

Modeling MEMS With Matlab's Simulink

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Abstract

Matlab's Simulink has been used to simulate a dynamic feedback MEMS comprising a generator with field winding, mechanical shaft system and encoder as well as a feedback to a referenced signal. The model of this system has been suggested used in Simulink for simulation.

Keywords: Simulink, MEMS, Modeling, Feedback, Field Winding, Simulation

1. INTRODUCTION

With Matlab's Simulink, it's possible to simulate dynamical models of linear and time invariant systems (LTI) implemented in MEMS applications [1], whereby a prime-mover such as a DC motor being the electromechanical system [2] driving an inertial load in a closed loop feedback configuration with supplementary blocks such as compensating blocks, filters, integrators and geometrically coordinated converters such as those used for robotic systems.

More complicated types of models can be studied and simulated, ranging from single-input, single-output (SISO) and multi-input, multi-output (MIMO) to non-linear and discrete models [3].

The operands of the interconnected linear models can be of many types such as state-space, transfer function, pole/zero plots, etc. Other procedures such as system inversion, transposition and per-transposition can be performed. More complicated feedback structure operations to derive closed loop models and to convert continuous to discrete, discrete to continuous and re-sampling [discrete to discrete] can be manipulated too.

Various discretization /interpolation methods such as a zero or first hold, Tustin approximations with or without pre-warping and matched zero-pole can also be conducted.

Simulink LTI viewer is an open and extensible graphical user interface GUI environment used to linearize models or parts of models, analyze linearized models and compare linear with nonlinear models. It's used to obtain:

- Step/impulse response
- Bode/Nyquist plots
- Nichols plots
- Singular values of frequency response
- Pole/zero plots
- Response to general input signals
- Unforced response starting from given initial states

Most importantly one can identify locations of inputs and outputs of the portions of a model and specify the operating conditions about which the model is linearized for further analysis. Other important feature of Simulink is a Linear-Quadratic-Gaussian LQG control technique which is used to design optimal dynamic regulators, Kalman estimators and filters.

2. MEMS MODEL

The electromechanical prime mover in MEMS is basically a DC motor with series field to avoid having another supply for the field. DC series motor is used extensively in traction applications

where steady state speed is determined by the friction and gradient forces. The dynamical model of the load is expressed as an inertial system with friction and assuming different line-of-shaft orientation both for the input and output.

For precise speed control of servo system, a closed loop control system is advised to get advantages of improved accuracy, fast dynamic responses and reduced effects of load disturbances and system nonlinearities.

Finally a phase locked loop PLL configuration can be implemented for speed sensing and comparing means. In PLL control system the motor speed is converted to a digital pulse train by using a speed encoder. The output of the encoder acts as speed feedback signal of frequency F_o . The phase detector compares the reference pulse train F_i with the feedback frequency F_o and provide a pulse width modulated output voltage V_c which is proportional to the difference in phases and frequencies of the reference and feedback pulse trains. The phase detector can be available in IC form. A LP filter then converts V_c to a continuous DC level which varies the output motor speed.

This can be depicted in the following figure:

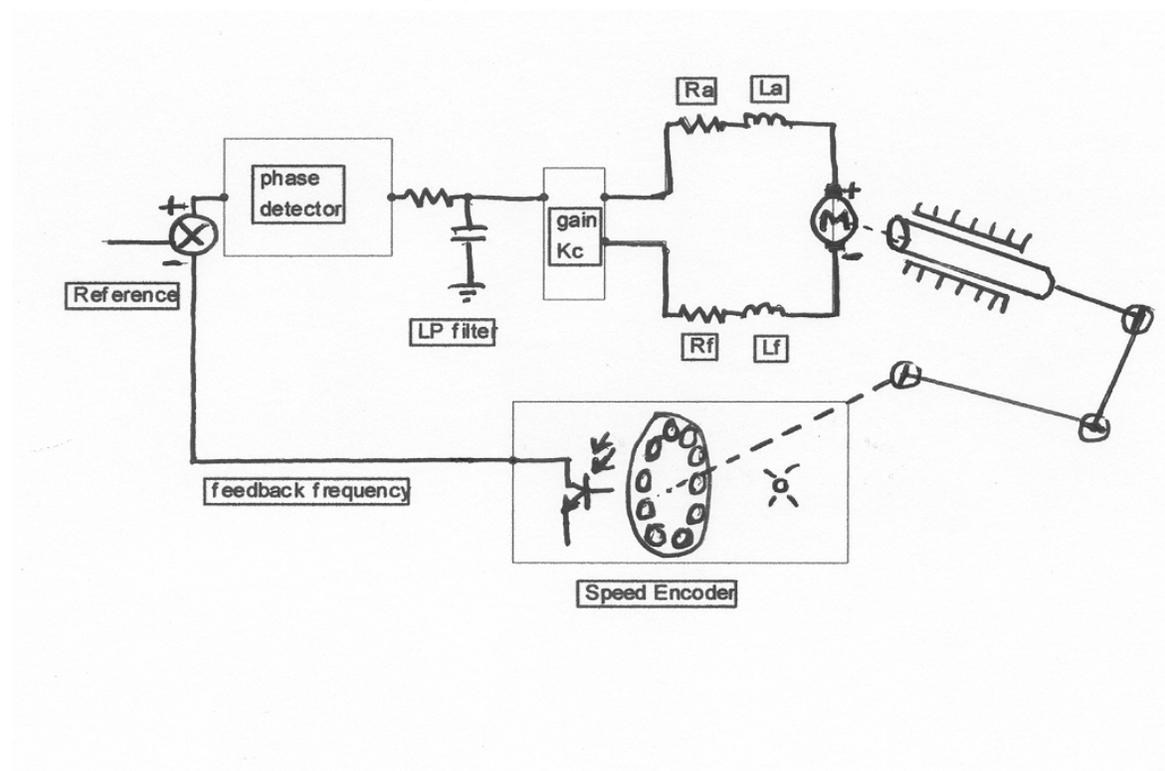


FIGURE 1: Typical MEMS Dynamical Model

The armature voltage is related to the control or reference voltage by a linear gain K_c , with the assumption that the back emf constant K_v remains constant. Then:

$$v_a = K_c v_c$$

$$e_g = K_v i_a \omega$$

also $v_a = R_m i_a + e_g + L_m di_a/dt$

$$t_d = K_t i_a = K_t i_a^2$$

also $t_d = J d\omega/dt + B\omega + t_f$

Due to nonlinear terms, these equations can be made linear by considering a small perturbation at the operating point, noting that: $\Delta i_a \Delta w$ and $(\Delta i_a)^2$ are too small; hence

$$\begin{aligned} \Delta v_a &= K_c \Delta v_c \\ \Delta e_g &= K_v (I_{a0} \Delta w + w_0 \Delta i_a) \\ \text{And } \Delta v_a &= R_m \Delta i_a + L_m d(\Delta i_a)/dt + \Delta e_g \\ \Delta t_d &= 2 K_v I_{a0} \Delta i_a \\ \text{And } \Delta t_d &= J d(\Delta w)/dt + B \Delta w + \Delta t_l \end{aligned}$$

I_{a0} and w_0 are the steady state values. Transferring these equations in Laplace's domain yields:

$$\begin{aligned} \Delta V_a(S) &= K_c \Delta V_s(S) \\ \Delta E_g(S) &= K_v [I_{a0} \Delta W(S) + w_0 \Delta I_a(S)] \\ \text{And } \Delta V_a(S) &= R_m \Delta I_a(S) + S L_m \Delta I_a(S) + \Delta E_g(S) \\ \Delta T_d(S) &= 2 K_v I_{a0} \Delta I_a(S) \\ \text{And } \Delta T_d(S) &= S J \Delta W(S) + B \Delta W(S) + \Delta T_l(S) \end{aligned}$$

The block diagram for these open-loop series drive equations is depicted as:

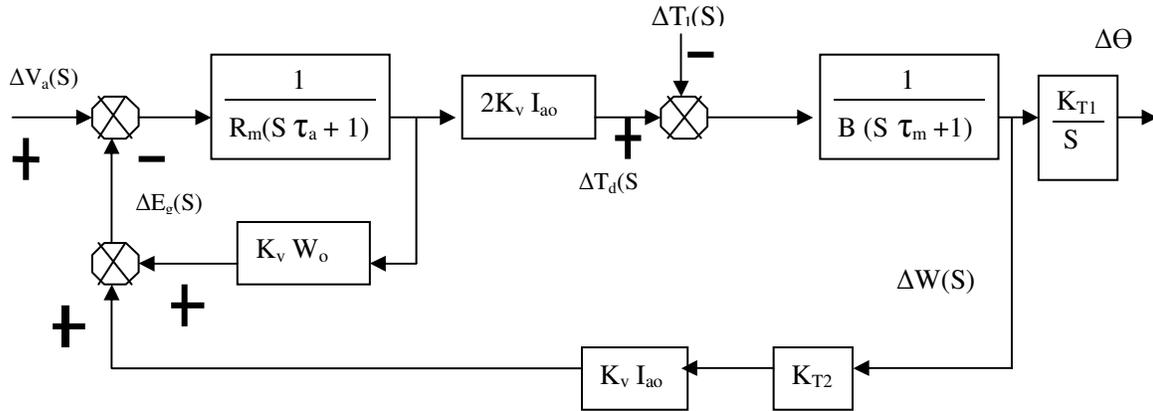


FIGURE 2: Transfer Function Feedback Model of MEMS

where τ_a and τ_m are electrical and mechanical time constants $\tau_a = L_m/R_m$ and $\tau_m = J/B$. It can be noted that any change in either control voltage or load torque will result in a change of speed. Obviously, there may be succession of joints and links which can be either linear (prismatic) or rotational (revolute), and which can be in any order or sequence and in any plane too.

These links can also be of any length, including zero, can be twisted or bent; thus the transformation matrices to any reference coordination can be calculated using different methods such as Denavit-Hartenberg representation. This is shown in the block diagram as K_{T1} and K_{T2} .

Now, by adding the PLL closed loop feedback the final block diagram becomes as shown:

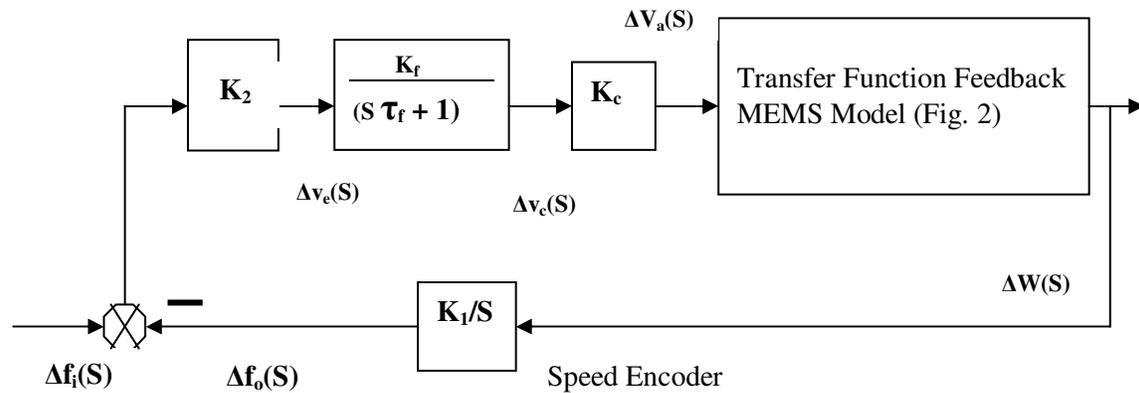


FIGURE 3: Complete MEMS Model with PLL

3. SIMULINK

The derived dynamical electromechanical linear model represented in S-domain, can be now simulated in Matlab's Simulink represented as S-domain block diagram. Input and output outlets can be specified at different locations in order to get; among others:

- Response due to a step change in the control/reference voltage keeping constant load torque
- Response due to a change in load torque disturbances keeping constant control voltage
- Response due to a change in links location and orientation keeping both constant voltage and load
- Multiple view screens at different locations simultaneously
- Platform for solver parameters to be varied for further simulations
- Platform for embedded libraries related to the blocks implemented
- Platform to integrate Matlab files and C codes
- Platform to visualize and input different signals such as noise and vibrations
- Platform to add hierarchical features of blocksets and general parameters

It can be noticed from the above features that precise and accurate simulation of MEMS models can be obtained.

4. CONCLUSION

It has been demonstrated that MEMS models can be derived and later simulated with Matlab's Simulink, which shows to be an esteemed and powerful platform for multi domain simulation and a model based design environment for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries that let help to accurately design, simulate, and test control, signal processing, communications, and other time-varying systems.

5. REFERENCES

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