Motors and Position Determination
Feedback is used to control position.

- Measure the position, subtract a function of it from the desired position and then use this resulting signal to drive the system towards the desired position. This is negative feedback.

- The natural frequencies of the feedback system are the “zeros” of $1 + G(s)H(s)$.
  - The total system is unstable if these “zeros” are in the right half plane (RHP).
  - With 180 degrees phase shift, “negative” feedback becomes “positive” feedback.
  - So we want these “zeros” to be in the left half plane (LHP).
  - Putting an integrator into $H(s)$ drives steady state error to zero.
  - But high order systems are more likely to have RHP zeros.
  - Time delay and high gain lead to RHP zeros.

\[
\frac{Y(s)}{X(s)} = \frac{H(s)}{1 + G(s)H(s)}
\]
We can control parts of the servo, but the system dynamics is often a part we can’t control.

- The system dynamics results from masses, springs, losses, etc.

Likely, we will implement servos as digital systems.

- Digital systems are more flexible to design.
  - They are more repeatable; they are not subject to gain drift.
  - We can use as many bits as we like so we can keep the computation noise small.

- Digital systems can have significant delays.
  - These delays are sometimes fixed, but are sometimes stochastic.
Voltage is proportional to position.

A linear or rotary potentiometer can be used.

Accuracy is limited to that of the potentiometer and the noise of the power supply voltage.

Two sinusoidal potentiometers are used.

\[ V_1 = V_0 \cos(\theta) \]
\[ V_2 = V_0 \sin(\theta) \]

This can also be done magnetically.

This is called a resolver and requires a complex analog signal detection. The computation can be done with either analog or digital circuitry.
Digital Position Measurement

- Sense light transmission to determine position.
  - Typically through a transparent sector
  - Gives a reading over a range of positions.
    - Depends on extent of transparent sector.
  - We may need a lot of sensors to determine multiple positions.

Diagram:
- Sensing Ring
- Opaque
- Transparent
- Light Source
- Photosensor
Typically, this is used for relatively low resolutions.

Here is a 4-bit (22.5 degree) resolution wheel. One source per sensor bit.

Can make these wider. Resolution is

\[
\frac{360^\circ}{2^N}
\]

Use a Gray code to eliminate chatter.
Two-Phase Encoder

- Two Source – Sensor Sets
  - Their position is offset by half the sector width.
  - This example has 30 degree sectors
  - and 15 degree resolution.
Use of Two-Phase Encoder

- This circuit generates:
  - An Up/Down signal depending on whether the motion is clockwise (CW) or counterclockwise (CCW).
  - A clk signal which rising edge is to operate the counter.
 waveform A and B are signals derived from sensors.
 Rotating one way, the rising edge of clk is when U/D is high.
 Rotating the other way, the rising edge of clk is when U/D is low.

\[
\begin{align*}
A \quad & B \\
\text{CLK} = A \cdot B \\
\overline{S} \\
\overline{R} \\
\text{CounterClockwise} \quad & U/\overline{D} \\
\text{Clockwise} \quad & U/\overline{D}
\end{align*}
\]
Another Way of Making an Encoder

- Use two sensors like the two-phase encoder but use only one ring and displace the sensors by $\frac{1}{2}$ band.

- Add another ring and a sensor to sense the “home” position.
Simple servomechanisms are made with DC motors.

- DC motor model is very simple:
  - It consists of a resistor in series with a voltage source.
  - The voltage source is proportional to the rotational speed.

- The mechanical system (controlled system) determines the speed as influenced by the torque.

\[ V = G \Omega + R I \]

Torque \( T = G I \)
Permanent Magnet DC Motors

- They are very commonly used.
  - The ‘Back Voltage’ is proportional to speed.
  - The torque is proportional to the current.

- **Servo Strategy:**
  - Command torque by setting current.
  - Measure the speed.

- **Running open loop:**
  - There is a ‘zero torque’ speed.
  - Torque is proportional to the difference from that speed.

\[ \Omega_0 = \frac{V}{G} \]

\[ T = \text{Constant} \]
Stepper Motors

- Digital Motors
  - Two ‘stacks’ (phases)
  - Usually biased by permanent magnets
  - Move a discrete distance per ‘step’.
  - This is an axial view cut through both of two sections.
Stepper Motor Windings

- Two distinct ‘phases’
  - May be driven as distinct windings.
  - Or may be driven as ‘bifilar’ windings.
  - Bifilar is easier but less efficient.

**Bipolar Winding**

**Unipolar (Bifilar Winding)**
Bipolar Winding

- Driven by ‘H-bridges’ of transistors
  - Can put current through windings in either direction.
  - But note that the upper transistor drive is tricky.
  - Uses all of the winding.
Bifilar Winding

- Driven by four transistors to ground.
  - Note that the center of the windings is held high.
- Transistors are between winding and ground.
- NPN bipolar transistors work well.
- Transistor drives are easily handled.

Unipolar Motor

\[ +V \quad N \]
\[ A^- \quad A^+ \quad B^- \quad B^+ \]

\[ I_{A^+} \]
\[ I_{A^-} \]
\[ I_{B^+} \]
\[ I_{B^-} \]
Motors Run in Either Direction

- **Current drive strategy:**

  **Bipolar Winding**

<table>
<thead>
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<th>Step</th>
<th>$I_A$</th>
<th>$I_B$</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>+</td>
<td>+</td>
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<tr>
<td>2</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

  **Counter-Clockwise**

  **Bifilar Winding**

<table>
<thead>
<tr>
<th>Step</th>
<th>$I_{A^+}$</th>
<th>$I_{A^-}$</th>
<th>$I_{B^+}$</th>
<th>$I_{B^-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Clockwise

Counter-Clockwise
Dynamics are Important

- Stepper can hold a certain torque.
- Stepper can carry more torque at low speed.
- At high speed, torque must be de-rated.
- Motors draw CURRENT! Make sure your power supply is adequate by measuring the power supply voltage with a 'scope.
  - Use an external supply, not the kit supply.
    - You don’t want motor drive noise in your digital circuit (or analog circuit).
- You need to make sure that devices can handle the current and torque.

Must sometimes ‘ramp up’ speed. Holding torque is limited by heating and by saturation.