IEEE
Std 58-1978
(Revision of IEEE Std
58-1956)

IEEE Standard
Induction Motor Letter Symbols

Sponsor

Rotating Machinery Committee of the
IEEE Power Engineering Society

The Institute of Electrical and Electronics Engineers, Inc.

Foreword

(This Foreword is not a part of IEEE Std 58-1978, Standard Induction Motor Letter Symbols.)

Originally issued as a trial-use standard in 1956, IEEE Standard Induction Motor Letter Symbols has been enlarged to reflect those additional symbols required by the state of the art, and it has been approved and published as a full-status IEEE Standard. It is expected that experience with the present document may generate interest in further additions or other modifications. Suggestions for changes should be forwarded to:

Secretary
IEEE Standards Board
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New York, NY 10017

At the time it approved this standard, the Working Group on Induction Motor Letter Symbols of the Induction Machinery Subcommittee of the Rotating Machinery Committee had the following members:

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IEEE Standard
Induction Motor Letter Symbols

1. Introduction ②

At present, technical papers on induction machinery use letter symbols selected by their authors. As a result, readers lose too much time becoming familiar with the symbols used by each author. It has long been felt by many in this field that a fair exchange of ideas on induction machinery would be promoted if all writers used the same letter symbols for the same quantities. A Working Group was set up by the Rotating Machinery Committee to develop a unified system of letter symbols that ~~could~~ can be used ① for this purpose. This standard is the outcome of a trial period of several years as a proposed standard.

The standard usually applies only to steady-state or quasi-steady-state conditions. ④

2. Scope

Section 8 gives the letter symbols for those quantities needed to define an induction motor in terms of a recognized equivalent circuit, with lumped constants or parameters. Section 9 gives the letter symbols for dimensional values. The~~se~~ symbols cover both polyphase and single-phase motors. ③ Every effort has been made to avoid use of the same symbol for different meanings.

3. Guiding Principles

It is not intended to recommend or to favor any particular theoretical approach. The symbols developed are suitable for wide application.

Letter symbols have been selected on as logical a basis as possible. Recognizing typewriter limitations, Greek letters have been avoided as much as possible.

Some of the principles used to set up the system of symbols covered in this report follow:

3.1 All secondary quantities (such as impedances,[1] currents, etc) are understood to be in primary winding terms, unless otherwise specified. In the case of single-phase motors primary winding terms mean the main winding terms unless otherwise indicated.

3.2 Impedances of a single winding only—such as a primary or secondary—are written in lower case letters.

3.3 Impedances of a combination of primary and secondary winding (all secondary windings if there are more than one) are written in upper case letters. (Partial exception: Z_f and Z_b do not include primary leakage impedance.)

3.4 Impedances of external auxiliary devices, such as capacitors, for example, are written in upper case letters.

3.5 The sum of two or more like impedances, both of which are written in upper case letters, is usually indicated by use of the single upper case letter with the two or more applicable subscripts. (Example: $R_a + R_c = R_{ac}$.) This rule does not apply to lower case symbols.

3.6 All impedances for three-phase motors refer to line-to-neutral quantities or equivalents, unless otherwise specified.

3.7 For polyphase single-cage and wound rotor motors, primary impedances are denoted by the subscript "1" and secondary impedances referred to the primary are denoted by a subscript "2."

3.8 For polyphase motors with more than one cage, the total impedance of all the secondary cages is denoted by a lower case letter with subscript "2." Leakage impedances of individual cages are denoted by single digits "3," "4,"

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[1] The word "impedance" as used in these guiding principles is understood to include resistance, and reactance terms, which follow the same rules.

"5," etc; "3" is used for the cage nearest the air gap, "4" for the next. That is, the cages are numbered consecutively starting at the air gap and working away from it. Mutual impedances between cages are denoted by use of multidigit (for example, two-digit) subscripts to indicate the cages concerned.

3.9 For single-phase motors, primary inpedances of the main winding are denoted by the subscript "1"; those of the auxiliary winding by "1a." Secondary impedances, referred to the main winding, are denoted the same as for polyphase motors. If secondary impedances are referred to the auxiliary winding, "a" is added to the subscript.

3.10 Magnetizing reactance is denoted by the symbol x_M which, in this report, means the apparent magnetizing reactance due to the space fundamental component of the mutual air-gap flux. For polyphase motors, this refers to the reactance voltage developed in each phase by the mutual air-gap flux set up by all the phases.

3.11 Total impedance, at any slip, is denoted by a single upper case letter with subscripts as follows:

(a) Polyphase motors, line-to-neutral—no subscript.
(b) Single-phase motors, main winding only —no subscript, or T. (When motor is running on main winding only, this is simply the ratio of impressed voltage divided by the current drawn; when both windings are energized, this is not true because of voltages induced from the other winding.)
(c) Single-phase motors, auxiliary phase impedance—T_a.

3.12 Impressed voltages are denoted by an upper case V,[2] with suitable subscripts as needed. Generally speaking, these are the same as for impedances, so far as practicable. The positive direction of the voltage should be indicated.

3.13 Impedance drop and induced voltages are denoted by an upper case E, with suitable subscripts, generally paralleling the subscripts used for impedance quantities.

3.14 Root-mean-square currents are indicated by an upper case I with suitable subscripts, generally the same as the impedance through which the current flows.

3.15 Efforts have been made to keep to a minimum the number of subscripts. However, it is recognized that there are not enough single subscripts. Consequently, double subscripts are frequently used, and occasionally triple subscripts, particularly when the logic of the situation makes the double or triple subscript easier to learn.

3.16 Additional subscript letters can usually be avoided by use of explanatory notes. However, if necessary, they may be added to indicate quantities at specific slips as follows:

(a) "L" for locked-rotor quantities,
(b) "o" for no-load quantities,
(c) "fl" for full-load quantities.

3.17 For certain other areas, some of which are covered explicitly in this standard, the following subscripts are recommended.

(a) for shading-coil quantities in shaded-pole motors: s;
(b) for positive-sequence quantities: [2] p;
(c) for negative-sequence quantities; [2] n;
(d) for zero-sequence quantities: [2] z;
(e) for direct-axis quantities (two-reaction theory): d;
(f) for quadrature-axis quantities (two-reaction theory): q.

The circuits employed to illustrate the letter symbols are not to be interpreted as official or necessarily recommended. They are merely typical and serve to illustrate the usage of the symbols. It is hoped that authors using other circuits will follow the guiding principles as far as possible. When other circuits are developed, using quantities not covered by the guiding principles of this standard, it is recommended that the author of the paper show the correlation between the new quantities he is establishing in terms of the quantities given in

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[2] ANSI Y10.5-1968 recommends designating the symmetrical components of the currents and potential differences in unbalanced polyphase systems by adding double subscripts to the symbols. The first subscript designates phase and the second designates the sequence; 1 for positive, 2 for negative, and 0 for zero sequence. Subscripts 1 and 2 have been so firmly established in the literature of induction-motor theory as identification of primary and secondary quantities that the above shown usage of p, n, and z are herein recommended.

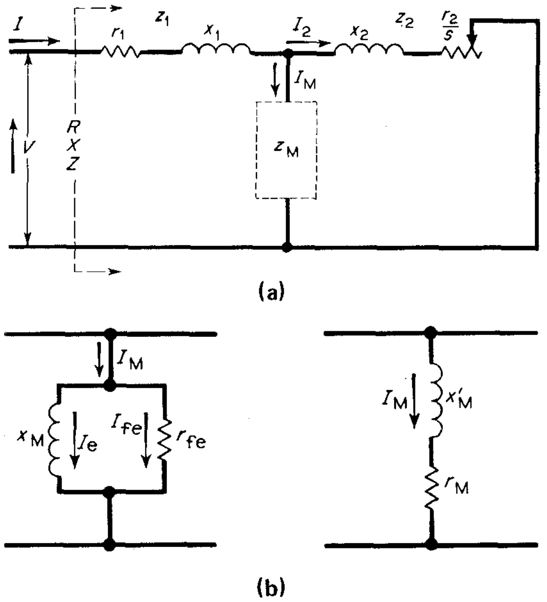


Fig 1
Equivalent Circuit of a Polyphase Induction Motor, with Alternate Iron Loss Circuits
(a) Basic Circuit
(b) Alternate Methods of Showing Z_M

this standard, so far as possible. (For an example of this practice, see Figs 8 and 9.)

4. Polyphase Motors

For a single-cage or wound rotor motor, a commonly used equivalent circuit is shown in Fig 1. The letter symbols recommended are shown. At no-load, the line current I becomes I_o. For load conditions, the symbols would be as shown. For locked-rotor conditions the subscript L can be used (example I_L and r_{2L}) if it is not convenient to indicate otherwise, that is, by note or prefatory phrase, that these are values with rotor locked.

For double- and triple-cage rotors, equivalent circuits with letter symbols are given in Fig 2. The cages are numbered consecutively away from the air gap, starting with "3." If the cages have independent end rings, all individual impedance quantities, r_3, r_4, r_5, x_3, x_4, and x_5 include resistances and the leakage reactances of the end rings. If the rotor has common end rings, these quantities refer to the resistances and leakage reactances of the bars of cages, 3, 4, and 5, respectively; and in this case, the resistance and leakage reactance values of the end rings are r_e and x_e.This numbering system can be extended to any number of cages and any other combinations.

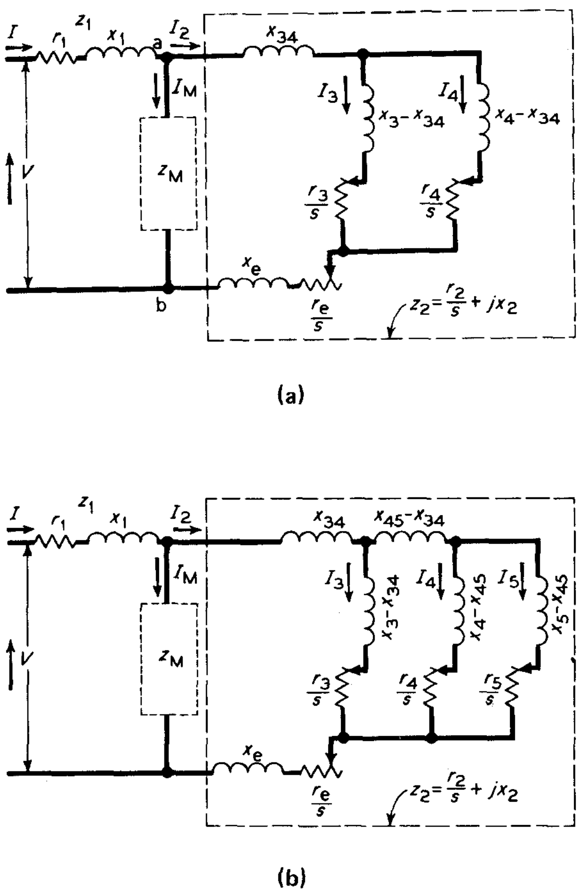


Fig 2
Equivalent Circuits for Multiple-Cage Polyphase Induction Motors
(a) Double-Cage Motor (b) Triple-Cage Motor

Wound-rotor motors involve actual quantities referred to the secondary as well as some referred to the primary. Recommended additional symbols for line-to-neutral quantities are:

Leakage impedance of rotor winding referred to itself
$= Z_{22} = r_{22} + jx_{22}$.
Impedance of external secondary controller, actual
$= Z_{2x} = r_{2x} + jx_{2x}$.
Impedance of external secondary controller, referred to the stator
$= Z_x = r_x + jx_x$.
Actual current in slip ring $= I_{22}$.
Actual secondary voltage, line-to-neutral $= E_r$.
Actual secondary voltage, ring-to-ring $= \sqrt{3}E_r$.

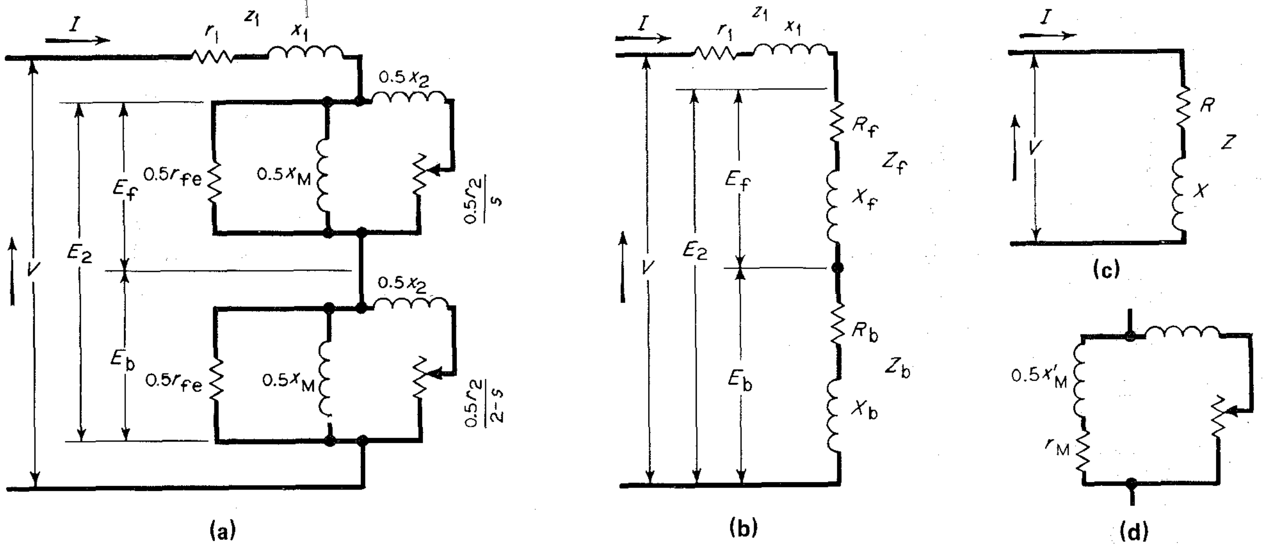


Fig 3
Equivalent Circuit of a Single-Phase Induction Motor Running on Main Winding Only — Revolving-Field Theory
(a) Detailed Circuit (b) Simplified Circuit (c) Simple Circuit (d) Alternate Iron Loss Circuit

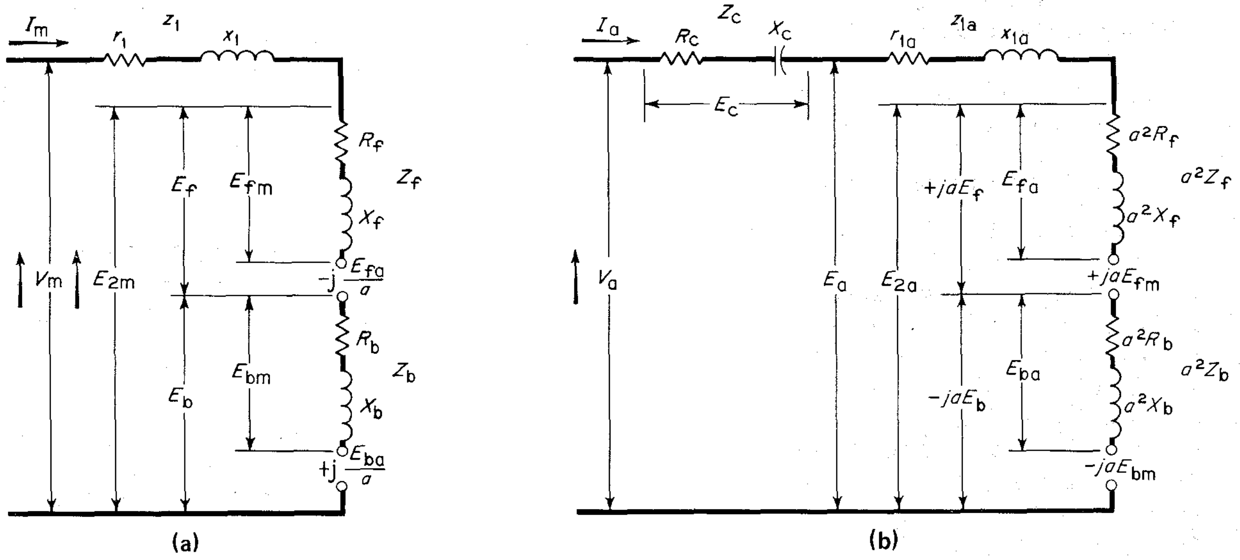


Fig 4
Equivalent Circuit of a Capacitor Motor Running with Both Windings Energized — Revolving-Field Theory
(a) Main Winding (b) Auxiliary Winding

A guide for nomenclature of polyphase motors under unbalanced conditions is shown by the equivalent circuits of Fig 12. The case of unbalanced voltages is shown, which may serve as a guide for extension to the cases of specific unbalanced windings.

Phase voltages and currents are used. Phase *A* is used as the reference phase. Positive sequence is in the order from phase *A* to *B*.

5. Single-Phase Motors—Revolving-Field Theory

Circuits and applicable letter symbols are illustrated in Figs 3, 4, and 5.

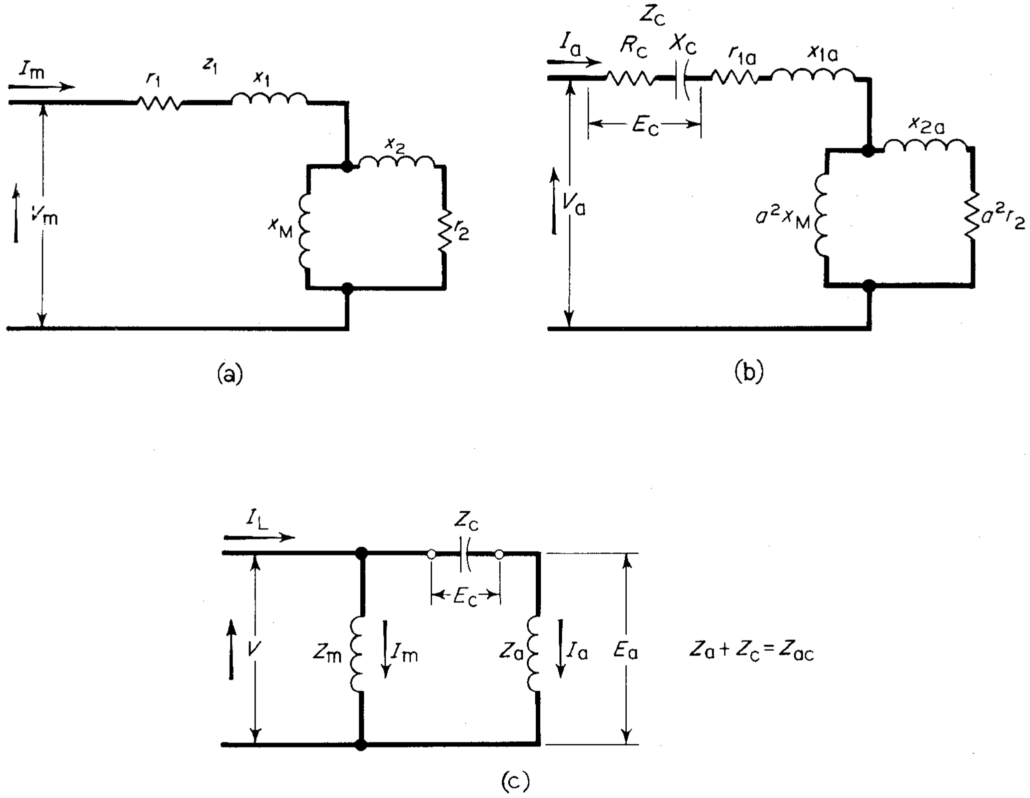


Fig 5
Equivalent Circuits of a Capacitor Motor
Under Locked-Rotor Conditions
(a) Main Winding (b) Auxiliary Winding
(c) Simplified Circuit

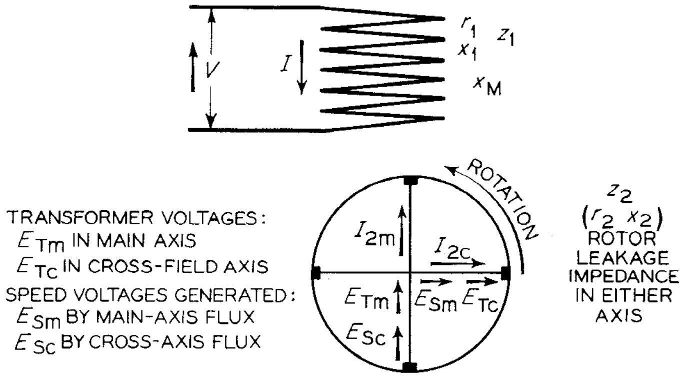


Fig 6
Schematic Representation of a
Single-Phase Motor — Cross-Field Theory

6. Single-Phase Motors—Cross-Field Theory

Quantities needed to define a single-phase induction motor in terms of the classical cross-field theory are given in Fig 6, wherein the three circuits are represented. Fig 7 shows the fluxes according to this theory. Fig 6 represents the motor in terms of three coupled circuits. By suitable transformations of the equations of these basic circuits, numerous network-type circuits have been developed.

Fig 8 shows a network-type circuit where the quantities involved are defined in terms of the same fundamental quantities of Fig 6.

Fig 9 shows another network-type circuit in which new symbols, I_a, I_b, and E_{ab}, are introduced for convenience, because the relationship of these circuit quantities to those of Fig 6 is more complex.

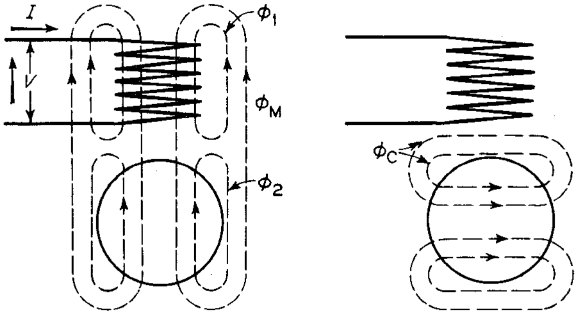


Fig 7
Fluxes in a Single-Phase Motor — Cross-Field Theory

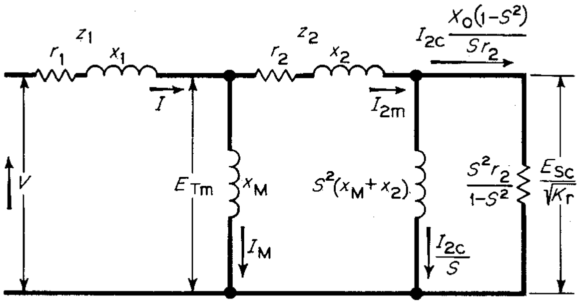


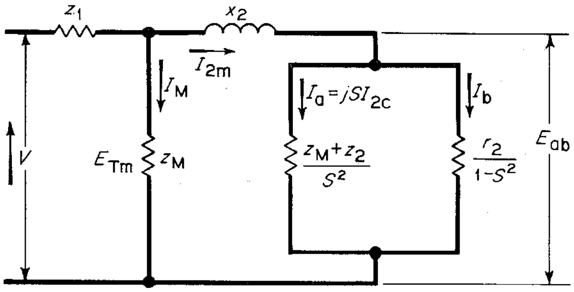
Fig 8
One Form of the Equivalent Circuit, Based on the Cross-Field Theory

A capacitor motor with windings in space quadrature is represented, according to the cross-field approach, in terms of four coupled circuits in Fig 10. Here the auxiliary axis coincides with the cross axis.

Fig 11 shows one network-type circuit developed from Fig 10 with the significant quantities defined in terms of those of Fig 10.

7. Single-Phase Motors—Symmetrical Components Theory

Fig 13 shows a symmetrical components circuit and applicable letter symbols.



$$I_b = jI_{2c}\frac{1-s^2}{sr_2}(z_M+z_2)$$

$$E_{ab} = \frac{E_{Sc}}{s^2}\left(1-\frac{jr_2}{x_M+x_2}\right)$$

Fig 9
Another Form of Equivalent Circuit for the Single-Phase Motor, Based on the Cross-Field Theory

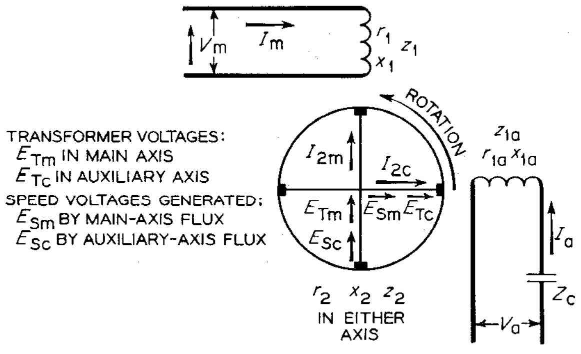


Fig 10
Schematic Representation of a Capacitor Motor Running with Both Windings Energized — Cross-Field Theory

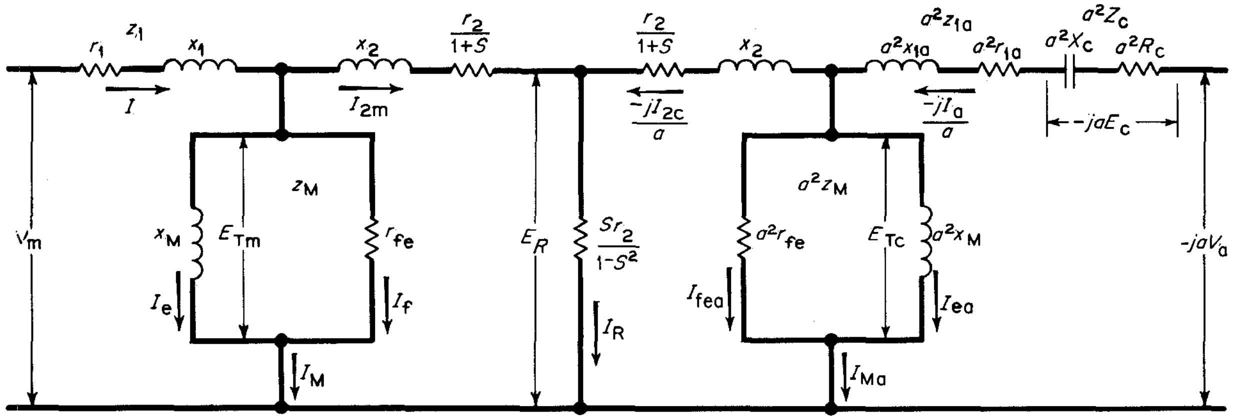
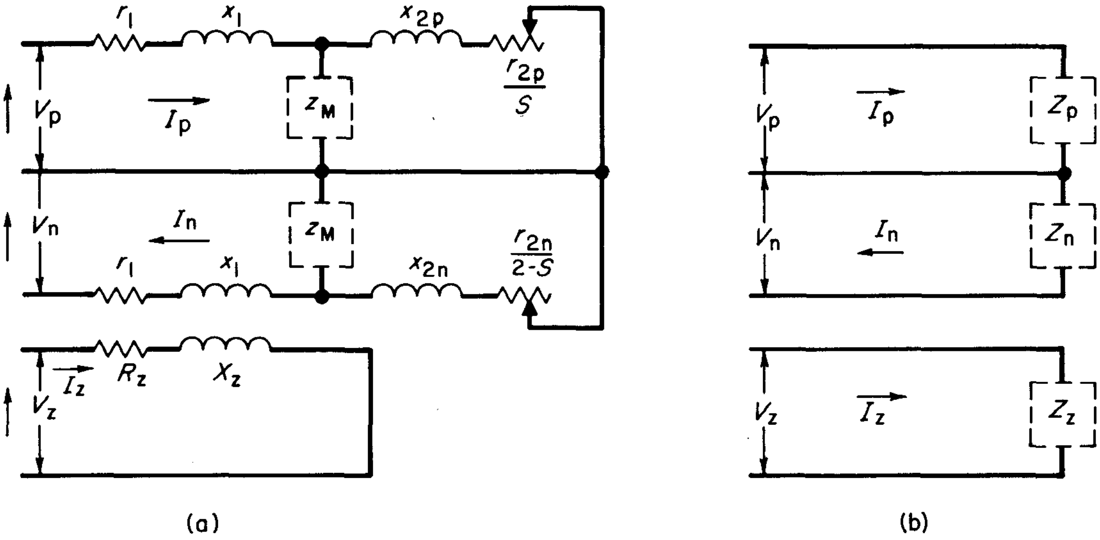


Fig 11
An Equivalent Circuit (Network Form) for the Capacitor Motor Running with Both Windings Energized — Cross-Field Theory



(a)

(b)

Two Phase

$$V_P = \frac{1}{2}(V_A + j\,V_B)$$

$$V_n = \frac{1}{2}(V_A - j\,V_B)$$

$$V_Z = 0$$

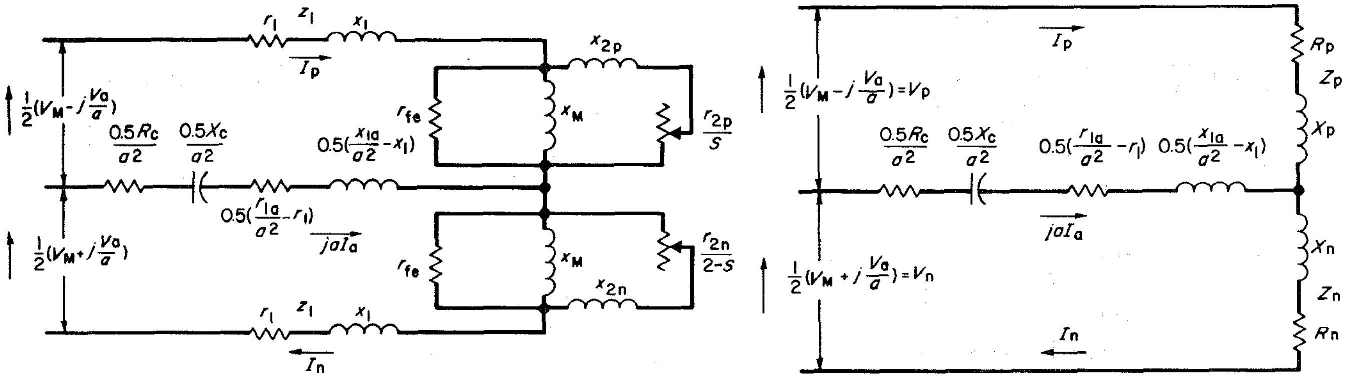
Three Phase

$$V_P = \frac{1}{3}(V_A + V_B \angle 120 + V_C \angle 240)$$

$$V_n = \frac{1}{3}(V_A + V_B \angle 240 + V_C \angle 120)$$

$$V_Z = \frac{1}{3}(V_A + V_B + V_C)$$

Fig 12
Equivalent Circuits for Polyphase Motors with Unbalanced Voltages — Symmetrical Component Theory
(a) Detailed Circuits (b) Simplified Circuits



(a) (b)

Fig 13
Equivalent Circuit of a Capacitor Motor Running with Both Windings Energized — Symmetrical Component Theory (a) Detailed Circuit (b) Simplified Circuit (These Circuits Simulate One-Half the Total Power of the Motor)

8. Letter Symbols for Equivalent Circuit

Symbol	Use	Description
a	single-phase motor	$= \frac{\text{effective conductors in auxiliary winding}}{\text{effective conductors in main winding}}$
b	polyphase wound-rotor	$= \frac{\text{effective conductors per phase in primary}}{\text{effective conductors per phase in secondary}}$
E_2	polyphase motor and single-phase motor	total voltage induced in primary (main) winding by space fundamental component of mutual air-gap flux
E_2a	single-phase motor two windings revolving-field theory	total voltage induced in auxiliary winding by space fundamental component of mutual air-gap flux
E_2m	single-phase motor two windings revolving field theory	total voltage induced in main winding by space fundamental component of mutual air-gap flux
Ea	single-phase motor two windings	voltage across auxiliary winding
Eab	single-phase motor cross-field theory	fictitious voltage used in equivalent circuit of Fig 9 (*q.v.*)
E_b	single-phase motor	voltage induced in main winding by total backward-field flux
E_{ba}	single-phase motor	voltage induced in auxiliary winding by backward-field component of auxiliary winding flux
E_{bm}	single-phase motor two windings revolving field theory	voltage induced in main winding by backward-field component of main-winding flux

Symbol	Use	Description
E_c	capacitor motor	voltage across capacitor
E_f	single-phase motor revolving field theory	voltage induced in main winding by total forward-field flux
E_{fa}	single-phase motor two windings revolving field theory	voltage induced in auxiliary winding by forward-field component of auxiliary-winding flux
E_{fm}	single-phase motor two windings revolving field theory	voltage induced in main winding by forward-field component of main-winding flux
E_R	single-phase motor two windings cross-field theory	fictitious voltage used in circuit of Fig 11 (*q.v.*)
E_r	wound-rotor motor	actual secondary voltage, line-to-neutral
E_{Sc}	single-phase motor cross-field theory	voltage induced in main axis of rotor by rotation through cross-axis flux
E_{Sm}	single-phase motor cross-field theory	voltage induced in cross axis of rotor by rotation through main-axis flux
E_{Tc}	single-phase motor cross-field theory	transformer voltage induced in cross axis (by cross-axis flux)
E_{Tm}	single-phase motor cross-field theory	transformer voltage induced in main axis (by main-axis flux)
f	polyphase motor and single-phase motor	frequency
I	polyphase motor	primary current per phase
I	single-phase motor	line current
I_2	polyphase motor	secondary current, referred to primary; in multiple-cage machines, the total secondary current
I_3	polyphase motor multiple cage	secondary current in cage 3 (the cage nearest the air gap)
I_4	polyphase motor multiple cage	secondary current in cage 4 (see paragraph 3.8 of Guiding Principles)
I_5	polyphase motor multiple cage	secondary current in cage 5 (see paragraph 3.8 of Guiding Principles)
I_{22}	wound-rotor motor	actual secondary current per ring
I_{2c}	single-phase motor cross-field theory	secondary current in cross-field axis
I_{2m}	single-phase motor cross-field theory	secondary current in main-field axis
I_a	single-phase motor; two windings	auxiliary winding current
I_a	single-phase motor; cross-field theory	fictitious current in Fig 9 (*q.v.*) $I_a = jSI_2c$
I_b	single-phase motor cross-field theory	fictitious current in Fig 9 (*q.v.*)
I_e	polyphase motor	exciting or magnetizing current, excluding iron-loss component
I_e	single-phase motor; cross-field theory	exciting or magnetizing current flowing in main winding

Symbol	Use	Description
I_f	capacitor motor cross-field theory	that portion of main-winding current supplying fundamental-frequency iron losses
I_{fa}	capacitor motor cross-field theory	that portion of auxiliary winding current supplying fundamental-frequency iron loss
I_{fe}	polyphase motor	that portion of primary current that supplies iron losses
I_{fl}	polyphase motor and single-phase motor	full-load current (optional)
I_L	polyphase motor and single-phase motor	locked-rotor current (optional)
I_M	polyphase motor and single-phase motor	magnetizing current, including iron-loss component
I_m	single-phase motor two windings	main-winding current
I_n	polyphase motor and single-phase motor	negative sequence current
I_o	polyphase motor and single-phase motor	no-load current
I_p	polyphase motor and single-phase motor	positive sequence current
I_R	single-phase motor two windings cross-field theory	fictitious current in circuit of Fig 11.
I_Z	polyphase motor	zero sequence current
K_1	polyphase motor and single-phase motor	$K_1 = \frac{x_M}{x_M + x_1}$
K_r	polyphase motor and single-phase motor	$K_r = K_1K_2$ $K_r = K_1^2$ if $x_1 = x_2$
K_2	polyphase motor and single-phase motor	$K_2 = \frac{x_M}{x_M + x_2}$
m	polyphase motor	number of phases
p	polyphase motor and single-phase motor	number of poles
q	polyphase motor and single-phase motor	paths in parallel
R	polyphase motor and single-phase motor	real component of motor impedance, per phase. For single phase, applies on main-winding operation only; in this case, same as R_T
R_a	single-phase motor	real component of locked-rotor impedance, auxiliary winding only
R_{ac}	capacitor motor	real component of locked-rotor impedance of auxiliary winding phase, including capacitor
R_b	single-phase motor revolving-field theory	real component of apparent impedance to backward field, including magnetizing impedance (see Fig 3)
R_c	capacitor motor	equivalent series resistor representing losses in capacitor
R_f	single-phase motor revolving-field theory	real component of apparent impedance to forward field, including magnetizing impedance (see Fig 3)
R_m	single-phase motor	real component of locked-rotor impedance, main winding, including rotor
R_n	polyphase motor and single-phase motor	real component of apparent impedance to negative sequence field (see Figs 12 and 13)

Symbol	Use	Description
R_p	polyphase motor and single-phase motor	real component of apparent impedance to positive sequence field (see Figs 12 and 13)
R_{mac}	capacitor motor	real component of locked-rotor impedance of following, connected in series: main winding, auxiliary winding, and capacitor
R_T	single-phase motor revolving-field theory	real component of total impedance of main winding at any slip, s, $R_T = r_1 + R_f + R_b$
R_{Ta}	single-phase motor revolving-field theory	real component of total impedance of auxiliary winding at any slip, s, $R_{Ta} = R_c + r_{1a} + a^2 (R_f + R_b)$
R_z	polyphase motor	real component of apparent impedance to zero sequence field (see Fig 12)
r_1	polyphase motor	primary resistance per phase
r_1	single-phase motor	resistance of main winding
r_2	polyphase motor	secondary resistance, referred to primary. For multiple-cage rotors, this represents resistive component of total rotor impedance, referred to primary (Fig 2)
r_2	single-phase motor	secondary resistance, referred to main winding, equivalent two-phase value
r_{2n}	polyphase motor and single-phase motor	secondary resistance at rotor frequency of negative sequence field (see Figs 12 and 13)
r_{2p}	polyphase motor and single-phase motor	secondary resistance at rotor frequency of positive sequence field (see Figs 12 and 13)
r_3	polyphase motor multiple cage	resistance of cage 3 (the one nearest the air-gap) (see text)
r_4	polyphase motor multiple cage	resistance of cage 4 (the next cage inward from cage 3)
r_5	polyphase motor multiple cage	resistance of cage 5 (the innermost cage of a triple-cage motor)
r_{22}	wound-rotor motor	actual ac resistance of secondary, line-to-neutral
r_{2x}	wound-rotor motor	actual ac resistance of external secondary controller, line-to-neutral
r_e	polyphase motor multiple cage	resistance of end rings common to all cages, referred to primary
r_{fe}	polyphase motor and single-phase motor	resistance in parallel with magnetizing reactance, to simulate iron losses
r_M	polyphase motor and single-phase motor	resistance in series-circuit representation of z_M, to simulate iron loss (Figs 1 and 3)
r_x	wound-rotor motor	resistance to external controller in secondary circuit, referred to primary
S	single-phase motor cross-field theory	$S = \frac{\text{actual speed of rotor}}{\text{synchronous speed}}$
s	polyphase motor and single-phase motor revolving-field theory	slip of motor, expressed as a fraction of synchronous speed
V	polyphase motor	impressed voltage per phase
V	single-phase motor	voltage impressed on main winding
V_A	polyphase motor	voltage impressed on phase A

Symbol	Use	Description
V_a	single-phase motor two windings revolving-field theory	total voltage impressed on phase (outside of capacitor, if any, see Fig 4)
V_B	polyphase motor	voltage impressed on phase *B*
V_C	polyphase motor	voltage impressed on phase *C*
V_m	single-phase motor two windings revolving-field theory	total voltage impressed on main phase
V_n	polyphase motor and single-phase motor	impressed negative sequence voltage per phase
V_p	polyphase motor and single-phase motor	impressed positive sequence voltage per phase
V_z	polyphase motor	impressed zero sequence voltage per phase
X	polyphase motor and single-phase motor	reactive component of motor impedance, per phase; for single phase, applies to main-winding only or, "ideal" short-circuit reactance $X = x_1 + \frac{x_2 x_M}{x_M + x_2}$
X_a	single-phase motor	reactive component of locked-rotor impedance, auxiliary winding only
X_{ac}	capacitor motor	reactive component of locked-rotor impedance of auxiliary winding phase, including capacitor
X_b	single-phase motor revolving-field theory	reactive component of apparent impedance to backward field, including magnetizing impedance (see Fig 3)
X_c	capacitor motor	reactance of external capcitor (negative sign for capacitive reactance)
X_f	single-phase motor revolving-field theory	reactive component of apparent impedance to forward field, including magnetizing impedance (see Fig 3)
X_m	single-phase motor	reactive component of locked-rotor impedance, main winding
$X_{m\,ac}$	capacitor motor	reactive component of locked-rotor impedance of following, connected in series: main winding, auxiliary winding, and capacitor. Sign is negative when reactance is capacitive
X_n	polyphase motor and single-phase motor	input reactance to negative sequence field (see Figs 12 and 13)
X_o	polyphase motor and single-phase motor	total primary (or "open-circuit") reactance = $x_1 + x_M$
X_p	polyphase motor and single-phase motor	input reactance to positive sequence field (see Figs 12 and 13)
X_r	single-phase motor revolving-field theory	reactive component of total impedance of main winding at any slip, *s*, $X_r = x_1 + X_f + X_b$
X_{Ta}	single-phase motor revolving-field theory	reactive component of total impedance of auxiliary winding at any slip, *s*. $X_{Ta} = X_c + x_{1a} + a^2 (X_f + X_b)$
X_z	polyphase motor	input reactance to zero sequence field (see Fig 12)
x_1	polyphase motor	primary leakage reactance per phase

Symbol	Use	Description
x_1	single-phase motor	primary leakage reactance of main winding
x_2	polyphase motor	secondary leakage reactance, referred to primary. For multiple-cage rotors, this represents reactive component of total rotor impedance, referred to primary (Fig 2)
x_2	single-phase motor	secondary leakage reactance, referred to main winding, equivalent two-phase value
X_{2n}	polyphase motor and single-phase motor	secondary leakage reactance to negative sequence field (see Figs 12 and 13)
X_{2p}	polyphase motor and single-phase motor	secondary leakage reactance to positive sequence field (see Figs 12 and 13)
x_3	polyphase motor multiple cage	leakage reactance of cage 3 (the one nearest the air-gap) (see text)
x_4	polyphase motor multiple cage	leakage reactance of cage 4 (the next cage inward from cage 3)
x_5	polyphase motor multiple cage	leakage reactance of cage 5 (the innermost, or deepest cage of a triple-cage motor)
x_{22}	wound-rotor motor	leakage reactance of rotor winding, referred to itself
x_{34}	polyphase motor multiple cage	mutual reactance between cages 3 and 4
x_{45}	polyphase motor multiple cage	mutual reactance between cages 4 and 5
x_{2x}	wound-rotor motor	reactance of external controller in secondary circuit, actual line-to-neutral value
x_e	polyphase motor multiple cage	leakage reactance of end rings common to all cages, referred to primary
x_M	polyphase motor and single-phase motor	apparent magnetizing reactance due to space fundamental component of the mutual air-gap flux
x_M	polyphase motor and single-phase motor	equivalent magnetizing reactance used in series-circuit representation of z_M (see Fig 1)
x_x	wound-rotor motor	reactance of external controller in secondary circuit, referred to primary
Z	polyphase motor and single-phase motor	motor impedance, per phase, $Z = V/I$ on single phase, applies to main winding only
Z_a	single-phase motor	locked rotor impedance of auxiliary winding only
Z_{ac}	capacitor motor	total locked rotor impedance of auxiliary winding phase, including capacitor
Z_b	single-phase motor revolving-field theory	apparent impedance to backward field, including magnetizing reactance, excluding stator leakage impedance.
Z_c	capacitor motor	impedance of capacitor
Z_f	single-phase motor revolving-field theory	apparent impedance to forward field, including magnetizing reactance, excluding stator leakage impedance.
Z_m	single-phase motor	locked rotor impedance of main winding
$Z_{m\,ac}$	capacitor motor	locked rotor impedance of following, connected in series: main winding, auxiliary winding, and capacitor
Z_n	polyphase motor and single-phase motor	input impedance to negative sequence voltage (see Figs 12 and 13)

Symbol	Use	Description
Z_{p}	polyphase motor and single-phase motor	input impedance to positive sequence voltage (see Figs 12 and 13)
Z_{T}	single-phase motor revolving-field theory	total impedance of main winding at any slip, s $Z_{\mathrm{T}} = R_{\mathrm{T}} + jX_{\mathrm{T}}$
Z_{Ta}	single-phase motor revolving-field theory	total impedance of auxiliary winding at any slip, s $Z_{\mathrm{T}}a = R_{\mathrm{Ta}} + jX_{\mathrm{Ta}}$
Z_Z	polyphase motor	input impedance to zero sequence voltage (see Fig 12)
z_1	polyphase motor	primary leakage impedance per phase
z_1	single-phase motor	primary leakage impedance, main winding
z_2	polyphase motor	secondary leakage impedance, referred to primary
z_2	single-phase motor	secondary leakage impedance, referred to main winding, equivalent two-phase value
z_{22}	wound-rotor motor	leakage impedance of rotor winding, referred to itself
$z_{2\mathrm{x}}$	wound-rotor motor	impedance of external controller in secondary circuit, actual line-to-neutral value
z_{M}	polyphase motor and single-phase motor	impedance of magnetizing branch of equivalent circuit; may include iron loss
z_{x}	wound-rotor motor	impedance of external controller in secondary circuit, referred to primary
ϕ_1	polyphase motor and single-phase motor	primary leakage flux
ϕ_2	polyphase motor and single-phase motor	secondary leakage flux
ϕ_{c}	single-phase motor cross-field theory	cross-field flux
ϕ_{M}	polyphase motor and single-phase motor	space fundamental component of mutual air-gap flux

8.1 Additional Subscripts. Use of these subscripts, usually added to others, is recommended for specific values of certain constants when it is inconvenient or undesirable to indicate the meaning in the written text. See also Sections 3.16 and 3.17.

Symbol	Description
d	direct-axis quantities (two-reaction theory)
fl	full-load quantities
L	locked-rotor quantities
n	negative-sequence quantities
o	no-load quantities
p	positive-sequence quantities
q	quadrature-axis quantities (two-reaction theory)
s	shading-coil quantities in shaded pole motor
z	zero-sequence quantities

9. Letter Symbols for Dimensional Values

A_{b} — bar area
A_{g} — air-gap area per pole
A_{r} — end ring area
A_{t1} — effective stator tooth section area per pole
A_{t2} — effective rotor tooth section area per pole
A_{y1} — effective stator yoke magnetic section area
A_{y2} — effective rotor yoke magnetic section area
A_1 — net winding area of stator slot
A_2 — net winding area of rotor slot
b_{w} — width of tooth at wedge — see Fig 14
b_1 — effective stator tooth width — (this is equal to the tooth width for parallel-sided teeth)

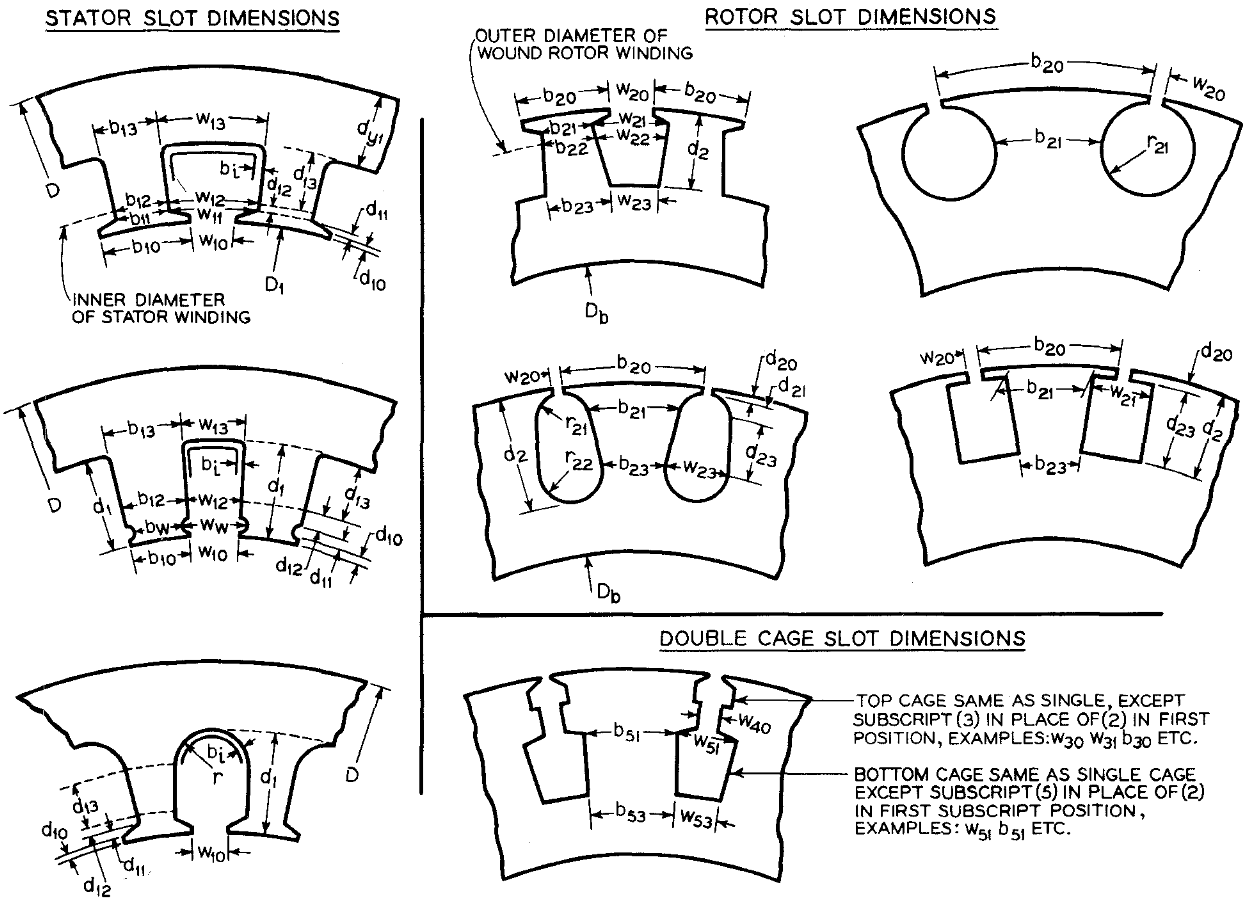


Fig 14
Stator and Rotor Slot Dimensions

b_2 — effective rotor tooth width
b_{10} —
b_{11} —
b_{12} —
b_{13} —
b_{20} — see Fig 14
b_{21} —
b_{22} —
b_{23} —
b_{51} —
b_{53} —
b_i — insulation width in slot
C — series conductors per phase
C_{sk} — skew factor
D — outside diameter of finished stator core
D_b — rotor bore diameter
D_e — diameter at the centroid of winding area in slot
D_f — diameter across stator flats

D_i — inside diameter of end ring at the core
D_o — outside diameter of end ring at the core
D_r — effective diameter of current flow in end ring
D_y — diameter at inside of yoke or slot bottom
D_w — outer diameter of stator end winding
D_1 — stator bore diameter
D_2 — finished diameter of rotor
D_{11} — diameter at wedge circle
d_b —
d_{b23} — see Fig 15
d_r —
d_w —
d_{y1} — depth of stator yoke
d_{y2} — depth of rotor yoke (laminated portion)
d_1 — depth of stator slot

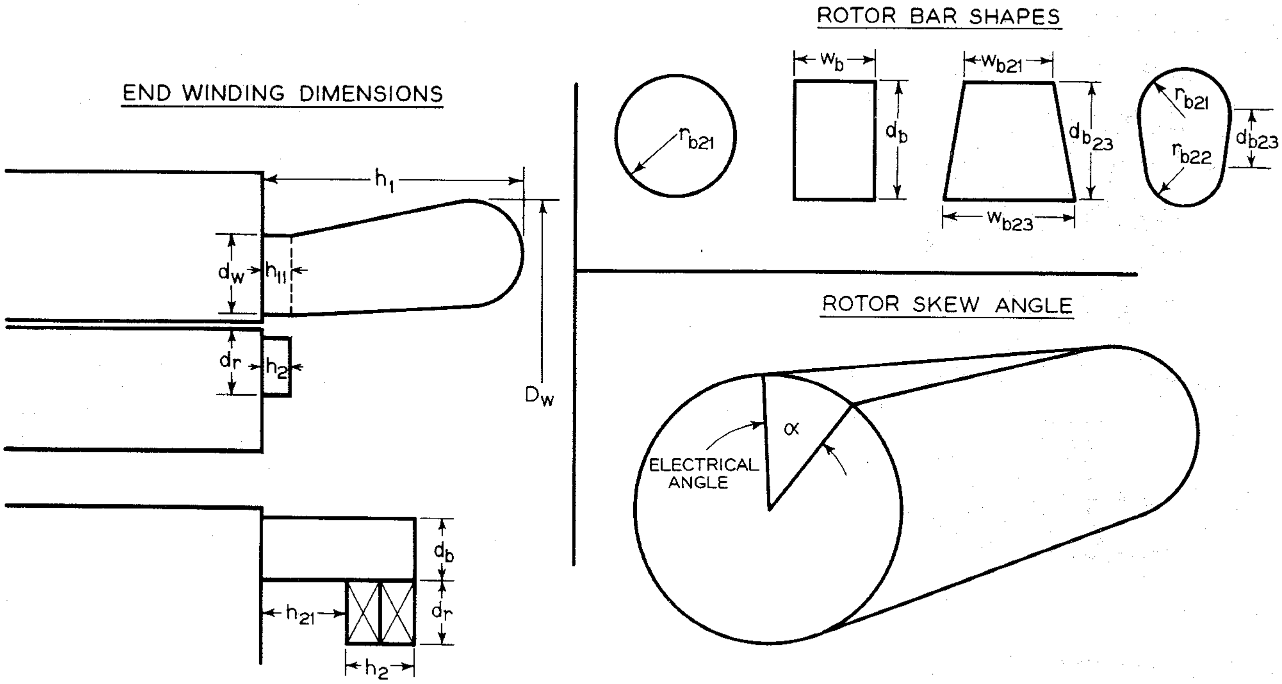


Fig 15
End Winding Dimensions, Rotor Bar Shapes and Skew Angle

d_2 — depth of rotor slot
d_{10} —
d_{11} —
d_{12} —
d_{13} — see Fig 14
d_{20} —
d_{21} —
d_{23} —
F — stacking factor
g — length of single air gap
g_e — effective length of single air gap
h_1 —
h_2 — see Fig 15
h_{11} —
h_{21} —
k_d — distribution factor
k_p — pitch factor
k_w — winding factor, usually the product of pitch and distribution factors
L — measured stack length less ducts (if any)
L_g — gross stack length
n — actual rotational speed
n_s — synchronous rotational speed

N_v — Number of radial vent ducts
r — see Fig 14
r_{b21} — see Fig 15
r_{b22} —
r_{21} — radii of rotor slots, see Fig 14
r_{22} —
S_1 — number of stator slots
S_2 — number of rotor slots
w_b —
w_{b21} — see Fig 15
w_{b23} —
w_v — width of radial vent duct
w_w —
w_{10} —
w_{11} —
w_{12} —
w_{13} —
w_{20} — see Fig 14
w_{21} —
w_{22} —
w_{23} —
w_{40} —
w_{51} —
w_{53} —
α — rotor skew angle. See Fig 15