# Lab 9: Motor Feedback and Control

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**Abstract**

This lab further explores the electrical and mechanical domains, and qualitatively explores feedback and control systems. This study will lead to an introduction to second order systems in lab 10 that will use a feedback and control system to produce decaying oscillations similar to those found in some heaters, car shocks, airplanes, and earthquake proof skyscrapers.

## 1 Source-Meter

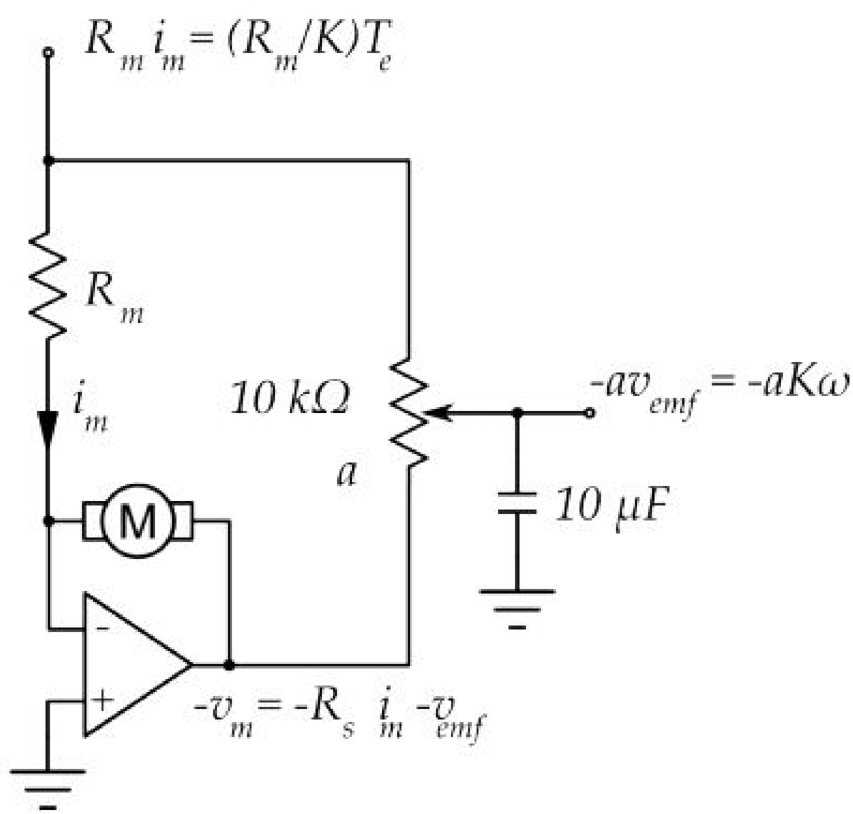


Figure 1: The Source-Meter

### 1.1 Circuit Analysis

Assuming $V_{out}$ =0 when the motor is stationary:

$$\frac{R_m}{R_s} = \frac{a}{1-a} \tag{1}$$

Now...

$$V_{out} = (1-a)\, Ri_p - Vemf - R_s i_m \tag{2}$$

but $i_p = \frac{V_{in} - V_{out}}{aR}$ so...

$$V_{out} = (1-a)\, R \frac{V_{in} - V_{out}}{aR} - Vemf - R_s \frac{V_{in}}{R_m} \tag{3}$$

$$V_{out} = \frac{1-a}{a} \left( V_{in} - V_{out} \right) - V_{emf} - V_{in} \frac{1-a}{a} \tag{4}$$

$$V_{out} = \frac{1-a}{a} \left( V_{in} - V_{out} - V_{in} \right) - V_{emf} \tag{5}$$

$$V_{out} = \frac{1-a}{a} \left( -V_{out} \right) - V_{emf} \tag{6}$$

$$V_{out} \frac{a}{1-a} = -V_{out} - V_{emf} \frac{a}{1-a} \tag{7}$$

$$V_{out} \left( \frac{a}{1-a} + \frac{1-a}{1-a} \right) = -V_{emf} \frac{a}{1-a} \tag{8}$$

$$V_{out} \frac{1}{1-a} = -V_{emf} \frac{a}{1-a} \tag{9}$$

$$V_{out} = -aV_{emf} \tag{10}$$

## 2 Why oh Why, Emily?

Why can't I get things to be on the correct page?
Is it due to some kind of rage
Held against me by this Works,
This thing they call Latex,
To keep me and my hopes and my words
From getting a plus and a check?

i'll just add lots of blank lines...

## 2.1 Horizontal Results

With only the source meter circuit, the motor won't spin on its own. I set up the motor and pendulum horizontally and spun it as smoothly as possible with my hand, obtaining the graph in Figure 2. Because pendulum was rotating in the horizontal plane, gravity had no affect on the rotational velocity. Thus the negative acceleration of the pendulum is relatively smooth and constant.

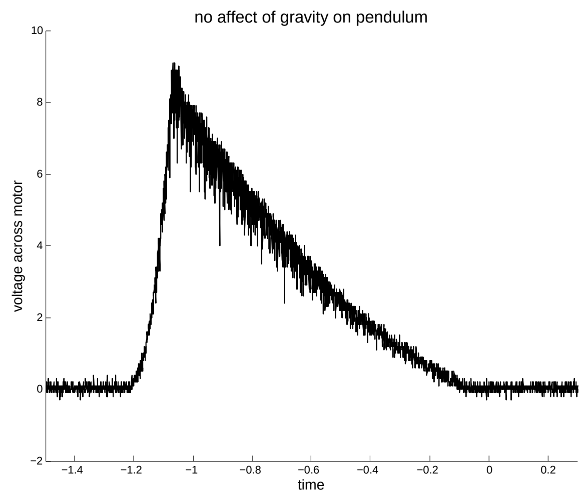


Figure 2: The smooth exponential decay seen here is due to negligible vertical forces acting on pendulum.

## 2.2 Vertical Results

The experiment was repeated with the motor secured vertically. The affect of gravity on the negative acceleration is obvious, seen as prominent bumps, or oscillations, in the decay of the curve in Figure 3.

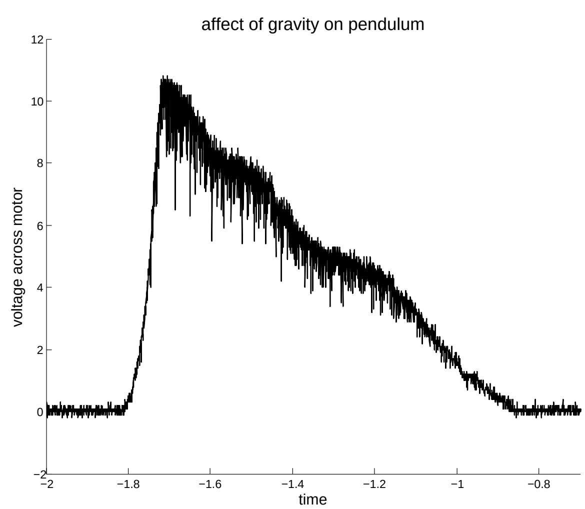


Figure 3: The oscillating decay seen here is due to the affect of gravity on the speed of the pendulum.

# 3 ControllerAnalysis

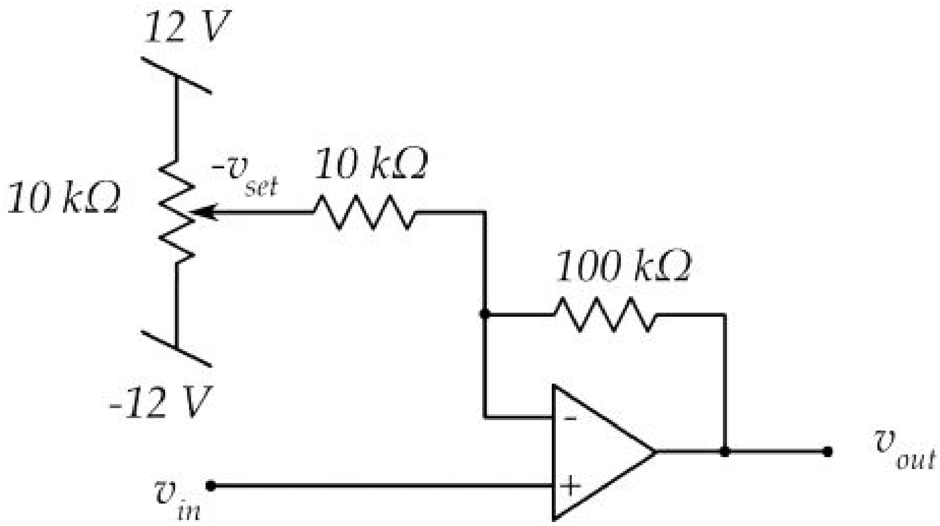


Figure 4: The Controller

assuming region I of the op amp:

$$\frac{V_{in} - V_{out}}{R_2} = \frac{-V_{set} - V_{in}}{R_1} \tag{11}$$

$$V_{in} - V_{out} = \frac{R_2}{R_1}\left(-V_{set} - Vin\right) \tag{12}$$

$$V_{out} = V_{in} + \frac{R_2}{R_1}\left(V_{set} + V_{in}\right) \tag{13}$$

or, substituting in $V_{out}$ from line 10 and substituting $K$ for $\frac{R_2}{R_1}$:

$$V_{out} = -aV_{emf} + K\left(V_{set} - aV_{emf}\right) \tag{14}$$

## 4 Open-Loop Control

The controller was added to the circuit and configured for open-loop control. This means the output of the source meter does not give feedback to the controller...yet. Here we see the shortcomings of an open-loop system. In section 5 we will see the vast improvements made by configuring a closed-loop system.

### 4.1 Friction

Figure 5 demonstrates the lack of feedback control in the open-loop configuration. Simply by placing a finger on the axle of the motor, enough friction is created to significantly effect the speed of the motor, with no attempt made by the control to maintain constant voltage.

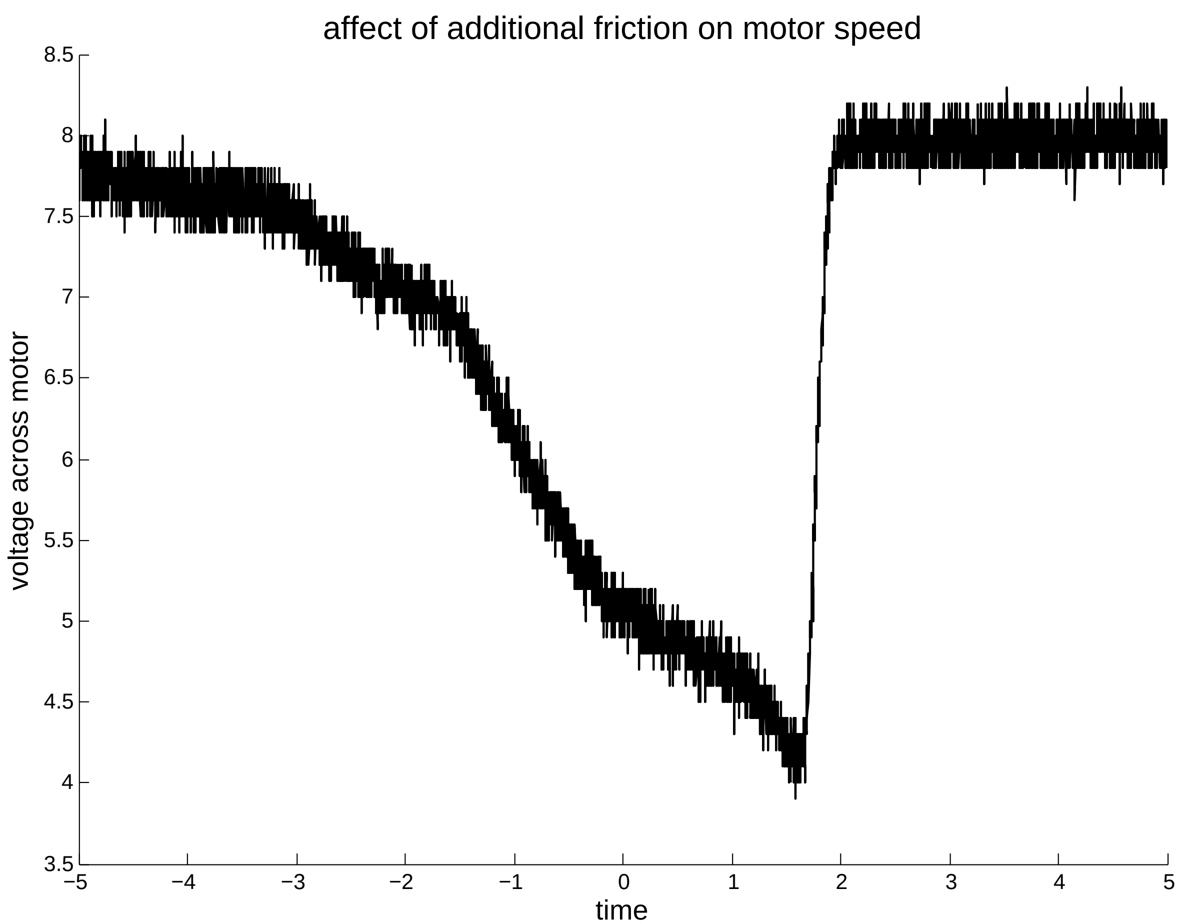


Figure 5: The affect of additional friction added to the shaft by placing a finger on the axle for a couple of seconds.

## 4.2 Gravity

In Figure 6 we can see the effect of gravity on the pendulum in the vertical plane.When the motion of the pendulum is opposite to the force of gravity, the voltage decreases in magnitude. Conversely, the voltage increases in magnitude when the pendulum is 'falling' with gravity. The result is sinusoidal.

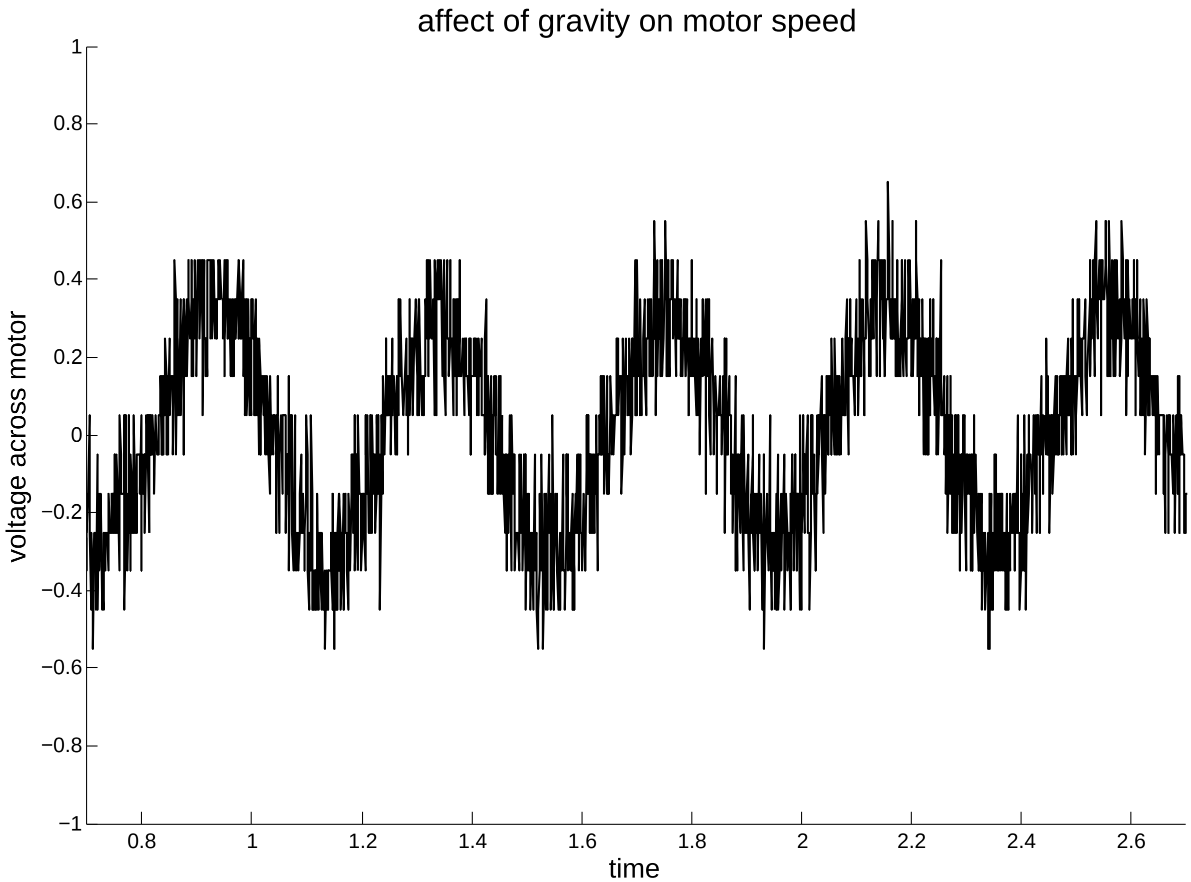


Figure 6: The rotational speed of the motor (proportional to $V_m$) oscillates in the presence of gravity.

### 4.3 Recovery Time

Grabbing the pendulum and then releasing it, seen in Figure 7, shows the slow response of the open-loop system in getting back up to speed.

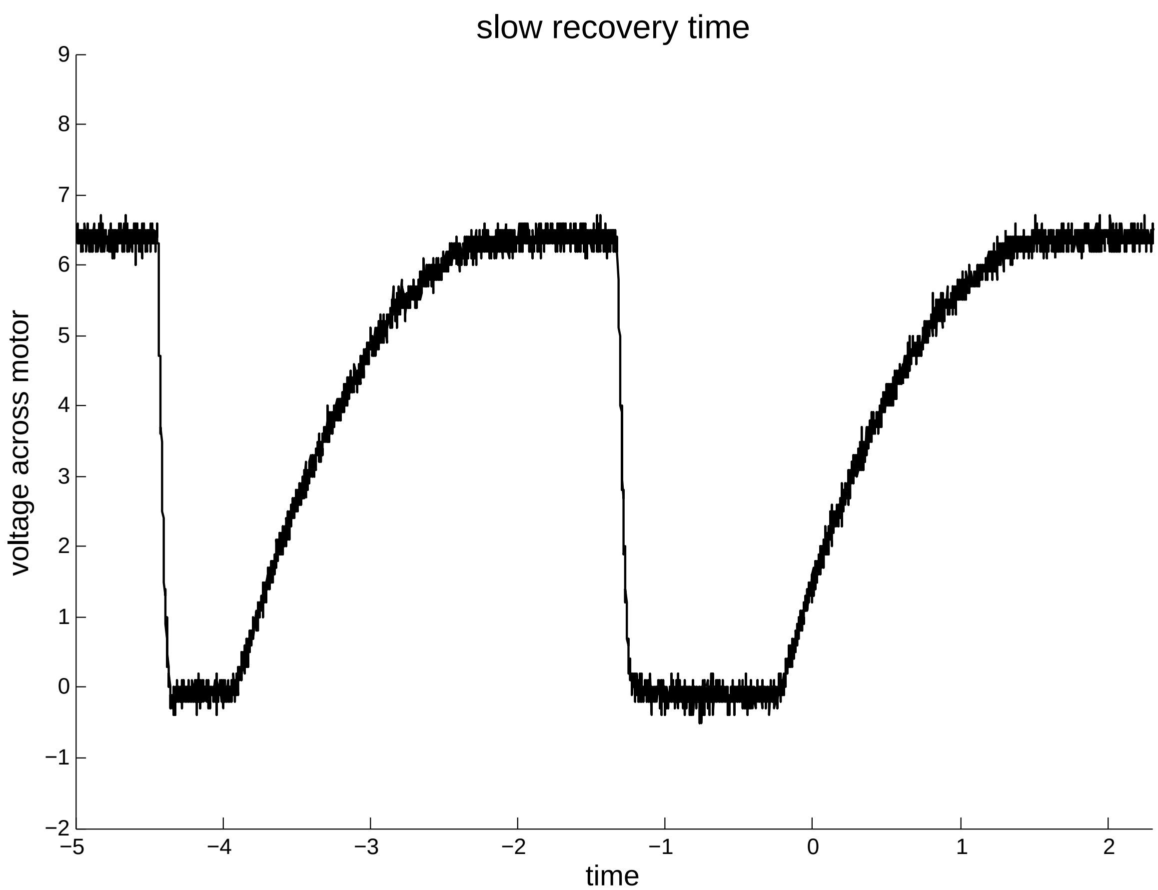


Figure 7: When disturbed, the motor accelerates slowly back up to speed.

# 5 Closed-Loop Control

With feedback now connected, the closed-loop system has the ability to respond to forces acting on the pendulum by adjusting $V_{set}$, which is proportional to the torque of the motor.

## 5.1 Gravity

Gravitational force is now countered by the control, which adjusts $V_{set}$ such that the torque of the motor maintains constant speed. Repeating the experiment from section 4.2 in Figure 8, below, shows how $V_{set}$ changes over time as the pendulum is acted upon by gravitational force.

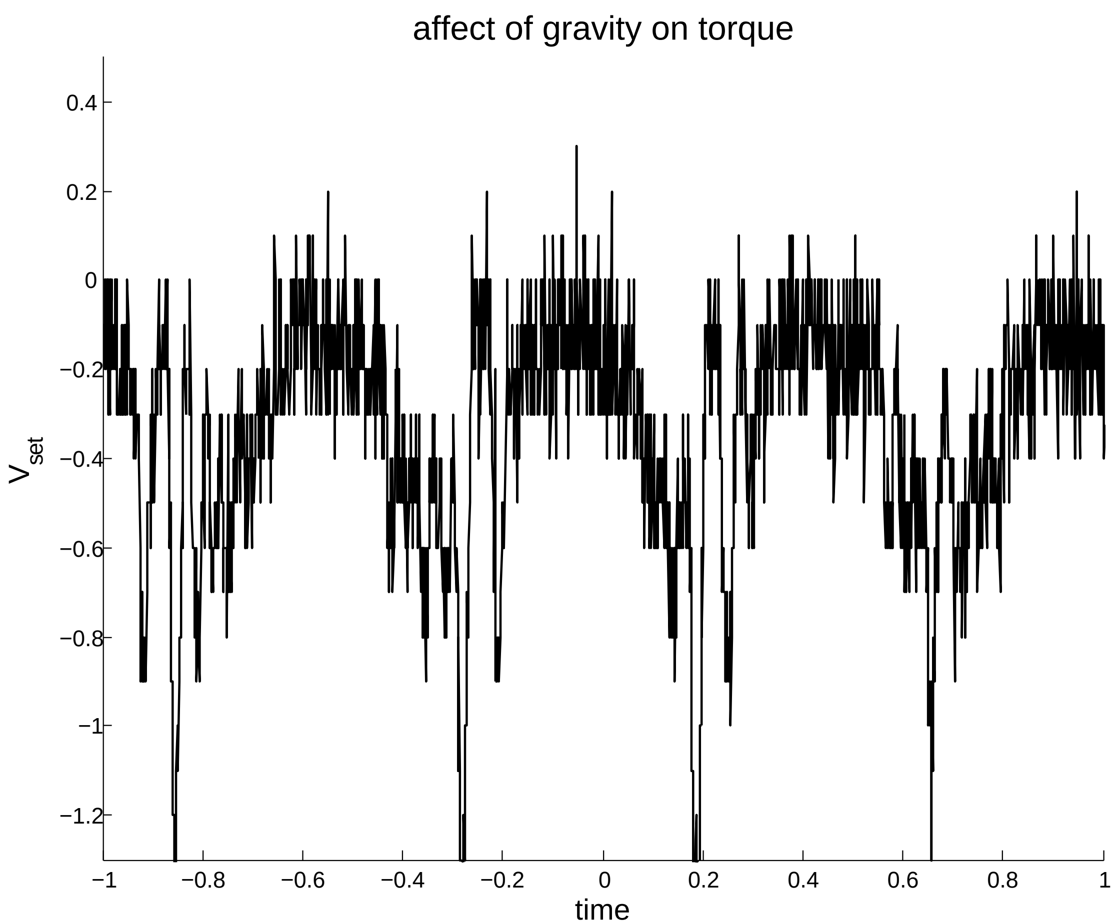


Figure 8: The torque of the motor (which is proportional to $V_{set}$ )oscillates in the presence of gravity in order to maintain constant roational speed.

### 5.2 Recovery

Repeating the experiment in section 4.3 yields the results in Figure 9. Recovery is significantly faster, however it is interesting to note the initial overshooting of $V_{set}$. This suggests second-order behavior, which I don't think I'm supposed to be seeing in this lab. But who the hell knows.

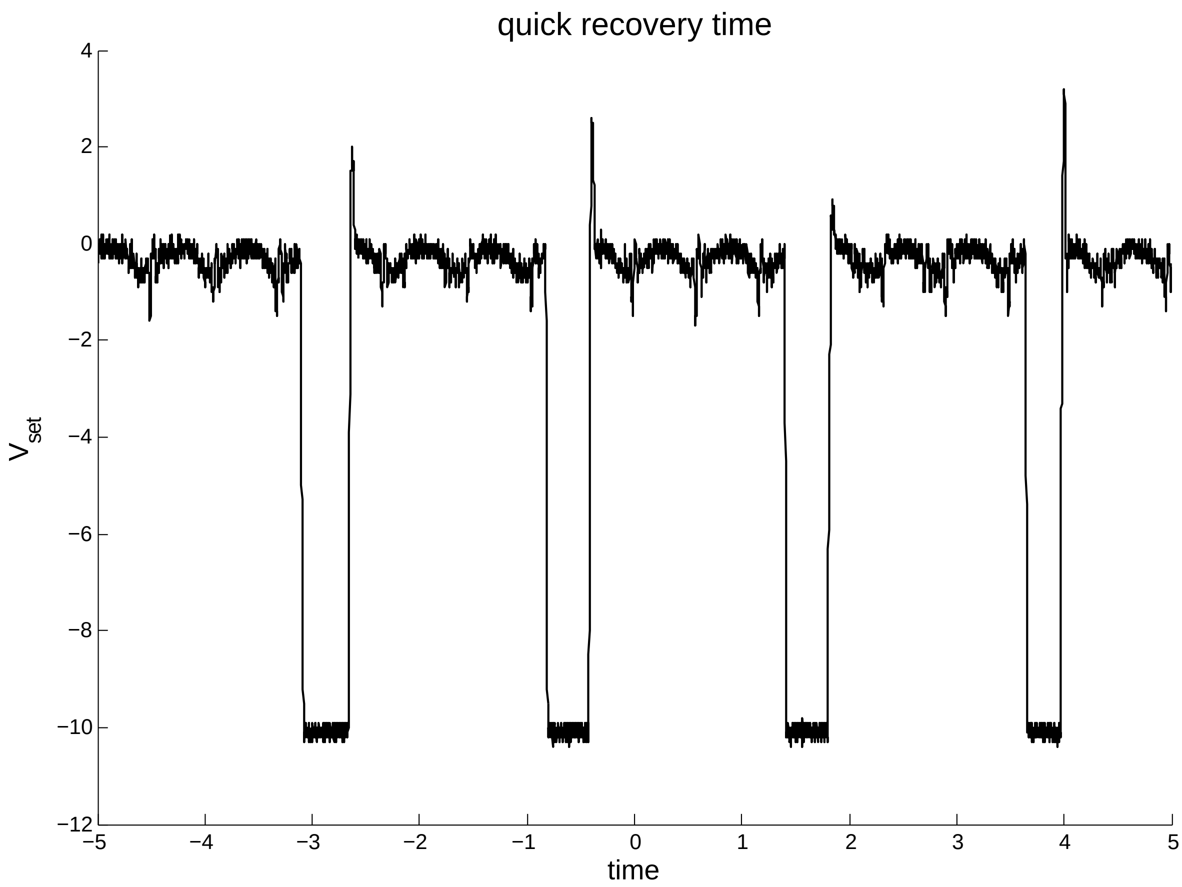


Figure 9: When disturbed, the motor accelerates quickly back up to normal speed.