University of New Hampshire
Department of Mechanical Engineering

ME 747 – Lab # 2
(18 Sept 2017)

Rotating Mechanical System: Parameter Identification and Signal Integration

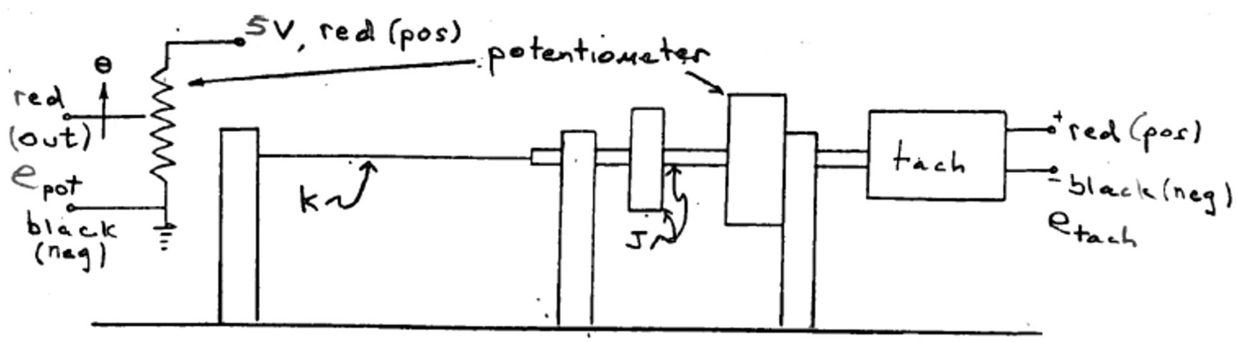
Purpose:

In this lab, you will investigate the dynamics of a rotating mechanical system in order to identify the second-order system parameters. A tachometer will be used to measure the rotational velocity and a potentiometer will be used to measure the angular position of the shaft. Integration of the rotational velocity signal will be compared to the potentiometer signal

Note: Numbered questions are lab work, lettered questions are for the write-up. You should make sure that you have all necessary data to answer these questions.

1 Position and Velocity Measurements

The figure below represents a rotating mechanical system, where a rotating disk (inertia J) is connected to a thin wire that acts as a torsional spring (stiffness k). An initial displacement will cause a transient response that is measured with a potentiometer (angular position θ) and a tachometer (angular velocity ω).



The given spring-mass-damper system has an analog potentiometer and tachometer. The tachometer ($e_{tach}(t)$) has a sensitivity of 7 *m*V/rpm and the potentiometer ($e_{pot}(t)$) has a sensitivity of 0.015 V/degree.

1. Wire the setup as shown in the figure and connect the tachometer output $e_{tach}(t)$ to the scope channel 0, and the potentiometer output $e_{pot}(t)$ to scope channel 1. Use a scale of 0.5V or 1.0V for the potentiometer output. The potentiometer needs a 5V supply while the tachometer needs no input. Also, click on the HORZ button on the scope and change the points recorded to 5000.

2. Displace the rotating mass (gear) by 2 to 3 teeth and release, making sure that both signals are visible and of similar magnitude on the scope. If the potentiometer signal cannot be seen completely, use the vertical position slide on the scope to see the signal. (If the signal is still not completely visible because of bias, use the vertical offset under "CHAN" to bring the signal within range, ask TA's for help.)

3. Displace the rotating mass (gear) by 2 to 3 teeth, and use a trigger on the tach signal (channel 0) to capture the response of the tack and potentiometer. Make sure you get at least 3 oscillation cycles.

4. Obtain the following plots, making sure you (1) sketch and save the data (as an Excel file) and (2) obtain a "screenshot" for each plot:

   i) $e_{tach}(t)$ vs time and $e_{pot}(t)$ vs time (both on one plot)

ii) $e_{tach}(t)$ versus $e_{pot}(t)$ (use XY display in the scope)

a) Using the given sensitivities, plot :
   i. angular velocity ω (rad/sec) vs time and angular position θ (rad) vs. time (both on one plot). If necessary, you can subtract the dc bias from the potentiometer signal to get both curves on one plot.
   ii. $\omega(t)$ vs $\theta(t)$.

b) Comment on the meaning of plot (a) i.

c) Comment on the meaning of plot (a) ii.

d) Use Matlab to integrate the $\omega(t)$ data to obtain $\theta_{int}(t)$, and plot $\theta_{int}(t)$ and $\theta(t)$ vs time. Compare the plots and comment on the use of numerical integration.

2 <u>Second-Order Parameter Identification</u>

In this section, the parameters for the second order rotational mechanical system are to be experimentally determined and compared to their corresponding theoretical values. For our system, the moment of inertia for the potentiometer J_{pot} is 2.44×10^{-3} oz_f-in-sec^2, and for the tachometer J_{tach} is 1.32×10^{-4} oz_f-in-sec^2. The gear (rotating mass) is stainless steel with a pitch diameter of 2.5 in, outer diameter of 2.58 in, width of 0.188 in, and a mass of 0.268 lb_m. The flex couplers have masses of 0.0249 lb_m (D = 0.744 in) and 0.0253 lb_m (D = 0.75 in) for the coupling between the pot and tach, and between the pot and the spring, respectively.

1. Measure the spring wire length and diameter of your setup. Take multiple measurements for averaging.

2. Sketch the mass of the system and take all appropriate measurements so you can approximate the mass moment of inertia of the system.

a) Write the differential equation of the rotating mechanical system.

b) Calculate an experimental value for k of the wire, given that a wire of the same diameter and different length (5 in.) has a value of 0.253 lb_f-ft/rad.

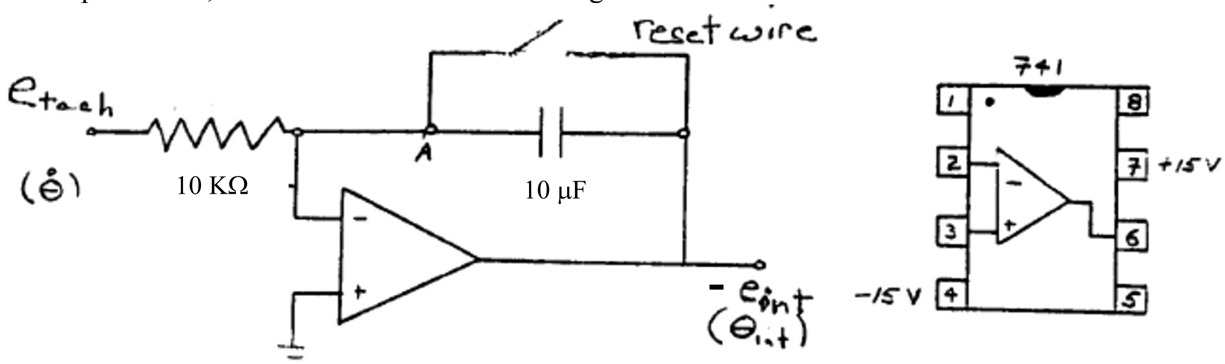
c) Using plots $\omega(t)$ and $\theta(t)$ from section **1**, find ω_n and ζ of the system.

d) Calculate the experimental rotational inertia J from ω_n and k. Also find the experimental damping coefficient B from ζ.

e) Calculate the theoretical values of J and k and compare them to the experimental values. Note that $G_{steel} = 16.562 \times 10^8$ lb_f/ft^2. Comment on any differences.

3 Integration of Velocity and Signal Drift

If the tachometer output is the only available signal, a position signal can still be obtained by integrating the velocity signal with an op-amp integrator. If a simple op amp integrator is used for this task, there will be output drift due to offset current and offset voltage in the op amp. The effect of drift (a changing bias voltage) can be eliminated momentarily by shorting across the capacitor with a piece of wire. This brings the output to zero, from which the drift will start again.



1. Wire up the integrator circuit using a 741 op amp (note that the input to the integrator is your tachometer signal). Connect the op amp output - e_{int} to the input of another op-amp on the breadboard that has been wired to invert the signal, i.e. a gain of -1. Connect the output of the inverting amp + e_{int} to channel 0 of the scope. The potentiometer signal should be connected to channel 1.

2. This type of integrator will have drift due to offset current and voltage in the op-amp, so one must include a wire(s) in the circuit that can be used to short across the capacitor, which resets the output to zero:
   (i) Connect a wire to the inverting node of the op-amp. Connect a wire to the output of the op amp. (Note that these wires should be long enough such that they can touch each other without interfering with the rest of the circuit.)
   (ii) To reset your op-amp, simply touch both wires in (i) together and then release. Once both wires lose contact with each other, the signal will immediately start to drift.

3. Obtain an integrated tachometer signal using the scope trigger on the potentiometer signal (channel 1). First displace (do not release) the mass and reset the op amp to zero by shorting across the capacitor. ***Immediately after*** the op amp is reset, release the mass making sure you capture the output of the potentiometer and the integrator.

4. Sketch the time responses for the output curves $e_{int}(t)$ and $e_{pot}(t)$, and save this data to an Excel file.

5. Set the scope trigger to immediate-normal and watch the signal drift. Record the amount of drift when the integrated signal reaches steady state.

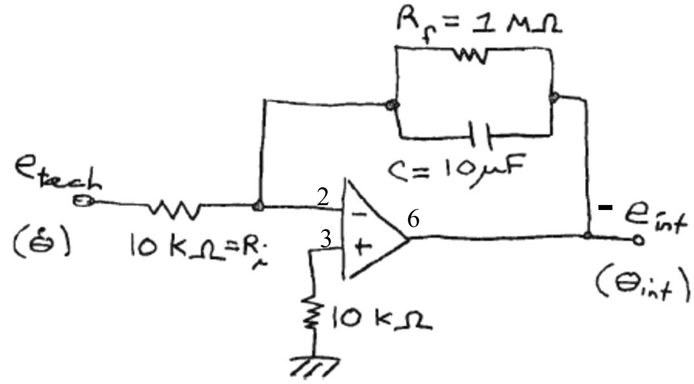
a) Derive the ideal transfer function of the op-amp integrator using the values of R and C, and compare this to an ideal integrator.

b) Convert $e_{int}(t)$ and $e_{pot}(t)$ to angular displacements $\theta_{int}(t)$ and $\theta_{pot}(t)$, respectively, and plot both angular displacements on the same graph using Matlab. Note that the elements of the op amp integrator must be accounted for.

c) Discuss the output from the integrator $\theta_{int}(t)$ and compare it to $\theta_{pot}(t)$. Is it usable for measuring position?

4 Integration of Velocity Without Signal Drift

To eliminate drift, one can use a more precise op-amp, .e.g. an instrumentation amplifier, or change the design to eliminate integration of the bias signals. A pseudo-integrator circuit (first-order) is considered here, where the low frequency content is not integrated. The proposed design is shown below with $R_i = 10$ KΩ, C = 10 μF, $R_f = 1$ MΩ.



1. Measure and record the resistor and capacitor values to be used in the pseudo-integrator circuit.

2. Wire the 741 op amp circuit as given above making sure the input to the pseudo-integrator is your tachometer signal. Connect the op amp output - e_{int} to the input of another op-amp on the breadboard that has been wired to invert the signal, i.e. a gain of -1. Connect the output of the inverting amp + e_{int} to channel 0 of the scope. The potentiometer signal should be connected to channel 1.

3. Obtain an integrated tachometer signal using the scope trigger on the integrated tach signal (channel 0). Displace and release the mass making sure you capture the output of the potentiometer and the integrated tach signal.

4. Sketch the time responses of the output curves $e_{int}(t)$ and $e_{pot}(t)$, and save this data to an Excel file.

5. Frequency response can be used to find the steady state gain, break frequency, and system order of the pseudo-filter. Connect the function generator to the input of the pseudo-integrator and to channel 0 of the scope. Connect the output of the inverted pseudo-integrator signal + e_{int} to channel 1 of the scope.

6. Input a 0.1 V dc voltage offset (<u>not</u> 0.2 V) from the function generator to the pseudo-integrator. Wait for the output to stabilize and measure the input and output amplitudes. Now set the dc offset back to zero.

7. Set the function generator to 0.4 sin (ωt) with ω at 0.15 Hz. Click on scope HORZ and make sure the record length is 5000. Set the scope time base to its lowest value and record both input and output signal peak-to-peak amplitudes using the cursors. Now increase the sine frequency by one decade and record the amplitudes and phase shift. Repeat measurements for a two decade increase in the input frequency.

a) Derive the ideal transfer function of the pseudo-integrator for the measured R’s and C, and use Matlab to make a Bode plot containing the theoretical curve and the experimental data points. Compare the Bode plots to that of an ideal integrator.

b) Convert the data in step (3) to their corresponding angular displacement values. Plot $\theta_{pot}(t)$ and $\theta_{int}(t)$ vs. time on the same plot. Compare the converted values to each other and discuss the results. Is the integrated signal usable for measuring position, why or why not?

c) Compare the experimental time constant and steady-state gain (from the measured Bode plot values) to the calculated theoretical values for the pseudo-integrator (with inverter).