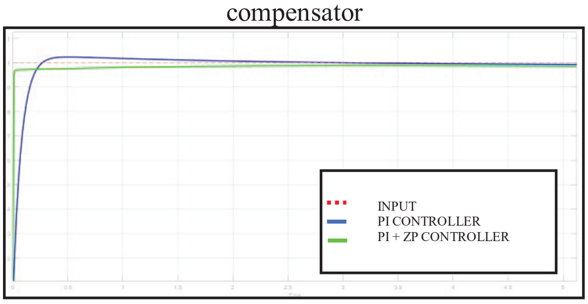

Figure 3 Comparison of transient response between PI controller and PI with compensators controller.

The transient response parameters of PI with compensator versus PI controller are tabulated in Table 3. Most of the parameters show an improvement over the latter controller. Peak time, T_P, and steady-state, C_{Final}, show a slight drawback with the performance of the controller. Although T_P occurs later in the transient response curve (at 3.478 seconds), the overshoot is very broad and most importantly, occurs in the settling-state condition. This phenomenon may not be a significant drawback for the system. As for C_{Final}, an improvement of the controller is required to reduce the error. The gain for this system is still adjustable and can be fine tuned for a better performance of the controller.

Table 3 Comparison of transient response parameters between PI and PI+ZP Controller

Parameter	PI	PI + ZP
Rise time, T_R	0.148 seconds	0.016 seconds
Percent overshoot, %OS	2.28 %	1.69%
Maximum overshoot, C_{Max}	1.0228	0.993
Peak time, T_P	0.764 seconds	3.478 seconds
Steady state, C_{Final}	1	0.977
Settling time 2%, T_S	0.504 seconds	0.015 seconds

4. CONCLUSION

An improvement of a PI controller for a pneumatic actuator plant, using a pole placement method has been successfully designed and simulated to improve the transient response of a pneumatic system. The resulted controller observed, is simple and highly adaptable to the system, or any application. The transient state results shows an improvement in almost all of the parameters. The next step is to experimentally apply the controller to the actual plant, perform the analysis and compare to the simulated data. The steady-state can be the focusing parameter to improve the controller. This research also serves as a fundamental study to a more advanced intelligent or adaptive type of root-locus controller.

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