Open loop positioning

Torque w/o current — "holding torque"

Stepper Motors

Gabriel Hugh Elkaim
Stepper Motors

- Different types of stepper motors
- Differences in Characteristics
- Stepper Drive Techniques
- Stepper Dynamics
- Snubbing for Stepper Motors
Permanent Magnet (PM) Stepper Motor

24 steps/rev (15°/step)
48 steps/rev (2.5°/step)
PM Stepper Motor Operation

1 → 3
2 → 4
3 → 1
4 → 2
Torque vs. Angular Displacement

Holding Torque

Static Torque

θm

Displace from Equilibrium

STEP ANGLE
Variable Reluctance (VR) Stepper Motor

- Rotor: Laminated Steel
- Magnetically Permeable
- Stator: Rotor/Stage

<table>
<thead>
<tr>
<th>PM</th>
<th>VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Torque</td>
<td>Low inertia, higher speed, high actuation</td>
</tr>
<tr>
<td>Defeat torque</td>
<td>Low inertia, higher speed, high actuation</td>
</tr>
</tbody>
</table>
Hybrid Stepper Motor

Good Parts & Both

Tooth structure gives high resolution
200 steps/rev
400 steps/rev

Gabriel Hugh Elkaim
Hybrid Rotor

Laminated core of silicon steel

Permanent magnet
Hybrid Rotor Offset Teeth
Fig. 2.74. Examples of $T/I$ characteristics: (a) a $1.8^\circ$ four-phase VR motor; and (b) a $1.8^\circ$ four-phase hybrid motor. (After Ref. [17].)
Stepper Motor Wiring

- 2 phase
  - 4 wires

- 3 phase
  - 6 wires

- 4 phase
  - 8 wires

- Universal drive

- 2 phase
  - 5 wires
  - Universal wind
Wiring Direction is Important

The diagram illustrates the concept of bipolar winding, where wires are connected in a specific direction to achieve a particular effect or function.
2-Phase Universal Wound vs. 4-Phase

a

b
Two Full N-BRIDGES / 4 Half N-BRIDGES

Driving Stepper Motors

Two phase bipolar wound
Stepper Sequences: Full Step
### Stepper Sequences: Full Step

#### Bipolar

<table>
<thead>
<tr>
<th>Step</th>
<th>Q1-Q4</th>
<th>Q2-Q3</th>
<th>Q5-Q8</th>
<th>Q6-Q7</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>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

CW Rotation

CCW Rotation

![Diagram of stepper motor and control circuit](image-url)
Stepper Sequences: Wave Drive
Stepper Sequences: **Wave Drive**

<table>
<thead>
<tr>
<th>Step</th>
<th>Q1-Q4</th>
<th>Q2-Q3</th>
<th>Q5-Q8</th>
<th>Q6-Q7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
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<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
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</tr>
<tr>
<td>4</td>
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<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

The diagram shows the connection of coils, where the highlighted coils are active at different steps. The direction of rotation is indicated by the arrow on the gear.
Stepper Sequences: **Half-Step**

*DOUBLE STEPS*

*TORQUE RIPPLE*
Stepper Sequences: Wave Drive

<table>
<thead>
<tr>
<th>Step</th>
<th>Q1-Q4</th>
<th>Q2-Q3</th>
<th>Q5-Q8</th>
<th>Q6-Q7</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>
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<tr>
<td>3</td>
<td>ON</td>
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<tr>
<td>4</td>
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<td>5</td>
<td>OFF</td>
<td>ON</td>
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<td>ON</td>
</tr>
<tr>
<td>6</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>7</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>8</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>
Stepper Sequences: Micro-stepping

100%
75\%
50\%
25\%

QRT Finer Motion

V+ 50\% Sine Wave

Gnd
Generating the Drive

PNSE Train

Logic Sequencer

Motor

N-bridge

SN 754402

DRV8814

2.8A

DIN 8811 ~ 2A

McFadzean

Uno 32
Stepping Dynamics

\[ \Delta \theta_s \]

Time

\[ \text{Forward} \]

\[ \text{Reverse} \]
Load Effects on Step Dynamics

No Load

Motor: PH326-01

X axis: A 0.5 ms/div.
B 20 ms/div.
Y axis: 0.9°/div.

Inertia Load 0.82 oz-in² (150 g-cm²)

Motor: PH326-01

X axis: A 0.5 ms/div.
B 20 ms/div.
Y axis: 0.9°/div.

Friction Load 6.95 oz-in (4.9 N-cm)
Drive Effects on Step Dynamics

Fig. 2.55. Difference in single-step response between the single-phase (a) and two-phase (b) excitation.
Stepper Motor Performance Curves

- Hold Torque
- Max Hold Torque
- Pull-in Range
- Run-out Torque
- Max Speed Torque
- Stepping Rate (MTRS)

106J

Gabriel Hugh Elkaim

CMPE 118/218 – Intro. to Mechatronics
Stepper Motor Current Dynamics

- Current
- Time
- High Force
- Low Force

Graph showing current and time with different force levels.
L/nR Drive (1.3)
L/nR Drive (2.3)
L/R Drive (3.3)

- Torque vs. Speed (PPS)
- Units: [N-cm] and [oz-in]
- Curves for different L/R ratios: L/4R, L/R, L/2R
- Comparison between pull-in and pull-out torques
2-Level Drive
Chopper Drive
Diode Snubber for H-bridge
Zener Snubber for H-bridge
Other Snubbing Alternatives (1.3)
Other Snubbing Alternatives (2.3)
Other Snubbing Alternatives (3.3)
Snubbing Techniques Compared (1.2)

- Diode Only
- Resistor + Diode
- Zener Only
- Diode + Zener
- No Snubber
Figure 6-5 Torque-speed curves of Oriental Motor PH266-01 stepping motor with no diode, diode + 150 ohm resistor and diode suppression circuits
Questions?
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Aidan Forrest, Brandon Lake, Christopher Villalpando Estrada
Garrett Deguchi, Michael Grimes, Taylor Gotfrid
Aaron Ramirez, Roger Berman, Sterling Dreyer
Announcements

Turn in MIDTERM!!
Horse Trading Rules

- You are allowed to swap one member of one team for one member of another team under the following conditions:

1. You have 24 hours to do this.
2. All members of both teams must agree to the swap.
3. One swap per team ONLY
Working w/ Teams

- Communicate
- Set meeting/go to those meetings
- Manage conflicts
  → Bring me in.
Join LinkedIn group

"Current and Former Skyllers"

First Group Assignment
Exchange your cell numbers.
P.D.R. on Thursday

Preliminary Design Review