LAB #9: SPEED CONTROL OF A D.C. MOTOR SENSING MOTOR SPEED VIA TACH FREQUENCY

INTRODUCTION

Precise control of the speed of a D.C. motor requires that one be able to accurately measure the speed so that corrective action can be taken if the speed is not the desired value. The D.C. motor used in this lab contains a tachometer that produces a sinusoidal signal as the motor rotates. The frequency of this sinusoidal waveform is proportional to the speed of the motor. The objective of this week's lab is to convert the signal produced by the motor's tachometer to a voltage whose value is proportional to motor speed. This will be done by converting the tachometer signal to a digital square wave, and then measuring its period with one of our timer/counter channels.

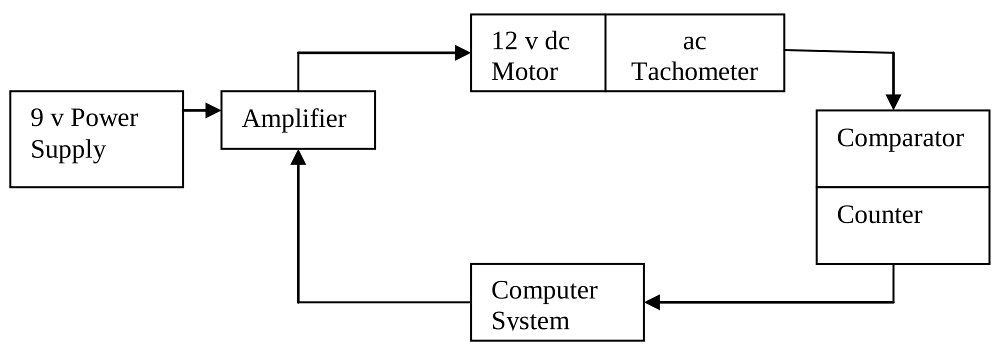

Figure 9.1. D.C. Motor Speed Controller Block Diagram

TACHOMETER/ENCODER

A tachometer is a device that generates a periodic electrical signal whose frequency and/or amplitude is proportional to the speed of the motor in which it is installed. Therefore, motor speed is "encoded" in the frequency/amplitude of this signal. Figures 9-1 and 9-2 illustrate the operation of a variable-reluctance magnetic pickup and an optical encoder, respectively. Figure 9-3 shows the Buehler 12v DC motor and AC tachometer.

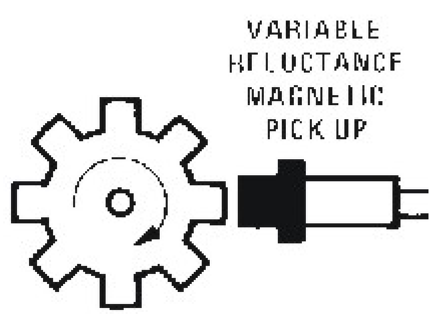

Figure 9-1. Variable-reluctance, magnetic pickup tachometer

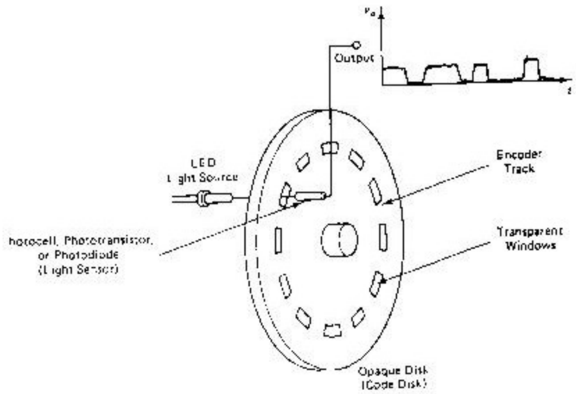

Figure 9-2 Optical encoder

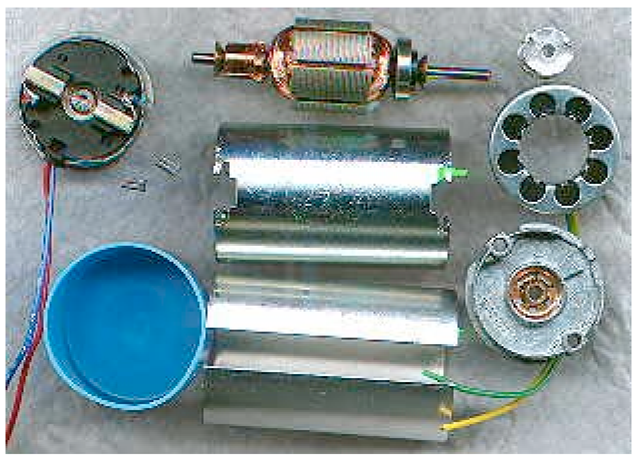

Figure 9-3 Buehler 12v DC motor windings and tachometer

In the Buehler motor used in the lab, the AC tachometer comprises a separate winding, or "pickup coil", that senses the magnetic field at one end of the motor rotor. The frequency and amplitude of the voltage induced in this coil are proportional to the rotational speed of the motor. Therefore, measuring the speed of the motor requires measuring either the frequency or amplitude of the tachometer output signal.

COMPARATOR CIRCUITS

A comparator can be used to convert the sinusoidal waveform generated by the tachometer described above to a simple square wave. This square wave can, in turn, control a binary counter to measure the frequency or period of the signal. To measure frequency, the signal should drive the clock input of a binary counter circuit, to increment/decrement the counter once per period of the tachometer signal. To measure period, a binary counter with a separate clock source (CLK) would be used. In this case, the counter should be enabled for one period of the tachometer signal. The number of times the counter is decremented by CLK during this period is a measure of the duration of the period of the tachometer signal.

A number of operational amplifier circuits have been designed for use as "comparators". As illustrated in Figure 9.4, a comparator has two voltage inputs, V1 and V2, and produces one voltage level on Vout whenever V1 > V2, and a second voltage level on Vout whenever V1 < V2. The two voltage levels represent saturated conditions in the comparator, and will generally be equal to the power supply rails on the circuit.

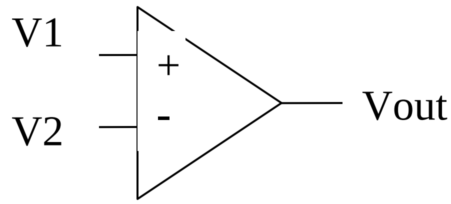

Figure 9.4. Basic Voltage Comparator

The comparator to be used in this lab is the National Semiconductor LM311 Voltage Comparator. Its data sheet is linked to the course web site. Figure 9.5 shows the pin functions on the LM311 DIP package.

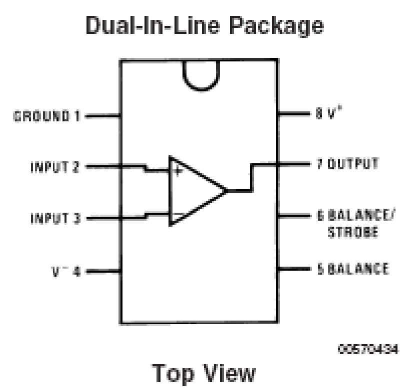

Figure 9.5 LM311 Voltage Comparator Package[1]

In our application, we can convert the tachometer signal, V_{signal}, to a square wave by comparing the voltage level of V_{signal} to that of a reference value, $V_{reference}$, where $V_{reference}$ is some value between the minimum and maximum levels of V_{signal}. By connecting V_{signal} and $V_{reference}$ to the plus and minus inputs of the comparator, respectively, the comparator output will be high when $V_{signal} > V_{reference}$ and low when $V_{signal} < V_{reference}$.

If the tachometer output is symmetric around 0 volts, as is the case with the tachometer in the Buehler motor, then $V_{reference}$ for the comparator can be simply be 0 volts (ground).

If the tachometer output has a D.C. bias, around which the signal is symmetrical, then there are two alternative configurations that can be used to provide the reference voltage. One is to provide a low-pass filter to the output of the tachometer, removing the time-varying signal and passing the bias value. This bias value can then be used as the

[1] LM111/LM211/LM311 Voltage Comparator Data Sheet, National Semiconductor Corp., 2004 (DS005704)

reference input $V_{reference}$ and compared to the tachometer signal, $V_{signal.}$ The second alternative is to filter out the DC component of the tachometer signal with a high pass filter, producing a waveform symmetric around 0 volts. In this case, the value of $V_{reference}$ for the comparator can be 0 volts (ground).

In our application the two "balance" pins on the comparator package (Balance and Balance/Strobe) should simply be shorted together. The positive power supply pin should be connected to our +5v supply. The negative power supply pin, V-, can be connected to ground, along with the GND pin.

However, if the second alternative is used above, allowing the signal voltage to be both positive and negative, then V- should be connected to -5v. The LM311 output is open collector. Therefore, a pull-up resistor in the range 1K-10K should be connected between that pin and +5v.

FREQUENCY MEASUREMENT

Given that there are only 8 pulses produced by the tachometers on the Buehler motors per revolution of the motor, the frequency of the tachometer signal will be difficult to measure with acceptable resolution at the sampling rates required for subsequent experiments. <u>Therefore, the "period-measurement" procedure should be used.</u>

Refer to class slides for description of using the HCS12 timer "input capture mode" to measure period. Since we are using 7 of the Port T pins for the keypad, you should use the remaining Port T pin to capture the signal from the comparator.

HARDWARE AND SOFTWARE DESIGN

The hardware for this lab requires the addition of the LM311 comparator to the previous lab setup, along with either a constant source or potentiometer to set the reference voltage. If there is a DC bias in the tachometer signal, then a high pass filter will be needed to remove it. **The LM311 comparators will be provided in lab.** There will be a variety of resistors and capacitors available in the lab in the event that your computed values do not produce acceptable results. As before, each team must have a hardware design and components ready to wire and a test at the start of lab, so that lab time can be used for construction and testing.

Prior to building the circuit, it is recommended that you model and simulate the circuit in PSPICE, to verify the circuit and your choice of component values. In this simulation, model the tachometer as a "VSTIM" (voltage stimulus) source, and select the LM111 comparator component (same as LM311, except for rated temperature range.) Verify that the comparator output is a square wave with frequency equal to that of the tachometer signal.

After constructing the circuit, use the oscilloscope to ensure that the comparator inputs and output match the signals in your simulation. Then connect it to your Port T pin.

The software from the previous lab should then be modified to enable the HCS12 input capture mode to measure the period of the waveform.

NOTE: Circuits can be destroyed during these tests, just as easily as in the previous weeks! This chip can be protected by continuing to practice careful design and by observing the guidelines given in the previous lab write-ups.

LABORATORY EXPERIMENTS

1. Prior to the start of lab, it is recommended that you design, model and simulate your comparator circuit in PSPICE, verifying that the circuit produces a square wave with frequency equal to that of the tachometer signal.

2. As before, you will need to design experiments to test your hardware. Prior to the lab, design and write a test procedure in your lab books, as well as entering any component calculations.

3. During the lab period, be sure to document each experiment in your lab notebook, and summarize the most significant ones in your report.

4. Construct the comparator circuit and test it prior to connecting it to the microcontroller. Verify that the circuit produces the desired square wave frequencies over the entire range of motor speeds. (Plot the tachometer output and square wave on the oscilloscope.)

   If you wish to test your comparator circuit without the motor, you may use one of the EEboard arbitrary waveform generators (AWGs), in the ANALOG block at the bottom of the board. These are set up and controlled via the *Waveforms* WaveGen instrument.

5. Connect the tachometer signal to the microcontroller and run your application program, measuring the tachometer signal period for each of the seven switch-selectable speeds over the motor's operating range. **Plot the period as a function of the duty cycle of the PWM signal used to drive the motor at these different speeds, relating observed speed to the timer control parameter(s) used in the control program.**

LABORATORY REPORT

1. Briefly describe the circuit (but not “wire by wire”) and attach a circuit diagram. If you made changes to the test program from that used in the previous week, you should describe the changes and attach a copy of the revised program. Make sure your program includes descriptive comments.

2. Discuss your results, including plots of comparator output frequency vs. measured speed, and measured tachometer signal period vs. PWM signal duty cycle.