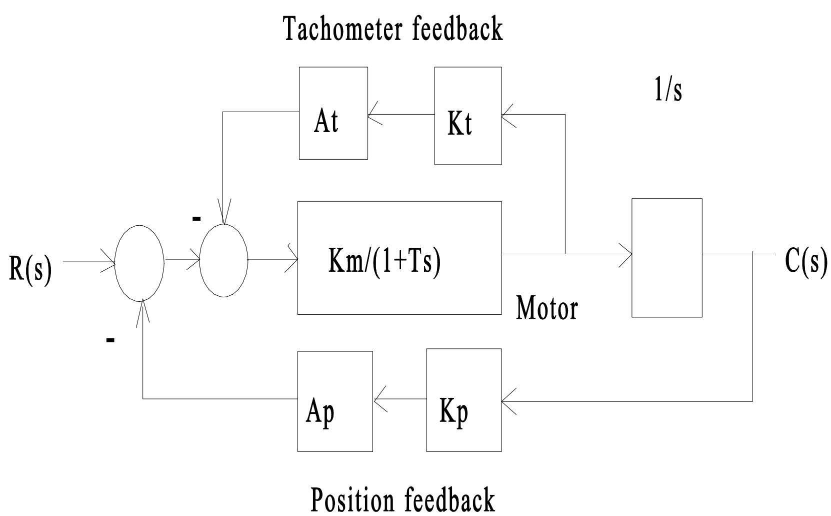
MEM 01
DC MOTOR-BASED SERVOMECHANISM WITH TACHOMETER FEEDBACK

Motivation

Closing a feedback loop around a DC motor to obtain motor shaft position that is proportional to a varying electrical signal is the most fundamental of mechanical control problems. In fact, this is called, “the basic regulator problem”, *i.e.*, making the output position of a relatively massive device follow a low-power input signal by addition of position feedback and a power amplifier. Often the performance can be further improved by adding to the outer position feedback loop an inner velocity feedback loop. Since the position is often the angular position of a shaft, the angular velocity will be measured by a tachometer and the inner loop is then called the “tachometer feedback loop” although we recognize it as being equivalent to a PD controller in the feedback path.

Virtually every undergraduate controls textbook discusses tachometer feedback performance improvement, including Ogata, Modern Control Engineering, 3rd edition, page 156. Root locus is the usual design method, although the use of root contour to simultaneously set both attenuation factors would be appropriate also.



Block diagram of basic servomechanism-based regulator

Before coming to lab, do the following

(1) Every line in a block diagram represents a signal. In physical systems, signals have engineering units. Add the appropriate units to every line in the diagram of the basic

servomechanism-based regulator if the reference signal, r(t), has units of volts.

(2) Study the attached excerpt from the book by Graupe, Identification of Systems, and explain how you are going to validate the assumption here and in Ogata that the motor transfer function is appropriately represented by a first-order lag. Consider applying the test of section **3.3.3-c**.

In the lab, before performing the experiment

(3) Examine the experimental setup and be prepared to associate every block in the block diagram with system hardware. In particular, how is the integrator block implemented in hardware?

Experiment

The first part is to be completed during the first afternoon session

(1) Demonstrate familiarity with the operation of the equipment by completing PRACTICAL 1.1 from the equipment manual (excerpted below) and determining the 'speed constant'. Pick a positive rotation direction of the motor and wire the output potentiometer and output tachometer to produce corresponding positive voltages. Use a DVM to demonstrate your system. Reverse the Servo Amplifier connection from +15v to -15v and observe that directions and polarities are reversed.

(2) Determine the numerical values for the symbols in the block diagram, except At and Ap. To accomplish this, you have at your disposal a DVM, a power supply with 0->15v, 0-> -15v, and -15 -> +15v. By wiring the rotary potentiometer in the Reference Module as a voltage divider, you can obtain any constant voltage between -15 and +15volts. What is your plan?

Using a signal generator a step input can be applied to the open-loop motor and the tachometer voltage measured using the digital memory oscilloscope. What should the response look like? If it resembles what you expect plot a hardcopy to take with you.

The second part is to be performed between lab sessions.

(3) Apply the method of **3.3.3-c** in Graupe to verify the assumed form of the motor transfer function and to obtain numerical values for Km and T, the motor time constant. Draw a root locus and determine the P-control gain for a closed-loop, position-feedback system that will have the specified overshoot of__________. Determine the value of Ap that will implement this gain.

By root locus, show that you can improve performance by adding tachometer feedback. Improved performance is evidenced by reduced overshoot without extending the risetime, or reduced risetime without incurring increased overshoot. What value of At will allow you to demonstrate this improved performance?

The third part is to be completed in lab during the second session

(3) Wire up your positional feedback system and set Ap to your design value. Do not rely on the knob settings on the potentiometer box. A careful determination of the setting can be made with the DVM before incorporating it into the loop. Show that the expected performance results by performing a closed-loop step test. If you do not get the results you expect using your design value, by trail and error, determine what value of Ap would produce the anticipated performance improvement. Obtain a hardcopy.

Leave Kp at the setting that produces the performance you predicted, wire up the tachometer feedback and set At to your design value. Repeat the step test of step (3) and demonstrate your expected performance improvement using your value, or tune At by trial and error to obtain the expected performance. Obtain a hardcopy of the step response that shows the improvement.

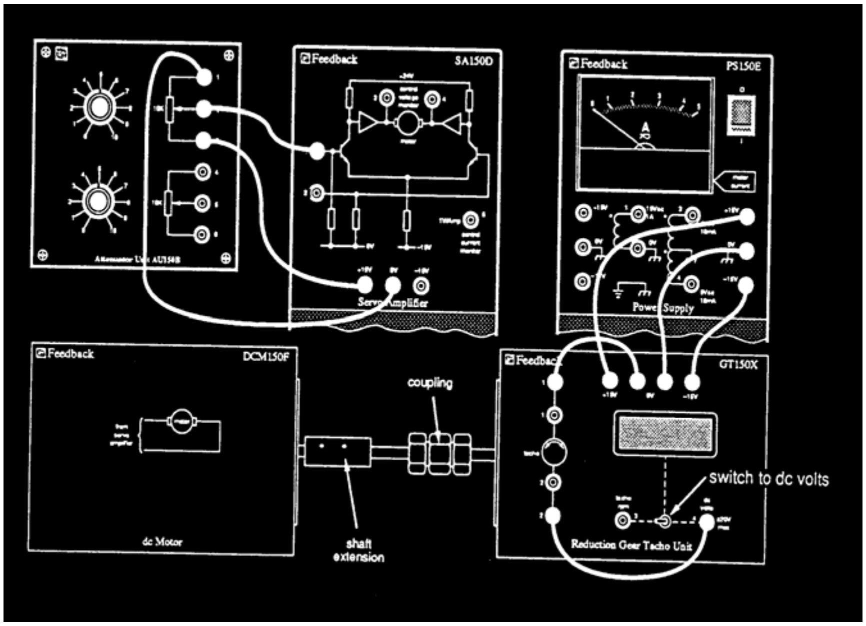
And the fourth part is to be handed in one week after the second lab session

(4) Include in your report the demonstrations that your design values succeeded or explanations for the differences between the trial-and-error values that did improve performance and your design values. Show the open-loop poles and closed-loop poles on your root loci.

Safety

Safety glasses are to be worn whenever working in the Undergraduate Automatic Controls laboratory, room 378. In addition, it is important for the protection of the apparatus in this experiment to always turn off the power supply before making wiring changes. Some of the modules are protected by fuses and some are not. A lot of time can be lost wondering why nothing is happening after you have gotten careless and blown a fuse.

The experiment involves unguarded, rotating parts. Tuck in dangling hair, neckties, etc., to avoid getting entangled in the equipment.



Circuit for PRACTICAL 1.1 from the apparatus manufacturer. This circuit should enable you to control the speed of the motor in one direction of rotation using the AU150B potentiometer. For some reasonable speed, use a DVM to measure the Servo Amplifier input voltage relative to ground and the tachometer output voltage at terminal 2 relative to grounded terminal 1. The ratio **tach volts/input volts** is called the "speed constant" of the motor-amplifier combination. Add the OP150K output potentiometer to your system and become familiar with its behavior. It may be useful to apply zero volts to the servo amplifier input and turn the motor shaft by hand. Always switch off the PS150E power supply when making changes to your system.

Improved method for determining the time constant of a first-order system

If the experimental response looks like it may have resulted from a step input to a first-order plant, *i.e.*,

$$input\ X(s) = \frac{c}{s}, \quad output\ Y(s) = \frac{c*k}{s(1+Ts)}$$

that is, the transfer function is anticipated to be

$$G(s) = \frac{k}{1+Ts}$$

where

$$y(\infty) = \underbrace{\lim}_{t\to\infty} y(t) = \underbrace{\lim}_{s\to 0} sY(s) = ck$$

The time constant T can be estimated from the time of 63.2% of final response. To improve on this estimate, plot

$$y(\infty) - t(t) \quad vs \quad t$$

on semilog paper. Since

$$y(t) = ck(1 - e^{-t/T})$$

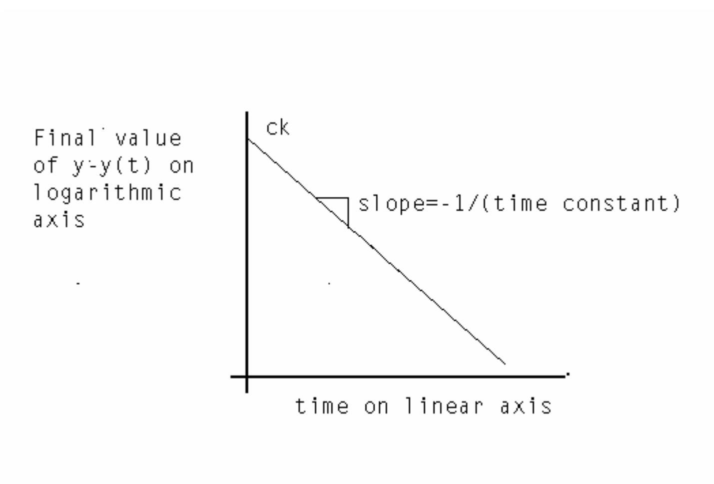
then

$$y(\infty) - y(t) = ck - ck + cke^{-t/T} = cke^{-t/T}$$

and taking the natural log of both sides

$$\ln[y(\infty) - y(t)] = \ln[ck] - t/T$$

which is a straight line on semilog paper with slope -1/*T*. If your plot isn't straight adjust your estimate of $y(\infty)$ a little and replot. If you are uncertain if you have calculated the semilog slope correctly try a second pair of points and see if you get the same slope.



If the upper left part of your plot tails away from a straight line it is likely that your plant is better represented by a second-order transfer function. In MEM1 this should not happen, or at least it should not be significant. Simple as it is, this is a typical identification problem with the plant transfer function assumed *a priori*.