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2.004 Dynamics and Control II  
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
DEPARTMENT OF MECHANICAL ENGINEERING

2.004 *Dynamics and Control II*

Laboratory Session 5:  
Elimination of Steady-State Error Using Integral Control Action<sup>1</sup>

Laboratory Objectives:

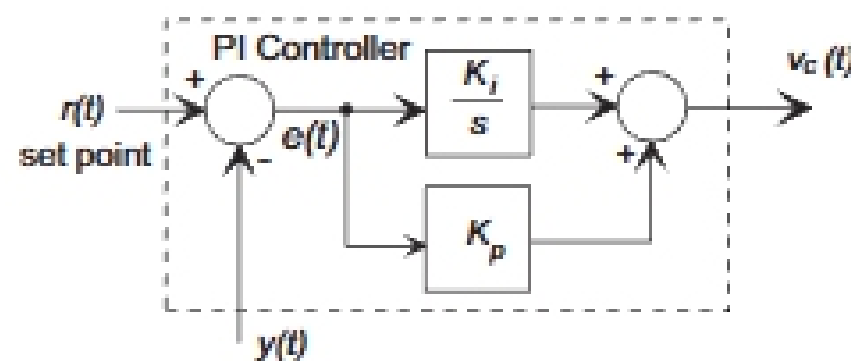
- (i) To investigate the elimination of steady-state error through the use of *integral* (I), and *proportional plus integral* (PI) control.
- (ii) To compare your experimental results with a Simulink digital simulation.

**Introduction:** In the previous laboratory experiments you have noted that there was a steady-state error to a constant angular velocity command, and that the error magnitude depended on the degree of viscous damping present. In many control problems it is desirable to eliminate the steady-state error, and the most common way of doing this is through the use of *integral* control action and *proportional plus integral* (PI) control.

A PI controller has a transfer function

$$G_e(s) = K_p + K_i \frac{1}{s}$$

with a block-diagram



and a time domain response

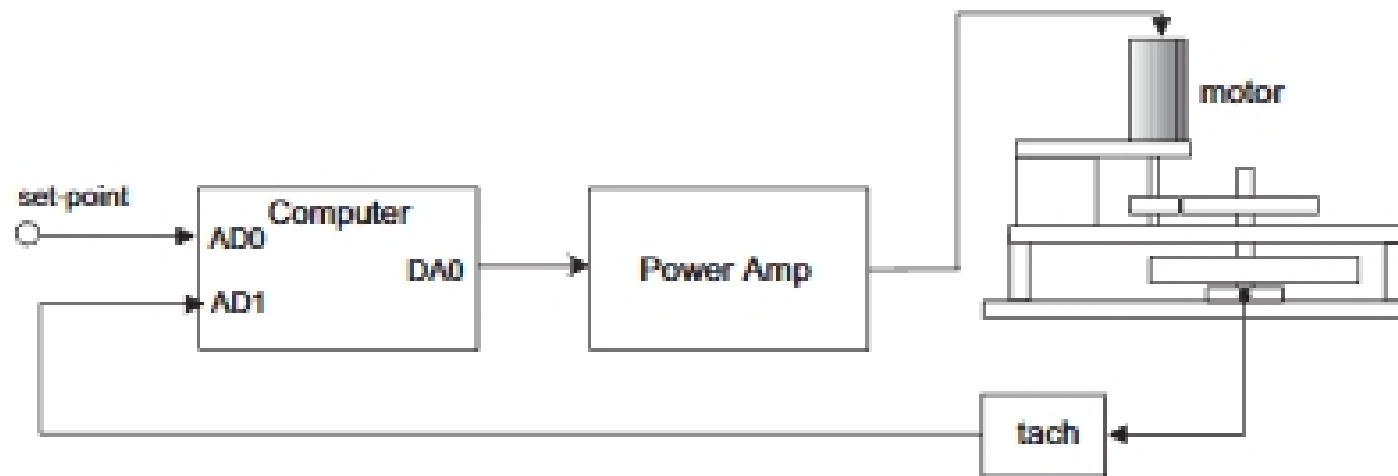
$$v_c(t) = K_p e(t) + K_i \int_0^t e(t) dt$$

where  $v_c(t)$  is the controller output. A description of how the integral component acts to eliminate steady-state error is given in Appendix A. Please take a few minutes to read through and understand the Appendix.

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<sup>1</sup>March 15, 2008

**The Experimental Setup:** The set-up is the same as in Lab. 4, using the 2.004 PID Controller as shown below:



In this lab, in addition to proportional control you will be using integral control, adjusted by the knob labelled **Int. Gain (Ki)** on the front panel. In digital control systems such as this, real-time integration is done through an approximate numerical algorithm, such as rectangular integration, where the integral is represented as a sum  $s_n$

$$s_n = s_{n-1} + e_n \Delta T$$

where  $e_n$  is the error at the  $n$ th iteration, and  $\Delta T$  is the time step, or trapezoidal integration

$$s_n = s_{n-1} + (e_{n-1} + e_n) \Delta T / 2$$

**Note:** Always make sure that the power amp is on and the breaker switch is on before starting the controller.

**Experiment #1: Verification of Integrator Performance** Verify that the integrator is functioning correctly using the following steps:

- Connect the computer-based controller, but keep the power amp turned off for all parts of this experiment.
- Set the function generator to produce a step (square) function of amplitude 1 volt, at a frequency of 1 Hz.
- Open the controller, and select a sampling rate of 100 samples/sec. (Maintain this value for all parts of the lab.)
- Set  $K_p = 0$  and  $K_i = 1$  on the front panel. Start the controller and observe the error trace. Visually confirm that the PID controller output trace is the integral of the input. Either save and plot the output, or make a sketch of it.
- Add a 0.5 volt offset to the square wave and repeat part (d).
- Now set a 1 Hz. triangular wave (no offset) on to the function generator and repeat the experiment.