Overview Electrical Machines and Drives

- 7-9 1: Introduction, Maxwell's equations, magnetic circuits
- 11-9 1.2-3: Magnetic circuits, Principles
- 14-9 3-4.2: Principles, DC machines
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- 21-9 5.2-5.6: IM introduction, IM principles
- 25-9 Guest lecture Emile Brink
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- 2-10 5.13-6.3: IM drives, SM
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- 19-10: rest, questions
- 9-11: exam

Other machines

- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase motors (7)
  - Single phase induction motors
  - Single phase synchronous motors
- Universal motors

Switched reluctance machine (6.14)

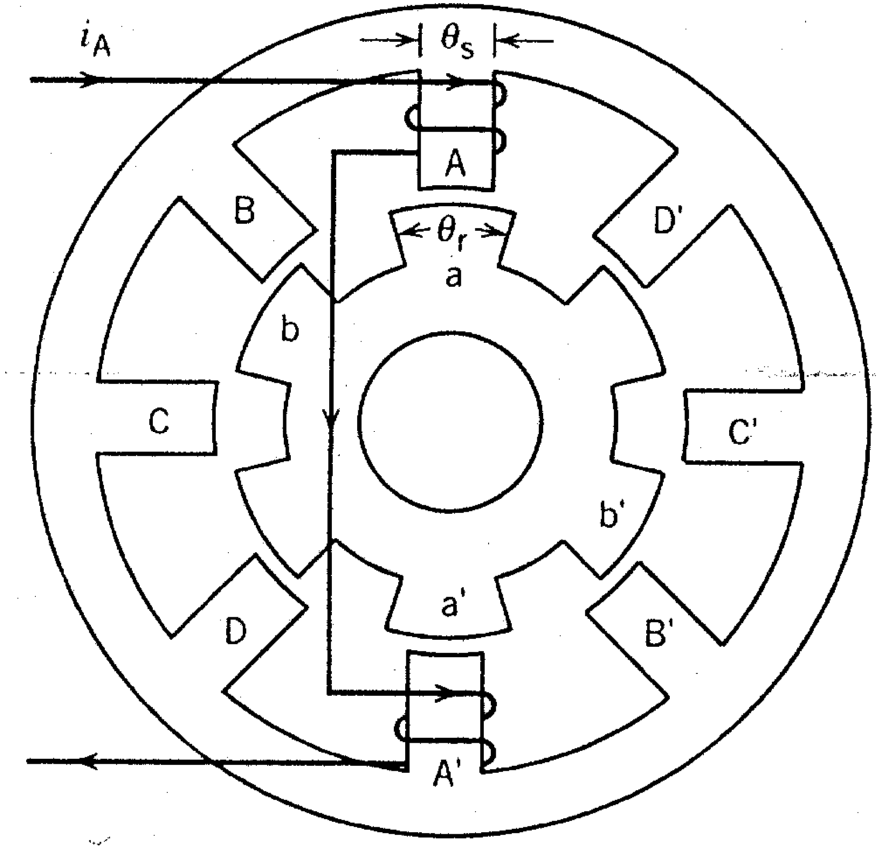
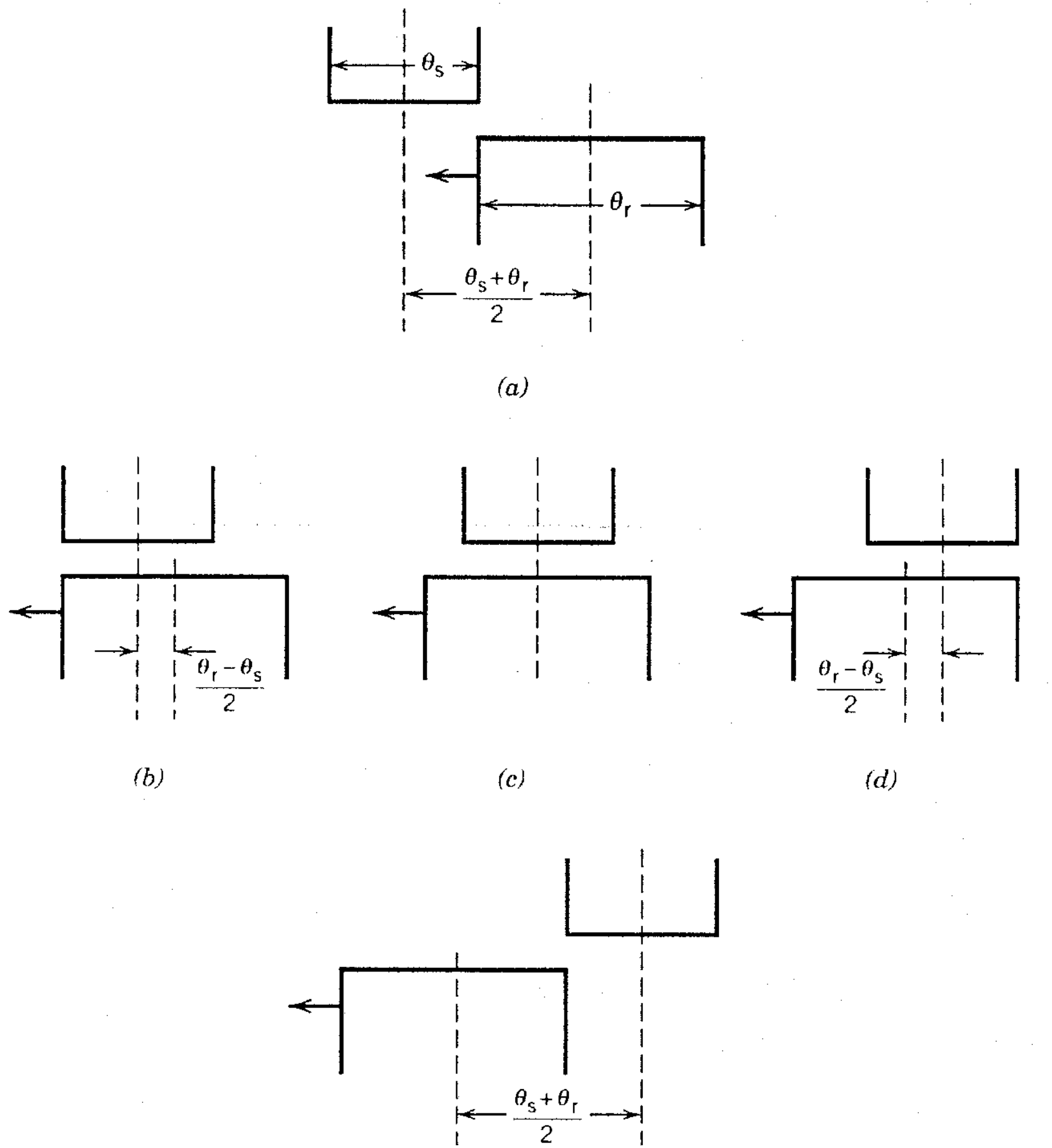


FIGURE 6.42 Cross section of a switched reluctance motor (SRM).

Calculations



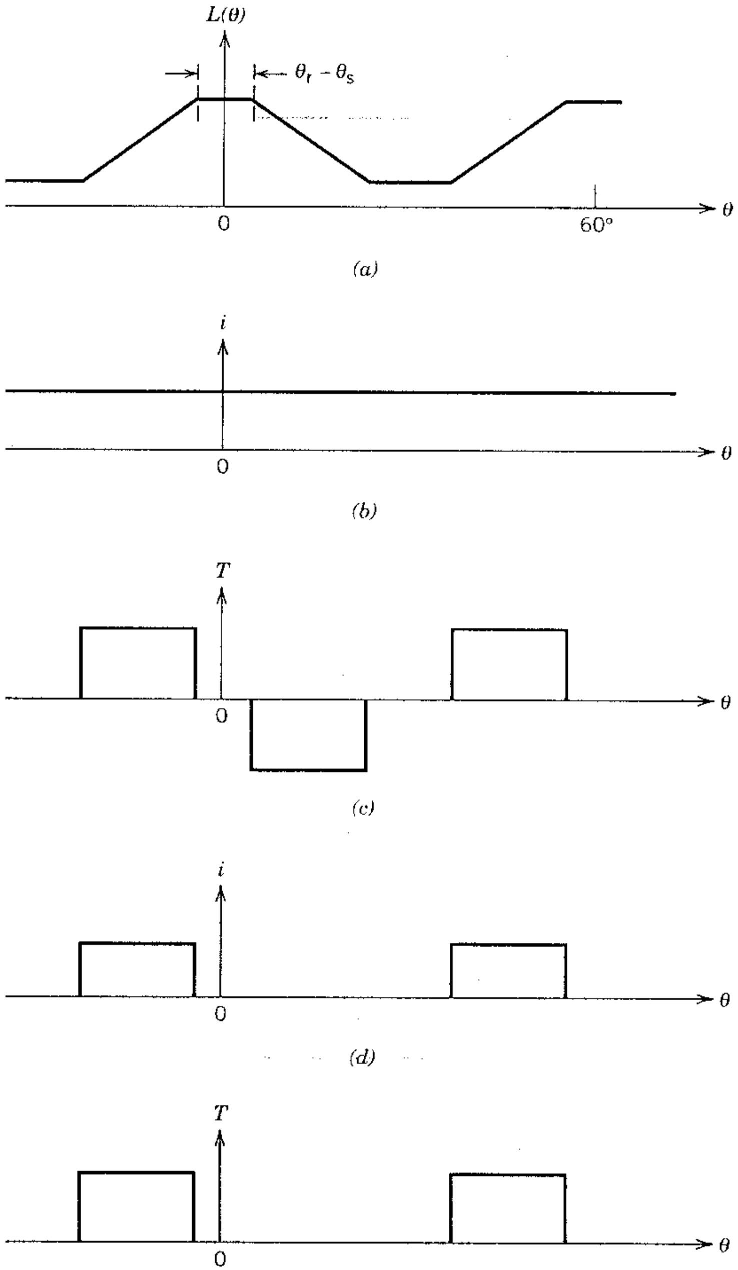
Assumptions:

- no mutual flux linkage between phase windings
- iron used in linear part of BH characteristic

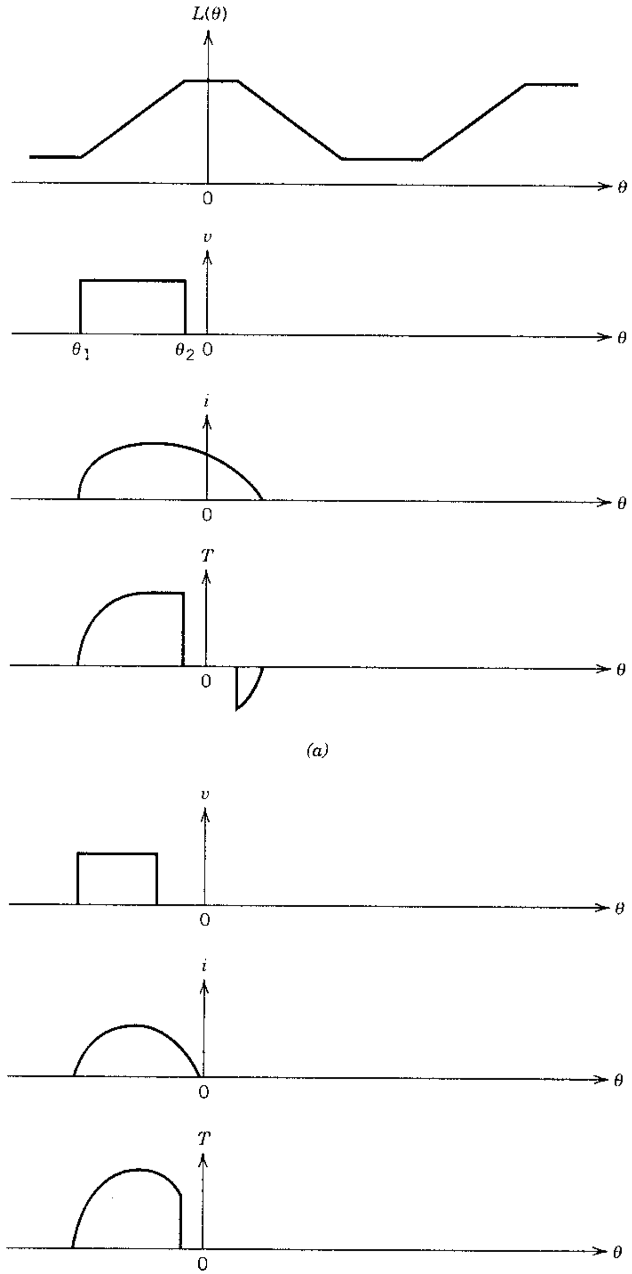
$$T = \frac{1}{2} i^2 \frac{\mathrm{d}L}{\mathrm{d}\theta}$$

- torque independent of current direction

Idealized current waveforms



Real current waveform



Converter for SRM

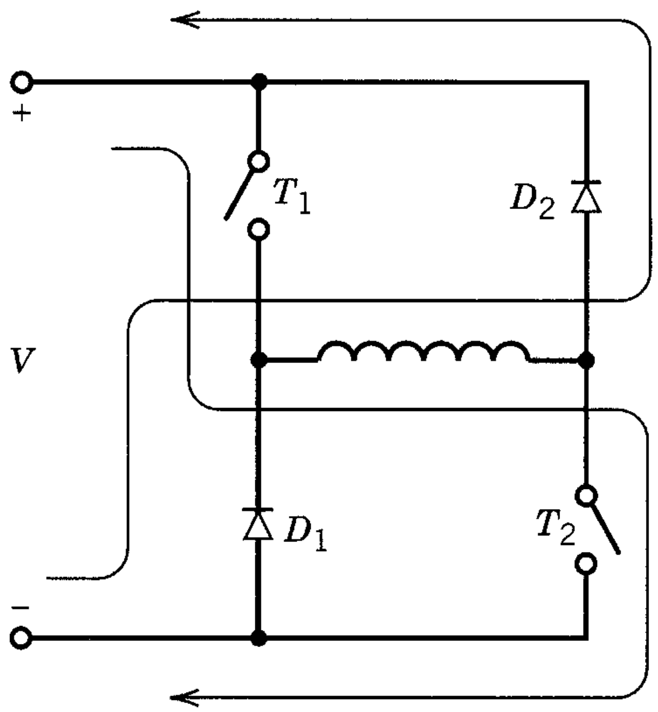
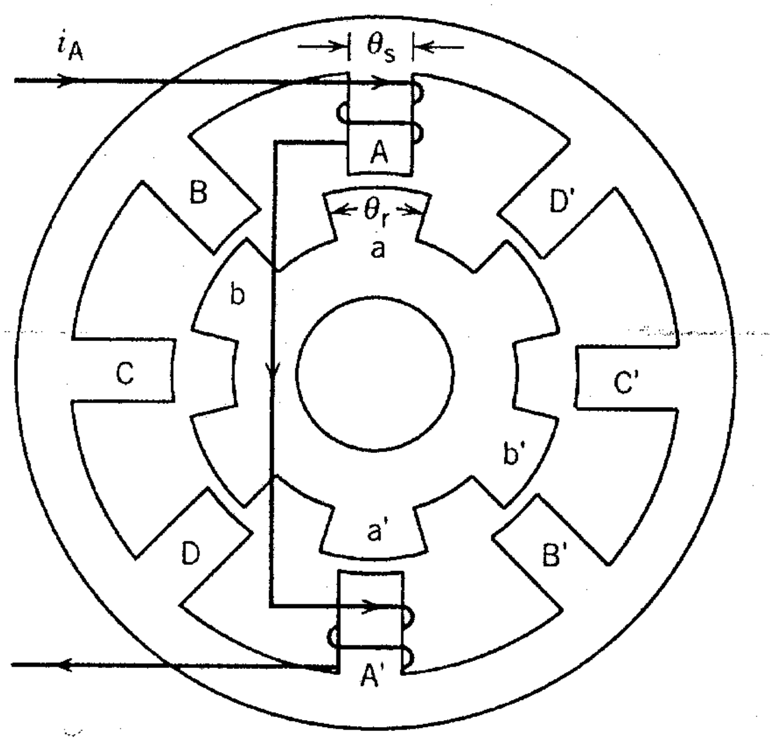


FIGURE 6.46 A typical converter circuit to excite a stator phase winding.

applications:

- torque ripple causes noise
- simple and robust construction and converter

Calculation example



- θ_s = 15º = π/12
- θ_r = 30º = π/6
- The gap radius is r_s
- The axial length is l_s
- The air gap is l_g
- The stator current around the excited stator teeth is I
- The number of turns around a stator tooth is N_s
- Calculate the inductance as a function of the overlap angle θ_o ($0<\theta_o<\pi/12$) where the overlap angle is the overlap angle between the excited stator teeth and the rotor teeth
- Calculate the torque

Answer

$$L(\theta_o) = \frac{(2N_s)^2}{\dfrac{2l_g}{\mu_0 l_s r_s \theta_o}} = \frac{2N_s^2 \mu_0 l_s r_s \theta_o}{l_g}$$

$$T = \frac{1}{2} I^2 \frac{\mathrm{d}\, L(\theta_o)}{\mathrm{d}\,\theta_o} = \frac{N_s^2 \mu_0 l_s r_s}{l_g} I^2$$

Other machines

- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase motors (7)
  - Single phase induction motors
  - Single phase synchronous motors
- Universal motors

Stepper motors

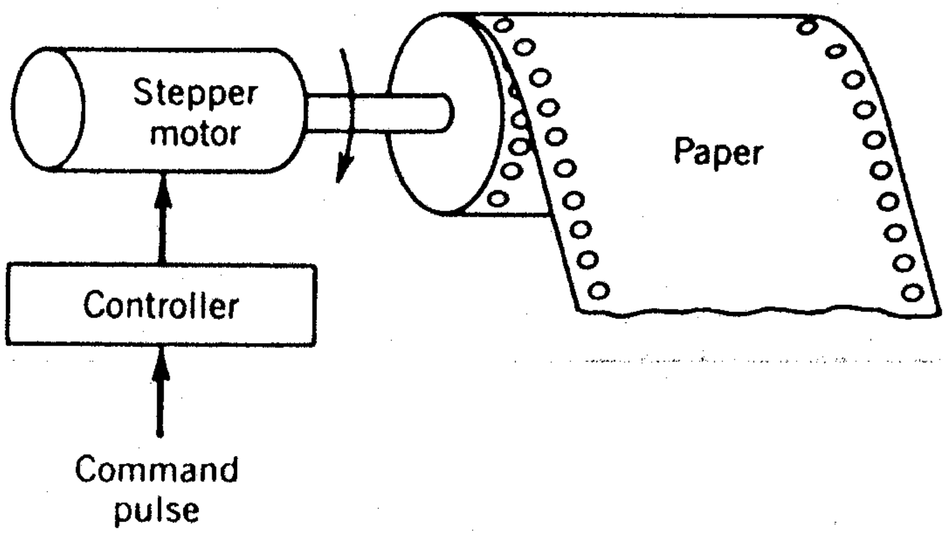
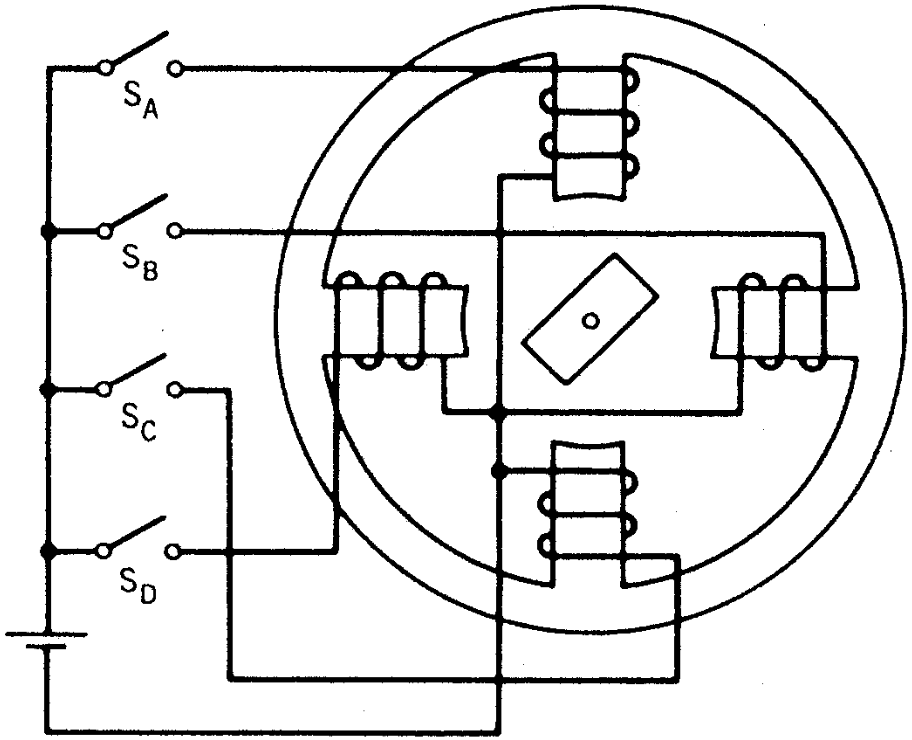
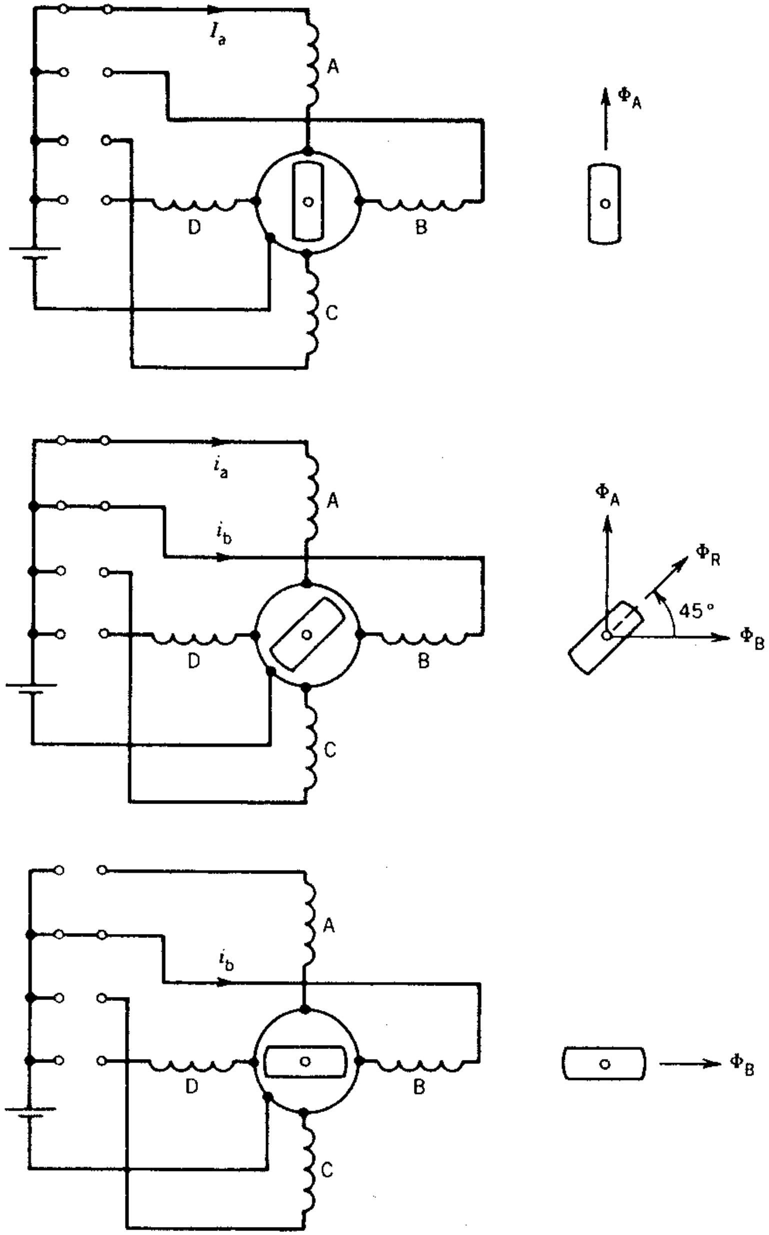


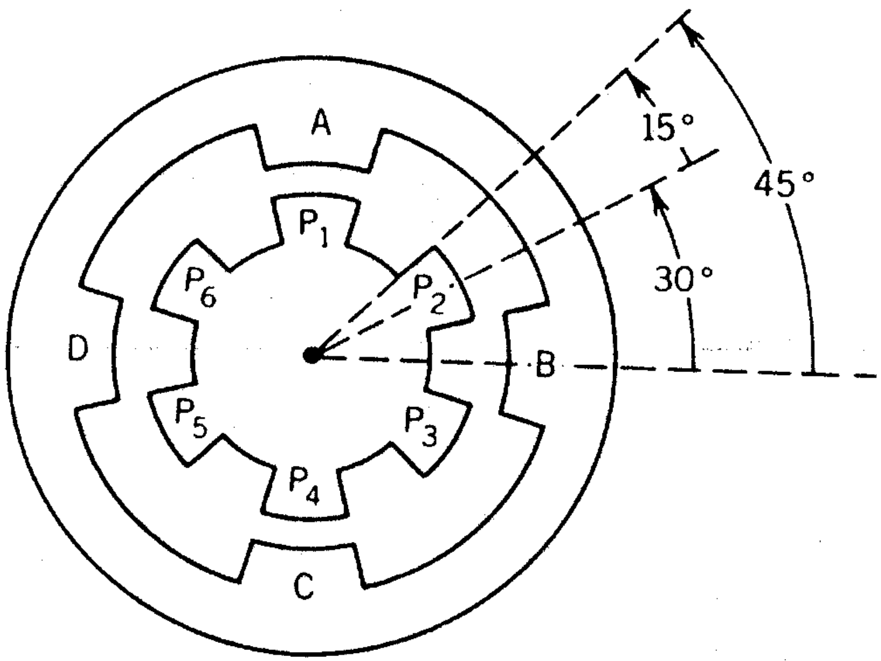
FIGURE 8.15 Paper drive using stepper motor.

Variable reluctance stepper motor

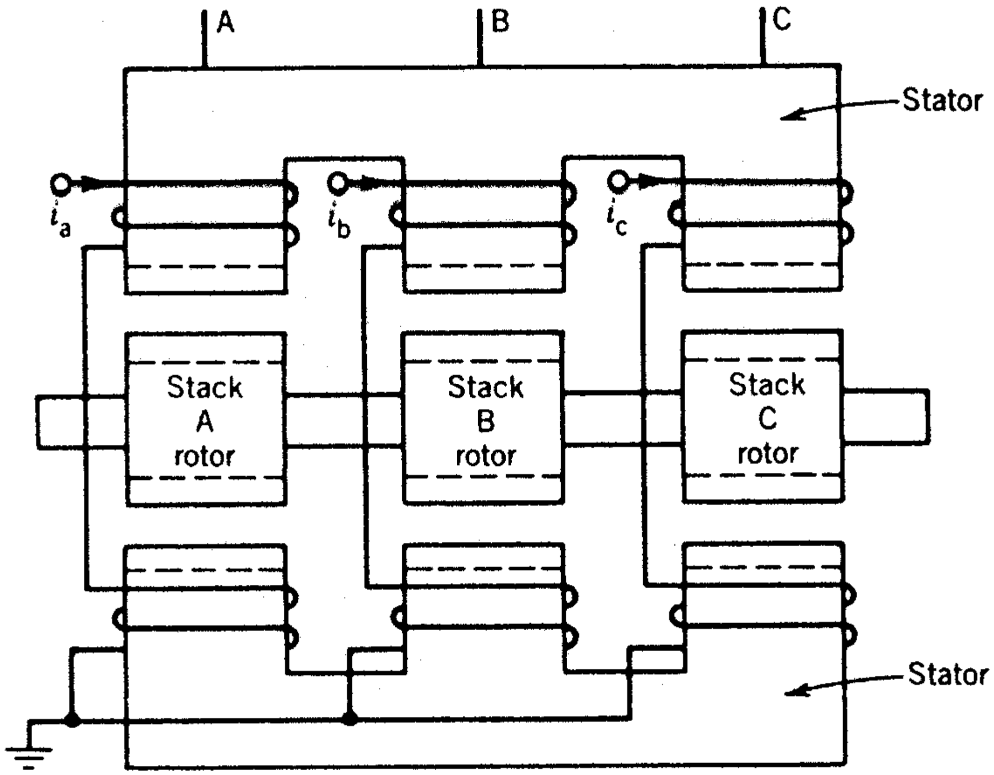


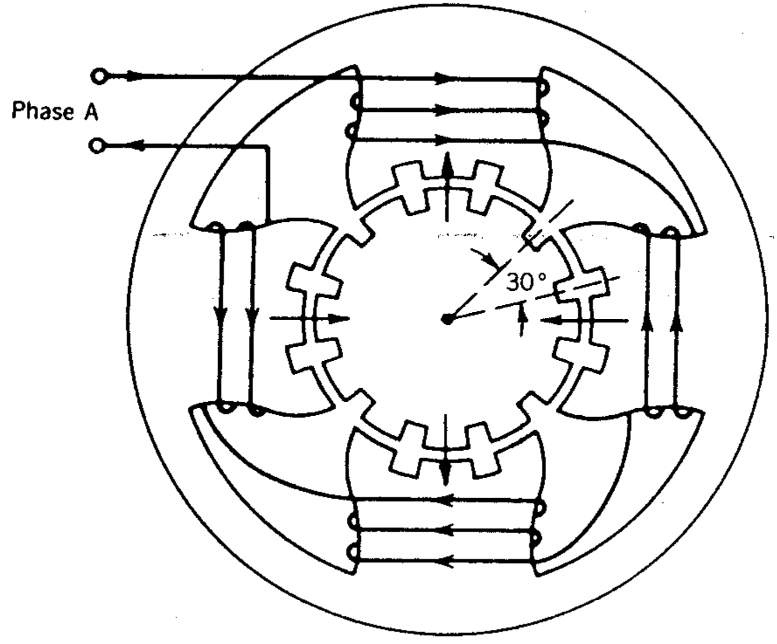


Variable reluctance stepper motor

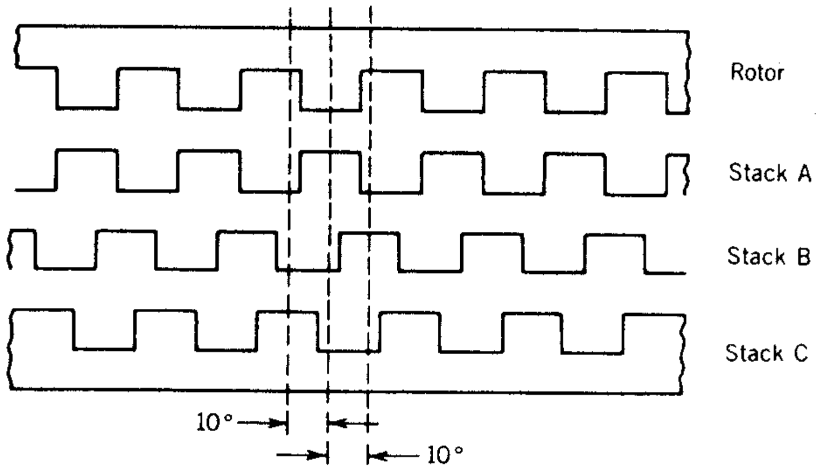


Variable reluctance stepper motor

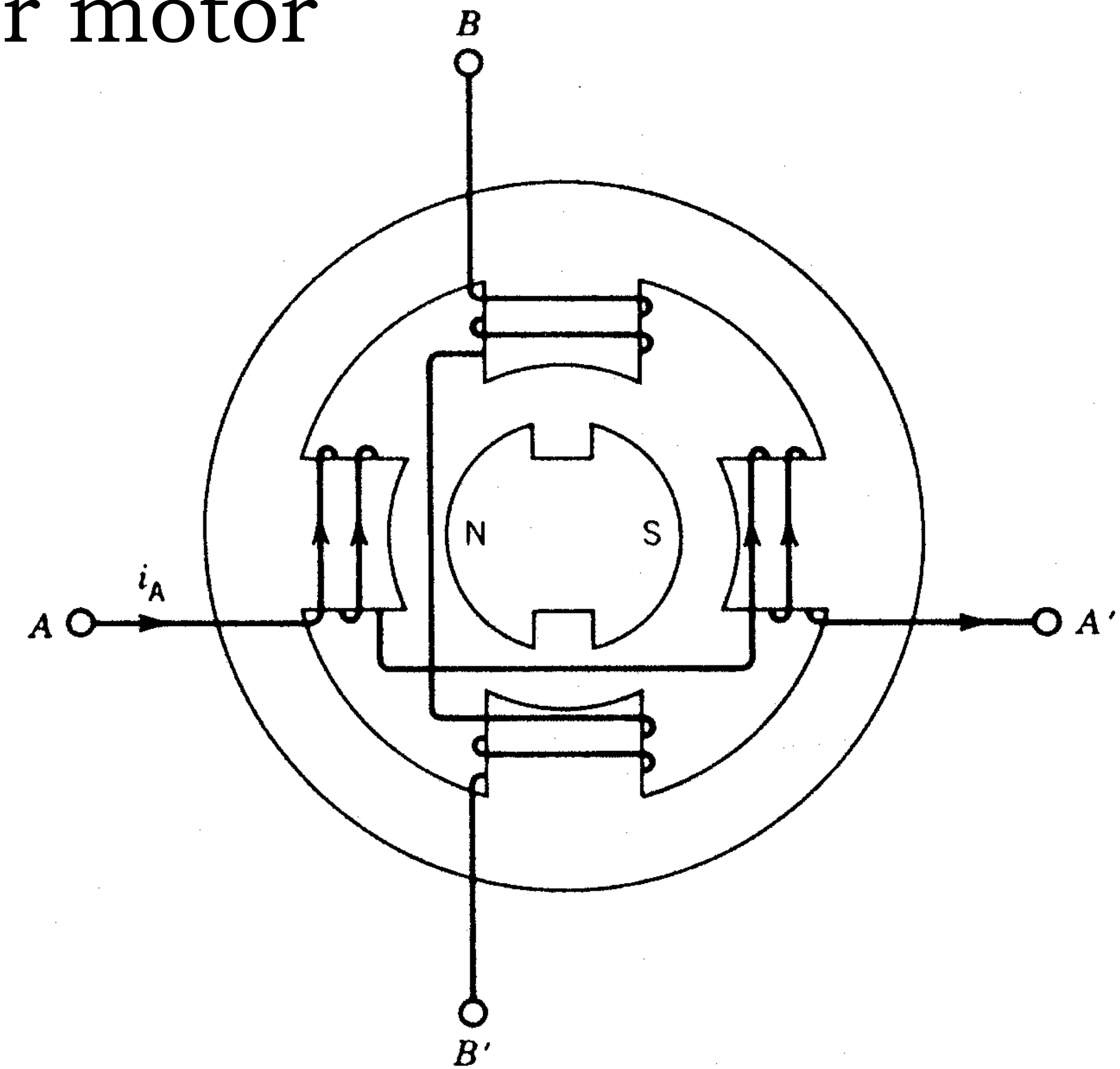




(a)



PM stepper motor

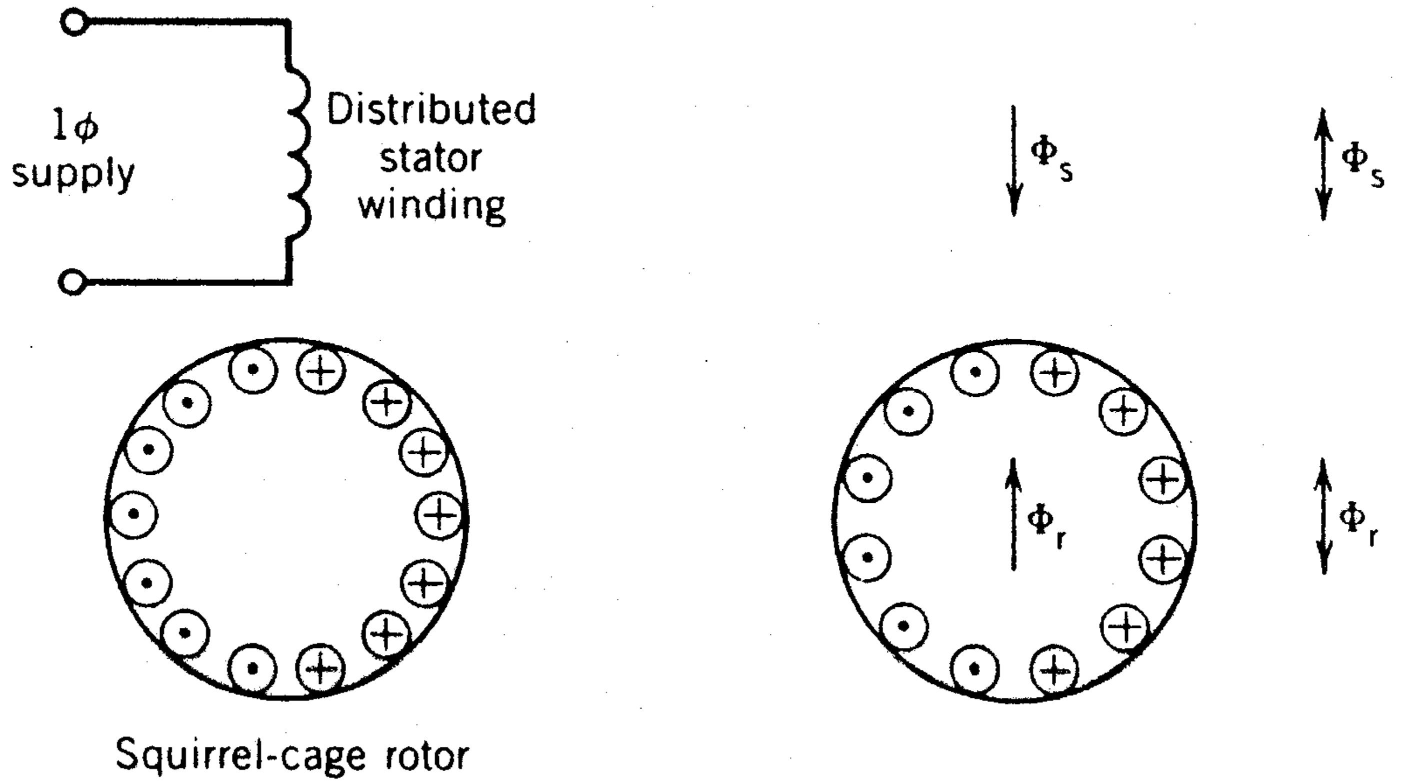


Other machines

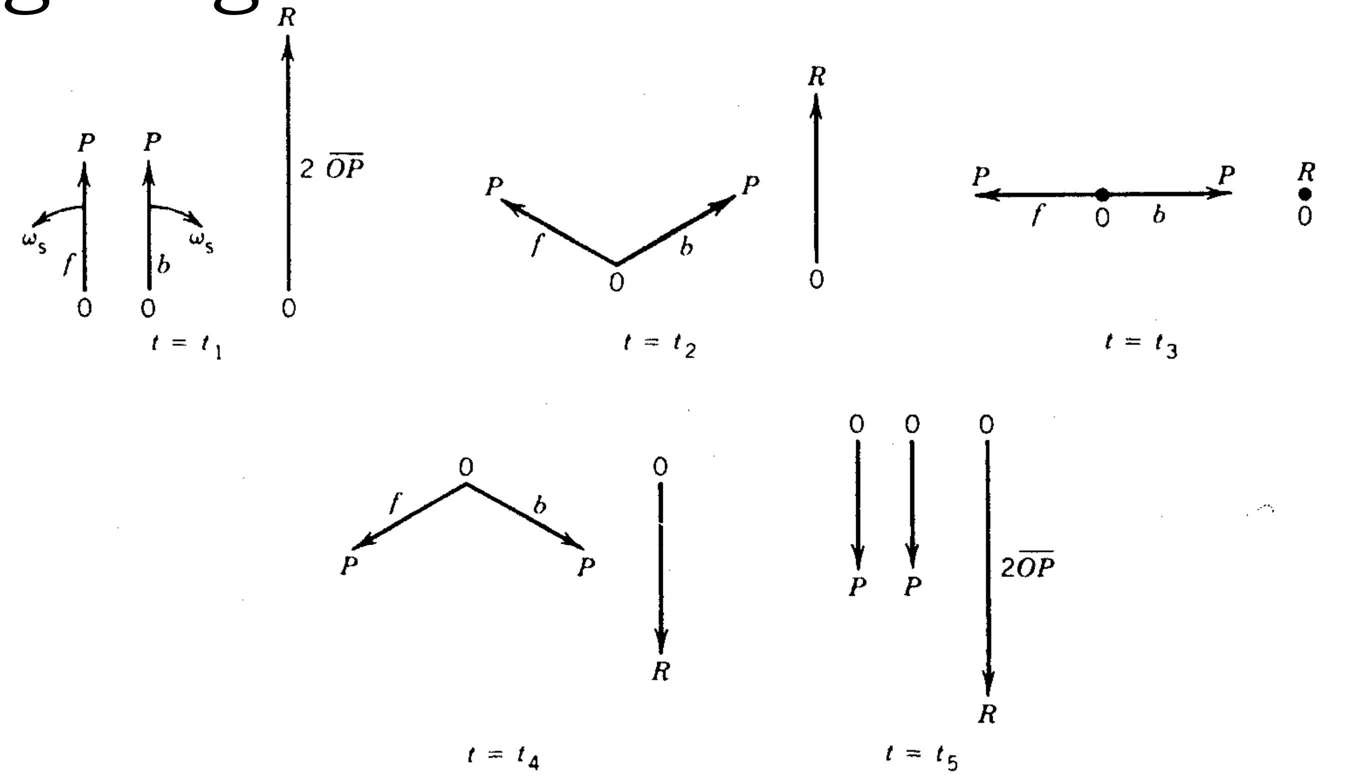
- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase motors (7)
    - Single phase induction motors
        - Pulsating field
        - Starting methods
    - Single phase synchronous motors
- Universal motors

Single-phase induction motors

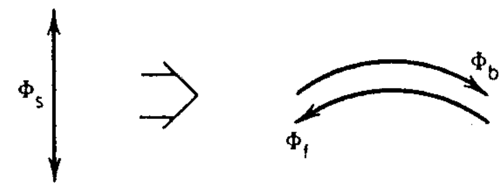
applications: pumps, fans, kitchen machinery



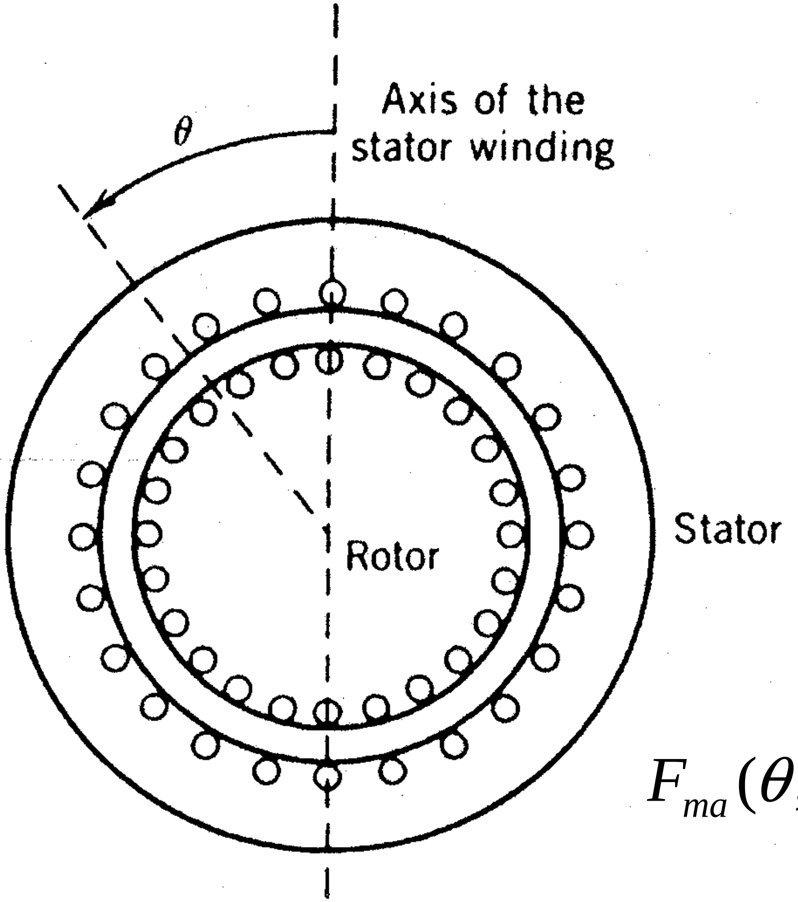
Pulsating magnetic field



(a)



Pulsating magnetic field



$$i_a(t) = \hat{i}\cos(\omega t)$$

$$N_a(\theta) = \tfrac{1}{2} N \sin(\theta)$$

$$F_{ma}(\theta, t) = N i_a \cos(\theta) = N\hat{i}\cos(\theta)\cos(\omega t)$$

$$F_{ma}(\theta, t) = \tfrac{1}{2} N\hat{i}\cos(\theta - \omega t) + \tfrac{1}{2} N\hat{i}\cos(\theta + \omega t)$$

Torque-speed characteristic

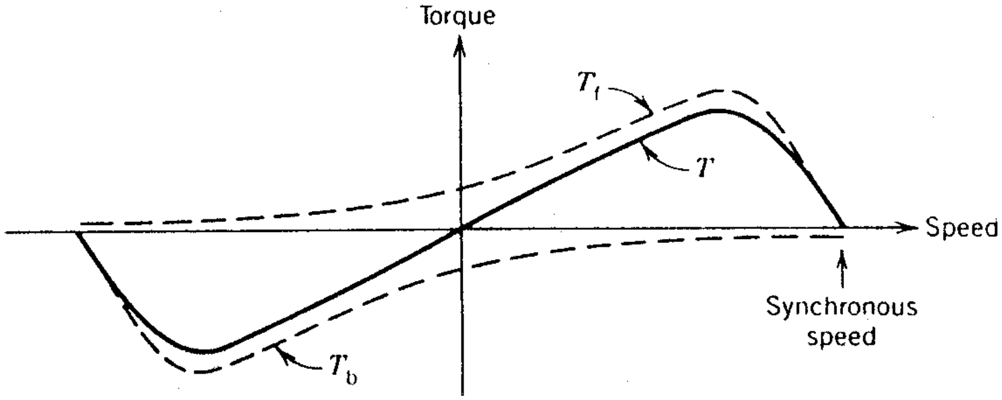


FIGURE 7.4 Torque–speed characteristic of a single-phase induction motor based on constant forward and backward flux waves.

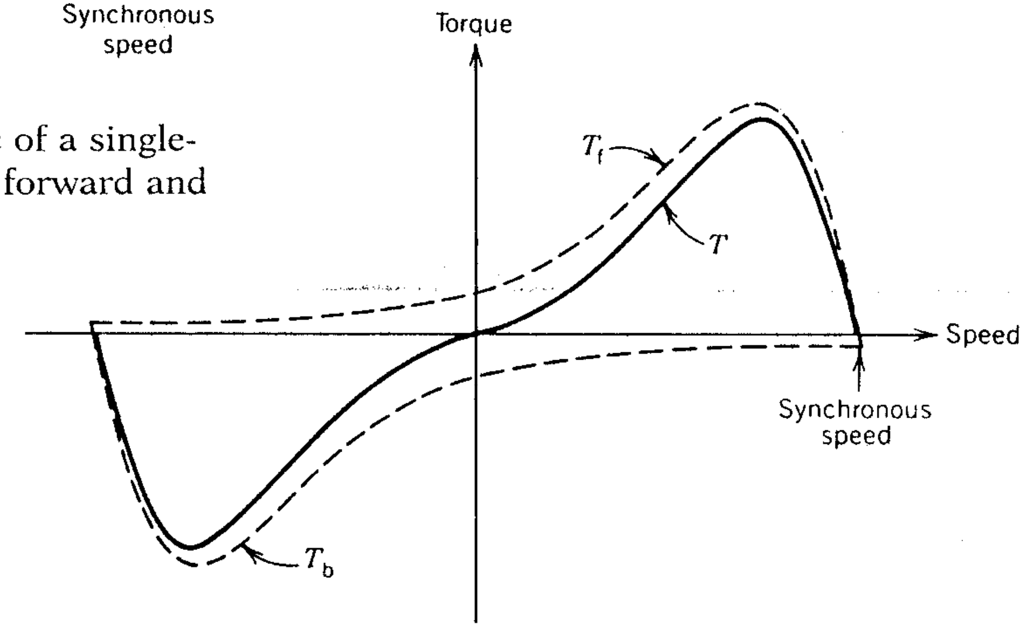


FIGURE 7.6 Actual torque–speed characteristic of a single-phase induction motor taking into account changes in the forward and backward flux waves.

Power input

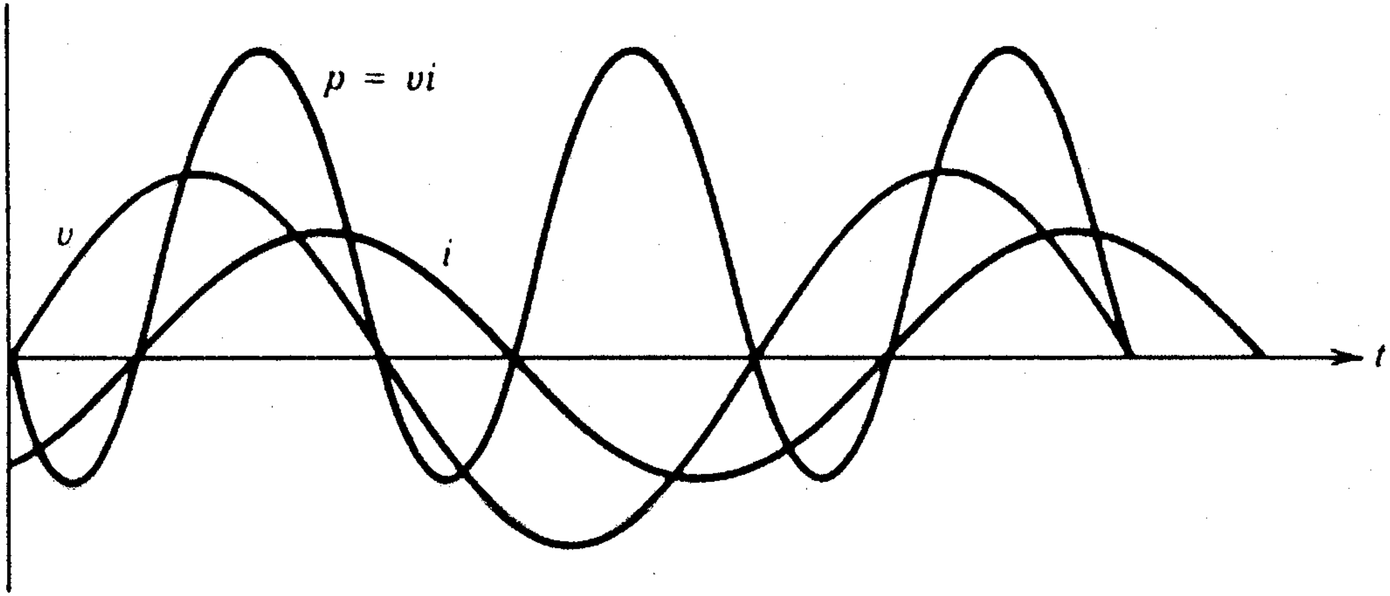
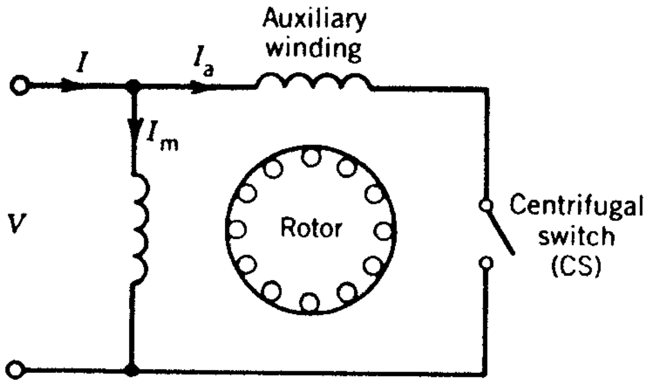


FIGURE 7.7 Waveforms of voltage, current, and power in single-phase induction machine.

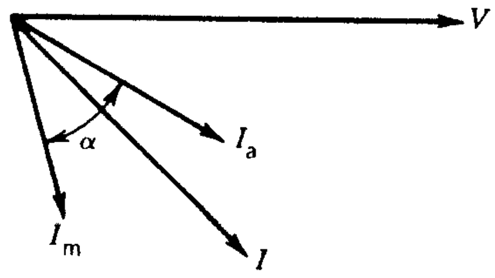
Other machines

- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase motors (7)
    - Single phase induction motors
        - Pulsating field
        - Starting methods
            - Split phase
            - Capacitor start
            - Capacitor run
            - Shaded pole
    - Single phase synchronous motors
- Universal motors

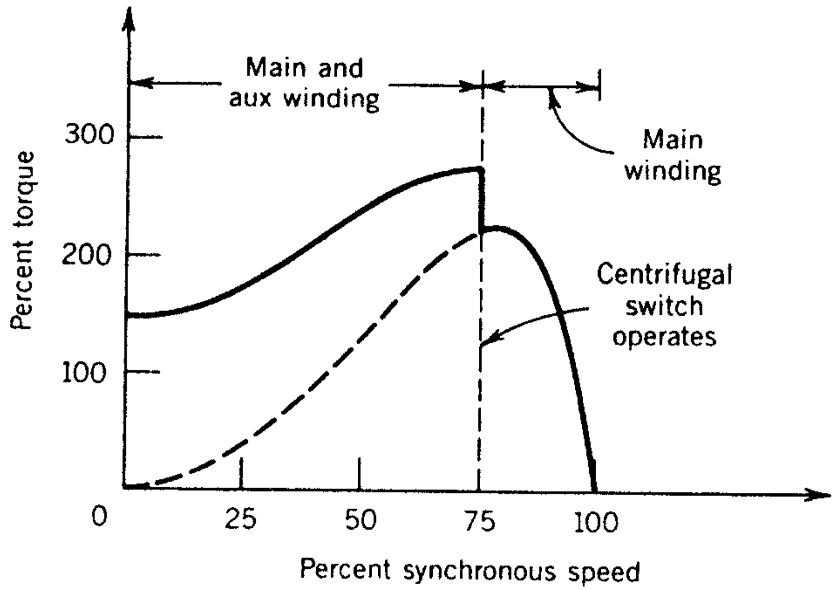
Split-phase induction motor



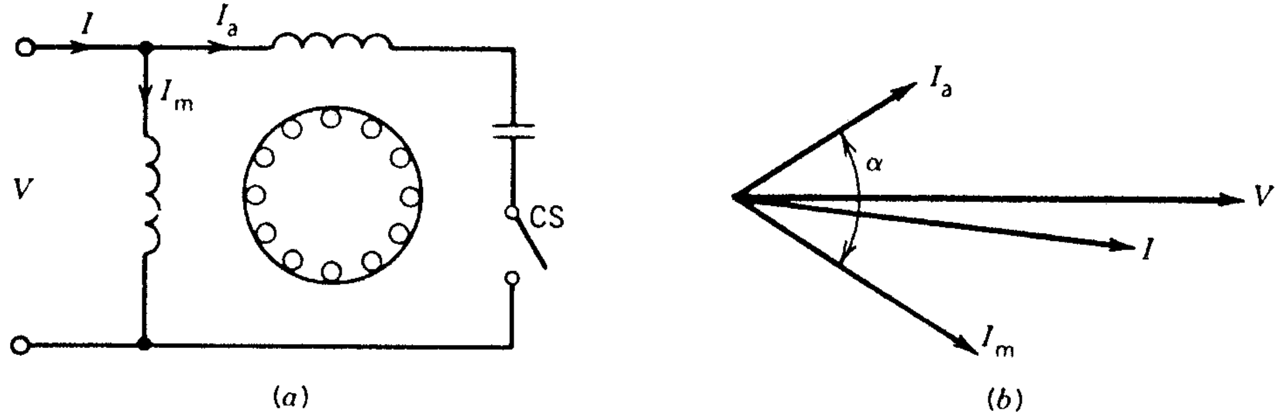
(a)



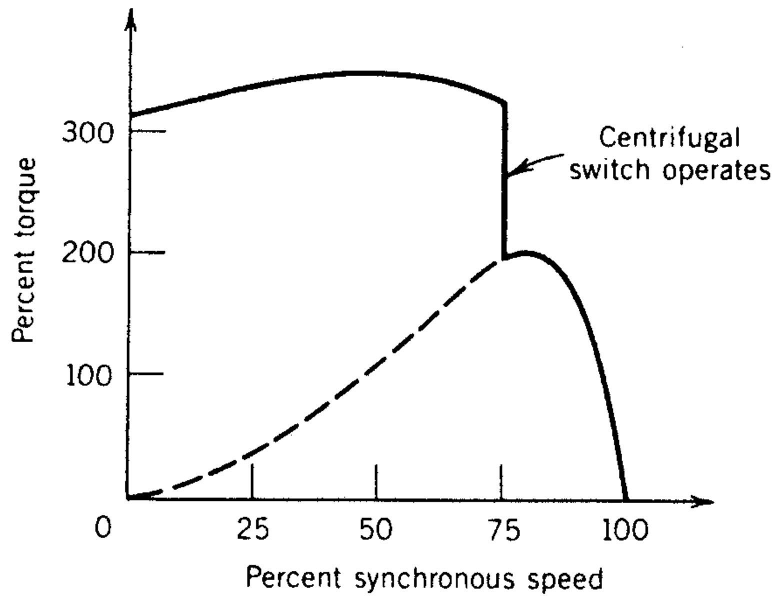
(b)



Capacitor-start induction motor



capacitor optimized
for starting



Capacitor-run induction motor

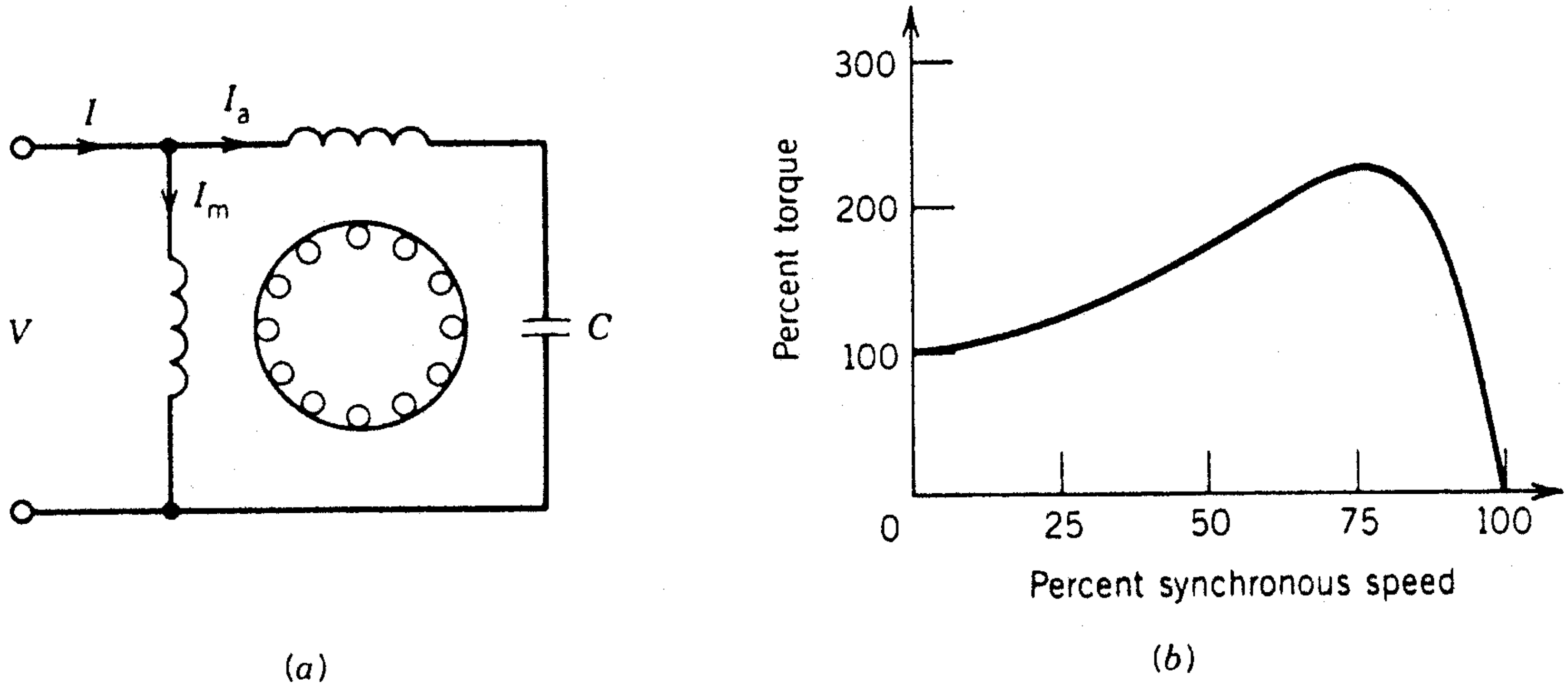


FIGURE 7.11 Capacitor-run induction motor.

capacitor compromise between starting and continuous torque

Shaded-pole induction motor

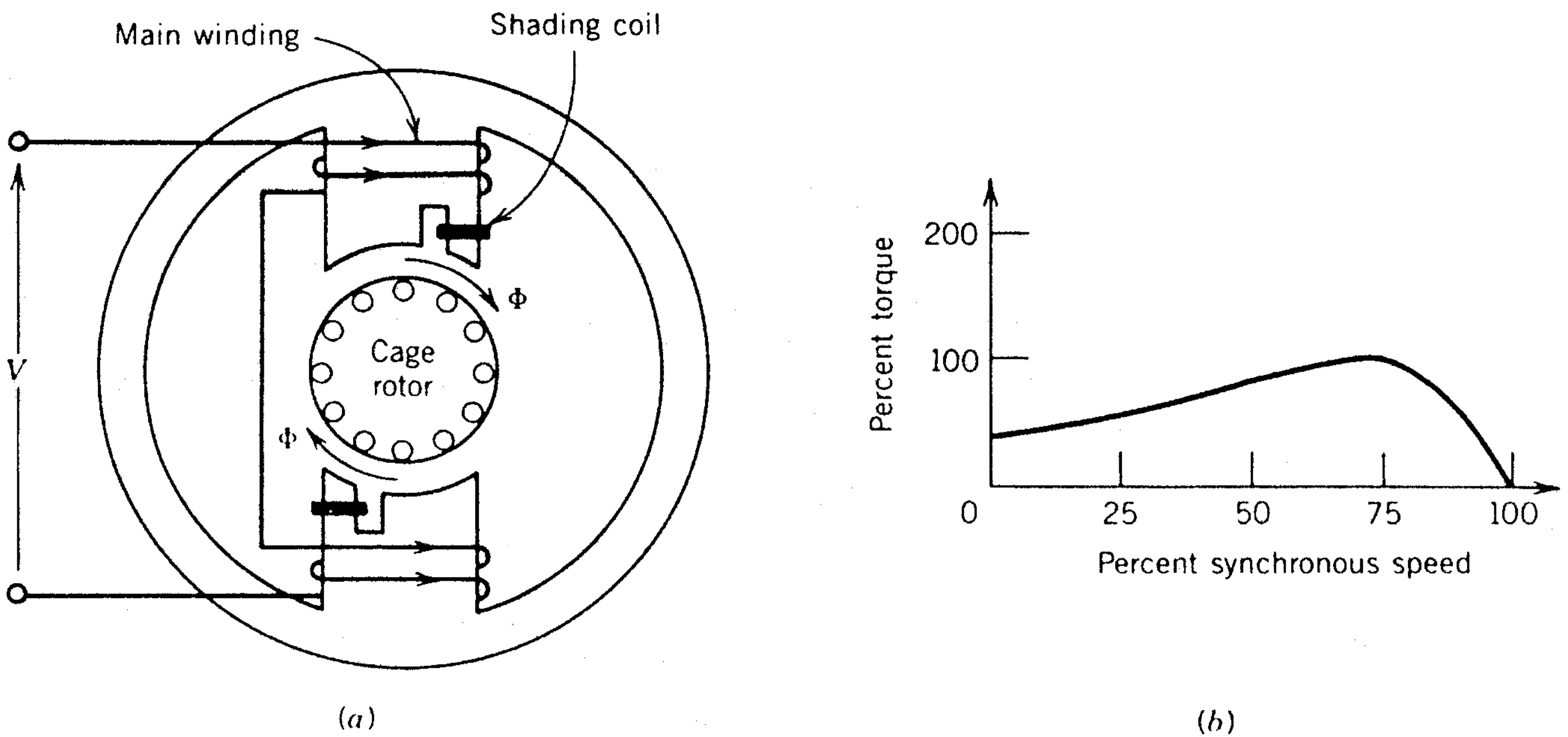


FIGURE 7.13 Shaded-pole induction motor.

Other machines

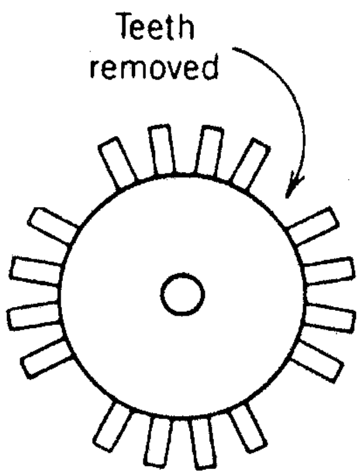
- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase machines (7)
    - Single phase induction motors
    - Single phase synchronous machines
- Universal motors

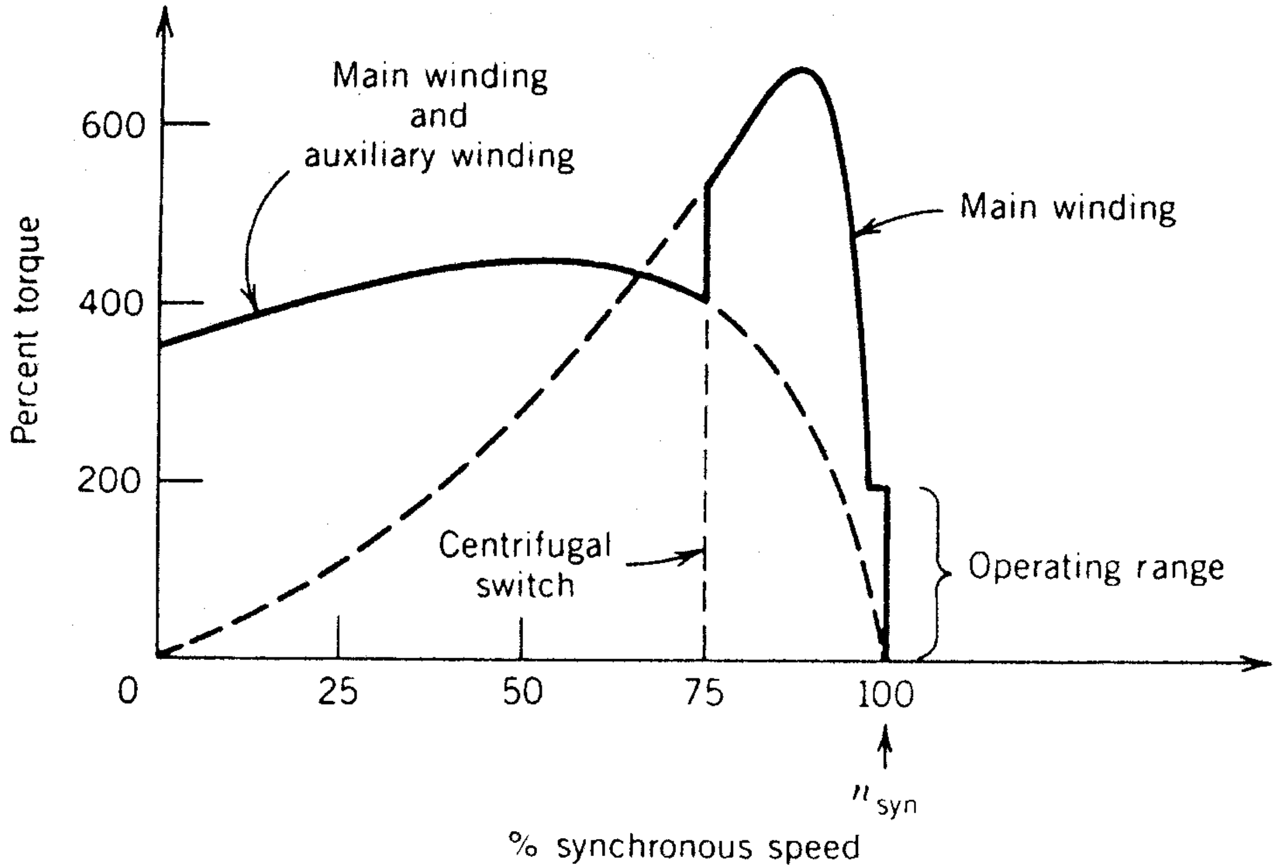
Single-phase synchronous machines

Types:
- synchronous PM (bicycle dynamo)
- synchronous reluctance (7.5.1)
- hysteresis (7.5.2)

Applications
- small generators
- clocks, timers
- turntables

Single-phase reluctance motors





Single-phase hysteresis motor

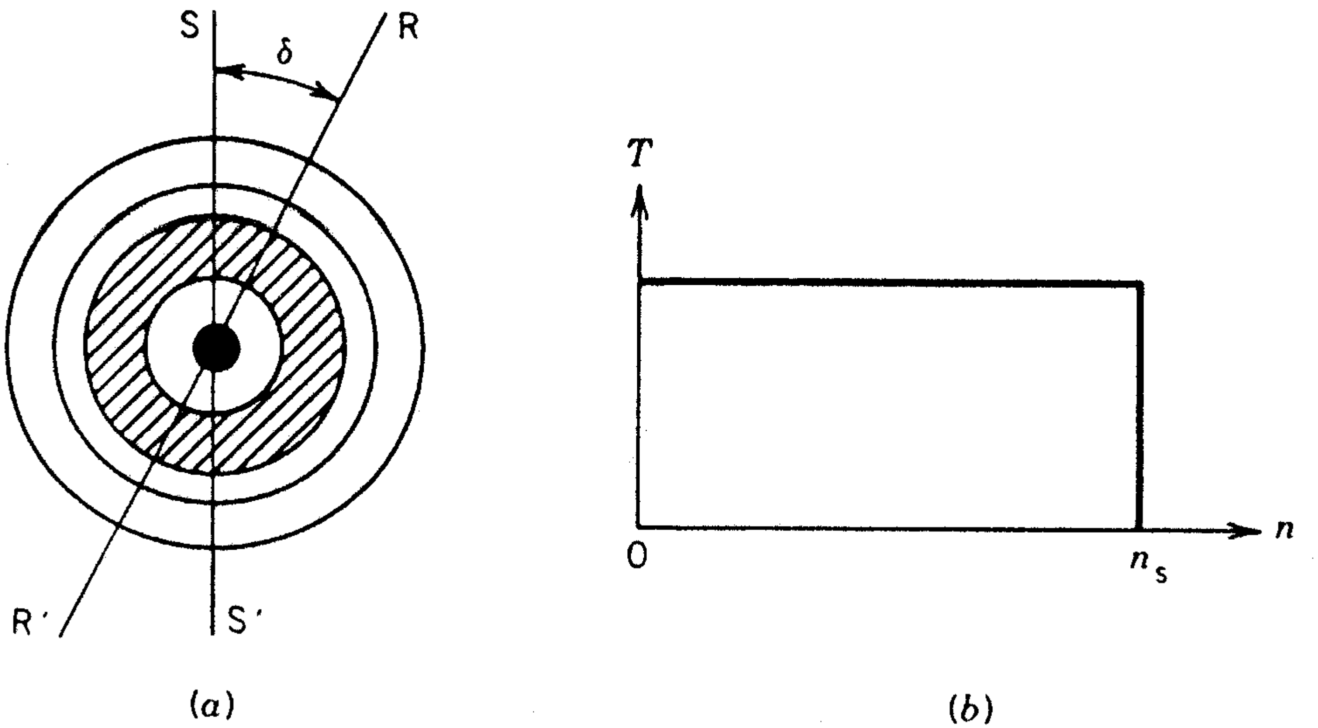


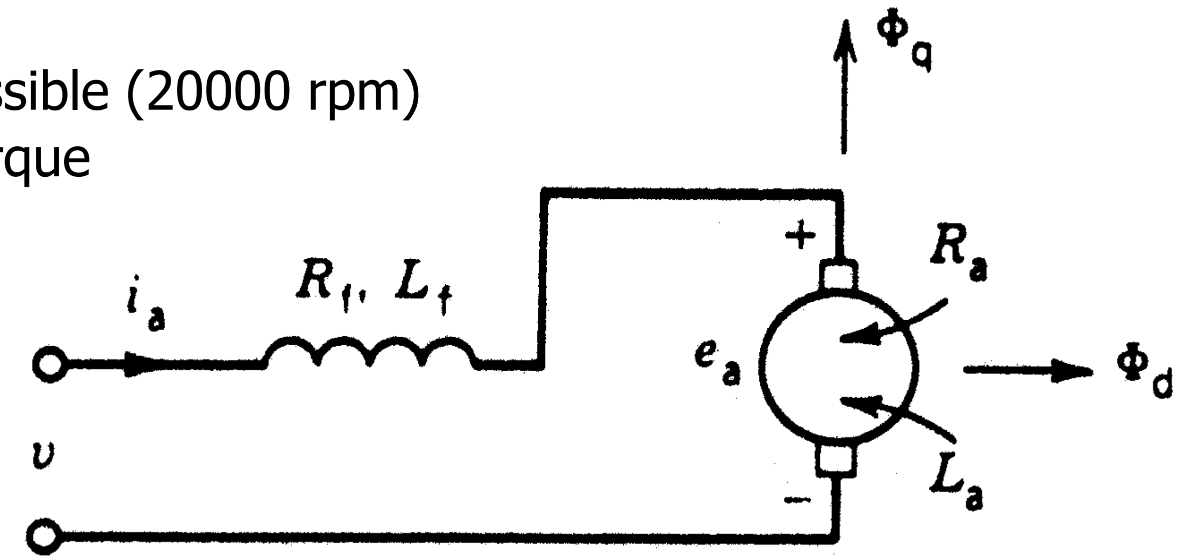
FIGURE 7.28 Hysteresis motor. (*a*) Stator and rotor field. (*b*) *T*–*n* characteristic.

Other machines

- Switched reluctance machine (6.14)
- Stepper motors (8.3)
- Single phase machines (7)
    - Single phase induction motors
    - Single phase synchronous machines
- Universal motors

Universal motor

- operate from AC or DC source
- applications:
  - vacuum cleaner
  - drilling-machine
- properties:
  - high speeds possible (20000 rpm)
  - high starting torque



Universal motor waveforms

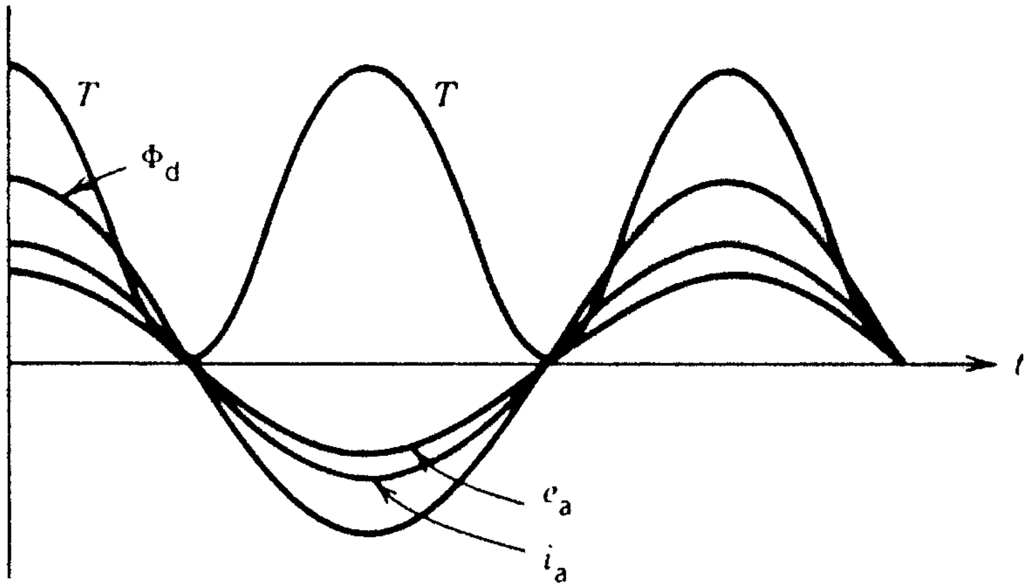


FIGURE 7.21 Voltage, current, flux, and torque waveforms.

Terminal voltage is shifted with respect to the emf because of the voltage drop over the inductance.

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Objectives: Overview over electric drives

- Students must be able to
  - recognize
  - sketch cross sections of
  - explain the principle of operation of
  - derive steady-state equations for voltage and torque of
  - mention suitable PE converter types used to drive
- the following types of electric machines
  - DC machines
  - induction (asynchronous) machines
  - synchronous machines
  - PMAC machines
  - switched reluctance, single-phase machines (qualitative)

Preparing your exam

- Study book, but do not forget
  - slides
  - old exams
- Important aspects covered in the slides but not in Sen
  - Maxwell
  - Permanent magnet machines
- Key elements of this course:
  - Ampere for calculating flux density $$\oint_{C_m} \vec{H} \cdot \vec{\tau}\,\mathrm{d}s = \iint_{S_m} \vec{J} \cdot \vec{n}\,\mathrm{d}A$$
  - Faraday for calculating voltages $$u = Ri + \frac{\mathrm{d}\lambda}{\mathrm{d}t}$$
  - Power balance for calculating forces and torques

Objectives: scientific methods

- Laws of nature:
  - Formulation of hypothesis
  - Validation by means of observations

- Development of theory / hypotheses
  - Starting points: laws of nature
  - Explicit assumptions
  - Sound derivations
  - Resulting equations, models
- Experimental validation

- Reduction of reality!!

Evaluation

- I would like to receive any feedback on this course:
  - course
  - use of blackboard
  - old examinations
  - laboratory work

Questions