ECE 433 Industrial Electronics and Control Systems

Lab #2 Modeling and Simulation of a Loudspeaker System

<u>*Objectives*</u>:
Analyze and simulate the dynamic model of an electromechanical system in time and frequency domains using MATLAB and Simulink.

<u>*Introduction*</u>:
A *voice coil actuator* is a linear motion device. It consists of two separate parts: the permanent magnetic housing and the coil. Applying a voltage across the terminals of the motor produces electric current flowing in the coil, which results in an electromagnetic force in the coil to move in one direction. Reversing the polarity of the applied voltage will move the motor to the opposite direction. The electromagnetic force is proportional to the current. One of the most well-known voice coil actuators is a loudspeaker driver, which couples electrical signals to mechanical motion to create sound waves. The functional parts of a loudspeaker driver are shown in Fig. 1.

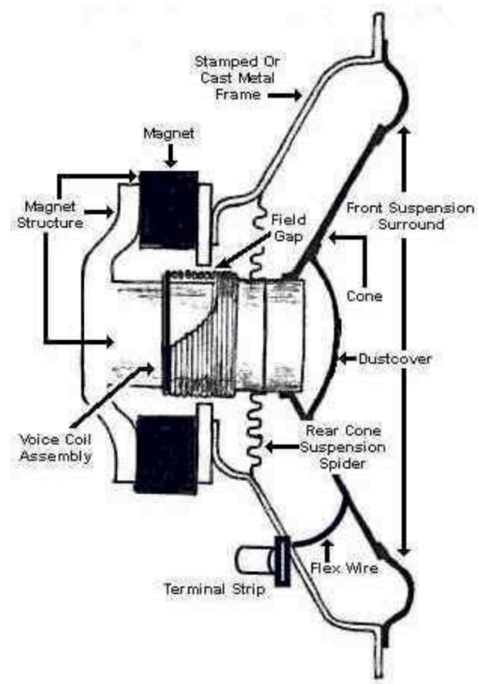

Fig. 1

The schematic of a loudspeaker is shown in Fig. 2. The mathematical model of the loudspeaker contains two parts: the electrical portion and the mechanical portion. The circuit diagram of the electric portion of the model is shown in Fig. 3, where u is the voltage applied across the voice-coil, and i, L, and R are the voice-coil current, inductance, and resistance, respectively. The motion of the coil in the magnetic field generates a back-emf voltage V_B, which is proportional to the velocity v of the coil. K_F is the force constant, expressed as

$$K_F = 2\pi r N \beta$$

where r is the radius of the voice coil, N is the total number of turns of the coil, and β is the magnetic field. The diagram of the mechanical portion is shown in Fig. 4. The electric force F_E produced in the coil is proportional to the current through the coil,

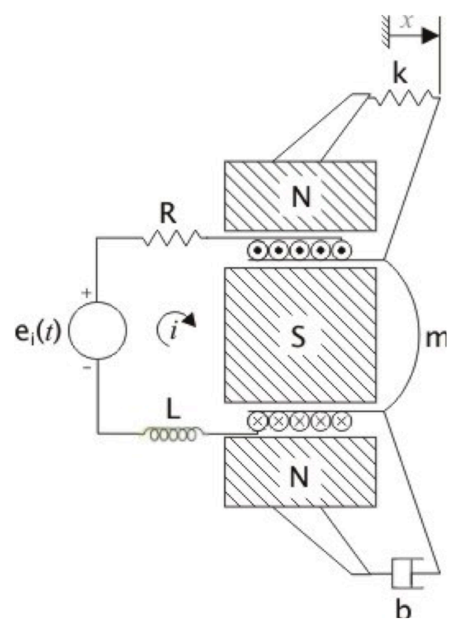

Fig. 2

$$F_E = K_F i\,.$$

The electric force is against by the mechanical suspension, which can be modeled as a spring with the spring constant k and a linear damper with the viscous damping coefficient b connected in parallel. The net force provides the acceleration of the moving cone with the mass m. The variable x in Fig. 4 represents the displacement of the cone.

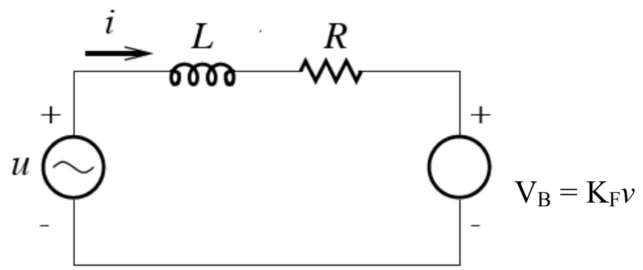

Fig. 3

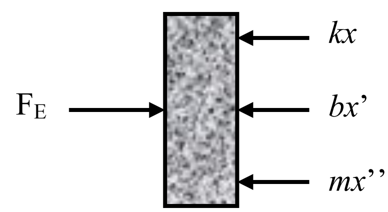

Fig. 4

Pre-Lab Exercise: Provide clear derivation to find answers the following questions.

1. Derive the governing electrical and mechanical equations of the loudspeaker.

2. Let u(t) and x(t) be the input and output of the loudspeaker, determine the transfer function $G(s) = \dfrac{X(s)}{U(s)}$.

3. Let $x_1 = i$, $x_2 = x$, and $x_3 = v$, the governing equations from part 1 can be written in three simultaneous first-order differential equations. Arrange them in a state-space form
$$\underline{\dot{x}} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} \dot{i} \\ \dot{x} \\ \dot{v} \end{bmatrix} = A\underline{x} + Bu = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} u\,.$$
Express the elements in A and B in terms of R, L, k, b, m, and K_F.
Hint: Read your textbook section 3.2.

Lab Problems:

1. Use Matlab to plot the unit-step response of the loudspeaker, giving R = 5 Ω, L = 0.05 mH, $k = 2\times10^5$ N/m, b = 50 Ns/m, m = 4×10^{-3} kg, r = 0.04 m, N = 50 turns, and β = 0.25 Tesla. Show the settling time, peak time, percent overshoot, and steady-state output on the graph.

2. Use the **bode()** command in Matlab to generate the bode plots for the model of the loudspeaker. Determine the dc gain. What is the relationship between the dc gain and the steady-state output from part 5?

To start the Simulink software, the MATLAB environment must be running. You can then start the Simulink software in two ways:

- *On the MATLAB environment toolbar, click the Simulink icon.*
- *Enter the Simulink command at the MATLAB prompt.*

The Simulink Library Browser appears first. It displays a treestructured view of the Simulink block libraries installed on your system. You build models by dragging blocks from the Library Browser into a model window. To create a new model, select
File > New > Model *in the Simulink Library Browser and the software will open a new model window.*

3. Implement the model equations of the loudspeaker in Simulink with the parameters given in part 5 to simulate the dynamics of the device. Apply a sinusoidal function as the input voltage with unity amplitude. Set the frequency of the input as 200 rad/s and run the simulation for 0.2 second. Connect the displacement $x(t)$ to a scope. Determine its amplitude after the signal reaches its steady-state and compare it with the bode plots from part 5. Do they agree with each other?

4. Determine the magnitudes of the transfer function $G(s)$ from part 2 at different frequencies: 200, 2000, and 20000 rad/sec respectively. Use the model parameters from part 5 to determine the coefficients in $G(s)$.

5. Change the frequency of the input signal to 2000 and 20000 rad/sec in the simulation and run the simulation for 0.02 and 0.002 second, respectively. Compare your results with those from the Bode plots as well as your calculations in part 8. Provide your comments to the results.