EE MS016170

控制系统动力学（全英文）

Dynamics of Controlled Systems - 2023

Project #1

Prof. Jiyao Wang 王激尧

Origin from ME746, Prof. R.D. Lorenz

Due on Mar. 23, 2023

Modeling and Evaluation of an Actuator with Physical Nonlinear State Feedback

A lateral motion reluctance actuator can be modeled with an equivalent cross section, iron core actuator model shown in Fig. 1.

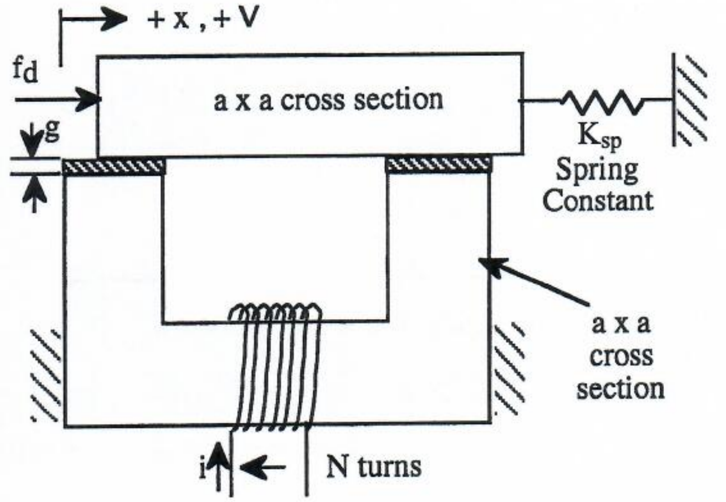

Fig. 1 Actuator equivalent electromagnetic model

Table 1: Definitions of Variables & Parameters

$e(t)$	= applied terminal voltage (manipulated input)		
$i(t)$	= current in the winding		
$f_{rel}(t)$	= electromagnetic air gap force		
$f_d(t)$	= external load disturbance force (unknown)		
$x(t)$	= position of moving core w.r.t. fixed core		
$v(t)$	= velocity of moving core w.r.t. fixed core		
R_p	= winding resistance	=	$1\ \Omega$
g	= fixed air gap (bearing)	=	0.5 mm
N	= number of winding turns	=	1500
a	= core dimension	=	1.5 cm
μ_o	= permeability of air	=	$4\pi 10^{-7}$ Tm/A
m_p	= mass of moving core	=	50 g
K_{sp}	= stiffness of suspension	=	71 N/cm

The sliding iron core bar is suspended via flexure springs which hold it in a position separated from the iron "U-core" by an air gap, g, (relative permeability $\mu_{r\text{-}air\_gap} = 1$) and also provide an open circuit (rest) position at x_i via a finite lateral spring constant, K_s. It is assumed that the relative permeability of the core, $\mu_{r\text{-}iron}$, is high enough so that the core reluctance can be neglected. The actuator is to follow a sinusoidal reciprocating motion about the open circuit position, x_i, i.e. $x^*(t) = x_i - x_{o\text{-}p}\,(1 - \cos(2\pi f t))$ which for this project is specified as $x_i = 9$ mm, $x_{o\text{-}p} = 4$ mm, $f = 50$ Hz

The key physical system equations:

From Faraday's Law and Kirchoff's Voltage Law (induced voltage and voltage loop):

$$e(t) = R_p\, i(t) + \frac{N^2 \mu_0 a^2 (a - x(t))}{g(2a - x(t))} \frac{di(t)}{dt} - \frac{N^2 \mu_0 a^3}{g} \frac{i(t)}{(2a - x(t))^2} v(t)$$

From Newton's Law :

$$m_p \frac{dv(t)}{dt} = f_d(t) + f_{rel}(t) - K_{sp}\,(x(t) - x_i)$$

From conservation of energy (co-energy):

$$f_{rel}(t) = -\frac{1}{2} \frac{N^2 \mu_0 a^3}{g} \frac{i(t)}{(2a - x(t))^2}\, i(t)$$

To do:

a. Calculate and plot the current and voltage (overlaid plots) needed to yield the specified sinusoidal reciprocating motion trajectory under conditions of zero disturbance forces.

b. Draw a global, nonlinear state block diagram model clearly showing all of the reluctance actuator's inherent nonlinear, cross-coupled physical state feedback.

c. Develop an operating point model of the reluctance actuator, documenting it in both physical state equation format and operating point state block diagram format.

d. Form the symbolic expression for the operating point dynamic stiffness of the reluctance actuator.

e. Evaluate dynamic stiffness over the expected motion trajectory and determine which "points" in the trajectory yield the best and the worst dynamic stiffness.

f. Evaluate Eigenvalue migration of the reluctance actuator over its reciprocating motion trajectory.

To Hand in:

An organized report (.doc/.docx + .pdf report files, in a .zip file) containing:

1. Plots of the current and voltage needed to achieve the desired trajectory (one "steady state" cycle) and documentation of how it was calculated.
2. A fully labeled, global, nonlinear state block diagram model of this reluctance actuator.
3. A fully labeled, operating point state block diagram model using the operating point state feedback gains, L_o, R_o, K_{eo}, K_{fo}, K_{xo}, and K_{so}, along with:

   a table to document the symbolic equations for these operating point state physical feedback gains, and

   plots of the numerical values of the operating point state feedback gains over one steady state cycle.
4. Analytical model for dynamics stiffness, $\frac{\Delta F_d(s)}{\Delta X(s)}$, using the operating point and physical symbols provided.
5. Superimposed (overlaid) dynamic stiffness, DS, magnitude frequency response function (FRF) plots $\left|\frac{\Delta F_d(j\omega)}{\Delta X(j\omega)}\right|$ for sufficient operating points such that the effect of the operating points can be shown.

   Use log (base 10) amplitude vs log (base 10) frequency format.

   Use N/m units (not dB) for the stiffness amplitude and Hz for frequency.
6. Plots of Eigenvalue (EV) migration over one steady state cycle, with 10 operating points labeled.
7. Explanation of the DS and EV migration plots based on the operating point physical state feedback gains.
8. Discussion of controller state feedback options and the individual effect they would have if used. Be careful to provide a physics-based explanation of the effect you would expect.

Note:

1) The insight you demonstrate in your physics-based discussion will have the greatest impact on your grade for this project. The technical content accounts for 80% of the grade.
2) A professional report format is also required and this counts for 20% of the grade.