

Welcome to

Electric Machines & Drives

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**Session 8:
 Single Phase Motors
 & Stepper Motors**

Fall 2011



Session 8

- Chapter 18 – Single Phase Motors
- Chapter 19 – Stepper Motors

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Chapter 18 – Single Phase Motors

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Chapter 18

Construction
 Main winding & auxiliary winding
 Same # poles
 “slot liners” insulation between coil and core lamination
 Main winding installed in slots
 Laid out for alternate N S poles
 Auxiliary winding overlaid
 Same # of poles
 Shifted 90° electrical

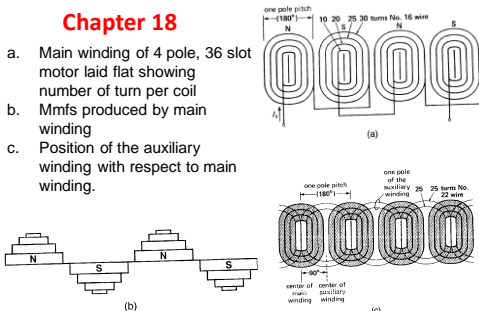
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- a. Main winding of 4 pole, 36 slot motor laid flat showing number of turn per coil
- b. Mmfs produced by main winding
- c. Position of the auxiliary winding with respect to main winding.



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Synchronous Speed

$$n_s = 120 f / p$$

n_s = synchronous speed (rpm)
 f = frequency of source (Hz)
 p = number of poles

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Example 18-1

Calculate the speed of a 4 pole, single phase motor if the slip at full load is 3.4 %. The line frequency is 60 Hz.

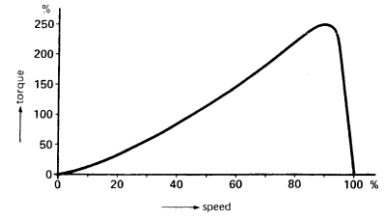
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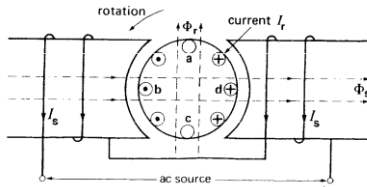
Torque Speed curve
Without Aux Winding, Torque at Locked Rotor = 0
Once rotor turns, torque developed



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Θ_r (flux of rotor) lags Θ_s (flux of stator) by 90°
Produces "Rotating Magnetic Field"
As speed increases, Θ_r increases
-> torque

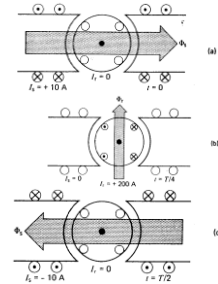


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Instantaneous currents and flux in a single phase motor with main winding excited. The duration of cycle is T seconds and conditions are shown at successive quarter cycle intervals.

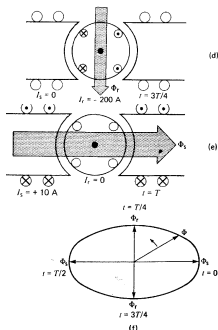
- a. Stator current Is is max, rotor current Ir is zero
- b. Stator current is zero, rotor current is max, however, Θ_r is smaller than Θ_s
- c. Stator current is max, but negative



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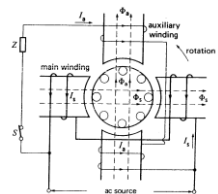
- d. Rotor current is max, but negative
- e. After one complete cycle conditions repeat
- f. Resulting flux Θ in the air gap rotates CCW at synchronous speed. Its amplitude varies from max of Θ_s to min of Θ_r .
- g. $\Theta = \Theta_s + \Theta_r$



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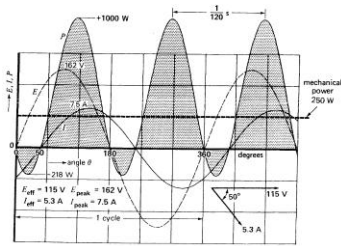
Resistance Split Phase Motor
Locked rotor Is lags V by large amount, Ia lags V by little (more resistive)
Therefore Θ_s lags Θ_a under locked rotor.
Thus producing starting torque.



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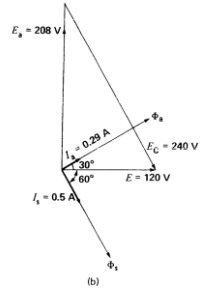
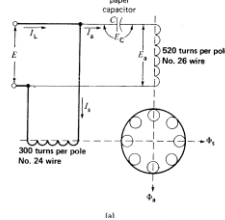
Pe > Pm
 Motor accel
 Pe < Pm
 Motor decel
 Oscillate
 2 * f



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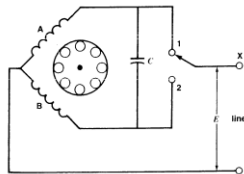
Cap Run Motor –
 Quite low Tstart



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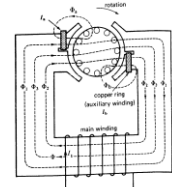
Motor Reversing – centrifugal switch motor
 can not be reversed.
 Cap run motors can be reversed.



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Shaded pole motor
 Φa & Φb lag Φ1, Φ2, Φ3
 Induce rotating field
 Very small < 0.05HP



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Example 18-3

Calculate the full load efficiency and slip of the shaded pole motor having 2 poles, rated 6 W, 115V, 60 Hz whose properties are listed below;

No Load	Main
current	Wind
0.26A	0.26A
input power	15W
speed	3550RPM
Locked Rotor	
current	0.35A
input power	24W
torque	10 mN m
Full Load	
current	0.33A
input power	21W
speed	2900RPM
torque	19 mN m
mech power	6W
breakdown speed	2800RPM
breakdown torque	21 mN m

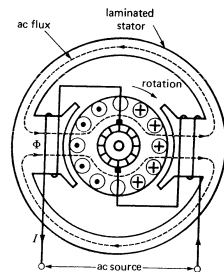
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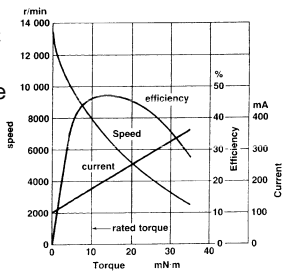
Universal Motor
 AC or DC causes
 rotation in same
 direction
 Same as DC series
 motor



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Similar Torque speed curve as DC series motor
 High starting torque
 Speed drops rapidly as torque increases



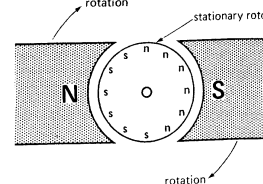
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Hysteresis Motor
 External field magnetizes rotor
 Hysteresis loss in rotor proportional to speed

$$P_h = W / t \text{ (W)}$$

$$P_h = n E_h / 60 \text{ (W)}$$



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Mechanical Power is proportional to speed

$$P = n T / 9.55$$

$$P = P_h = n T / 9.55 = n E_h / 60$$

Or

$$T = E_h / 6.28$$

Torque is independent of speed

T = torque exerted on rotor (N m)

E_h = hysteresis energy dissipated in rotor per turn (J/rev)

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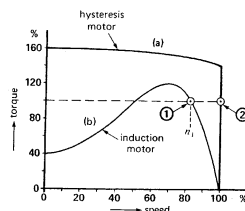
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At synch speed,
 rotor still polarized -

>

Operates like PM Synchronous Motor
 Typical torque speed curve of;
 a. Hysteresis motor
 b. Induction motor



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Example 18-4

A small 60 Hz hysteresis clock motor possesses 32 poles. In making one complete turn with respect to the revolving field, the hysteresis loss in the rotor amounts to 0.8 J. Calculate

- The pull in and pull out torques
- The max power output before the motor stalls
- The rotor losses when the motor is stalled
- The rotor losses when the motor runs at synchronous speed.

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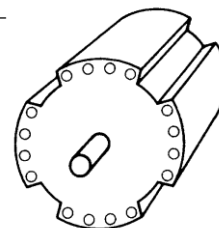


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Synchronous Reluctance Motor –
 Rotor appears as salient pole
 Pulls into sync when up to speed –
 Energy to pull into synch is:
 $\Delta E_k = 5.48 \times 10^{-3} \text{ J (ns}^2 - n1^2)$

Time to pull into synch is
 $\Delta t = 60 / (ns - n1)p$



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Therefore Power to pull into synch (min) is

$$P_a = \Delta E k / \Delta t$$

$$P_a = 1.8 \times 10^{-4} n_s (n_s - n_1)^2 J p \text{ (approx)}$$

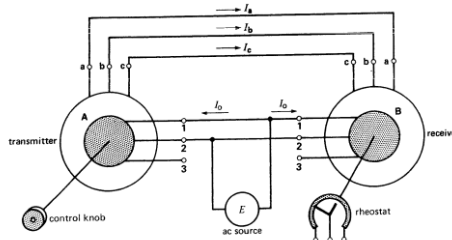
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Synchro System – wound rotor motor



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Consider Wound Rotor motor as xfmr with

movable secondary

If motors matched and rotor position same, secondary voltages in phase.

When one motor shaft moves, secondary voltage phase shifts, causes current to flow till second motor shaft matches first motor shaft

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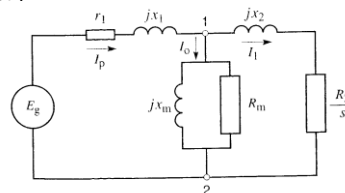


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Single phase motor equivalent circuit

Since motors small, magnetizing circuit placed correctly



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MMF distribution –
Fixed in place
Sinusoidal distribution
Pulsing

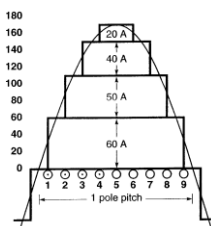


TABLE 18C

Coil pitch	Turns	Mmf
slot 1-9	30	2 × 30 = 60 A
slot 2-8	25	2 × 25 = 50 A
slot 3-7	20	2 × 20 = 40 A
slot 4-6	10	2 × 10 = 20 A
	85 turns	170 ampere-turns

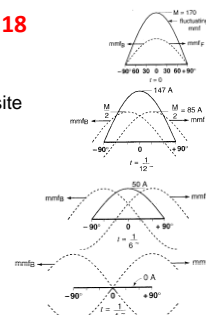
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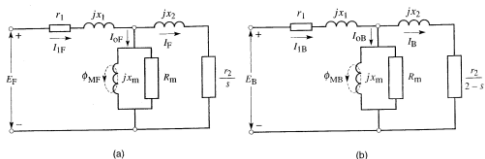
Mathematically replace one Pulsating MMF
By two rotating MMF (but opposite Rotations)
Pr for + and – rotating MMF different
Two circuit diagrams



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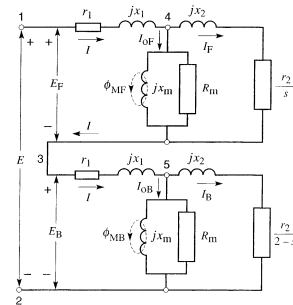
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- a. Equivalent circuit regarding forward moving mmf
- b. Equivalent circuit regarding reverse moving mmf



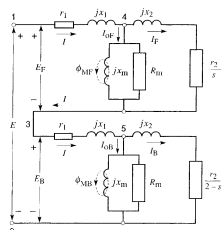
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Equivalent circuit of single phase motor
 $I = I_f + I_b$
 $E = E_f + E_b$
 Circuits in series



Chapter 18

- 2r1 = stator resistance
- 2r2 = rotor resistance referred to stator
- 2jx1 = stator leakage reactance
- 2jx2 = rotor leakage reactance referred to stator
- 2Rm = resistance of winding, friction and iron loss
- 2jxm = magnetizing reactance



Example 18-5

A test on a 1/4 HP, 120V, 60Hz, 1725 rpm, single phase motor reveals the following results:

stator resistance	2 ohm
rotor resistance referred to stator	4 ohm
stator leakage reactance	3 ohm
rotor leakage reactance referred to stator	3 ohm
resistance of winding, friction, iron loss	600 ohm
magnetizing reactance	60 ohm

Determine power output, efficiency, and power factor of the motor when it turns at 1725 rpm.

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Chapter 19 – Stepper Motors

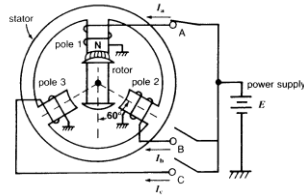
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Motor position precision applications
 # of stator poles is not equal to # of rotor poles
 One winding at time energized with DC
 Create mag field that lines up with rotor pole

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Chapter 19

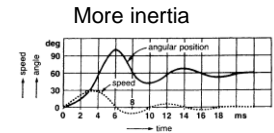
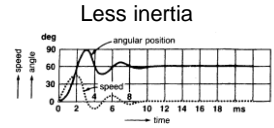
Rotor soft iron - Lines up with field induced on stator
 Holding torque – rotor locked in place
 Stepper motor with each step moves rotor by 60°



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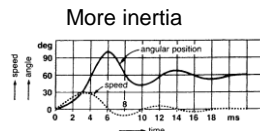
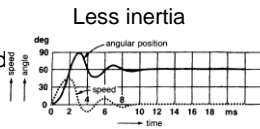
Effect of inertia
 Overshoot more
 Settle time greater



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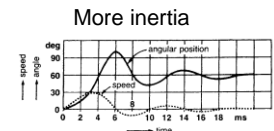
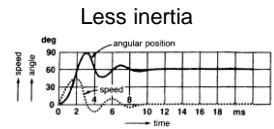
Effect of dampening
 Overshoot less
 Oscillation dampened
 Viscous Damping
 Brake ∞ Speed



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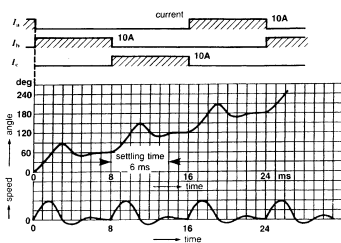
Effect of mech load
 Overshoot less
 Settle time greater



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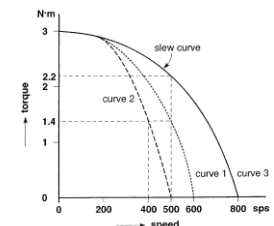
Rotor angle / speed vs time



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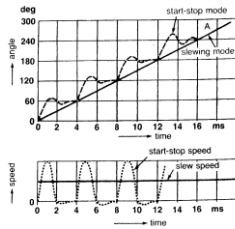
Start without error mode
 Slewing mode
 Increased inertial reduces max sps
 When slewing, can carry greater torque for same sps (steps per sec)
 Curve 1: start stop curve with only stepper motor inertia
 Curve 2: same as curve 1, but with additional load inertia
 Curve 3: slewing curve



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Start/stop mode – oscillating speed
 Slew mode
 Constant speed
 Ramping – controlled accel and decel to ensure no missed steps
 a. Angular position vs time
 b. Instantaneous speed vs time



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Chapter 19

Three main types of stepper motors:
 variable reluctance stepper motors
 permanent magnet stepper motors
 hybrid stepper motors

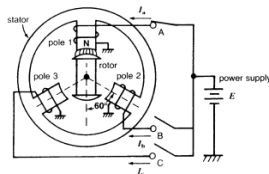
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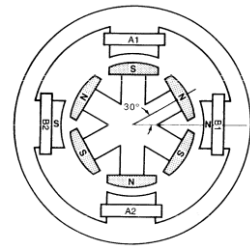
Variable reluctance stepper motor:
 Similar to figure 1 but teeth in pole face constitute poles.
 Very small angular steps



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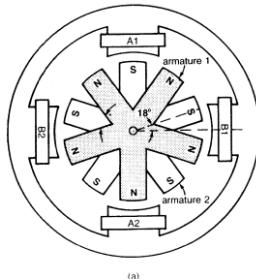
Permanent Magnet Stepper Motors
 Rotor consists of PM
 Detent Torque – residual flux holding rotor in place with no field current
 Higher power applications



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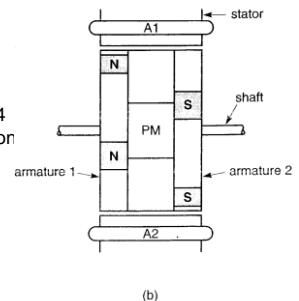
Hybrid Motor:
 2 Soft Iron armatures interlaced
 PM between Iron armature
 Alternating S N poles
 A1/A2 coils in series



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Side view of rotor showing PM sandwiched between two armatures. The 4 pole stator is common to both armatures



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Specifications

Ordering Part No. (Add Suffix)	L82401		L82402	
	Unipolar		Bipolar	
Suffix Designation	-P1	-P2	-P1	-P2
DC Operating Voltage	5	12	5	12
Res. per Winding (Ω)	9.1	52.4	9.1	52.4
Ind. per Winding (mH)	7.5	48.8	14.3	77.9
Holding Torque (mNm/oz-in)*	73.4/10.4		87.5/12.4	
Rotor Moment of Inertia (g·m ²)	12.5 × 10 ⁻³			
Detent Torque (mNm/oz-in)	9.2/1.3			
Step Angle	7.5°			
Step Angle Tolerance*	5°			
Steps per Rev.	48			
Max Operating Temp	100°C			
Ambient Temp Range	-20°C to 70°C			
Operating Storage	-60°C to 85°C			
Bearing Type	Bronze sleeve			
Insulation Res. at 500Vdc	100 megohms max			
Dielectric Withstanding Voltage	650 ± 50 VRMS 60 Hz for 1 to 2 seconds			
Weight (g/oz)	144/5.1			
Lead Wires	26 AWG			

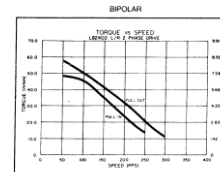
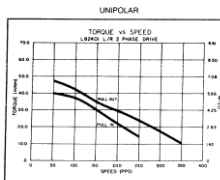
*Measured with 2 phases energized



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Pull out Torque -> slewing
Pull in Torque -> start without error
For same speed, T slew > T stepping



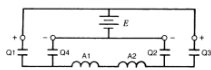
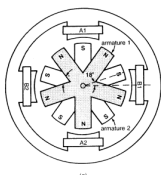
NOTE: The above curves are typical.



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Bipolar Winding:
Current reverses via switching – three methods of sequencing Q1-Q8
wave drive
normal drive
half step drive



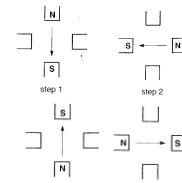
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Chapter 19

Wave Drive -
TABLE 19A WAVE SWITCHING SEQUENCE FOR CW ROTATION

Only one set of coils is excited at a time
90° step

Step	1	2	3	4	1
Q1	Q2	on	—	—	on
Q3	Q4	—	—	on	—
Q5	Q6	—	on	—	—
Q7	Q8	—	—	on	—



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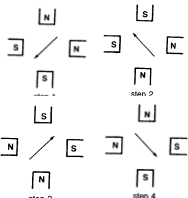
Chapter 19

Normal Drive

Both coils excited at same time
90° per step

TABLE 19B NORMAL SWITCHING SEQUENCE FOR CW ROTATION

Step	1	2	3	4	1
Q1	Q2	on	—	—	on
Q3	Q4	—	on	—	—
Q5	Q6	on	—	—	on
Q7	Q8	—	on	—	—



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Half-Step Drive -

Combination of Wave Drive and Normal Drive
45° steps
Improved resolution

Step	1	2	3	4	1
Q1	Q2	on	—	—	on
Q3	Q4	—	—	on	—
Q5	Q6	—	on	—	—
Q7	Q8	—	—	on	—

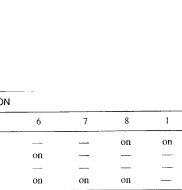


TABLE 19C HALF-STEP SWITCHING SEQUENCE FOR CW ROTATION

Step	1	2	3	4	5	6	7	8	1
Q1	Q2	on	on	—	—	—	—	—	on
Q3	Q4	—	—	on	on	—	—	—	—
Q5	Q6	—	on	on	—	—	—	—	—
Q7	Q8	—	—	—	—	on	on	—	—



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Chapter 19

2 coils per pole – current one direction
Simplified switching ckt
a. Coil arrangement 4 pole
b. Schematic diagram

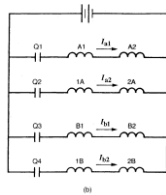
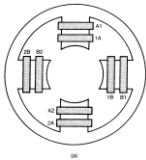


TABLE 19D WAVE SWITCHING SEQUENCE FOR CW ROTATION

Step	1	2	3	4	1
Q1	on	—	—	—	on
Q2	—	on	—	—	—
Q3	—	—	on	—	—
Q4	—	—	—	on	—

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Chapter 19

Real switching issues: current rises over time
1. Delay on Turnon -> Initial Torque less
2. Delay on Turnoff -> Delay in Torque cutoff
3. Turnon = 3*To
4. Turnoff = 3*To
5. To = L/R

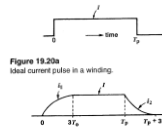


Figure 19.20a Ideal current pulse in a winding.

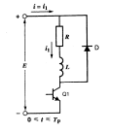


Figure 19.20b Typical circuit of a switching transistor and coil connected to a DC source. The diode protects the transistor against overvoltage.

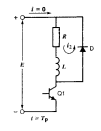


Figure 19.20c Steady-state current in coil and diode when transistor is switched off.



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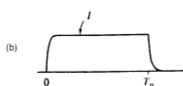
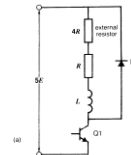
Chapter 19

Reduce To by:
1. Increased R (To = L/R)
2. Increased source voltage

Power Supply more \$
More power loss in increased R

To is equal to L/R seconds.

- a. Circuit to increase rate of growth and decay in current
- b. Resulting current pulse



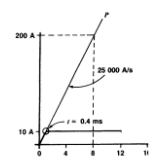
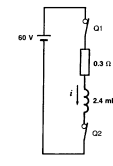
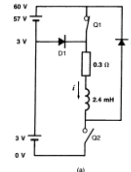
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Chapter 19

Bilevel Drive - Avoids power loss of higher R

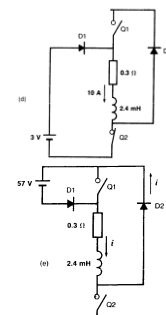
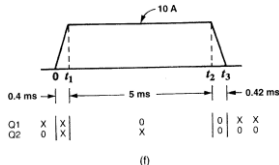
- 1. Initial voltage higher & Turnoff voltage reverse
- a. Ckt of drive when current zero
- b. Equivalent ckt when current increasing
- c. Rate of increase of current and time to reach 10A



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- a. Equiv ckt when current constant
- b. Equiv ckt when current decreasing



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Chapters 20 and 21 next session



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	<p>End of Session 8: Single Phase Motors & Stepper Motors</p> <p>Spring 2011</p>