Negative feedback: Servo Control

Introduction

Feedback, which can be described as the making of adjustments to a system based on observing its output, is commonplace in electronics and elsewhere. Examples include a thermostat-controlled central heating system, the automatic frequency control that keeps a radio tuned to a particular station, and the act of balancing on one leg[1]. In each case there is an output whose difference from the desired value can be observed (temperature, quality of signal, angle from the vertical) and an input that has to be changed appropriately (boiler switch, resonant frequency, shift of weight). In electronics, most things from the familiar op-amp inverting amplifier onwards incorporate feedback. In this experiment you will construct a feedback system that controls the position of an electric motor, first in response to an electrical input and later in response to a light, and investigate how its behaviour depends on the strength of the feedback. You should discover what happens when the feedback is too weak, or too strong, or has the wrong sign.

1 The motor

Use Blutack to fix the geared motor on the bench so that the output shaft can rotate in a horizontal plane. Attach something to the shaft to enable you to keep track of

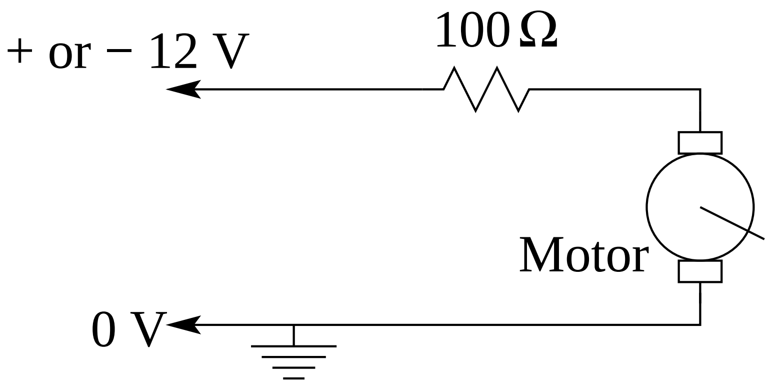

Figure 1: Motor connections

its position. Follow the motor wires, which emerge from the motor as a pair, and

[1] or indeed, two legs.

connect them, via a 100 Ω 1 watt resistor[2], to your power supply as shown in figure 1.

Check that the motor runs forwards and backwards, by applying positive and negative voltages. Its full range should be half a turn. Connect a voltmeter or oscilloscope across the resistor to measure a voltage from which you can calculate the current, both while the motor is moving and when it is stalled (stuck at one end of its range). Why is the stall current larger? Measuring the voltage across the motor itself may remind you. Attempt to drive the motor to a particular position by changing the sign of the drive voltage, as appropriate. Perhaps you will agree that this is not the most convenient control method.

Q Tipler 31.1

2 Voltage control

In this section you will use a control knob and amplifier to drive the motor. Ordinary potentiometers cannot handle the current that the motor needs, so a buffer amplifier will be necessary to increase the available current. Unfortunately, ordinary op-amps cannot provide sufficient current[3] either, so we use a high-powered op-amp, the L272. Build the circuit shown in figure 2. Note that the pinout of

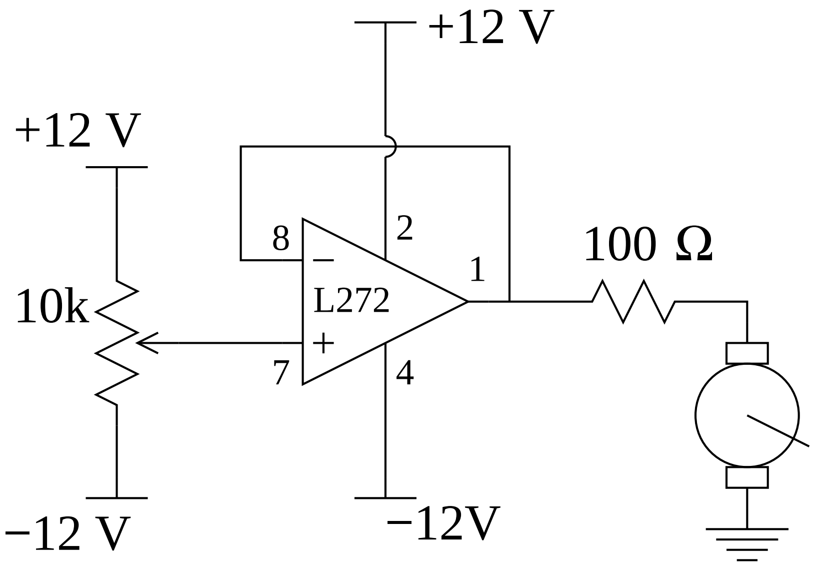

Figure 2: Voltage-controlled motor

the L272 deviates wildly from that of normal op-amps you may have used before.

[2]The resistor is large in size, to better cope with the heat it generates.
[3]Typical opamps can give only a few mA.

In figure 2, the power supply connections for the op-amp are shown explicitly. In future, we will sometimes follow the convention that they are not shown (but still have to be made).

Attempt to control the position of the motor using the potentiometer (usually called a "pot"). Use the two channels of the oscilloscope (dc coupled, 1 V/div, 1ms/div) to monitor the input and output voltage of the op-amp buffer (pins 7 and 1 of the op-amp). Adjust the pot up and down while watching the traces on the scope. You should find that the op-amp output voltage is an excellent reproduction of its input voltage, even though the position of the motor does not follow so well. In fact, the op-amp stage already has the benefit of negative feedback, via the wire connecting pin 1 to pin 8. Recall that in a properly designed circuit, the op-amp adjusts its output until the inputs have the same voltage. Why does this ensure that the output voltage follows the input in this circuit? **Q**

Horowitz & Hill, Chapter 3

To give an accurate reading of the position of the motor arm, the motor enclosure contains a second potentiometer that is directly coupled to the output shaft. The connections for this pot emerge from the motor as a ribbon of three wires. Connect the ends of this "motor" pot to the + and - 12 V supply in the same way as the 10 kΩ "control" pot in figure 2. The ends of the motor pot are connected to the wires on either side of the ribbon. Connect the moving contact of the motor pot (which **Q**

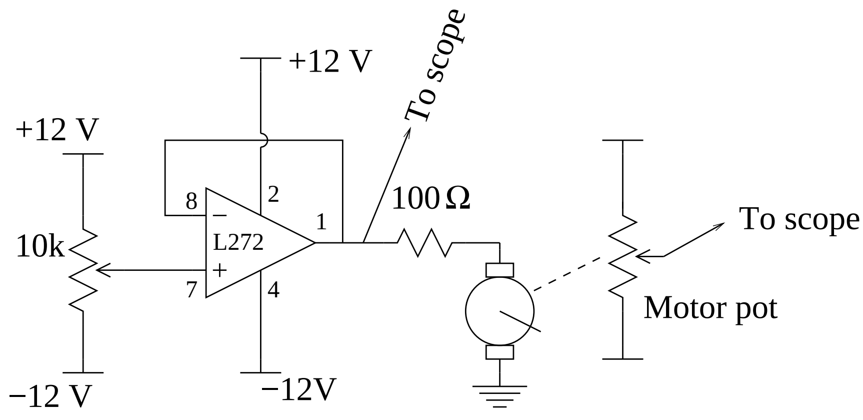

Figure 3: Adding the motor potentiometer. The **T** - shaped connections represent the + and - power supplies, even if sometimes the voltage labels are omitted.

is in the centre of the ribbon), to the scope probe that was previously connected to the control pot (see figure 3). You should now be able to see on the scope both the voltage applied to the motor and the position of the motor shaft. If you want to confirm that the motor pot reads out angular position, temporarily disconnect the motor wire from the op-amp (pin 1) and *gently* turn the motor by hand.

Investigate how well the motor position follows the motor voltage, as you oscillate the latter up and down by turning the control pot to and fro. Try both slow **Q** oscillations and as fast as you can manage. You will be running the scope timebase quite slowly to see this, so the MEM (memory) and possibly also SCROLL functions will be useful. Does the motor position lead or lag the setting of the motor voltage? Suggest two reasons for this. Hints: (i) what does the motor voltage actually control? (ii) what about inertia?

See the oscilloscope guide

Q

3 Position feedback

We mentioned before (section 2) that the power op-amp already has the benefit of feedback. Unfortunately, this feedback is of the motor voltage, which is not simply related to motor position. Add a TL081 op-amp to your circuit, connected to take

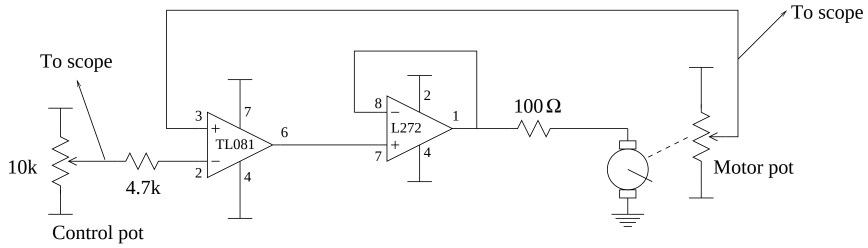

Figure 4: Adding position feedback. Note the different pinout of the TL081 op-amp.

the difference between the voltages produced by the motor pot and your contol pot, see figure 4. This should enable the motor shaft to follow the setting of the control pot fairly sensibly, probably with some small oscillations. If the motor just runs to one end of its range and sticks there ("latches up"), reverse the power supply connections at the ends of the motor pot. If you were lucky first time, temporarily reverse these connections to see how the other half lives. Why does the sense of the connections matter? The controllable state is one with *negative feedback*. The latched-up state has *positive feedback*: what in everyday language we call a vicious circle. **Q**

Discuss the difference with a demonstrator.

Use the scope to compare the signal from the control pot with the position read back by the motor pot (which might now better be described as the feedback pot). In particular, investigate how well the actual position follows the "target" position, when you make a step-like change in the latter. Sketch and comment on both waveforms. Why does the actual position overshoot its target? Then what happens? **Q** Move the scope probe from the control to the motor voltage to see what the op-amp is *trying* to do to the motor. You will get more precise results if you replace the control pot by a signal generator connected between ground and the 4.7k resistor, set to give (roughly) a 5 V, 0.5 Hz square wave.

4 Feedback gain control

The oscillations shown by the previous circuit arise from the over-reaction of the negative feedback circuit, in combination with the time lag in the system. In order

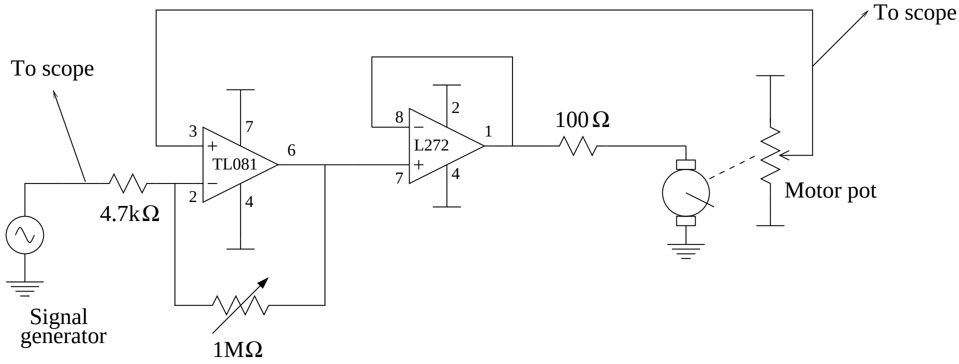

Figure 5: Negative feedback with gain control. The 1MΩ variable resistor is just a potentiometer with one end not connected.

to reduce the over-reaction, add to your circuit a 1MΩ variable resistor to act as a gain (amplification) control (see figure 5).

As the variable resistor is inserted and reduced in value, what happens to the gain by which the TL081 stage amplifies the signal from the motor pot? Investigate the effect of this on the settling time of the system, as you did previously. Sketch waveforms showing the different regimes of settling behaviour. How would you describe the regimes in the vocabulary of overdamped and underdamped resonant systems? What happens if the feedback is too weak, or too strong? **Q**

The equations of the feedback system closely parallel those of a damped harmonic oscillator. Tipler 14.4

5 Light-seeking robot

Rather than have the motor turn in response to a pot or a signal generator, it can follow other signals. Replace the signal generator in the circuit of figure 5 by a potential divider made from two light-dependent resistors (LDRs), as shown in the circuit fragment of figure 6. Mount the LDRs on the motor shaft, using Blutack or other ingenuity, and connect them using long wires to the circuit board. Does your system follow a torch? Explain how it works. What happens if the supply to the LDRs is reversed? How could you improve its performance? **Q**

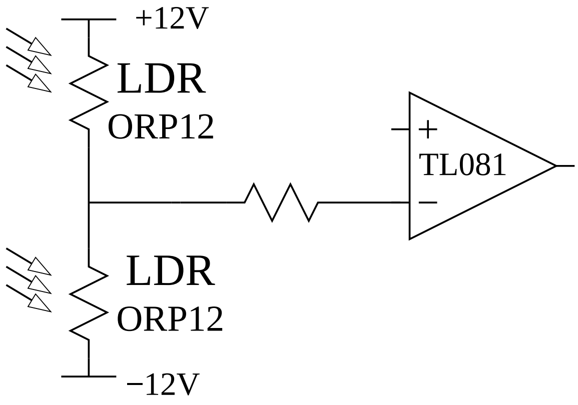

Figure 6: Control by light (circuit fragment — circuit is the same as figure 5 but with LDRs replacing the signal generator).

6 Checklist

Your lab book should contain:

- A *brief* explanation of what the experiment is about.
- All circuit diagrams, with explanations of the function of the parts.
- Description of all the behaviour you observed, with explanations and answers to questions in this manual, as prompted by the **Q** symbol.
- Labelled sketches of all waveforms and their relationships.
- A description of any changes you made, and the results.

MSC 2010-03-10