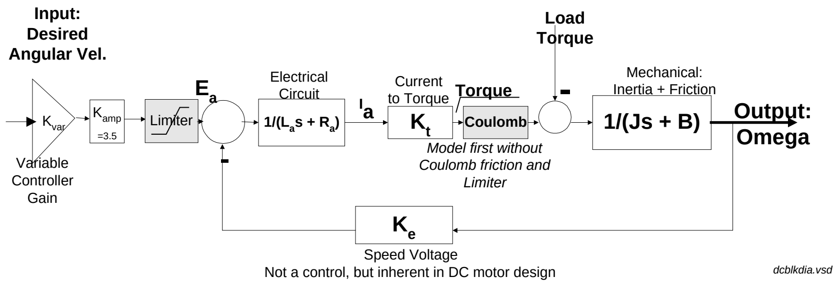
MEG 421 Automatic Control Lab

Lab #2 Introduction to Computer-Based Dynamic System Analysis



Your assignment:

MODEL OF A DC MOTOR

The open-loop transfer function of an armature controlled DC motor with armature inductance L_a is given by (see also p.48 f. of your textbook)

The simplified motor block diagram is shown above. In this Lab, you will gain more experience in the use of the VisSim graphical system modeling tool.

The open-loop transfer function (input is the Armature voltage E_a, output the shaft angular velocity Ω) is :

$$\frac{\Omega(s)}{E_a(s)} = \frac{K_{amplifier} K_t}{(L_a s + R_a)(Js + B) + K_t K_e}$$

Data

$\Omega(t)$ = $d\Theta/dt$ = Motor angular Velocity (variable)
$E_a(t)$ = Armature Voltage (variable)
R_a = Armature resistance = 2 Ω
L_a = Armature Inductance = $0.4 \cdot 10^{-3}$ H
K_t = Torque constant= 0.108 Nm/A
K_e = Back-emf constant = 0.114 Vs/Rad.
J = Rotor inertia = $0.6 \cdot 10^{-3}$ kg m^2
B = Viscous friction coefficient = $4 \cdot 10^{-5}$ Nms
C = Coulomb (static) Friction Torque = 0.03 Nm
The servo-amplifier (K_{amp}) has a constant gain of 3.5.

Steps:

1. Start VisSim.

Using the data and the text reference, develop VisSim continuous simulation model in the block diagram form of the figure. First develop a linear model (no limiter, no friction). The two first order elements are in submenu 'Linear systems → Transfer Function' as in Lab 1. Enter the transfer function parameters as per data sheet. At any time, click and drag the block to position it. Right-mouse click on a block if you wish to edit the parameters again.

All **gain elements** (amplifiers) are labeled K... in the schematic, such as K_{amp}, K_b etc. Go to the **Arithmetic → Gain** submenu or select the Gain icon from the icon bar. Enter the appropriate gain factor.

For summation select **Arithmetic → Summing Junction**. Position and click. Define and position all elements as they will appear in the block diagram. The summingJunction (Block Category: Arithmetic) produces the sum of two signed input signals. You can toggle the sign of the input signals (switch from positive to negative and vice versa) by holding down the CTRL key and clicking the right mouse button over the connector tab.

To simulate the load torque, choose '**Signal Producer → Const**' and enter a value; connect the constant block to the (negative) summation point for the load.

As the Figure shows, the speed voltage K_e appears in the feedback path. Place a gain bock there and enter the K_e-value above. The block's orientation to the right is unsatisfactory. To flip a block:

1. Select the block(s) to be flipped.
2. Choose Edit > Flip Horizontal.

Add a **summing block** with negative feedback as seen in Fig.2. Add a gain block for the fixed amplifier gain. The controller gain can also be a gain block. However, we'll wish to adjust K_contr easily, and therefore choose a different layout. The gain blocks (and some others) can accept a variable parameter (Signal Producer → Slider) rather than a fixed number. The slider in the upper left corner of Fig.2 can be dragged with the mouse, and assume values between 0 and 10. The slider output defines the value of the variable K_contr, which is also displayed to the right of the variable. The gain K_contr is then multiplied by the step input.

Labels – You see several Labels in Fig. 2. Select Label from the icon bar and enter the desired text. Please use labels generously. They help explain your work, and you'll remember more easily the purpose of each element when you'll re-use the simulation in the weeks ahead.

Variables – VisSim allows you to define variables. In Fig. 2, for instance, K_contr and Omega are variables. As you'll see below, variables are useful in large simulations.

Overplots – As you simulate the system's response at different (slider) gain settings, you'll want to compare the effects. You can do this by selecting 'overplot' in the plot menu (right mouse click after selecting the plot). Fig. 2 below shows three different step responses at gain settings K_contr = 2, 5, and 9. Please note thes gain settings and add them to your report., for instance by adding a Label. Save a nice graph of your choice, mark the parameter choices in the graph!

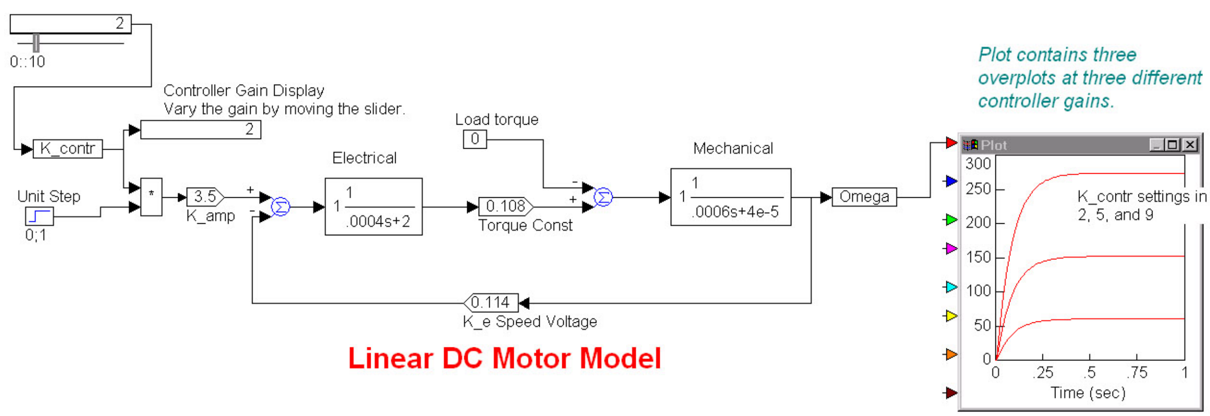


Figure 2 Linear DC Motor Model

Remember: Each submitted plot **must** contain: labeled and scaled axes; a title listing the type of response, the lab and problem description, and the student's name.

Compound Blocks – When simulations become larger than the one in Fig. 2, it is useful to group them by logical units.. In Fig. 3, the linear motor model was grouped into a compound block "Linear Motor". Procedure: Select the elements you wish to place into the compound block → Edit → Create compound block →Enter Block name. You can edit the compound block by clicking on it. A right mouse click returns you to the main screen. Those esthetically inclined may create a bitmap image for the motor, instead of the simple text in Fig. 3. To edit the compound block properties, select it, then Edit → Block Properties.

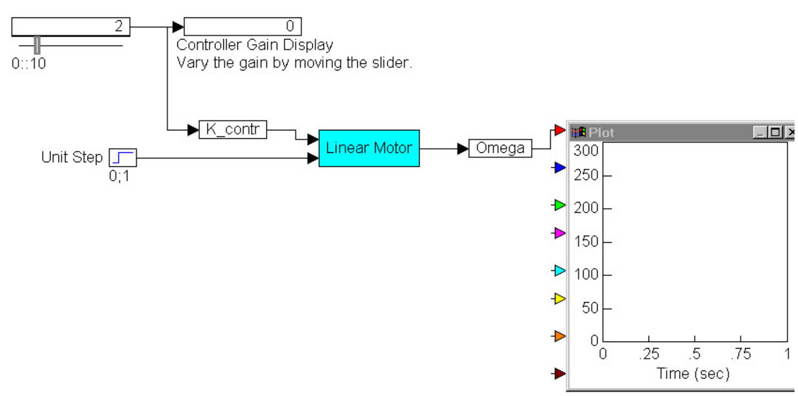


Figure 3 Compound Block

Compound block 'Linear Motor' has input and output variables K_contr and Omega, as well as the unit step input.

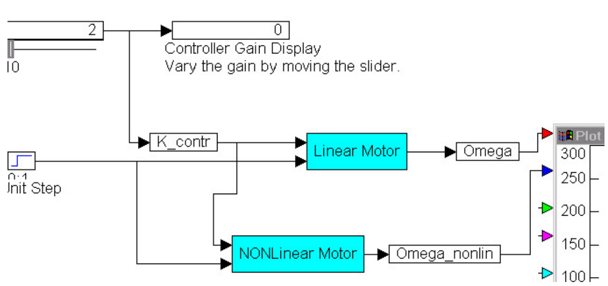


Figure 4 Two Compound Blocks

Getting Real: Nonlinearities - Duplicate the compound block 'Linear Motor' and rename it 'Nonlinear Motor'. Connect 'Nonlinear Motor' to inputs K_contr and unit step, and to a new output Omega_nonlin, connect Omega_nonlin to the plot. See Fig. 4. Edit the nonlinear block and insert the following nonlinearities from the Blocks → Nonlinear menu:

(a) Limiter: In reality our amplifier output is limited to ±35 Volts. Put a limiter between amplifier and summing point, see Fig. 1. Bounds are 35 and -35.
(b) Deadband: Our plant also has dry friction: select 'Deadband Function' from the 'Nonlinear' menu. Enter the Coulomb Friction data from the table *2 = 0.06 Nm. Place the nonlinear elements in the block diagram as indicated in Figure 1. Simulate with the same parameters as before.
By plotting both linear and nonlinear result vectors you can clearly see the differences. Coulomb friction is most noticeable at rather small torques. Saturation exists only at high amplifier inputs. Try a sinusoidal input function (perhaps omega=10; K_contr=20, vary omega a few times!) and observe clipping with the nonlinear model.
To see the effect of Coulomb friction, choose a small K_contr, perhaps K_contr = 0.1, and observe the lagging response of the motor. Plot a nice example of how each nonlinearity affects the motor performance. Figures 5 and 6 show the effects for controller gains 0.4 and 19, respectively. The motor torque and the Amplifier output are shown in separate plots. As you can see, clipping occurs only at large gains. The coulomb friction is most severe at low gains.

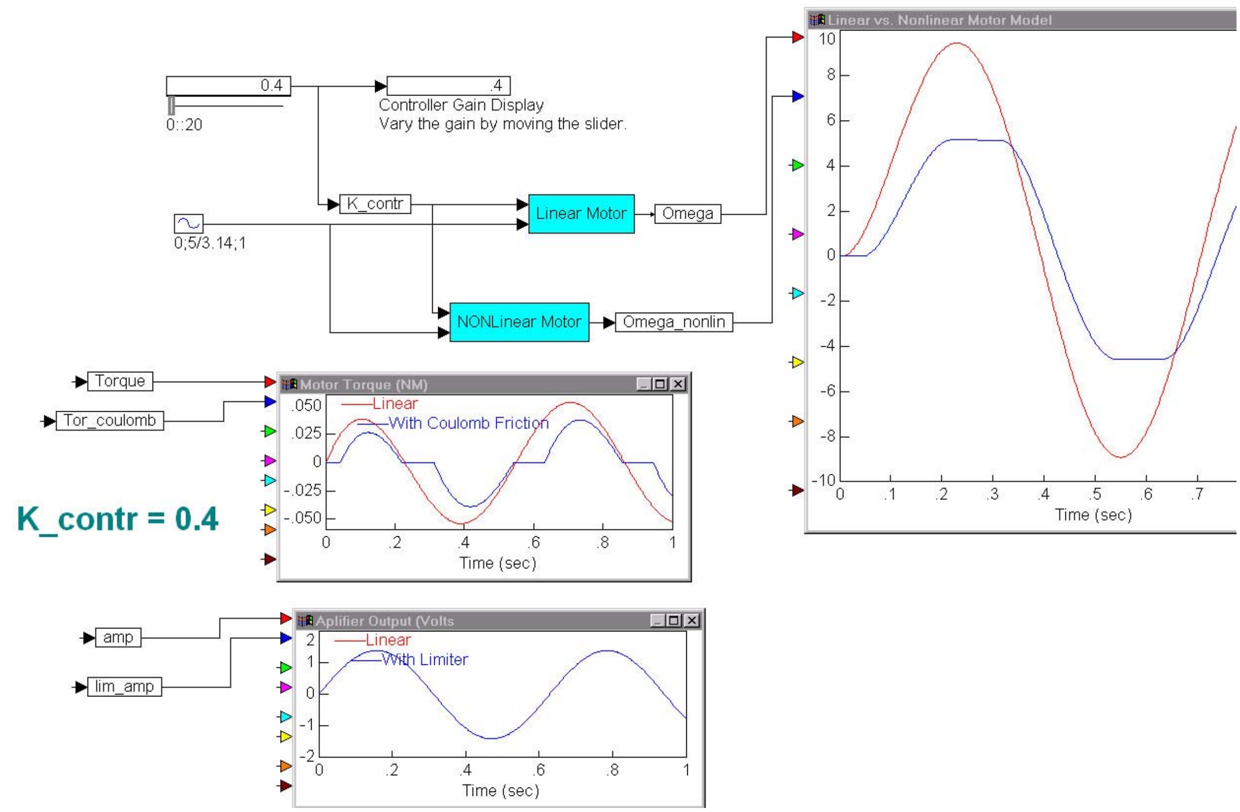


Figure 5 Coulomb Friction

Numerical Instability: Sometimes the simulation exhibits oscillations that reflect a numerical instability, not the system's dynamics . When you suspect a numerical instability, you can easily check for it by increasing the number of points in the simulation to say, 400. Procedure: Simulate → Simulation properties → set Frequency to the desired number.

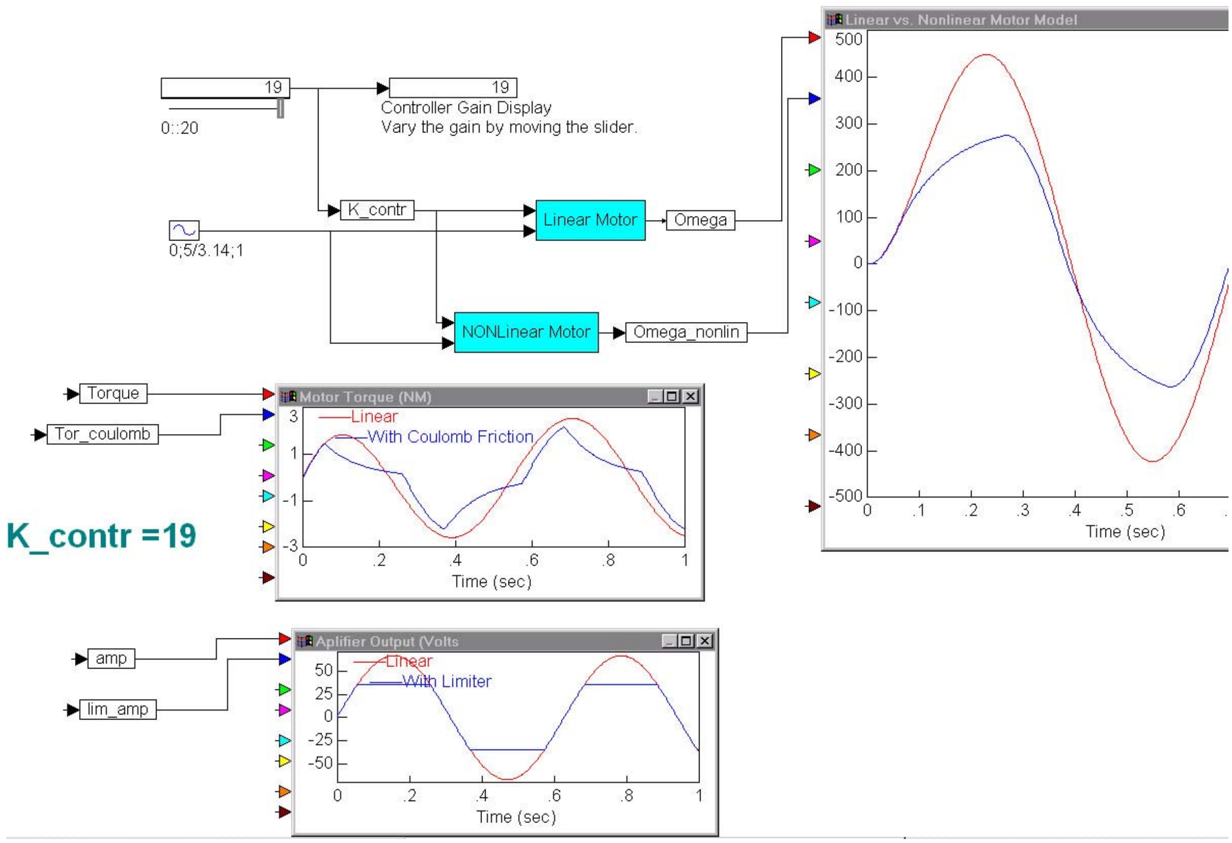


Figure 6 Limiter Effects at High Gains. The amplifier clipping (bottom left) distorts the motor torque (upper left) and distorts the motor's speed response (right)

Creating Variables for Display – Create variables such as the ones seen as inputs to the two smaller plots in Fig. 6 inside each compound block. As seen in Fig. 7, attach a variable name to each item you wish to display. You can access the variable anywhere in your model.

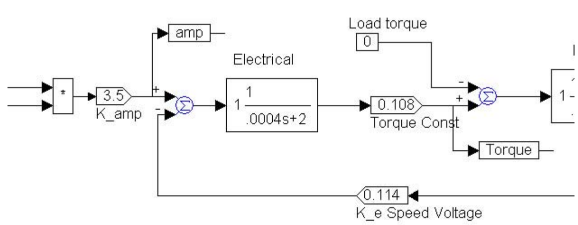


Figure 7 Defining Variables (linear motor compound block)

(c) Effect of Load Torques – All simulations above were conducted with zero loads. Enter the same small non-zero load in each compound block and observe the motor performance. Do NOT let the motor run backwards (negative speeds). Plot a nice example of driving a load.

Report

Plot of the linear and nonlinear system compound blocks, and a plot of the overall system similar to Fig. 4.(one each). You may import each image into a MSWord file.
One plot of linear/nonlinear system step response
One plot for each nonlinearity, show clearly the differences between linear and nonlinear simulation. Label each plot trace and list the parameters you applied.
Plot a nice example of driving a load, list the parameters you applied.

Please Remember to save your work on the hard disk and on USB Memory or on a diskette!