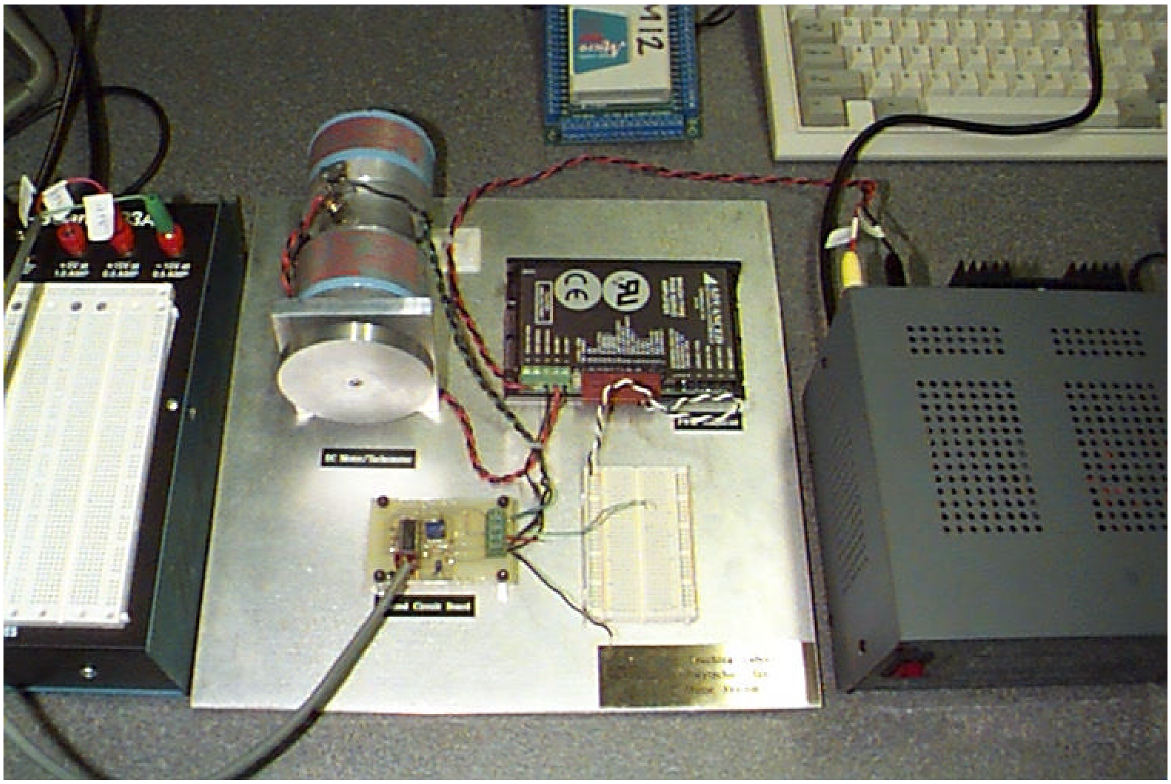
Mechatronics Lab Procedure:
DC Motor / Tachometer Closed-Loop Speed Control System



1. CAUTIONS

EXERCISE CAUTION DURING MAINTENANCE AND OPERATION !!
POTENTIALLY LETHAL VOLTAGES EXIST WITHIN THE POWER AMPLIFIER AND AUXILIARY ASSEMBLIES.

DO NOT SPIN THE MOTOR WITHOUT POWER.

DO NOT STALL THE MOTOR.

DO NOT SHORT THE MOTOR AT A HIGH SPEED.

DO NOT REVERSE THE POWER SUPPLY LEADS.

2. Assembly Instructions

1. Face the DC Motor system on a table such that the motor pulley faces you and the tags are all legible.
2. With the power supply off, connect the red, green and black connector group to the +15 volt, -15volt and ground, respectively, on the power supply.
3. With the power supply off, connect the black and red connectors to the rear of the EMCO power supply, red to the +24 volt (red) terminal and black to the ground (black) terminal.
4. DO NOT TURN THE POWER SUPPLIES ON UNTIL A PROPER COMMAND IS PLACED ON THE **REF IN** INPUT TO THE POWER AMPLIFIER.

3. Open-Loop Frequency Response Experiment

The goal of this experiment is to generate the frequency response from the amplifier command voltage **(REF IN)** to the tachometer voltage output. Read the entire experiment procedure before conducting the experiment.

1. Using the oscilloscope and a function generator, create a sine wave signal at 0.1 Hz with an amplitude of 0.5 volts peak-to-peak. Using the DC offset on the function generator, bias the signal by 0.5 volts.
2. Connect the high side of the function generator output to the white wire on the (+ **REF IN**) input of the black power amplifier, connect the low side to the black wire (- **REF IN**).
3. Connect an oscilloscope probe to the tachometer terminals, the black tachometer lead is ground, the green wire is the tachometer signal relative to ground.
4. The output of the function generator should also be connected to another channel of the oscilloscope so that both the input and output signals can be measured.
5. Turn on the 24-volt EMCO power supply.
6. If the motor begins to spin very quickly, or if the motor makes a high-pitched noise, turn off the 24-volt supply. Check your wiring and if all seems correct go to the troubleshooting section of this manual.
7. The motor should be turning constantly in one direction, and speeding up and slowing down at 0.1 Hz (once every 10 seconds).
8. Measure the magnitude of both the input and output signals, and the phase between the two signals.
9. The system gain at this frequency is the ratio of the output over the input voltage signals. The phase difference is the measured phase between the signals.
10. Increase the frequency of the function generator and make gain and phase measurements at each point. The frequencies should be selected to give a good picture of system response between 0.1 Hz and 100 Hz, i.e., look at 0.1, 0.5, 1, 5, 10, 20, 50 and 100 Hz.
11. The results of this experiment can be plotted as a function of frequency on a log-log scale to give a picture of the open-loop frequency response.
12. When you have finished the measurements, power down the 24-volt EMCO power supply, then the function generator, and then the (+15,-15) volt supply.

4. Open-Loop Time Response Experiment

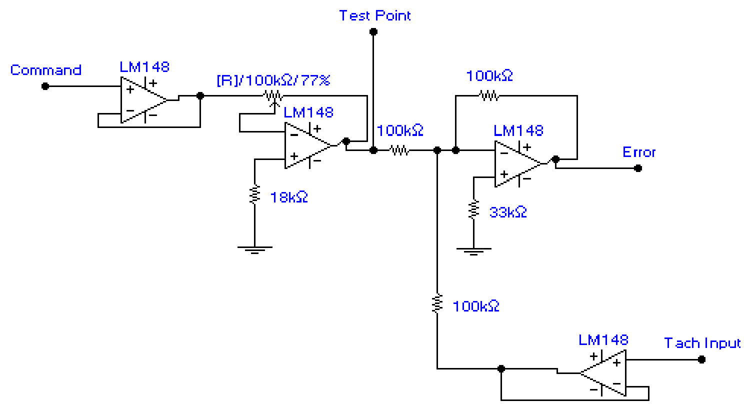
The goal of this experiment is to generate the tachometer response to a step command voltage applied to the amplifier. Read the entire experiment procedure before conducting the experiment.

1. Using the oscilloscope and a function generator, create a square wave signal at 0.1 Hz with an amplitude of 0.5 volts peak-to-peak. Using the DC offset on the function generator, bias the signal by 0.5 volts.
2. Turn on the (+15,-15) volt power supply.
3. Connect the high side of the function generator output to the white lead on the (+ **REF IN**) input of the black power amplifier, connect the low side to the black wire (- **REF IN**).
4. Connect an oscilloscope probe to the tachometer terminals, the black tachometer lead is ground, the green wire is the tachometer signal relative to ground.
5. The output of the function generator should also be connected to another channel of the oscilloscope so that both the input and output signals can be measured.
6. Turn on the 24-volt EMCO power supply.
7. If the motor begins to spin very quickly, or if the motor makes a high pitched noise, turn off the 24-volt supply. Check your wiring and if all seems correct go to the troubleshooting section of this manual.
8. The motor should be turning constantly in one direction, and speeding up and slowing down at 0.1 Hz (once every 10 seconds).
9. The step response is the tachometer response signal seen on the oscilloscope.
10. The time to 63% of the steady-state value of the step response is the time constant of the system, if we assume a first-order model. Use the cursors to measure this value.
11. The DC gain of the system can be found by taking the ratio of the peak-to-peak output tachometer voltage to the peak-to-peak input voltage signal.
12. Make note of any difference between the steady-state levels of the command and the response.
13. When you have finished the measurements, power down the 24-volt EMCO power supply, then the function generator, and then the (+15,-15) volt supply.

5. Compensator Implementation

The goal of this section is to guide you through the construction and implementation of a compensator using the equipment provided with the DC motor/ Tachometer system.

The printed circuit board consists of the command scaling and feedback summation circuit shown schematically below.

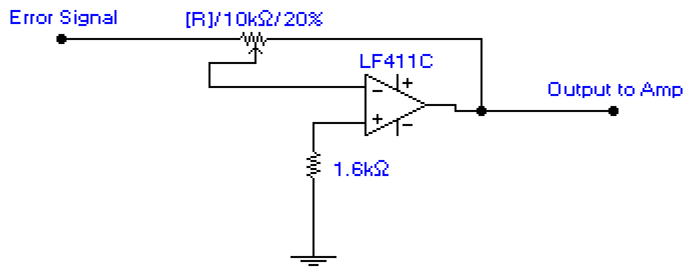


Command Scaling and Feedback Circuit

The green screw terminals on the printed circuit board allow access to the inputs and outputs of the summing circuit. They are labeled from top to bottom as: **tachometer in**, **error**, **command**, and **ground**. The board comes from the factory with the green tachometer lead connected to the **tachometer in** terminal, and the black lead from the tachometer connected to the **ground** signal. The **command** terminal is where the speed command input signal is applied. This signal is scaled by a factor of 0.3 and differentially summed with the **tachometer** signal to produce the **error** signal.

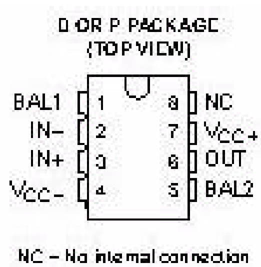
1. The first step is to verify the command scaling factor of 0.3. Connect the red, green and black connector group to the (+15,-15) volt power supply. Turn the supply on.
2. Using the oscilloscope, set the function generator to produce a 5 Hz sine wave with a peak-to-peak amplitude of 1 volt.
3. Connect the high-side output of the function generator to the command input on the green terminal block. Connect the low-side output of the function generator to ground.
4. Measure the signal at the pin marked **Test Point** on the printed circuit board using the oscilloscope.
5. Adjust the blue potentiometer (**Adjustment Potentiometer**) using a small screwdriver until the peak-to-peak voltage of the **Test Point** signal is 0.3 volts.
6. The command scaling gain has now been set.
7. Turn off the (+15, -15) volt power supply.

The next step is to implement the compensator design. An example compensator, a simple proportional controller, is used to illustrate this process. The circuit diagram of the proposed compensator is shown below.



Proportional Controller Schematic

1. Place the LF 411C operational amplifier in the protoboard provided (to the right of the command scaling and feedback summation circuit).
2. The pinout for the LF 411C is shown below. With the power supply off, connect +15 V and -15V to the **VCC+** (pin 7) and **VCC-** (pin 4) pins of the amplifier, respectively.
3. Connect a 1.6 kΩ resistor from **IN+** (pin 3) to **ground.**
4. Connect the right leg of a 10 kΩ potentiometer to the operational amplifier **output** (pin 6).
5. Connect the wiper of the potentiometer to the **IN-** (pin 2).



Pinout of LF 411C Operational Amplifier

We will now set the gain of the proportional compensator, e.g., a gain of 5.

1. Using the oscilloscope, set the function generator to produce a 5 Hz sine wave with a peak-to-peak amplitude of 1 volt.
2. Turn on the (+15, -15) volt power supply.
3. Connect the high-side output of the function generator to the left leg of the 10 kΩ potentiometer. Connect the low-side output of the function generator to ground.
4. Measure the signal at the **output** of the operational amplifier (pin 6) using the oscilloscope.
5. Adjust the 10 kΩ potentiometer until the peak-to-peak voltage of the **output** signal is 5 volts.

6. The proportional gain has now been set to 5.
7. Turn off the (+15, -15) volt power supply. Disconnect the function generator.
8. Connect the left leg of the 10 kΩ potentiometer to the **error** signal on the green terminal block.
9. Connect the **output** of the operational amplifier (pin 6) to the white wire that leads to the **+ REF IN** input on the power amplifier. Connect the black wire that leads to the **- REF IN** input on the power amplifier to ground.
10. The feedback loop has now been closed.

We will now set the command to the motor and run the system.

1. Using the oscilloscope, set the function generator to produce a 5 Hz sine wave with a peak-to-peak amplitude of 3 volt. Using the DC bias on the function generator, add a -6 volt offset to this command signal.
2. Turn on the (+15, -15) volt power supply.
3. Connect the high-side output of the function generator to the **command** on the green terminal block. Connect the low-side output of the function generator to ground.
4. Connect one of the channels of the oscilloscope across the terminals of the tachometer.
5. Connect a second channel of the oscilloscope to measure the **Test Point** on the printed circuit board. This is the negative of the scaled command voltage. Thus, if the oscilloscope is set to invert this signal, the tachometer signal should track this command during the closed-loop operation.
6. Connect the red and black connector from the power amplifier to the +24 volt (red terminal) and ground (black terminal) on the 24-volt EMCO power supply.
7. When you are ready to run the motor, turn on the EMCO power supply.
8. If the motor begins to spin very quickly, or if the motor makes a high pitched noise, turn off the 24-volt supply. Check your wiring and if all seems correct go to the troubleshooting section of this manual.
9. Change the frequency on the function generator, and note the response of the tachometer voltage.
10. When you have verified that the closed-loop system is operating properly, turn off the 24-volt EMCO power supply, then the function generator, and then the (+15, -15) volt power supply.
11. Proceed to section 6 to perform the experiments on the closed-loop system.

6. Closed-Loop Frequency Response Experiment

The goal of this experiment is to generate the frequency response from the control loop command voltage **(command)** to the tachometer voltage output. Read the entire experiment procedure before conducting the experiment.

1. Using the oscilloscope and a function generator, create a sine-wave signal at 1 Hz with an amplitude of 3 volt peak-to-peak. Using the DC offset on the function generator, bias the signal by -6 volts.
2. Turn on the (+15,-15) volt power supply.
3. Connect the high side of the function generator output to the **command** input on the green terminal block. Connect the low side of the output to ground.
4. Connect an oscilloscope probe to the tachometer terminals; the black tachometer lead is ground, the green wire is the tachometer signal relative to ground.
5. Connect a second channel of the oscilloscope to measure the **Test Point** on the printed circuit board. This is the negative of the scaled command voltage. Thus, if the oscilloscope is set to invert this signal, the tachometer signal should track this command during the closed-loop operation.
6. Turn on the 24-volt EMCO power supply.
7. If the motor begins to spin very quickly, or if the motor makes a high pitched noise, turn off the 24-volt supply. Check your wiring and if all seems correct go to the troubleshooting section of this manual.
8. The motor should be turning constantly in one direction, and speeding up and slowing down at 1 Hz (once every second).
9. Measure the magnitude of both the input and output signals, and the phase between the two signals.
10. The system gain at this frequency is the ratio of the output over the input voltage signals. The phase difference is the measured phase between the signals.
11. Increase the frequency of the function generator and make gain and phase measurements at each point. The frequencies should be selected to give a good picture of system response between 1 Hz and 200 Hz, i.e., look at 1, 5, 10, 20, 50, 70, 100 and 200 Hz.
12. The results of this experiment can be plotted as a function of frequency on a log-log scale to give a picture of the closed-loop frequency response.
13. When you have finished the measurements, power down the 24-volt EMCO power supply, then the function generator and then the (+15,-15) volt supply.

7. Closed-Loop Time Response Experiment

The goal of this experiment is to generate the tachometer response to a step command voltage applied to the **command** input on the green terminal block. Read the entire experiment procedure before conducting the experiment.

1. Using the oscilloscope and a function generator, create a square-wave signal at 1 Hz with an amplitude of 0.5 volt peak-to-peak. Using the DC offset on the function generator, bias the signal by -2 volts.
2. Turn on the (+15,-15) volt power supply.
3. Connect the high side of the function generator output to the **command** input on the green terminal block. Connect the low side of the output to ground.
4. Connect an oscilloscope probe to the tachometer terminals; the black tachometer lead is ground, the green wire is the tachometer signal relative to ground.
5. Connect a second channel of the oscilloscope to measure the **Test Point** on the printed circuit board. This is the negative of the scaled command voltage. Thus, if the oscilloscope is set to invert this signal, the tachometer signal should track this command during the closed-loop operation.
6. Turn on the 24-volt EMCO power supply.
7. If the motor begins to spin very quickly, or if the motor makes a high pitched noise, turn off the 24-volt supply. Check your wiring and if all seems correct go to the troubleshooting section of this manual.
8. The motor should be turning constantly in one direction, and speeding up and slowing down at 1 Hz (once every second).
9. The step response is the tachometer response signal seen on the oscilloscope.
10. The time to 63% of the steady-state value of the step response is the time constant of the system, if we assume a first-order model. Use the cursors to measure this value.
11. The DC gain of the system can be found by taking the ratio of the peak-to-peak output tachometer voltage to the peak-to-peak input voltage signal.
12. Make note of any difference between the steady-state levels of the command and the response.
13. When you have finished the measurements, power down the 24-volt EMCO power supply. Then turn off the function generator. Then turn off the (+15,-15) volt supply.

8. Troubleshooting

If the motor begins to spin very quickly, or if the motor makes a high pitched noise, turn off the 24-volt supply. Check your wiring to make sure it is not a simple mistake.

Q: How do I reset the PWM Amplifier to the factory settings?

A: The factory settings are:

1. Pot 1, the LOOP GAIN potentiometer, is turned all the way down (CCW) until a clicking is heard.
2. Pot 2, the CURR LIMIT potentiometer, is turned halfway through its setting. This is 7 turns from either extreme.
3. Pot 3, the REF IN GAIN potentiometer, is turned all the way up (CW) until a clicking is heard.
4. The four switches are set (from left to right): on, off, off, off. This puts the amplifier in "Voltage Mode" so that it will follow a voltage command.

Q: What if we hear a high-pitched noise?

A: High-pitched noise could be caused by a number of problems:

- The control gain could be set too high causing excessive voltages and/or currents to be applied across the motor terminals. This problem can be corrected by turning down the controller gain. The nonlinear simulation of the system can be used to avoid this problem.
- The tachometer signal may be very noisy. In this case the compensator could be amplifying the sensor noise and saturating the amplifier. A low-pass filter on the tachometer signal may be needed to provide a suitable feedback signal for control.

Q: What if the motor does not move when we turn on the +24-volt EMCO power supply?

A: Make sure the (+15, -15) volt power supply is also turned on. Make sure there is an appropriate signal (not ground) being applied to the **+ REF IN** input to the power amplifier.

Q: What if the motor spins uncontrollably when we turn on the +24-volt EMCO power supply?

A: Make sure the (+15, -15) volt power supply is also turned on. Make sure there is an appropriately scaled signal being applied to the **+ REF IN** input to the power amplifier.