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EE 315: Basic Electrical Engineering III**

Prepared by Brian Manhire, Ph.D.
Professor of Electrical Engineering



*Stocker Center, home of Ohio University's
Russ College of Engineering & Technology*

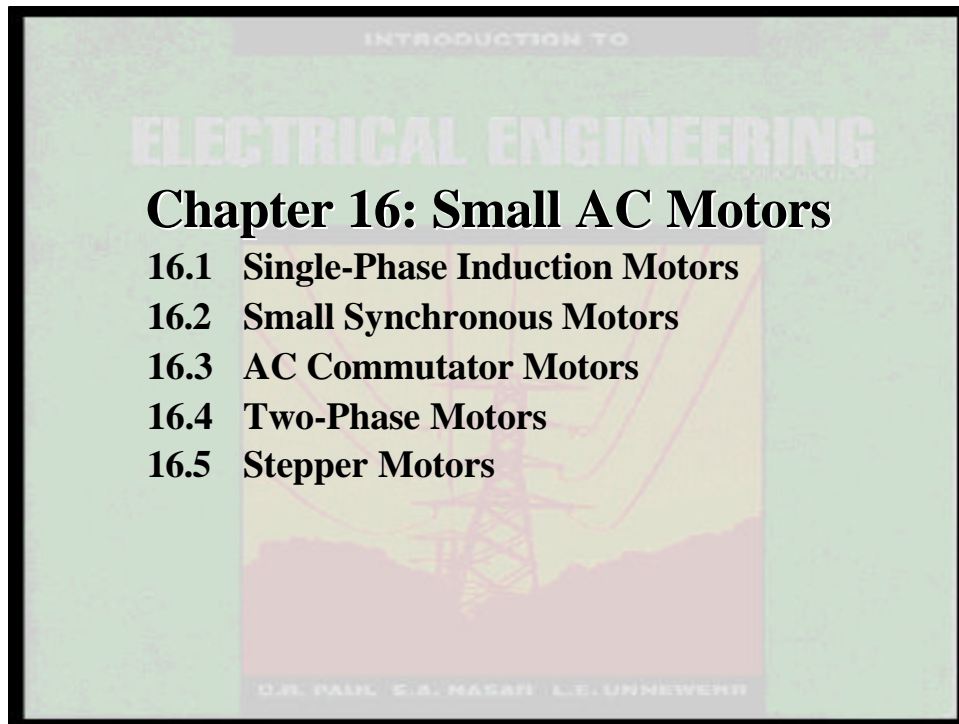
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For Part 3 of

**Introduction to Electrical
Engineering, 2/e**

**by C.R. Paul, S.A. Nasar
and L.E. Unnewehr**

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Introduction

In the vernacular, small AC motors means single-phase AC *fractional horsepower* motors (i.e., $< 1 \text{ hp} = 0.75 \text{ KW}$)

They are ubiquitous throughout the world!

The three most common types are:

1. Single-phase induction motors
2. Synchronous motors
3. AC Commutator (universal) motors

Special types include:

1. AC servomotors
2. Tachometers
3. Stepper motors

Only a qualitative overview is presented herein (see the textbook for more (quantitative) details)

Section 16.1: Single-Phase Induction Motors

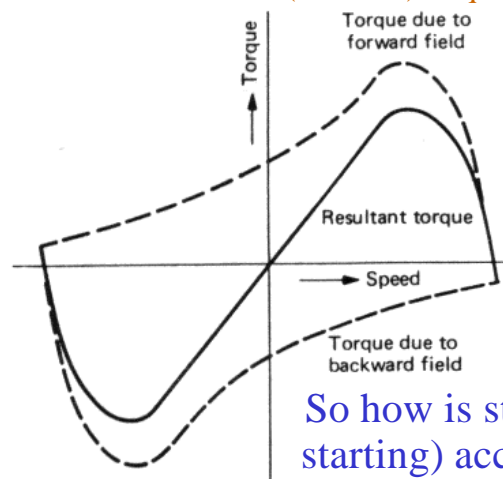
Applying single-phase AC voltage to the stator produces the magnetic field (flux density):

$$\begin{aligned} B(\theta,t) &= B_m \sin(\omega t) \cos(\theta) \\ &= (B_m/2) \sin(\omega t - \theta) \quad (\text{forward wave}) \\ &\quad + (B_m/2) \sin(\omega t + \theta) \quad (\text{backward wave}) \end{aligned}$$

The basic idea (explanation) of the motor's operation is that the motor favors one of the two revolving fields but not the other—such that its rotor experiences a net rotating stator field (ergo, the rotor chases this net rotating stator field)
(However, there is *no starting torque*)

Section 16.1: Single-Phase Induction Motors cont.

Note that, because the forward and backward torque-speed characteristics are negative mirror images of one another, the only speed for which there is no *net* (resultant) torque is standstill



Section 16.1: Single-Phase Induction Motors cont.

Mechanical Method

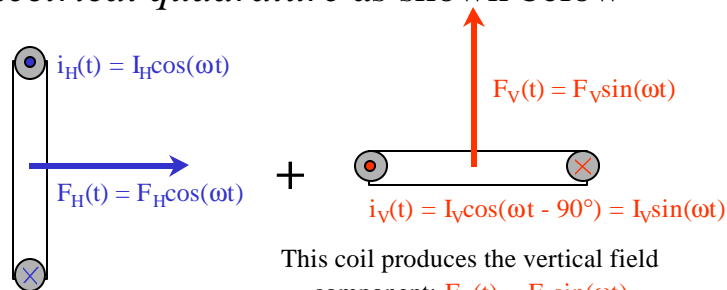
Tie a rope/strap around the rotor of the (electrically energized) motor and ***pull!***
(using another motor if necessary)

Note that the mechanical method can be used to troubleshoot a non-starting motor to see if the (yet to be described) electrical starting method(s) have failed (i.e.; if the motor won't start, but runs when coaxed mechanically, the problem is in the motor's (electrical) starting mechanism)

Section 16.1: Single-Phase Induction Motors cont.

Electrical Method(s)

Consider the hypothetical *two-phase motor* having two stator windings in *spatial (mechanical) quadrature* and stator currents in *electrical quadrature* as shown below



This coil produces the horizontal field component: $F_H(t) = F_H \cos(\omega t)$

This coil produces the vertical field component: $F_V(t) = F_V \sin(\omega t)$

Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

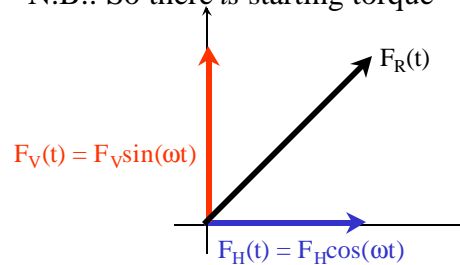
The resultant magnetic field (mmf) is:

$$\mathbf{F}_R(t) = \mathbf{F}_H(t) + j\mathbf{F}_V(t) = |\mathbf{F}_R(t)|\angle\theta(t)$$

Which for $\mathbf{F}_H(t) = F_H \cos(\omega t)$ and $\mathbf{F}_V(t) = F_V \sin(\omega t)$ with $F_H = F_V = F$ (by winding design) yields: $|\mathbf{F}_R(t)| = \sqrt{F_H^2 + F_V^2} = \sqrt{2}F$ (constant) and $\theta(t) = \tan^{-1}[F_V \sin(\omega t) / F_H \cos(\omega t)] = \tan^{-1}[\tan(\omega t)] = \omega t$ (linear)

Which describes a (stator field) vector of constant magnitude $\sqrt{2}F$ rotating CCW at a constant angular speed ω (which the rotor chases)

N.B.: So there *is* starting torque



Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

In single-phase induction motors, there are two windings (*starting* and *running*) in mechanical (spatial) quadrature which are energized by the motor's (single-phase) voltage supply. During startup, their currents are put *nearly* in electrical quadrature by phase-shifting them *nearly* 90° apart so as to realize (mimic) a (pseudo) two-phase motor (which *has* starting torque)

After the motor has begun to rotate (as a two-phase motor), the starting winding is withdrawn (e.g., via a centrifugal cutout switch) leaving the running (main) winding connected, which compels the motor to run as a single-phase (squirrel-cage) induction motor

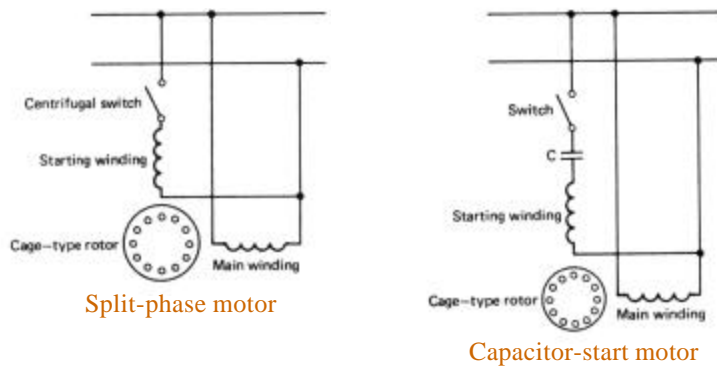
The two schemes used to achieve electric current quadrature are:

1. Split-phase motor
2. Capacitor-start motor

Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

In single-phase induction motors, the *starting* and *running* (main) windings are in *spatial* (mechanical) quadrature.

Given that they're both fed by the same single-phase electrical supply, *how are they also put in (nearly) electrical quadrature as well?*



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Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

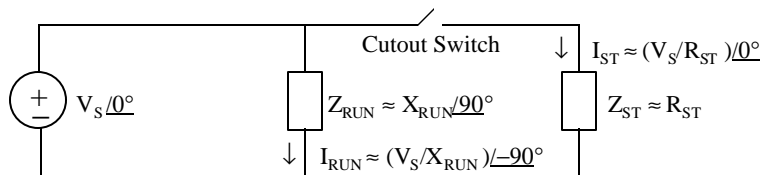
In the **split-phase motor**, the starting winding is designed for high resistance (thin wire) compared to its reactance ($R_{ST} \gg jX_{ST}$) so that:

$$Z_{ST} = R_{ST} + jX_{ST} \approx R_{ST} = R_{ST}/0^\circ$$

The running winding is designed to have the opposite impedance properties, namely $R_{RUN} \ll X_{RUN}$ (thick, low-resistance wire) so that:

$$Z_{RUN} = R_{RUN} + jX_{RUN} \approx jX_{RUN} = X_{RUN}/90^\circ$$

Then since the two windings are supplied from the same voltage source, it follows that the two winding currents will be 90° out of phase with each other



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Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

In the **capacitor-start motor**, the starting winding includes a series capacitor which reduces the overall reactance of the winding so that

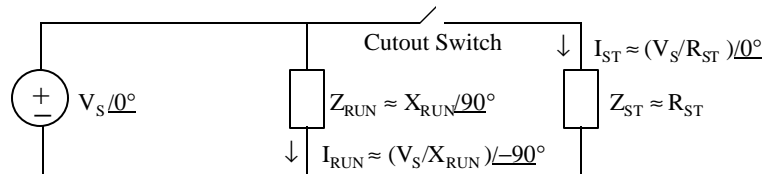
$$R_{ST} \gg |X_{NET}| = |jX_{ST} - jX_C| \text{ so that:}$$

$$Z_{ST} = R_{ST} + jX_{NET} \approx R_{ST} = R_{ST}/0^\circ$$

The running winding is designed to have mostly inductive reactance (thick, low-resistance wire) so that: $R_{RUN} \ll X_{RUN} \therefore$

$$Z_{RUN} = R_{RUN} + jX_{RUN} \approx jX_{RUN} = X_{RUN}/90^\circ$$

Again, since the two windings are supplied from the same voltage source, it follows that the two winding currents will be 90° out of phase with each other



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Section 16.1: Single-Phase Induction Motors cont. Electrical Method(s) cont.

In either the **split-phase motor** or **capacitor-start motor**, the starting and running (main) windings can be designed so as to produce winding mmfs that are nearly 90° (electrical) apart and as equal in magnitude as desired so as to produce an ersatz two-phase motor having starting torque

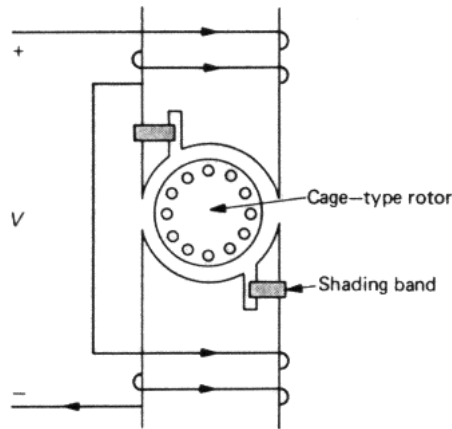
N.B.: If the winding mmfs aren't equal*, a rotating net mmf is produced nevertheless, but it "wobbles," i.e.; its *magnitude* varies with time

* Typically, $F_{ST} \neq F_{MAIN}$ for economical reasons. Unlike the relatively expensive main winding, which is designed to withstand full-load running duty, the starting winding need only be designed for (brief) startup duty—so it's less expensive to produce. The same economics applies to the capacitor-start motor's capacitor design requirements as well.

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Section 16.1: Single-Phase Induction Motors cont.
Electrical Method(s) cont.

Shaded-pole Motor



The shading bands alter the magnetic properties of the magnetic poles such that the maximum flux of the shaded and unshaded pole-portions occur at different times

This time delay results in a temporally progressive shift in the overall flux across the pole faces—tantamount to a rotating field (so there is both starting- and running torque)

Section 16.1: Single-Phase Induction Motors cont.

Type	hp Range	Applications
Split-phase	1/20 to 2	Constant-speed service where starting is easy. Fans, saws and grinders
Capacitor-start	1/6 to 2	Constant-speed service for any starting duty and quite operation where polyphase is not available. Ideal for all heavy duty drives such as compressors and pumps. High starting torque with low starting current.
Shaded Pole	1/300 to 1/6	Low power applications (small fans, blowers)

Source: A. Norton Chaston, *Electric Machinery*, Prentice-Hall (A Reston Book), Englewood Cliffs, 1986, pp. 326-328.

Section 16.2: Small Synchronous Motors

Reluctance and hysteresis motors are found in low-power applications (analog clocks, timers, turntables, etc.) and are described on text pp. 580-581

Section 16.3: AC Commutator Motors

Universal Motors

The universal motor is essentially a series (DC) motor with a laminated field structure (to reduce the hysteresis and eddy-current losses resulting from its applied AC voltage)

Because its field circuit is in series with armature circuit ...

It runs when supplied with AC voltage because ...

When the applied voltage reverses polarity (during its negative half cycle), *both* the armature current *and* the field current (and hence the field flux) reverse direction resulting in unidirectional torque on the armature during both the AC's positive and negative half cycles

See text pp. 582-584 for further details)

Section 16.4: Two-Phase Motors

Tachometers and Two-Phase Servomotors

These motors are usually found in instrumentation applications (tachometers) and control systems (two-phase servomotors)—see text pp. 584-585 for further information

Section 16.5: Stepper Motors

Stepper motors rotate in discrete angular steps (rather than run continuously) in response to electrical pulses supplied by (from) a control unit—see text pp. 586-588 for further information

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***We welcome your
questions with
Enthusiasm!!***



OHIO UNIVERSITY

School of Electrical Engineering
& Computer Science
Stocker Center
Athens OH 45701-2979

Brian Manhire, Ph.D.
Professor of Electrical
Engineering

740-593-1579 phone
740-593-0007 fax
bmanhire1@ohiou.edu

**School of Electrical Engineering
and
Computer Science**



Ohio University

Russ College of Engineering & Technology