Open loop Positioning

Torque w/o current — holding torque.

Stepper Motors

Gabriel Hugh Elkaim
Fall 2015
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 (7.5°/step)
PM Stepper Motor Operation

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

Static Torque

Knee

Mass is NOT Initial

Forward Displacement from Equilibrium
Variable Reluctance (VR) Stepper Motor

Rotor - laminated steel
Hydraulically pressed

Positive / slots

PM | VR
---|---
High Torque | Low Inertia
Detent | (Higher Speed)
Hybrid Stepper Motor

Good Parts of Both

Tooth reduction gives a very high resolution

200 steps/cm
400 steps/1cm
Hybrid Rotor

- Laminated core of silicon steel
- Permanent magnet
Hybrid Rotor Offset Teeth

Diagram showing a hybrid rotor with labels for Ph A, Ph B, Pole 1, Reference mark, Permanent magnet, and arrows indicating flow or direction.
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

2-phase 5 wires

1 phase 2 wires

2 phase wound
Wiring Direction is Important

BIFILAR WOUND
2-Phase Universal Wound vs. 4-Phase

a

b
Driving Stepper Motors

Two full H-Bridges / 4 HME - H-Bridges

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: 1 → 2 → 3 → 4 → 1

CCW Rotation: 1 → 4 → 3 → 2 → 1

![Diagram of Bipolar Stepper Motor Connections]
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>
<td>OFF</td>
<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>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>4</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>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

CW ROTATION
CCW ROTATION
Stepper Sequences: Half-Step

TORQUE Ripples.
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>
<td>OFF</td>
</tr>
<tr>
<td>3</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>5</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<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>ON</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>
</tbody>
</table>

CW Rotation: Down, CCW Rotation: Up

Diagram showing the connection of Q₁ through Q₈ with RED, GRY, YEL, and BLK terminals.
Stepper Sequences: Micro-stepping

[Diagram of a stepper motor with connections labeled V+, Gnd, and arrows indicating the sequence of operations.]
Generating the Drive

Logic Sequencer

Coil Drive

H-bridge
SN754410E ~ 1 A/rev

Drive 8814 ~ 2.8 A/rev

\[ \times 39 \text{rad} \sim 3 \pi \]

\[ 88 \text{rev} \sim 2 \pi \]

\[ \times 3982 \sim 3 \pi \]
5 wire
Stepping Dynamics

Angle vs Time

- Forward Drift
- Reverse Drift

θ₅

Time
Load Effects on Step Dynamics

Motor PH266-01
No-Load

Motor PH266-01
Inertia Load 0.82oz-in (150g-cm)
Friction Load 6.95oz-in (4.9N-cm)

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

- Holding torque
- Maximum starting torque
- Pull-in torque
- Maximum stepping frequency
- Unrotatable range
-

CMPE 118/218 – Intro. to Mechatronics

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Stepper Motor Current Dynamics

Current

\( \frac{\text{Hi-Lo}}{2} \)

High Frequency

Low Frequency

Time
L/nR Drive (1.3)

\[ L_{\text{motor}} + R \]

\[ \frac{1}{n} = \frac{c}{an} \]

\[ R_e = 3R_m \]
L/nR Drive (2.3)

\[ I = \Phi \]

\[ \frac{d\Phi}{dt} = 2000 \text{ J/s} \]

\[ \frac{dI}{dt} = \frac{1}{3} \text{ A/s} \]

\[ \frac{d\Phi}{dt} = 1000 \text{ J/s} \]

\[ \frac{dE}{dt} = \Phi \]
L/nR Drive (3.3)

- Pull-in Torque
- Pull-out Torque

Torque [N-cm]

L/4R

L/R

L/2R

Speed [RPM]

0 1000 2000 3000

0 10 20 30 40 50

[oz-in]
Chopper Drive

V

I

t

Notes:

- For EMI
- RFI
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

Ref = Ground X = 89.2 uS/Div 241%

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Figure 6–5 Torque-speed curves of Oriental Motor PH266-01 stepping motor with no diode, diode +150 ohm resistor and diode suppression circuits
R/C Servos

±60°

95-150°/sec

Closed loop control

Clamp: ~82-9

Espurious Dynamic 5600
red + 5V
brown/black
green/orange

信号线
R/C Servos

1500 μsec.

0.5 μsec
1 μsec
2 μsec
3 μsec

1.5 μsec = 0°

Work Times
Questions?
Gears

\[ \omega_1 R_1 = \omega_2 R_2 \]

Input

Output

\[ N = 98 : 1 \]

\[ \omega_{\text{output}} = \frac{\omega_{\text{input}}}{N} \]

\[ T_{\text{output}} = T_{\text{input}} \times N \]
Laser Cutter w/ Foam Core

BE CAREFUL
| 1.   | Gilberto Barrios - Mariette Souppe - Danny Eliahu |
| 2.   | Austin Liddicoat - Luis Langarcia - Zach Levenberg |
| 3.   | Sharon Rabinovich - John Barritt - Chandrahas Ramalad |
| 4.   | Tyler Nepote - Carlo Figueroa - Daniel Bazor |
| 5.   | Ian Bloise - Isabel Azcona - Kevin Johnson |
| 6.   | Lon Blauvelt - Jessica Alipio - Felipe Contreras |
| 7.   | Kyle Lo - Gary Barrett - Francisco Alvarado |
| 8.   | Michael Garcia - Michael Powell - Michael Suinn |
| 10.  | Ryan Winters - Jessica Herrera - Isabel Stumfall |
| 11.  | Josh Guttermann - Ian Zentner - Victor Ardulov |
| 12.  | Zidong Tan - Hung Huynh - Paloma Fautley |
| 13.  | Justin Ewing - Daniel Ruatta - Daniel Lavell |
| 14.  | Marta Paulsson - Jose Maravilla - Aaron Lee |
| 15.  | Aaron Maloney - Jacob Lee - Luis Gonzalez - Edmond Lee |
| 17.  | Karthik Mohan Kumar - Michael Gonzales - Sergio Lopez |
| 18.  | Justin Bates - Tristan Bodmer - Viktor Jankov |
| 20.  | Amy Huang - Veronica Paez - Steven Santiago |
| 21.  | Scott Rad - Roberto Chavez - Randal Robinson |
| 22.  | Pavlo Vlastos - Harry Jackson - Ahren Roth |
| 23.  | Alexy Munishkin - Nick Elsmore - Pierre Baudin |
| 24.  | Patrick Lee - Tanvir Heer - Serena Mak |
| 25.  | Richard Pham - Juliana Hernandez - Joe Parsons |
| 26.  | Vijay Muthukumaran - Ryan Dickerhoff - Trieste Devlin |
| 27.  | Marcus Gronberg - Aaron Storrs - Sierra Catelani |
Team Horse Trading

• 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
Thursday
PDR
Preliminary Design Review
Preliminary design (Backup Design)
Team name.
Rapid Prototyping

Quick, dirty. Get the answer.

Beware the Gospel complex.

MEMBERS

Foam Core $2.50/ft
MDF $5/ft.