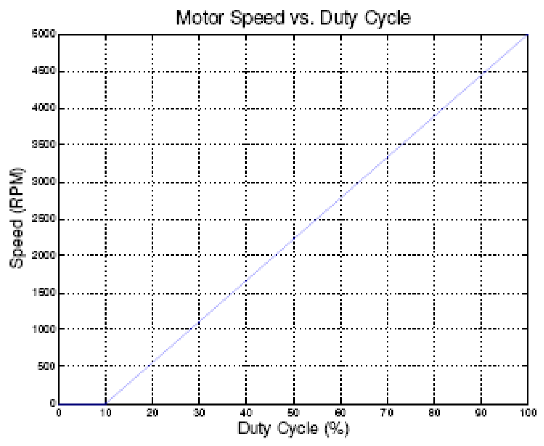
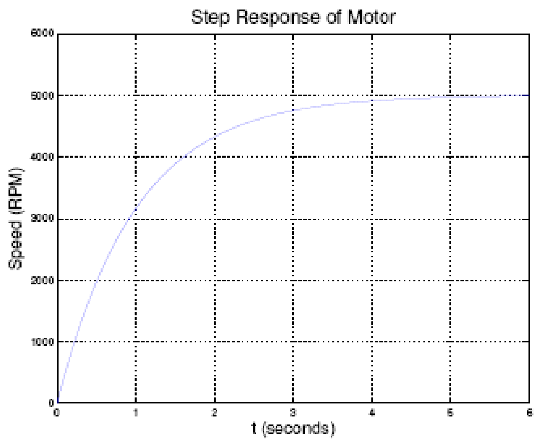
- **Preparation for final lab**
- **Motor Control**

Consider a motor which has a maximum speed of 5000 RPM. The speed vs. duty cycle may look something like this:



The motor doesn't start rotating until it is driven with a 10% duty cycle, after which it will increase speed linearly with the increase in duty cycle.

If the motor is initially stopped, and is then turned on (with 100% duty cycle), the speed vs. time might look something like this:



We will control the motor by adjusting the duty cycle with the HCS12.

We will do this by measuring the speed and updating the duty cycle on a regular basis. Let's do the adjustments once every 8 ms. This means that we will adjust the duty cycle, wait for 8 ms to find the new speed, then adjust the duty cycle again. How much change in speed will there be in 8 ms? The motor behaves like a single time constant system, so the equation for the speed as a function of time is:

$$S(t) = S_f + e^{-t/\tau}(S_i - S_f)$$

where Si is the speed at time 0, Sf is the speed at time ∞, and τ is the time constant of the system. With a duty cycle of D, the final speed will be:

$$S_f = \alpha D + S_0$$

where So is the speed the motor would turn with a 0% duty cycle if the speed continued linearly for duty cycles less than 10%, and α is the slope of the speed vs. duty cycle line (5000/0.9 in this example).

Here I assume that the time constant of the small motors we are using is about 1 second — i.e., it takes about 5 seconds (5 time constants) for the motor to go from a dead stop to full speed. If T = 8 ms, the motor will have changed its speed from Si to

$$\begin{aligned}
S(T) &= S_f + e^{-T/\tau}(S_i - S_f) \\
S(T) &= (\alpha D + S_0)(1 - e^{-T/\tau}) + e^{-t/\tau} S_i \\
S[n] &= (\alpha D + S_0)(1 - e^{-T/\tau}) + e^{-t/\tau} S[n-1]
\end{aligned}$$

where S[n] is the speed at the nth cycle.

Consider an integral controller where the duty cycle is adjusted according to:

$$D[n] = D[n-1] + k(S_d - S_m[n])$$

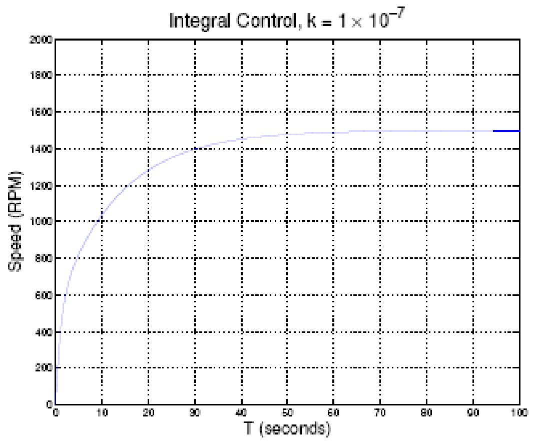
We can simulate the motor response by iterating through these equations.
Start with Sm[1] = 0, D[1] = 0, and Sd = 1500. Then we calculate

$$\begin{aligned}
S_m[n] &= (\alpha D + S_0)(1 - e^{-T/\tau}) + e^{-t/\tau} S_m[n-1] \\
D[n] &= D[n-1] + k(S_d - S_m[n])
\end{aligned}$$

In MATLAB we can simulate this as:

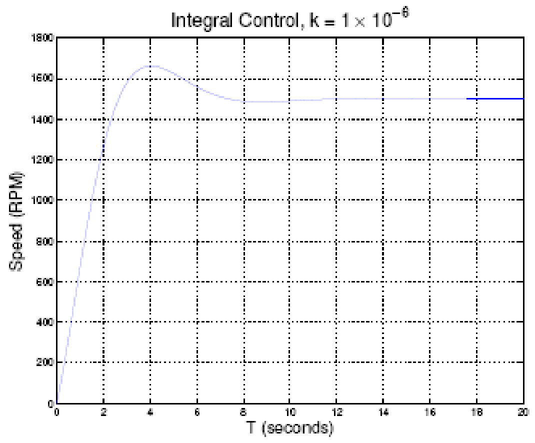
```
Sm = 0;
D = 0;
ee = exp(-T/tau);
for n=2:1000
        Sm(n)=(alpha*D(n-1) + S0)*(1-ee) + ee*Sm(n-1);
        D(n) = k*(Sd - Sm(n)) + D(n-1);
end
```

By changing the value of k we can see how this parameter affects the response. Here is the curve for k = 1.0 × 10−7:

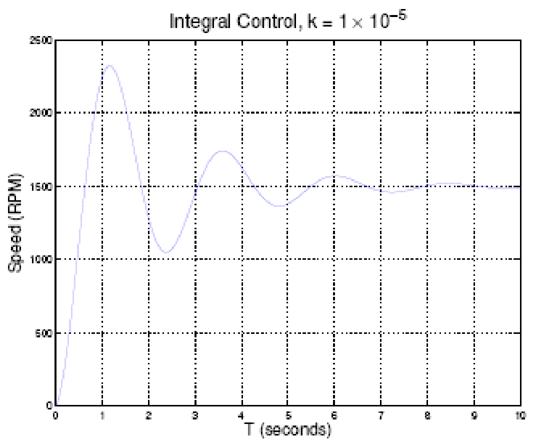


With this value of k, it will take about 1 minute for the motor to get to the desired speed.

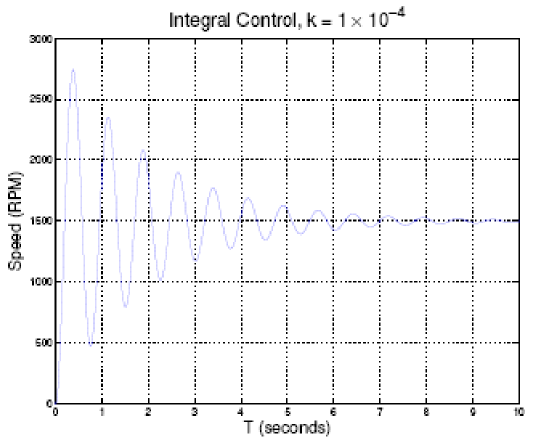
Here is the curve for k = 1.0 × 10−6:



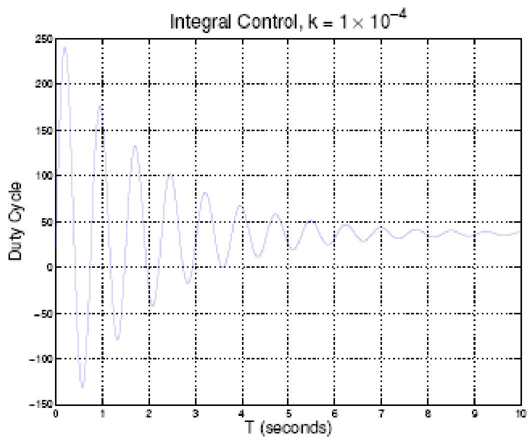
Now it takes about 10 seconds to get to the desired speed, with a little bit of overshoot. Let’s try k = 1.0 × 10−5:



This gets to the desired value more quickly, but with a lot of oscillation. Let’s increase k to 10−4.



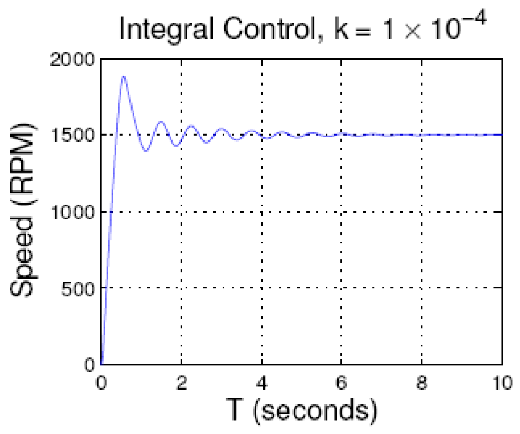
For this value of k there is a significant oscillation. However, a real motor will not act like this. If we look at the duty cycle vs time, we see:

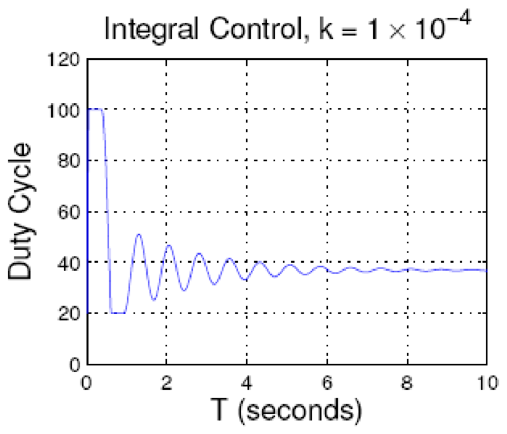


To get this oscillating response, the duty cycle must go to over 100%, and below 0%, which is clearly impossible. To get the response we expect in the lab, we need to limit the duty cycle to remain between 20% and 100%. Thus, we change our simulation to be:

```
Sm = 0;
D = 0;
ee = exp(-T/tau);
for n=2:1000
        Sm(n)=(alpha*D(n-1) + S0)*(1-ee) + ee*Sm(n-1);
        D(n) = k*(Sd - Sm(n)) + D(n-1);
        if (D(n) > 1)
                D(n) = 1;
        end;
        if (D(n) < 0.2)
                D(n) = 0.2;
        end;
end
```

When we use this to simulate the motor response, we get:





In your program for Lab 5, you will use a Real Time Interrupt with an 8 ms period. In the RTI interrupt service routine, you will measure the speed, and set the duty cycle based on the measured speed. Your ISR will look something like this:

```
void INTERRUPT rti_isr(void)
{
        Code to read potentiometer voltage and convert into RPM

        Code to measure speed Sm in RPM

        Code which sets duty cycle to

        DC = DC + k*(Sd-Sm)
        if (DC > 1.0) DC = 1.0;
        if (DC < 0.2) DC = 0.2;
        Code which writes the PWM Duty Cycle Register to generate duty cycle DC.
        Code which clears RTI flag

}
```

In the main program, you will print the measured speed, desired speed, and duty cycle to the screen.

Your values of k will probably be different than the values in these notes because speed vs. duty cycle, time constant, and maximum speed will most likely be different than the values I used.

Using Floating Point Numbers with the Gnu C Compiler
It will be much easier to do the necessary calculations by using floating point numbers. Here is an example of a program which uses floating point:

```
#include "DBug12.h"
main()
{
        float x;
        x = 10.2;
        printf("x = %d\r\n",(short) x);
}
```

To use floating point numbers with the Gnu C compiler, go to the Options menu, Project options submenu, and add -fshort-double to the list of compiler options: