Position Control of a Solenoid Based Linearly Movable Armature System using Robust Control Technique

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Abstract: In this study, a solenoid based linearly movable armature system is designed using robust control theory in order to improve the performance of the system. Reference track method is the best performance analysis for position control systems. Among the robust controllers, H∞ mixed-sensitivity and mixed H_2/H∞ with Regional Pole Placement Controllers are used to improve the performance of the system. Comparison of the proposed controllers for tracking a reference displacement signals (step and sine wave) and a promising simulation result have been obtained.

INTRODUCTION

A solenoid valve is an electromechanically operated valve. Solenoid valves fluctuate within the traits of the electric contemporary they use, the energy of the magnetic area they generate, the mechanism they use to alter the fluid and the kind and traits of fluid they control. The mechanism varies from linear action, plunger-kind actuators to pivoted-armature actuators and rocker actuators. The valve can use a -port layout to regulate a glide or use a 3 or more port design to switch flows between ports[1]. Multiple solenoid valves may be positioned collectively on a manifold. Solenoid valves are the most frequently used manipulate factors in fluidics. Their duties are to close off, launch, dose, distribute or mix fluids. They are discovered in many utility areas. Solenoids offer fast and safe switching, excessive reliability, lengthy carrier life, desirable medium compatibility of the substances used, low manipulate strength and compact design. In a few solenoid valves the solenoid acts at once on the fundamental valve. Others

use a small, complete solenoid valve, called a pilot, to actuate a larger valve. While the 2d type is genuinely a solenoid valve mixed with a pneumatically actuated valve, they may be offered and packaged as a unmarried unit referred to as a solenoid valve. Piloted valves require a lot less energy to control, however, they are highly slower[2]. Piloted solenoids normally want full power always to open and live open, wherein a direct acting solenoid may also simplest want full energy for a quick period of time to open it and handiest low power to maintain it. In this study, solenoid based linearly movable armature system is designed and controlled using robust control technique and the performance of the system is analyzed based on track a reference approach.

MATERIALS AND METHODS

Mathematical model: The dynamics of the solenoid based linearly movable armature system is shown in Fig. 1. The magnetic flux linkage can be described by:
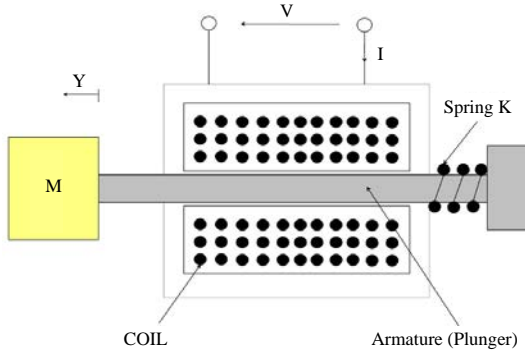
Fig. 1: Solenoid based linearly movable armature system

$$\Psi = \Psi_0 + L_d I + L_C Y \qquad (1)$$

Where:
Ψ_0 = Initial magnetic flux linkage
L_d = Differential inductance
L_C = Coil inductance

The magnet circuit equation will be:

$$V(t) = RI(t) + L_d \frac{dI(t)}{dt} + L_C \frac{dY}{dt} \qquad (2)$$

The force exerted by the magnetic circuit to the mass become:

$$F_m(t) = L_C I(t) \qquad (3)$$

The spring-mass system model equation is given by:

$$F_m(t) = M\ddot{Y}(t) + b\dot{Y}(t) + KY(t) \qquad (4)$$

Upon selecting the voltage $V(t)$ as the variable to be manipulated and the linear displacement as the variable to be controlled, substituting Eq. 3 in to Eq. 4 and in to Eq. 2 and taking the Laplace transform results the transfer function:

$$G(s) = \frac{Y(s)}{V(s)} = \frac{\dfrac{L_C}{KR}}{\dfrac{ML_d}{KR}s^3 + \left(\dfrac{M}{K} + \dfrac{bL_d}{KR}\right)s^2 + \left(\dfrac{b}{K} + \dfrac{L_d}{R} + \dfrac{L_C{}^2}{KR}\right)s + 1} \qquad (5)$$

The system parameters are shown in Table 1. The transfer function of the system numerically become:

$$G(s) = \frac{Y(s)}{V(s)} = \frac{0.1667}{0.25s^3 + 0.75s^2 + 2.667s + 1}$$

The state space model become:

Table 1: System parameters

Parameters	Symbols	Values
Mass of the body	M	3 kg
Resistance of the coil	R	10 Ω
Differential inductance	L_d	5 H
Coil inductance	L_C	10 H
Damping friction	b	3 N-s/m
Spring stiffness	K	6 N/m

$$\dot{x} = \begin{pmatrix} -3 & -10.667 & -4 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} x + \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} u$$

$$y = \begin{pmatrix} 0 & 0 & 0.6667 \end{pmatrix}$$

Proposed controllers design

H∞ mixed-sensitivity controller design: H∞ mixed-sensitivity evaluates a controller K that minimizes the H∞ norm of the closed-loop transfer function the mixed weighted sensitivity:

$$T_{y1u1\Delta} \begin{bmatrix} W_1 S \\ W_2 R \\ W_3 T \end{bmatrix} \qquad (6)$$

where, S and T are referred to as the sensitivity and complementary sensitivity, respectively. R measures the manipulate effort. The again controller K is such that S, R and T fulfill the following loop-shaping inequalities:

$$\bar{\sigma}(S(j\omega)) \leq \gamma \underline{\sigma}(W_1^{-1}(j\omega))$$
$$\bar{\sigma}(R(j\omega)) \leq \gamma \underline{\sigma}(W_2^{-1}(j\omega))$$
$$\bar{\sigma}(T(j\omega)) \leq \gamma \underline{\sigma}(W_3^{-1}(j\omega))$$

where, γ = GAM. Thus, the inverses of W_1 and W_3 determine the shapes of sensitivity S and complementary sensitivity T. Typically, you choose a W_1 this is large within the desired manipulate bandwidth to acquire accurate disturbance attenuation (i.e., performance). Similarly, you commonly pick a W_3 that is large outside the manage bandwidth which facilitates to make sure precise stability margin. The solenoid based linearly movable armature system with H∞ mixed sensitivity controller block diagram is shown in Fig. 2. Here, in this system we choose the three weighting functions W_1, W_2 and W_3 as:

$$W_1 = \frac{1}{s + 12}$$
$$W_2 = \frac{1}{s + 11}$$
$$W_3 = \frac{1}{s + 8}$$

The controller transfer function is:

$$K_{mixed} = 10\frac{s^2 + 107s + 70.5}{s^2 + 95s + 1}$$

Mixed H_2/H∞ with regional pole placement controller design: The mixed H_2/H∞ control hassle is to reduce the H_2 norm of overall state remarks gains K such that what also satisfies the H∞ norm constraint. Mixed H_2/H∞ synthesis with regional pole placement is one example of multi-objective layout addressed by means of the LMI[3,4]. The manipulate problem is sketched in Fig. 3. The output channel z is associated with the H∞ overall performance at the same time as the channel z 2 is associated with the H_2 overall performance.

The LMI region for the pole placement is determined the use of the command lmireg and we select the 1/2 plane region and the output region is:
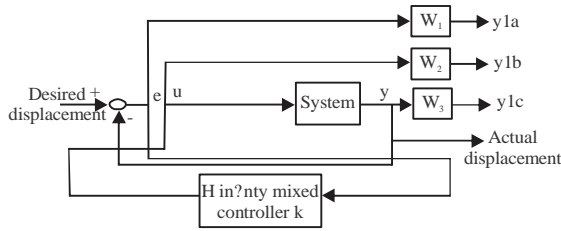

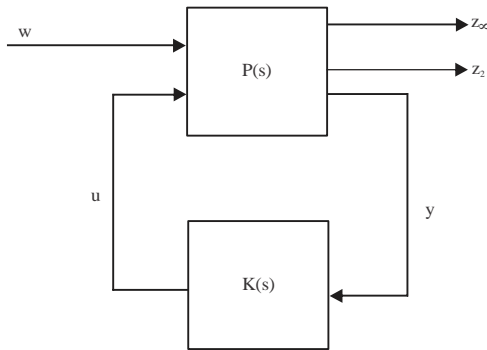Fig. 2: Solenoid based linearly movable armature system with H∞ mixed sensitivity controller block diagram

Fig. 3: Mixed H_2/H∞ configuration

2.0000+1.0000i and 1.0000+0.0000i

And we use this region for the mixed H_2/H∞ controller synthesis. The transfer function of the controller is:

$$K_{mixed} = 12\frac{s^2 + 118s + 100}{s^2 + 100s + 1}$$

RESULTS AND DISCUSSION

In this study, the Simulink model design and simulation of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H_2/H∞ with regional pole placement controllers by comparing the two proposed controllers for tracking the step and sine wave references displacement signals[5].

Comparison of the proposed controllers for tracking the step reference displacement: The Simulink model of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H_2/H∞ with regional pole placement controllers for tracking the step references displacement signal is shown in Fig. 4.

The solenoid based linearly movable armature system performance for the proposed controllers using a step reference (step change from 0-6 m) of the displacement output simulation is shown in Fig. 5. The data of the rise time, percentage overshoot, settling time and peak value is shown in Table 2.

Comparison of the proposed controllers for tracking the sine wave speed reference: The Simulink model of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H_2/H∞ with regional pole placement controllers for tracking the sine wave references displacement signal is shown in Fig. 6.

The solenoid based linearly movable armature system performance for the proposed controllers using a sine wave reference (displacement moving in the forward and reverse with 6 m) of the displacement output simulation is shown in Fig. 7.
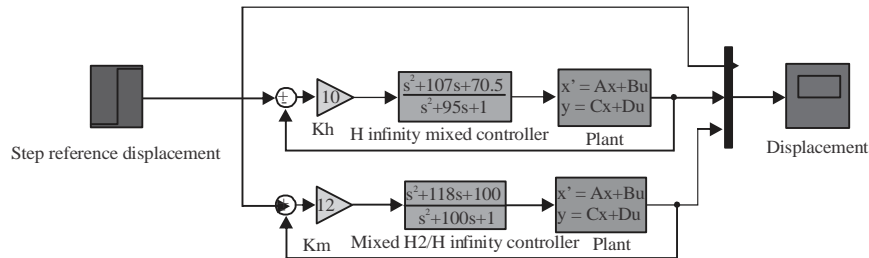

Fig. 4: Simulink model of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H_2/H∞ with regional pole placement controllers for tracking the step references displacement signal
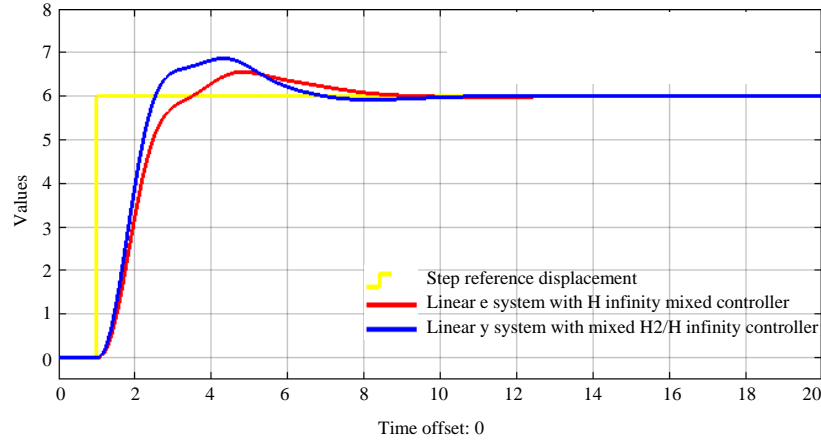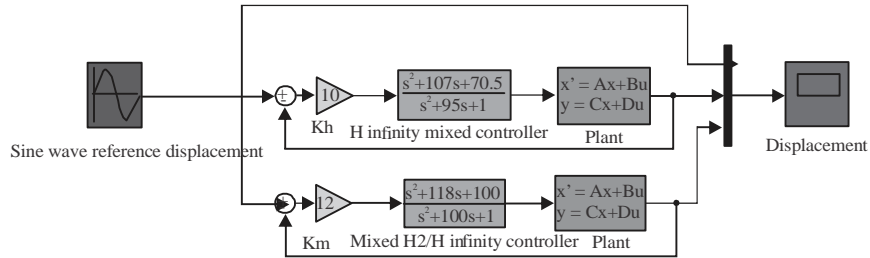
Fig. 5: Simulation result for a step reference input

Fig. 6: Simulink model of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H₂/H∞ with regional pole placement controllers for tracking the sine wave references displacement signal
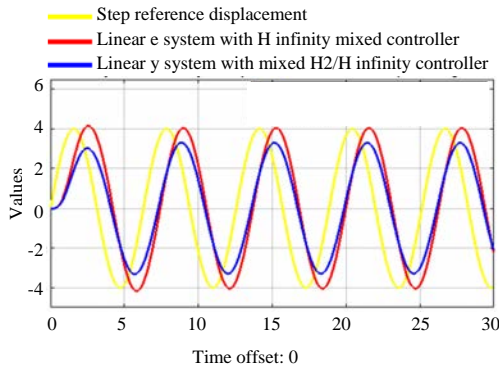

Fig. 7: Simulation result for a sine wave reference input

Table 2: Step response data

Performance data	H∞ mixed-sensitivity	Mixed H₂/H∞
Rise time	2 sec	1.9 sec
Per. overshoot	8.33%	15%
Settling time	10 sec	13 sec
Peak value	6.9 m	6.5 m

The simulation result shows that the solenoid based linearly movable armature system with H∞ mixed sensitivity controller track the reference speed better than the solenoid based linearly movable armature system with mixed H₂/H∞ with regional pole placement controller.

CONCLUSION

In this study, modelling, design and control of the solenoid based linearly movable armature system using H∞ mixed-sensitivity and mixed H₂/H∞ with regional pole placement controllers have been successfully done with the aid of MATLAB/Simulink Toolbox. The proposed controllers improved the performance of the position controlling mechanism and comparison of the system with the two controllers for tracking a reference displacement signals (step and sine wave) is done.

The solenoid based linearly movable armature system using H∞ mixed-sensitivity controller has better percentage overshoot and settling time in the step reference displacement signal and better tracking the input signal in the sine wave reference displacement signal than the solenoid based linearly movable armature system with mixed H₂/H∞ with regional pole placement controller.

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