4. Actuators

In this chapter we will do:

- Motor and Encoder
- H-Bridge
- Pulse-Width-Modulation (PWM)

• Actuators can be built in many different ways, most prominently:
  - electrical motors
  - pneumatics and valves.

• In this course we will only deal with electrical motors

4.1 Motor and Encoder

![Motor and Encoder Diagram]

Photos Faulhaber/Minimotor

**DC-Micromotors**
Precious Metal Commutation

<table>
<thead>
<tr>
<th>Series 2230</th>
<th>2230 F</th>
<th>060 S</th>
<th>064 S</th>
<th>065 S</th>
<th>065 S</th>
<th>068 S</th>
<th>068 S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque (in lbf-oz)</td>
<td>300</td>
<td>270</td>
<td>240</td>
<td>210</td>
<td>180</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>No load speed (rpm)</td>
<td>4000</td>
<td>3000</td>
<td>2500</td>
<td>2000</td>
<td>1500</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>Nominal efficiency (%)</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Stall current (A)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Stall torque (in lbf-oz)</td>
<td>500</td>
<td>450</td>
<td>400</td>
<td>350</td>
<td>300</td>
<td>250</td>
<td>200</td>
</tr>
<tr>
<td>Weight (oz)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Photos Faulhaber/Minimotor

Data Faulhaber/Minimotor
Motor and Encoder

- Motor speed determined by: supplied voltage
- Motor direction determined by: polarity of supplied voltage
- Difficult to generate analog power signal (1A ..10A) directly from microcontroller → external amplifier (pulse-width modulation)

• Encoder disk is turned once for each rotor revolution
• Encoder disk can be optical or magnetic
• Single detector can determine speed
• Dual detector can determine speed and direction
• Using gears on motor shaft increases encoder accuracy
4.2 H-Bridge

Allows a motor to be driven in both directions

- Drive forward:
  - Close 1 and 2
- Drive backward:
  - Close 3 and 4

Drive forward:
- Close 1 and 2

Drive backward:
- Close 3 and 4

H-Bridge

Hardware Implementation with Microcontroller:
- 2 Digital output pins from microcontroller, [one at Gnd, one at V_cc]
  feed into a power amplifier
- *Alternative:* use only 1 digital output pin plus one inverter, then feed into a power amplifier

4.3 Power Amplifier

PUSH-PULL FOUR CHANNEL DRIVER WITH DIODES

- GND
- 1.2A PEAK OUTPUT CURRENT (NON-REPEATING PER CHANNEL)
- ENABLE/FACILITY
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 15V
- HIGH-SIDE IMMUNITY
- Emitter clamp diodes

**Description**

The L293D is a monolithic integrated high voltage, four half-bridge driver designed to accept standard TTL or CMOS logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors and switching power transistors. To simplify use as two bridges in parallel channels, the outputs are designed to handle the maximum combined load current. A short-circuit protected logic allows operation at a low voltage and internal clamp diodes are included.

**Ordering Number:** L293D

This device is suitable for use in switching applications at frequencies up to 5 kHz. The L293D is assembled in a 16 lead plastic package which has 4 center pins connected together and one for bonding.
4.4 Pulse-Width Modulation

- A/D converters are used for reading analog sensor signals
- Why not use D/A converter for motor control?
  ⇒ Too expensive (needs power circuitry)
  ⇒ Better do it by software, switching power on/off in intervals
  ⇒ This is called “Pulse-Width Modulation” or PWM

Pulse-Width Modulation

- We do not change the supplied voltage
- Power is switched on/off at a certain pulse ratio matching the desired output power
- Signal has very high frequency (e.g. 20kHz)
- Motors are relatively slow to respond
  ⇒ The only thing that counts is the supplied power
  ⇒ Integral (Summation)
- Pulse-Width Ratio = $t_{on} / t_{period}$
Pulse-Width Modulation

- Now we are able to change the speed of a motor by varying the pulse-width ratio
- This can be done e.g. by linking a digital output of the controller to the power amplifier “enable” pin
- We can change the direction of the motor by setting the 2 inputs of the power amplifier (e.g. L293D) to logic {1, 0} or {0, 1} (e.g. using 2 digital outputs of the controller)
- This is “Open Loop Control”
- What is “Closed Loop control” (or short: “control”)?
  ⇒ Feedback! See next section.

4.5 Servos

- A servo is a unit combining motor and simple feedback electronics for position control
- A servo is set by supplying a PWM signal of a certain ratio
- Ratio determines servo position, not speed!
- Servos are usually used in model airplanes, etc.

Servos

- Servos usually have three cables: power, ground and PWM-signal
- Servos require a PWM signal with 50Hz frequency (20ms)
- The pulse should be between 0.5 ms and 2.0 ms long
  *this sets the servo to its extreme left or right position*

Remember:
- Servo speed cannot be set
  *servo tries to get to new position as fast as possible*
- Servos do not provide feedback to the outside
**Servos**

**Terminology:** Do not confuse “servos” with “servo motors”

DC motors (brushed or brushless) are also sometimes also referred to as “servo motors”

See: http://www.theproductfinder.com/motors/bruser.htm

“So when does a motor become a servo motor? There are certain design criteria that are desired when building a servo motor, which enable the motor to more adequately handle the demands placed on a closed loop system. First of all, servo systems need to rapidly respond to changes in speed and position, which require high acceleration and deceleration rates. This calls for extremely high intermittent torque. As you may know, torque is related to current in the brushed servo motor. So the designers need to keep in mind the ability of the motor to handle short bursts of very high current, which can be many times greater than the continuous current requirements. Another key characteristic of the brushed servo motor is a high torque to inertia ratio. This ratio is an important factor in determining motor responsiveness. Further, servo motors need to respond to small changes in the control signal. So the design requires reaction to small voltage variations.”

**Stepper Motors**

- Stepper motors are another kind of motors that do not require feedback
- A stepper motor can be incrementally driven, one step at a time, forward or backward
- Stepper motor characteristics are:
  - Number of steps per revolution (e.g. 200 steps per revolution = 1.8° per step)
  - Max. number of steps per second (“stepping rate” = max speed)
- Driving a stepper motor requires a **4 step switching sequence** for full-step mode
- Stepper motors can also be driven in **8 step switching sequence** for half-step mode (higher resolution)
- Step sequence can be very fast, the the resulting motion appears to be very smooth

**Full Step Sequence**

<table>
<thead>
<tr>
<th>Step</th>
<th>A</th>
<th>A'</th>
<th>B</th>
<th>B'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

Using two independent coils on motor shaft

Clockwise rotation: 1,2,3,4,1,2,3,4,...
Counterclockwise: 4,3,2,1,4,3,2,1,...

**Note:** In full step sequence, A is always negated to A' and B is always negated to B' (this is different for half-step sequence)

- Therefore it is sufficient to use only 2 control signals (the other 2 can be derived by NOT gates)

```
A
```

```
B
```

<table>
<thead>
<tr>
<th>Step</th>
<th>A</th>
<th>A'</th>
<th>B</th>
<th>B'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>
Stepper Motors

Advantages
• No feedback hardware required
• No H-Bridge hardware required

Disadvantages
• No feedback (!)
  Often feedback is still required,
  e.g. for precision reasons, since a stepper motor can “lose” a step signal.
• Requires 2 power amplifiers instead of 1

Other
• Driving software is different but not much more complicated
• Some controllers (e.g. M68332) support stepper motors in firmware (TPU)