

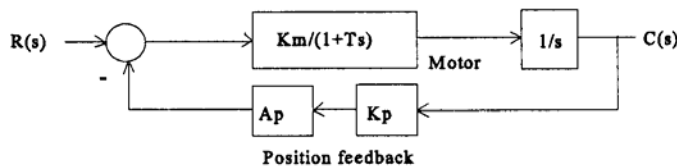
## ECE 02

# OP-AMP BASED COMPENSATION FOR A SERVOMECHANISM

### 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. P-control often produces a big improvement in performance, particularly for Type I plants. Often the performance must be or can be further improved by including a compensator. Since there are usually places in the system where low-voltage electrical signals exist, it is common to build compensators from op-amps plus passive circuit elements. Lead, lag and lead/lag compensators are easily constructed on circuit prototyping boards and inserted into the system for evaluation, before designing a more permanent black box.

Virtually every undergraduate controls textbook discusses DC-servomotor control, including Ogata, Modern Engineering, 3<sup>rd</sup> edition, page 142. Root locus is the usual



**Block diagram of basic P-controlled, uncompensated regulator**

design method, although the use of root contour would be appropriate also.

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 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.

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) Determine the numerical values for the symbols in the block diagram, except  $A_t$  and  $A_p$ . To accomplish this, you have at your disposal a DVM, a power supply with 0- $\rightarrow$ 15v, 0- $\rightarrow$  -15v, and -15  $\rightarrow$  +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 at home or in room 502 or ... .

- (2) 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  $K_m$  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  $A_p$  that will implement this gain.

Design a series compensator to improve step-response performance. Improved performance is evidenced by reduced overshoot without extending the risetime, or reduced risetime without incurring increased overshoot, or, even better, reduced risetime and reduced overshoot. This is not easy as the system has definite voltage-level limits. You must not exceed the power supply limits or damage the op-amps. Simulate your final, closed-loop design and look at the magnitudes of internal signals when you apply the step input you intend to use in the lab. Generate a Bode plot of the compensator alone.

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

- (3) Wire up your positional feedback system and set  $A_p$  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  $A_p$  would produce the anticipated performance improvement. Obtain a hardcopy.

Wire up your compensator and debug it until it seems to be working. Using a signal generator obtain an experimental Bode plot of the compensator alone. Is it what you expect? This is crucial to your design. Correct your circuit until it has the required Bode plot.

The fourth part is for home

- (4) Review your results so far. Do you need to refine your P-control design? Does your compensator have the expected Bode plot? Check your circuit until you find causes of anomalous behavior and fix them.

Back in lab for the third session

- (5) Retest your compensator to be convinced that it has the necessary transfer function. Perform step tests to demonstrate the anticipated performance improvements. Produce hardcopy. Check for limit violations. Make such tests as will help you establish that the system performs as predicted.

## 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.

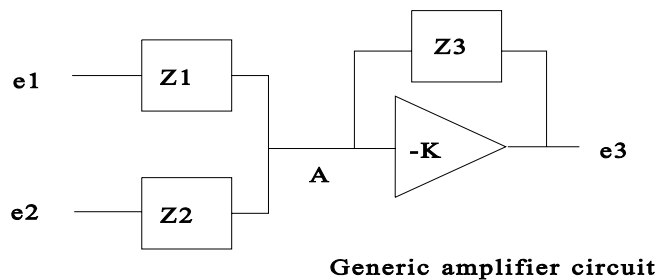
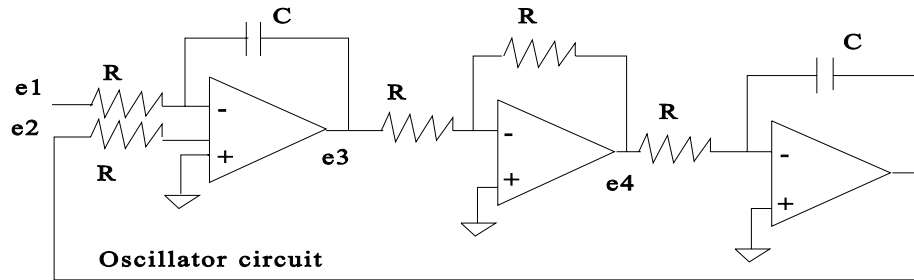
## Op-amp circuits

Ogata, Modern Control Engineering, 3<sup>rd</sup> edition, page 409 gives you the generic op-amp circuit for lead or lag compensators and a lead/lag is shown on page 428. Unfortunately the text circuit diagrams do not show the ancillary wiring needed by the op-amp, so you must translate the text circuit into an actual circuit based on the attached data sheet for the op-amp you are using.

Using the provided patch wires, resistors, capacitors and op amps, assemble on the provided proto board a compensator that will improve the step-response performance of the DC-motor servomechanism. The JAMECO power supply provides +12v for  $V_{CC}$  (instead of 18v), -12v for  $V_{EE}$  (instead of -18v) and COMMON. The provided plug and pigtailed put +12v on the red lead, -12v on the black lead and the white lead is common or 0v. Wire Your eight-pin op amps must be provided with  $V_{CC}$  and  $V_{EE}$ , in addition to the connections shown in Ogata. **ALWAYS DISCONNECT THE POWER SUPPLY BEFORE MAKING WIRING CHANGES.**

Use MATLAB to predict the step response and Bode plot of your compensator. Then you can use a slow squarewave input from a signal generator to test your circuit and compare the output to your step-input predictions and an input sinewave from a signal generator to compare to the Bode plot.

Draw a circuit diagram for your compensator, like that in Ogata, with numerical values shown for the resistors and capacitors with units. Work out the transfer function and list K, T and  $\alpha$  or  $\beta$ .



Consider the following example that corresponds to the sample proto board:

The brown-black-green resistors are  $10 \times 10^5$  ohms or 1 megohm abbreviated  $1M\Omega$ . The capacitors are labeled 1.0M meaning, in this case, 1 microfarad or  $1 \times 10^{-6}$  farad abbreviated  $1\mu f$ .

Kirchhoff says that the currents into point A must sum to zero.

$$\frac{e_1 - e_A}{Z_1} + \frac{e_2 - e_A}{Z_2} + \frac{e_3 - e_A}{Z_3} = 0 \quad e_3 = -Ke_A$$

If K is large —  $10^6$  is typical for op amps — then Kirchhoff's current rule reduces to

$$Z_2 Z_3 e_1 + Z_1 Z_3 e_2 + Z_1 Z_2 e_3 = 0 \quad e_3 = -\frac{Z_3}{Z_1} e_1 - \frac{Z_3}{Z_2} e_2$$

For this circuit all of the resistors are  $1M\Omega$  or  $R = 1 \times 10^6$  volt-sec/coulomb and both capacitors are  $1\mu f$  or  $C = 1 \times 10^{-6}$  coulomb/volt. Note that  $1M\Omega \times 1\mu f = 1$  sec therefore the equations for the three amplifier circuits are

$$e_3 = -RCse_1 - RCse_2 \quad e_4 = -\frac{R}{R} e_3 \quad e_2 = -RCse_4$$

and the loop overall transfer function is

$$\frac{e_2(s)}{e_1(s)} = \frac{-s^2}{s^2 + 1} \quad \omega^2 = 1 \quad \omega = 1 \quad f = \frac{1}{2\pi} = 0.16 \text{ Hz}$$

so the circuit should oscillate at about  $2\pi$  seconds per cycle and it does (actually 6.7 sec).