Slide #01

ECET 3000

Electrical Principles

3Φ Squirrel Cage Induction Motors

1

Three-Phase Induction Machines

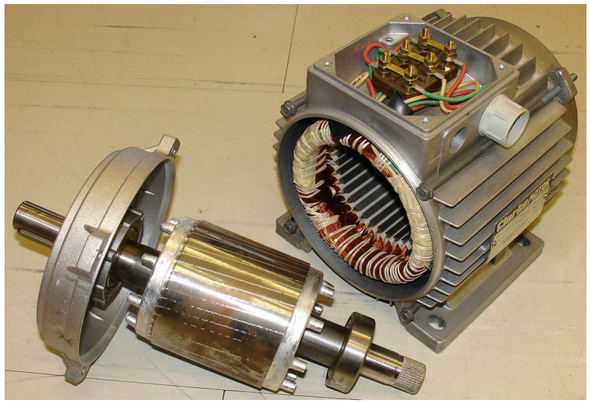
The <u>Three-Phase (3Φ) Induction Motor</u> is a type of AC motor that is commonly used to drive mechanical loads.

Although different versions of the induction motor exist, this presentation will cover the <u>Squirrel-Cage</u> type of induction motor since that type is widely used in industry due to its extreme durability, its operational characteristics, and its ease of control, especially when supplied by a Variable Frequency Drive (VFD).

*** - a VFD is a power-electronic device that produces a 3Φ, variable-frequency (and magnitude) voltage in order to control the operation of an AC motor.**

2

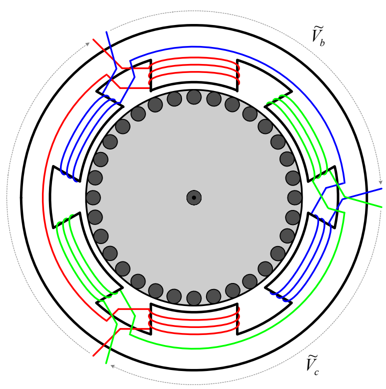
Three-Phase Induction Machines



The Three-Phase (3Φ) Induction Machine consists of a <u>stator</u> (stationary portion) and a <u>rotor</u> that are separated by a small air-gap.

3

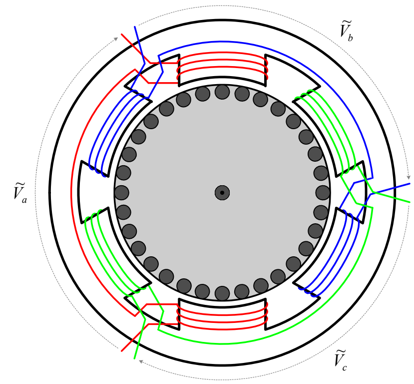
Induction Machine Construction



The <u>stator</u> is the stationary (outer) portion of the machine. It provides the primary magnetic field required for operation. This field will be referred to as the "stator field".

4

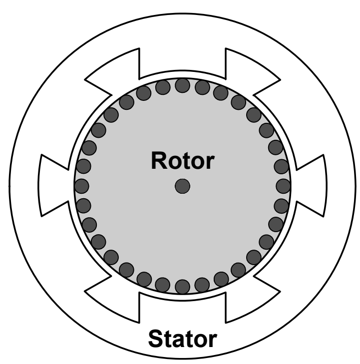
Induction Machine Construction



The **rotor** is the rotational portion of the machine that provides the mechanism for energy conversion (elec→mech or mech→elec) as it interacts with the stator field.

5

Squirrel-Cage Rotor



The construction of the rotor determines the type of induction machine. As stated, this presentation will focus on the **Squirrel-Cage** type of rotor construction.

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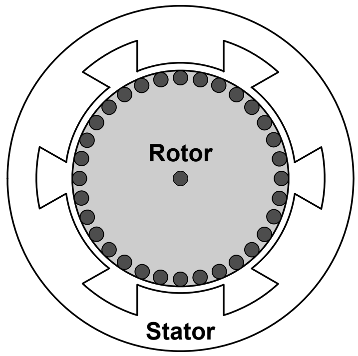
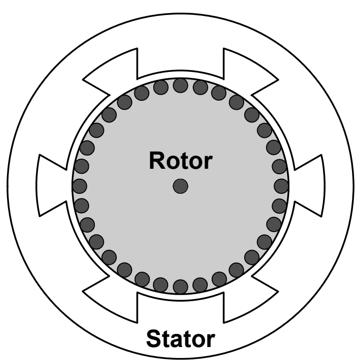
Squirrel-Cage Rotor



A “Squirrel-Cage” rotor is constructed as a cylinder with a set of conductive bars embedded just under its surface, allowing for only a small air-gap between the rotor and the stator.

7

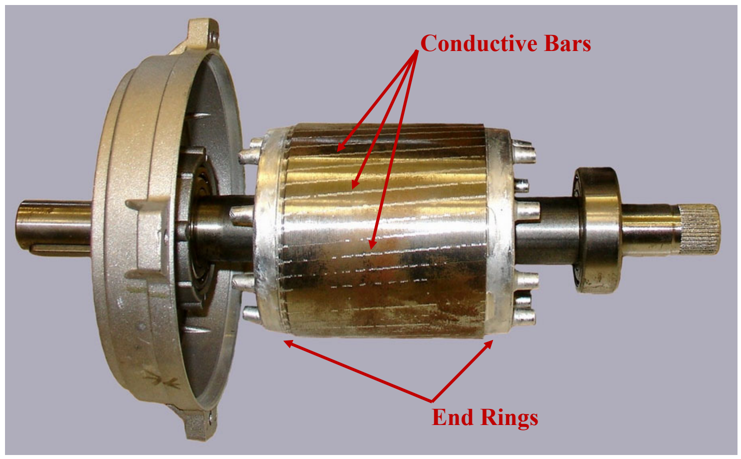
Squirrel-Cage Rotor



The ends of the conductive bars are shorted together by a pair of conductive rings, forming the “Squirrel-Cage” aspect of the rotor and providing closed-loop paths for currents to flow.

8

Squirrel-Cage Rotor



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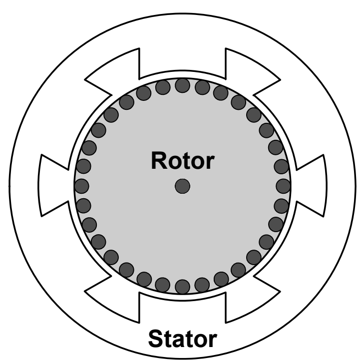
Squirrel-Cage Rotor



Note – The rotor itself is constructed using laminated sheets of steel. The laminations provide insulation between the sheets, preventing currents from flowing length-wise through the rotor unless they actually travel through the embedded conductive bars.

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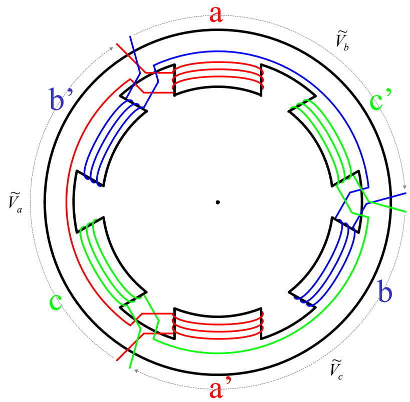
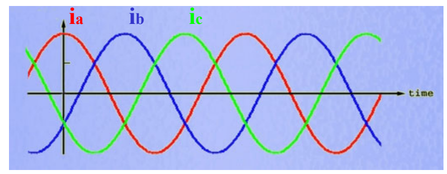
3Φ Induction Machine Stator

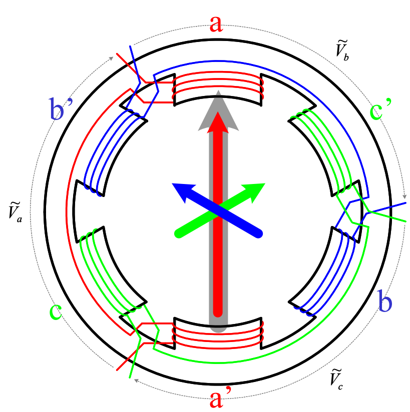


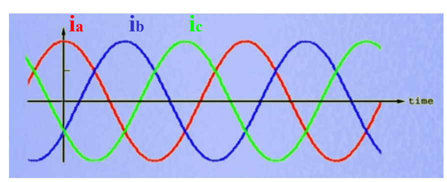


The stator of the machine has three symmetrically-placed windings through which a balanced set of 3Φ currents will flow when supplied by a balanced, 3Φ voltage source.

11

3Φ Stator Windings





Each winding current induces an instantaneous magnetic field, the vector sum of which results in a net magnetic field that passes linearly through the "rotor region".

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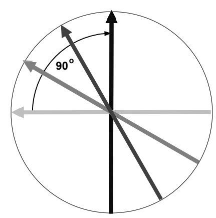
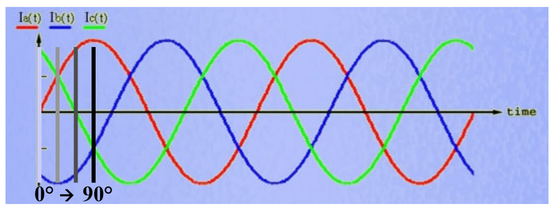
Rotating Stator Field

As time varies through ¼ of a cycle of the sinusoidal currents (i.e. – from 0°→90°), the resultant (net) vector field maintains a <u>constant magnitude</u> but <u>rotates in direction</u> clockwise by 90°.

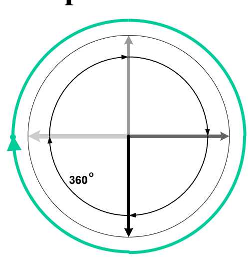


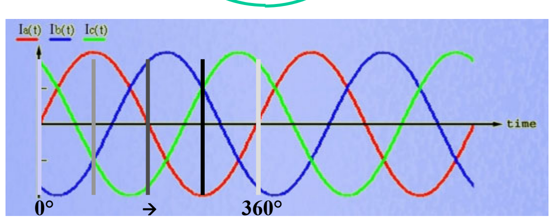


13

Rotating Stator Field

Over one full cycle of progression, the resultant field will have a constant magnitude and its vector direction will rotate 360° clockwise (i.e. – one complete revolution).





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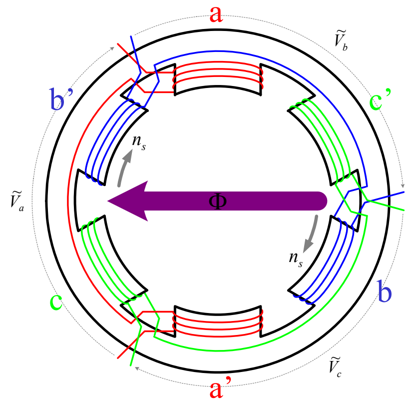
Rotating Stator Field



Thus, the individual fields created by the three windings all combine to form a net "stator field" field that is constant in magnitude but rotates in direction.

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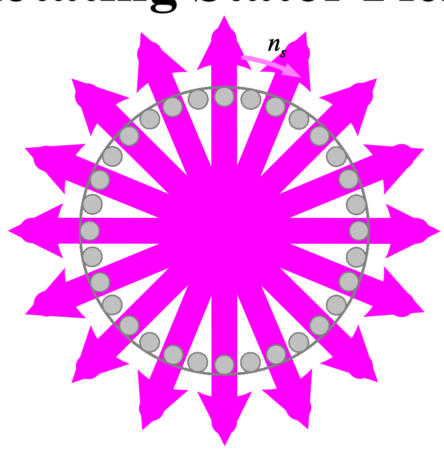
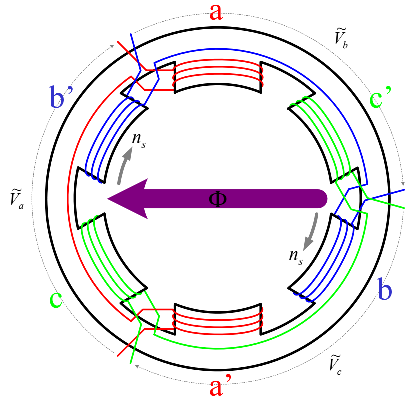
Rotating Stator Field



And, since the "stator field" passes through the rotor region, the squirrel-cage rotor conductors will be exposed to a time-varying (rotational) magnetic field.

16

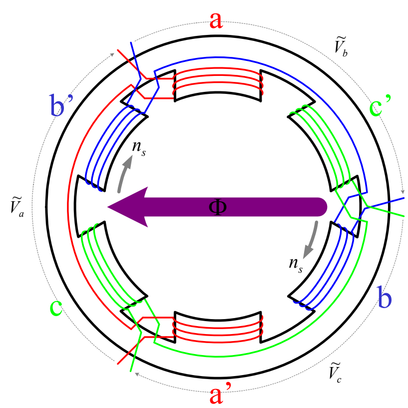
Synchronous Speed



The rotational speed, n_s, of the “stator field” defines the <u>synchronous speed</u> of the machine… (the speed at which the rotating rotor conductors and the stator field are synchronized).

17

Synchronous Speed



$$n_s = \frac{120 \cdot f_{elec}}{\#\,poles}$$

The <u>synchronous speed</u>, n_s, is a function of both the source frequency and the number of poles* of the machine.

[* – the # of poles is a constructional feature of the machine]

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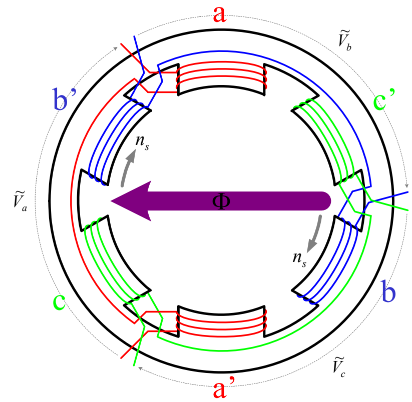
Two-Pole Stator Construction



$$n_s = \frac{120 \cdot f_{elec}}{\# \, poles}$$

The above stator is called a "two-pole" stator due to the nature of the stator field. A two-pole stator-field rotates one complete revolution per cycle of the stator's excitation.

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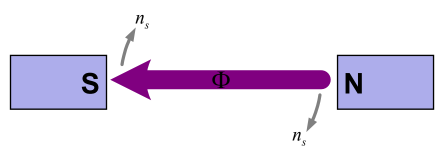
Two-Pole Stator Construction

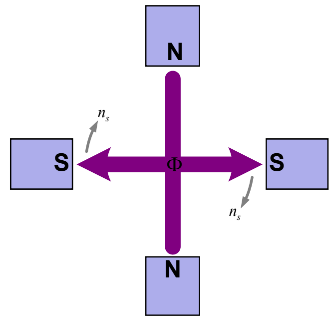


It is called a "two-pole" design because the resultant field is similar to the field that would be created by the opposing poles of two permanent magnets (i.e. – one N pole & one S pole).

20

Four-Pole Stator Construction

Note that the winding configurations for the 4-pole and higher-order stator designs will not be shown in this presentation



$$n_s = \frac{120 \cdot f_{elec}}{\#\, poles}$$

Note that higher-order stators also exist, such as a <u>four-pole</u> design that will result in the stator-field shown above.

A four-pole stator-field has 2x the number of poles but only rotates ½ revolution per cycle of the stator excitation.

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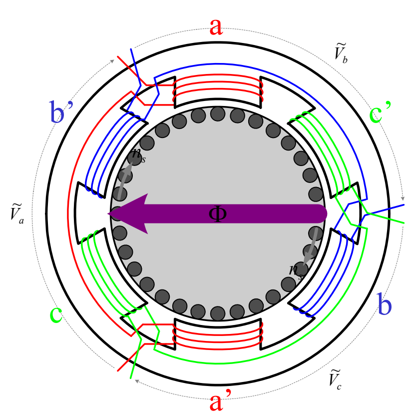
Stator Field – Rotor Interaction



What happens when the squirrel-cage rotor conductors are exposed to the rotating stator field?

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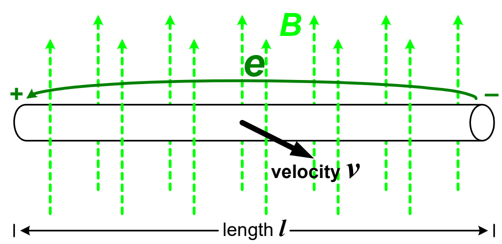
Faraday's Law of Induction
Applied to Linear Conductors

Based upon Faraday's Law, a voltage is induced across a conductor if the conductor is moving orthogonally through a magnetic field, the magnitude of which is defined by:

$$e = B \cdot l \cdot v$$



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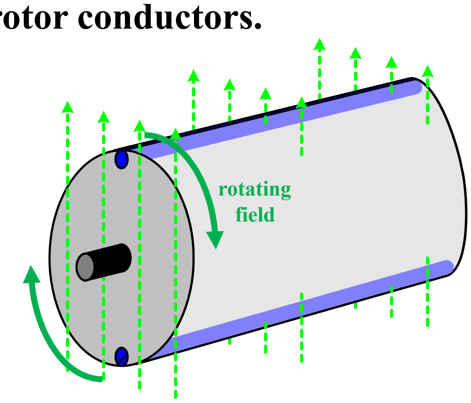
Faraday's Law of Induction
Rotating Stator Field & Stationary Rotor Conductors

If a pair of conductors are embedded under the surface of a rotor that is placed within the region through which the "stator field" is rotating, then the field lines will be cutting-across the rotor conductors.



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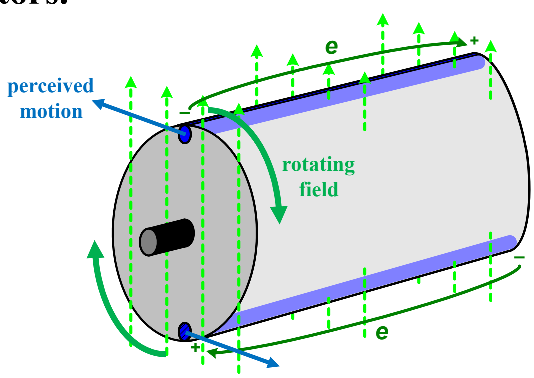
Faraday's Law of Induction

Rotating Stator Field & Stationary Rotor Conductors

From the conductors' perspective, they are moving orthogonally through the field lines. Thus, voltages that are proportional to the rotational speed of the field will be induced across the conductors.

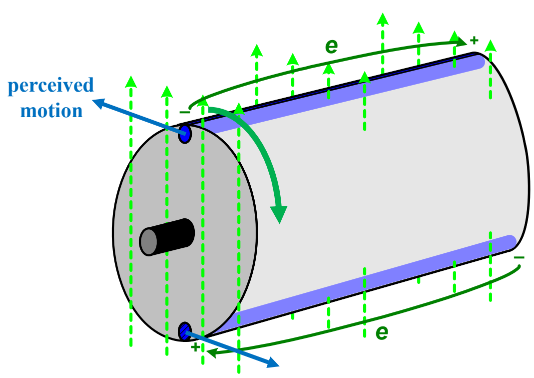


25

Faraday's Law of Induction

Rotating Stator Field & Stationary Rotor Conductors

Note that the polarities of the induced voltages will be opposite due to their perceived opposing directions of motion through the field lines.



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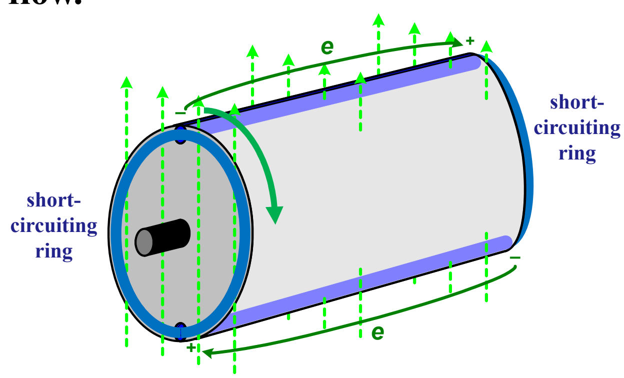
Stator Field – Rotor Interaction

Rotor Conductor Currents

In the case of the squirrel-cage rotor, the ends of the rotor conductors are shorted together by a pair of rings mounted on the ends of the rotor, providing a closed-loop path for current flow.



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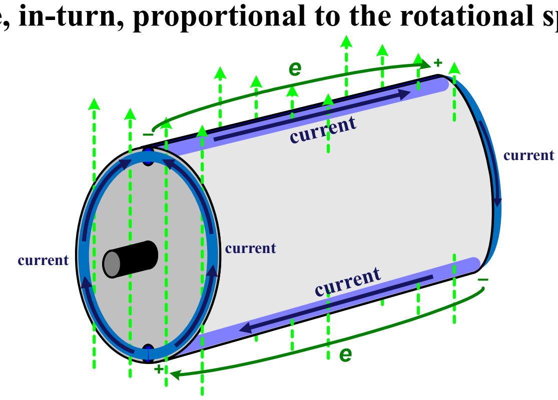
Stator Field – Rotor Interaction

Rotor Conductor Currents

Since the rotor conductor voltages sum around the closed-loop conductive paths, <u>currents</u> will be induced in the rotor conductors that are proportional to the conductor voltages (which are, in-turn, proportional to the rotational speed of the field).



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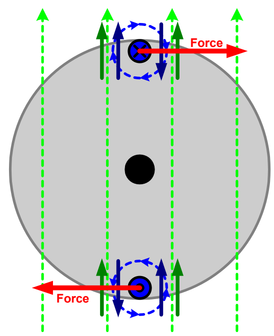
Stator Field – Rotor Interaction

Forces Developed on Rotor Conductors

The rotor conductor currents will interact with the stator field, resulting in localized forces being developed upon the affected rotor conductors.



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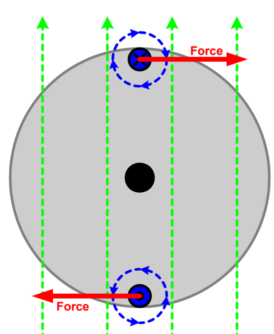
Stator Field – Rotor Interaction

Forces Developed on Rotor Conductors

The magnitude of the forces developed upon the conductors will be proportional to magnitude of the rotor currents (which are, in-turn, proportional to the rotational speed of the field).

$$F = B \cdot l \cdot I$$



Note that the forces developed upon the opposing conductors point in the opposite directions.

30

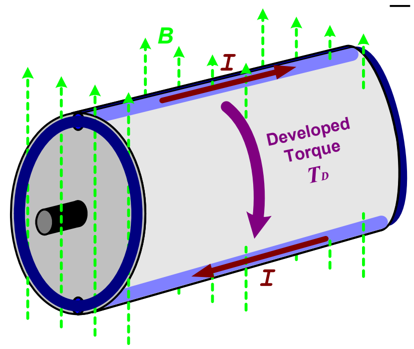
Stator Field – Rotor Interaction

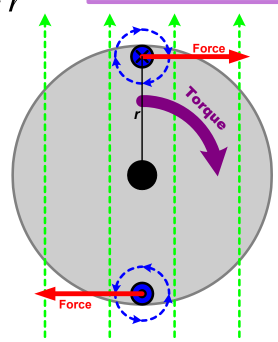
Developed Torque

Furthermore, the opposite-pointing forces result in a net <u>torque</u> (rotational force) being developed upon the rotor in the clockwise direction:

$$T_D = 2 \cdot F \cdot r$$
$$= 2 \cdot B \cdot l \cdot I \cdot r$$

T_D ≡ **<u>Developed Torque</u>** – the total torque (rotational force) that the machine develops.





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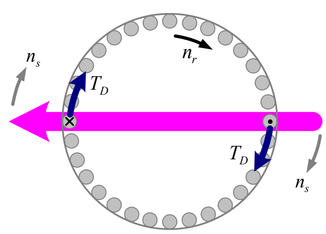
Stator Field – Rotor Interaction

Rotor Acceleration

T_{Load} ≡ **<u>Total Load Torque</u>** – the total torque applied to the shaft of the machine that opposes its rotation.

Note that T_{Load} includes both the stopping force provided by the mechanical load bolted to the shaft and any friction, windage, or other loss forces experienced by the rotor.



T_{accel} ≡ **<u>Acceleration Torque</u>** – the amount of torque available to accelerate the rotor and its attached mechanical load.

$$T_{accel} = T_D - T_{load}$$

If T_{accel} is positive, speed will increase.
If T_{accel} is negative, speed will decrease.
If T_{accel} is zero, speed will remain constant.

Provided that the developed torque, T_D, is greater than the total load torque, T_{Load}, then a positive acceleration torque, T_{accel}, will be available to accelerate the rotor in the same direction as the rotating stator field.

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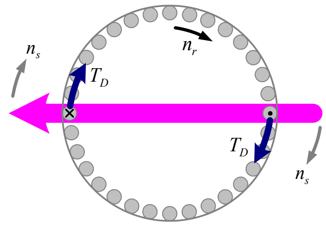
Stator Field – Rotor Interaction

Rotational Effects on Developed Torque



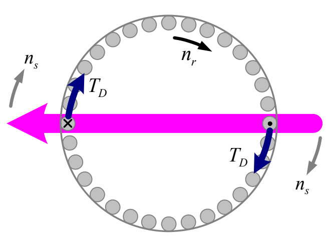
$$n_{effective} = n_s - n_r$$

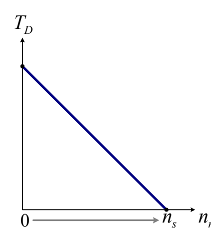
Note that the developed torque, T_D, is proportional to the rate at which the stator field cuts across the rotor conductors.

Thus, if the rotor begins to rotate, the <u>effective speed</u> at which the field-lines cut across the rotor bars decreases, resulting in a decrease in the developed torque, T_D.

Stator Field – Rotor Interaction

Rotational Effects on Developed Torque





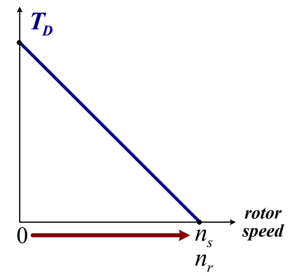
$$n_{effective} = n_s - n_r$$

Since the developed torque, T_D, is proportional to the effective speed, $n_{effective}$, at which the stator field cuts across the rotor bars, <u>the developed torque will decrease linearly as the rotor speed increases</u>, eventually decreasing to zero when the rotor is rotating at synchronous speed.

Stator Field – Rotor Interaction

No-Load Operation

If the rotor is rotating at synchronous speed ($n_r = n_s$), then the field lines will no longer be passing by the rotor conductors and no torque will be developed.



Under steady-state No-Load conditions:
$n_r \rightarrow n_s$
$T_D \rightarrow 0$
$T_{accel} = T_D - T_{Load} \rightarrow 0$

Under "**no-load**" conditions ($T_{Load} = 0$), the rotor will accelerate until it reaches **synchronous speed** ($n_r = n_s$), at which point the developed and the acceleration torques equal zero, and the motor maintains steady-state rotation at synchronous speed.

An induction motor cannot accelerate past its synchronous speed without the application of an external rotational force.

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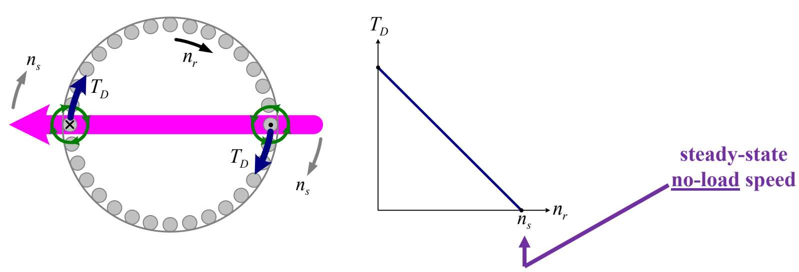
Ideal Motor – No-Load Operation



The torque-speed curve for an "ideal" induction machine is shown above for rotor speeds ranging from zero→n_s.

Under no-load conditions, the motor will accelerate to and run steady-state at its synchronous speed

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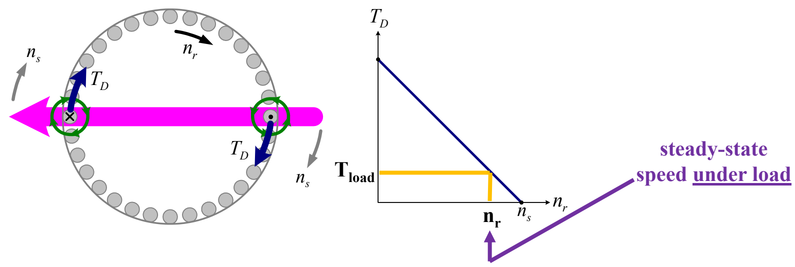
Ideal Motor – Operation Under Load



If the rotor is subjected to a load torque after reaching synchronous speed under no-load conditions, then the rotor will slow down to the speed at which the developed torque, T_D, equals to the load torque, T_{Load}.

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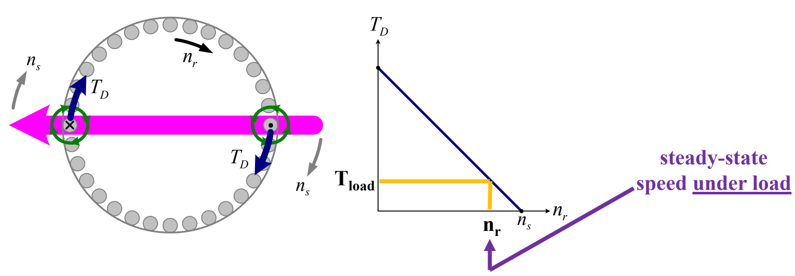
Ideal Motor – Operation Under Load



Or, if the rotor is subjected to a load torque at startup, then the rotor will only be able to accelerate up to the speed at which the developed torque, T_D, equals to the load torque, T_{Load}.

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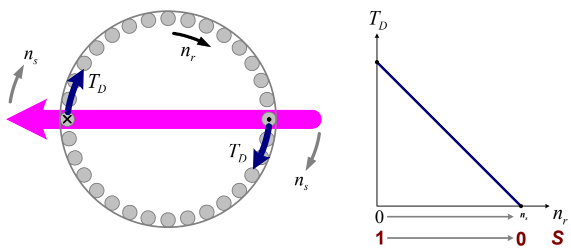
Stator Field – Rotor Interaction

Slip



$$slip \equiv s = \frac{n_s - n_r}{n_s}$$

Note – Rotor speed is often expressed in terms of <u>slip</u>, which provides a measure of how much slower the rotor is rotating compared to the speed of the stator field.

$$slip \equiv s = \frac{n_s - n_r}{n_s}$$

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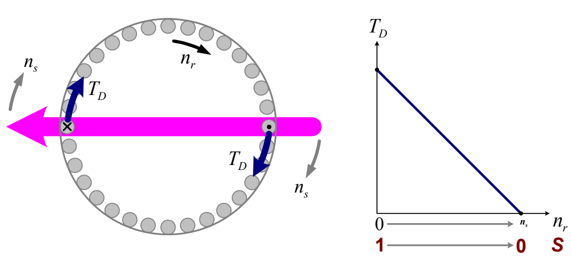
Stator Field – Rotor Interaction

Slip



$$slip \equiv s = \frac{n_s - n_r}{n_s}$$

As rotor speed varies from zero to synchronous speed ($n_r = 0 \rightarrow n_s$), the slip decreases linearly from one to zero ($s = 1 \rightarrow 0$).

Thus, slip and developed torque both vary in a similar manner.

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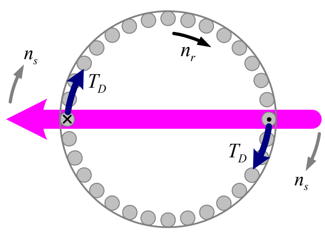
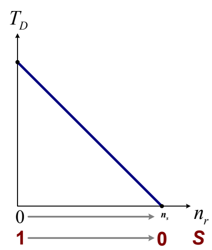
Stator Field – Rotor Interaction

Slip





T_{BR} ≡ **Blocked-Rotor Torque** – the torque developed by the machine when the rotor isn't moving ($n_r = 0$).

Note: Blocked-Rotor Torque may also be referred to as Locked-Rotor Torque and/or Starting Torque.

Since both slip and developed torque decrease linearly as rotor speed varies from zero to synchronous speed, T_D can be expressed in terms of the blocked-rotor torque, T_{BR}, and slip:

$$T_D = T_{BR} \cdot s$$

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Circuit Model
of the
Induction Machine

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Induction Machine Modeling Concepts

The interaction between a 3Φ Induction Machine's stator windings and rotor conductors is similar to the interaction between a transformer's primary and secondary windings:

- **Time-varying voltages are applied to the set of stator (primary) windings.**
- **Each stator winding creates a time-varying flux within the machine's rotor region, the sum of which can be expressed a constant-magnitude "stator" field whose directional vector rotates in time.**
- **The rotating (time-varying) "stator" field induces a voltage across the rotor conductors (secondary windings).**

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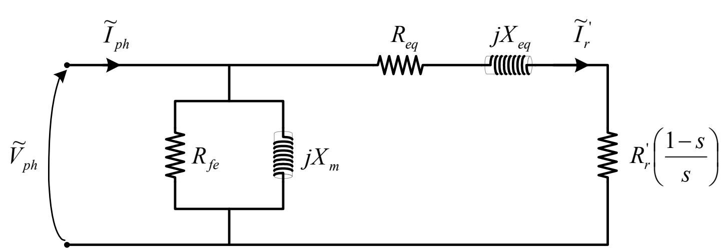
1Φ Equivalent Circuit

for a 3Φ Induction Machine

The following <u>1Φ Equivalent Circuit</u> is often used to model the operation of a Y-connected, 3Φ, Induction Machine.

Note that, if all three phases are supplied by a balanced source, then the voltages and currents of the other phases can be derived from the results of the 1Φ circuit solution.



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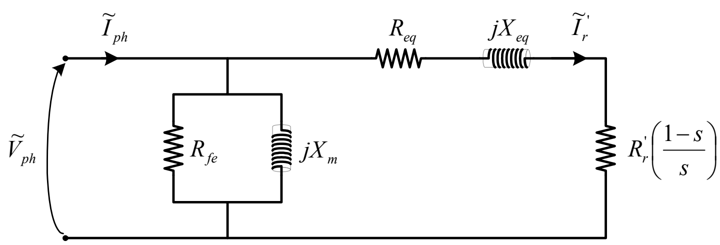
1Φ Equivalent Circuit

for a 3Φ Induction Machine

***R_{fe}* and *X_m* account for the magnetization effects due to the rotating (time-varying) magnetic field created by the stator windings within the core material that forms the physical structure of the machine.**



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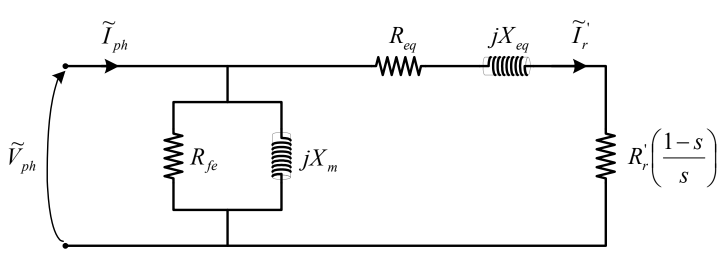
1Φ Equivalent Circuit

for a 3Φ Induction Machine

***R_{eq}* and *X_{eq}* account for the impedance of the stator windings combined with the effective per-phase impedance of the rotor conductors (referred to the stator side of the model).**



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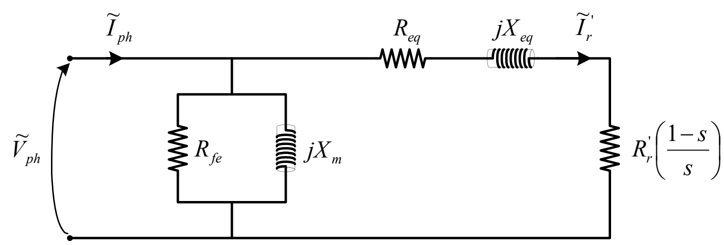
1Φ Equivalent Circuit

for a 3Φ Induction Machine

The remaining resistance, $R_r'\left(\frac{1-s}{s}\right)$, relates to the mechanical load that the machine is driving.

This resistance varies with slip, appearing as a short-circuit at a slip of one ($s=1$) and an open-circuit at a slip of zero ($s=0$).



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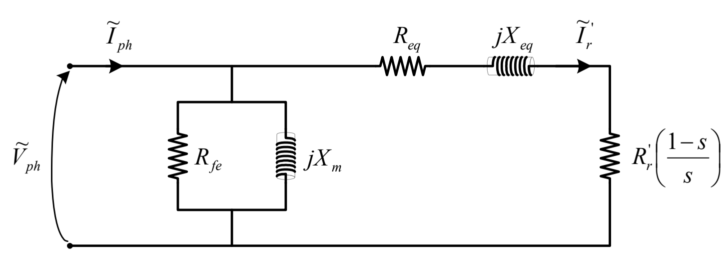
Mechanical Power

The power consumed by the resistance $R_r'\left(\frac{1-s}{s}\right)$ equals to the per-phase mechanical power produced by the machine.

(I.e. – the electrical power converted to a mechanical form)



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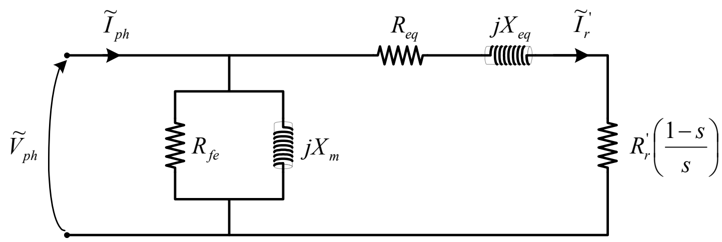
Mechanical Power

Assuming balanced operation, the total mechanical power produced by the machine, P_{mech}, will equal to three times (3x) the power consumed in one phase by $R_r'\left(\frac{1-s}{s}\right)$.

$$P_{mech} = 3 \cdot \left|\tilde{I}_r'\right|^2 \cdot R_r'\left(\frac{1-s}{s}\right) \quad \text{Watts}$$



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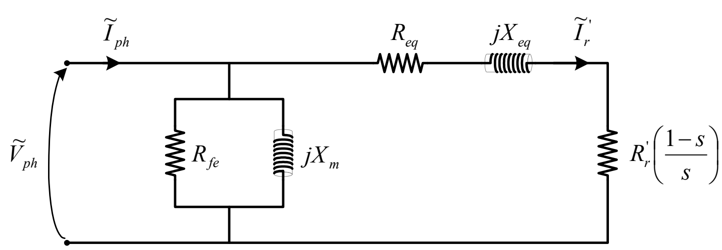
Developed Torque

Since $T_{D(lb\cdot ft)} = \frac{5252 \cdot P_{mech(hp)}}{n_{r(rpm)}}$ **and** $1\ hp \cong 746\ watts$,

the total torque, T_D, developed by the machine can be defined from the solution for mechanical power as:

$$T_D = \frac{21.12 \cdot \left|\tilde{I}_r'\right|^2 \cdot R_r'}{s \cdot n_s} \quad \text{lb} \cdot \text{ft}$$



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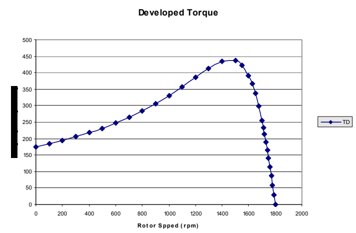
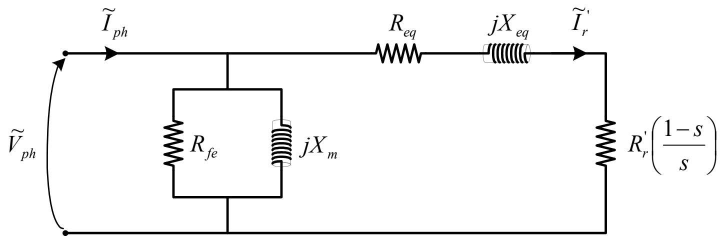
Developed Torque

If T_D is plotted as a function of speed over the range $n_r=0 \rightarrow n_s$, the resultant T_D vs n_r curve for a practical machine will resemble:





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Practical Concerns

Operational Characteristics

&

NEMA Ratings

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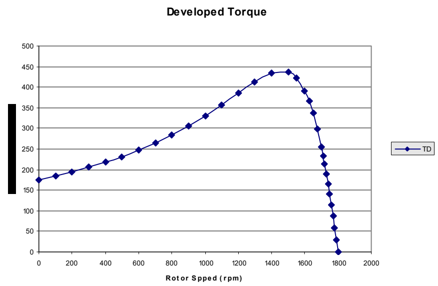
Operational Characteristics



The torque-speed curve for a practical 4-pole, 60Hz induction machine is shown above.

Based on this curve, several key operational characteristics can be defined for the machine.

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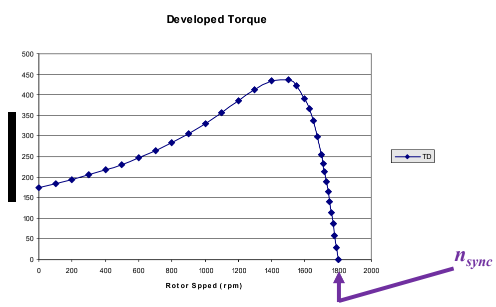
No-Load Operation



Similar to an "ideal" machine, a practical machine will still accelerate to its synchronous speed and run steady-state at that speed while under ideal "no-load" conditions.

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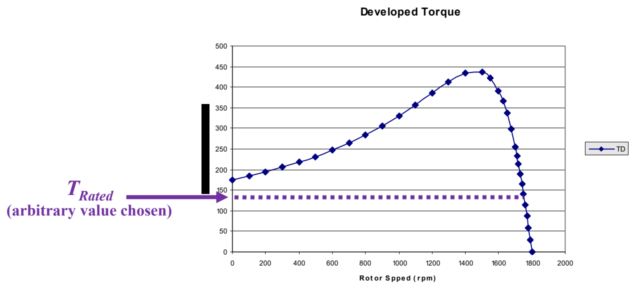
Rated Load



In terms of torque, rated load (T_{rated}) for an induction motor is the maximum steady-state torque that the motor can develop without overheating while supplied at rated voltage.

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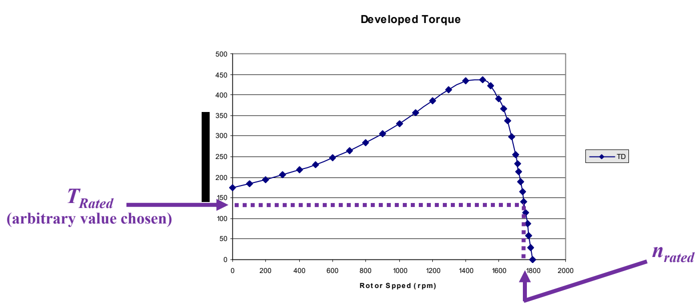
Rated Speed



The speed the motor operates at while driving rated load is defined as the motor's rated speed (n_{rated}).

Note that rated speed for a typical industrial-sized machine occurs within 5% of its synchronous speed (i.e. – when slip is less than 5%).

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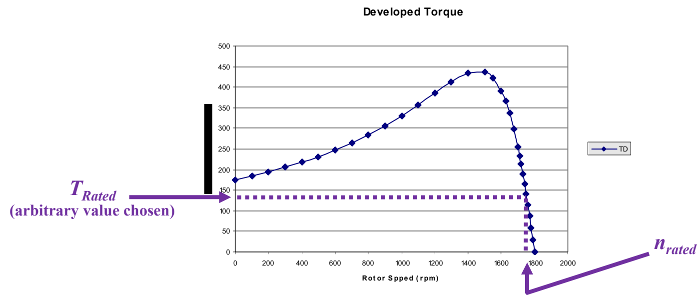
Rated Current



The <u>rated current</u> (I_{rated}) for the machine is defined as the line current that the motor will draw while supplied at rated voltage and driving rated load.

If more than rated current is drawn into the motor for too long, the motor may overheat due to increased internal losses.

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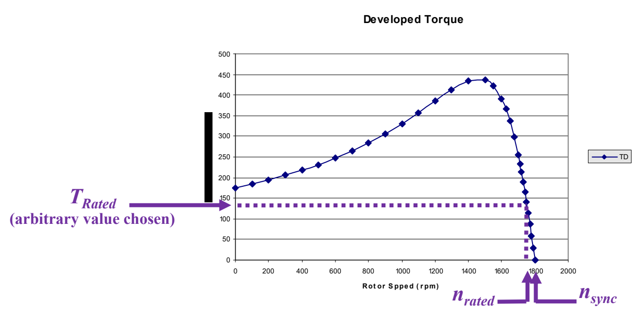
Normal Operation



Normal operation for the motor can be defined as operation of the motor while supplied at rated voltage and driving no more than rated load. ($0 \le T_D \le T_{Rated}$)

Under these conditions, the rotor's speed will be in the range:

$$n_{rated} \le n_r \le n_{sync}$$

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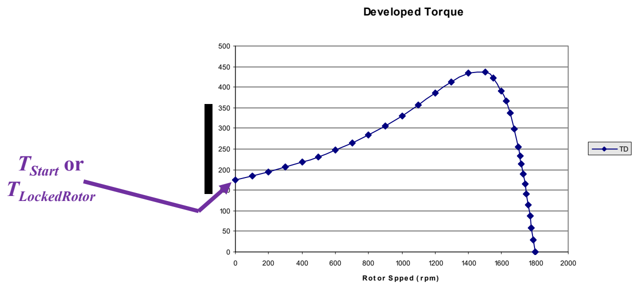
Motor Startup (Locked-Rotor Conditions)



At startup or under "locked-rotor" conditions ($n_r = 0$), the motor is only able to produce a limited amount of torque.

This torque, T_{Start} or $T_{LockedRotor}$, provides the maximum load torque that the motor can accelerate at startup.

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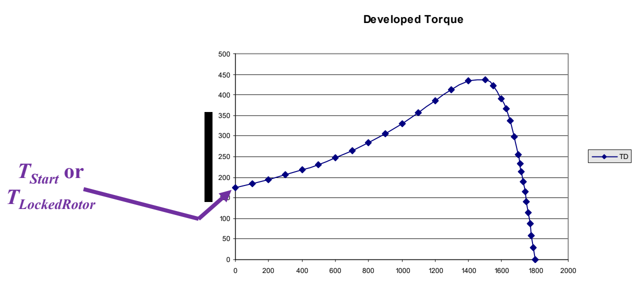
Motor Startup (Locked-Rotor Conditions)



Note that at startup or under "locked-rotor" conditions, the motor will draw a line current that is much larger than the motor's rated current, typically 4-10x larger.

Thus, if the motor is not able to accelerate quickly from startup, damage to the motor may occur due to overheating.

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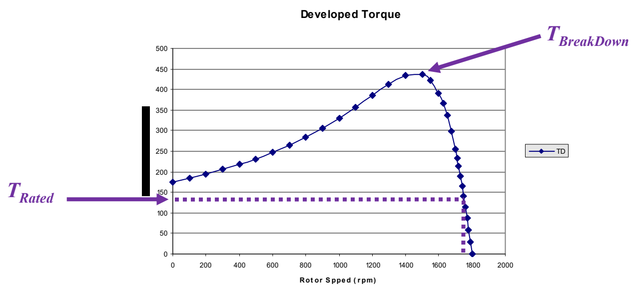
Breakdown Torque



The **breakdown torque** ($T_{BreakDown}$) for the machine is defined as the maximum torque that the motor is able to develop after is it already running under normal operating conditions.

If the load increases above the motor's breakdown value, the motor will stall (i.e. – the rotor will quickly stop rotating).

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National Electrical Manufacturers Association

- NEMA*
- Trade association whose 400+ member companies manufacture products used in the generation, transmission, distribution, control, and end-use of electricity
- Provides a forum for the development of technical standards that relate to the design, installation and use of electrical equipment

* - Information about NEMA and NEMA Standards found at: www.NEMA.org

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NEMA Standards

NEMA standards relating to motor control include:

Industrial Control and Systems

- **ICS 1 – General Requirements**
- **ICS 2 – Contactors and Overload Relays**
- **ICS 5 – Control Circuit and Pilot Devices**
- **ICS 7 – Adjustable Speed Drives**
- **ICS 19 – Diagrams, Designations & Symbols**

MG 1 – General Purpose Industrial AC Small & Medium Squirrel-Cage Induction Motors

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NEMA Rated Motors

Motors must adhere to a uniform set of standards provided by NEMA in order to be called a "NEMA Rated Motor"

The standards cover all aspects of the motor's design, testing and operation including:

- **the frame/mounting dimensions**
- **the motor's ratings (voltage, current, frequency, speed, horsepower…)**
- **the locked-rotor current & torque**
- **the operating efficiency & temperature**

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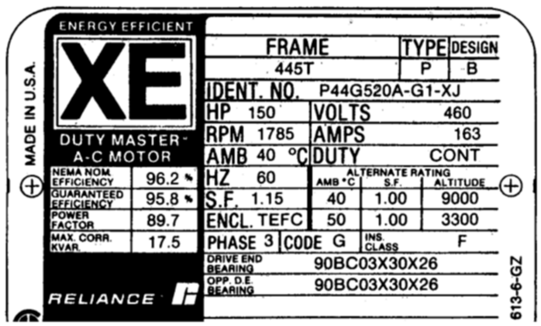
Motor Nameplates

A motor's ratings and other key specifications are provided by means of a <u>nameplate</u> attached to the frame of the machine.



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Nameplate Information

The nameplate typically includes the:

- **Manufacturer's Name and Logo**
- **Frame Designation and Type**
- **Rated Horsepower**
- **Rated Voltage**
- **Rated Frequency**
- **Rated Full Load Amps**
- **Number of Phases**
- **Rated Speed**

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Nameplate Information

The nameplate typically includes the:

- **Operational Efficiency**
- **Operational Power Factor**
- **Design Letter**
- **Rated Ambient Temperature**
- **Service Factor**
- **Duty Cycle**
- **(Locked-Rotor kVA) Code Letter**
- **Insulation Class Letter**

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NEMA Induction Motor Ratings

- **Frame Designation – information providing the shaft height / machine dimensions**
- **Horsepower – the maximum continuous load that the machine is able to drive**
- **Voltage – the expected operational "Line" voltage supplied to the machine**
- **Full Load Amps – the expected line current magnitude when supplied at rated voltage & frequency, driving rated load, and exposed to rated ambient temperature**

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NEMA Induction Motor Ratings

- <u>Speed</u> – the expected operational speed when supplied at rated voltage & frequency, driving rated load, and exposed to rated temperature
- <u>Service Factor</u> – a multiplier that may be applied to rated load under stated conditions provided that rated voltage/frequency is maintained
- <u>Design Letter</u> – indicates the torque-speed performance characteristics of the motor

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NEMA Induction Motor Designs

FIGURE 5–1
Torque-speed characteristics of basic NEMA-design squirrel-cage induction motors.

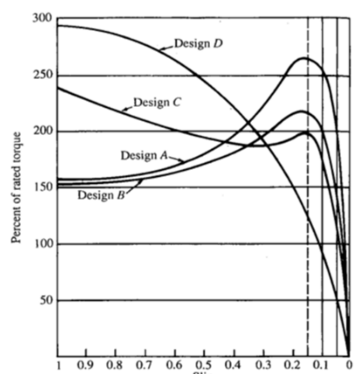
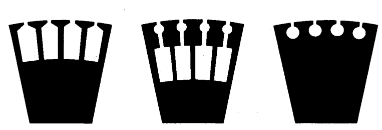


FIGURE 5–2
Representative cross sections of some NEMA-design rotors.



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NEMA Induction Motor Ratings

Additional operational characteristics of a NEMA-rated induction motor, such as:

- **Locked-Rotor Current,**
- **Locked-Rotor Torque, and**
- **Breakdown Torque**

are based upon the motor's ratings and can be determined by utilizing the tables provided in the MG1 standard.

Note – the torque values shown in the tables are often defined as a percentage of the machine's other rated values.

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NEMA Induction Motor Ratings

Locked-Rotor Current of 3Φ, 230V, 60Hz Motors

Table 31
LOCKED-ROTOR CURRENT OF 3-PHASE 60-HERTZ SMALL AND MEDIUM SQUIRREL-CAGE INDUCTION MOTORS RATED AT 230 VOLTS [MG 1-12.35.1]

HP	Locked-Rotor Current, Amperes	Design Letters	HP	Locked-Rotor Current, Amperes	Design Letters
1/2	20	B, D	60	870	B, C, D
3/4	25	B, D	75	1085	B, C, D
1	30	B, C, D	100	1450	B, C, D
1-1/2	40	B, C, D	125	1815	B, C, D
2	50	B, C, D	150	2170	B, C, D
3	64	B, C, D	200	2900	B, C,
5	92	B, C, D	250	3650	B
7-1/2	127	B, C, D	300	4400	B
10	162	B, C, D	350	5100	B
15	232	B, C, D	400	5800	B
20	290	B, C, D	450	6500	B
25	365	B, C, D	500	7250	B
30	435	B, C, D			
40	580	B, C, D			
50	725	B, C, D			

NOTE—The locked-rotor current of motors designed for voltages other than 230 volts shall be inversely proportional to the voltages.

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NEMA Induction Motor Ratings

Locked-Rotor Torque of Design A and B Motors

Table 32
LOCKED-ROTOR TORQUE OF DESIGN A AND B MOTORS [MG 1-12.38.1]

	Synchronous Speed, Rpm							
	60 Hertz	3600	1800	1200	900	720	600	514
HP	50 Hertz	3000	1500	1000	750	—	—	—
1/2		—	—	—	140	140	115	110
3/4		—	—	175	135	135	115	110
1		—	275	170	135	135	115	110
1-1/2		175	250	165	130	130	115	110
2		170	235	160	130	125	115	110
3		160	215	155	130	125	115	110
5		150	185	150	130	125	115	110
7-1/2		140	175	150	125	120	115	110
10		135	165	150	125	120	115	110
15		130	160	140	125	120	115	110
20		130	150	135	125	120	115	110
25		130	150	135	125	120	115	110
30		130	150	135	125	120	115	110
40		125	140	135	125	120	115	110
50		120	140	135	125	120	115	110
60		120	140	135	125	120	115	110
75		105	140	135	125	120	115	110
100		105	125	125	125	120	115	110
125		100	110	125	120	115	115	110
150		100	110	120	120	115	115	—
200		100	100	120	120	115	—	—
250		70	80	100	100	—	—	—
300		70	80	100	—	—	—	—
350		70	80	100	—	—	—	—
400		70	80	—	—	—	—	—
450		70	80	—	—	—	—	—
500		70	80	—	—	—	—	—

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NEMA Induction Motor Ratings

Breakdown Torque of Design A and B Motors

Table 34
BREAKDOWN TORQUE OF DESIGN A AND B MOTORS [MG 1-12.39.1]

	Synchronous Speed, Rpm							
	60 Hertz	3600	1800	1200	900	720	600	514
HP	50 Hertz	3000	1500	1000	750	—	—	—
1/2		—	—	—	225	200	200	200
3/4		—	—	275	220	200	200	200
1		—	300	265	215	200	200	200
1-1/2		250	280	250	210	200	200	200
2		240	270	240	210	200	200	200
3		230	250	230	205	200	200	200
5		215	225	215	205	200	200	200
7-1/2		200	215	205	200	200	200	200
10-125, inclusive		200	200	200	200	200	200	200
150		200	200	200	200	200	200	—
200		200	200	200	200	200	—	—
250		175	175	175	175	—	—	—
300-350		175	175	175	—	—	—	—
400-500, inclusive		175	175	—	—	—	—	—

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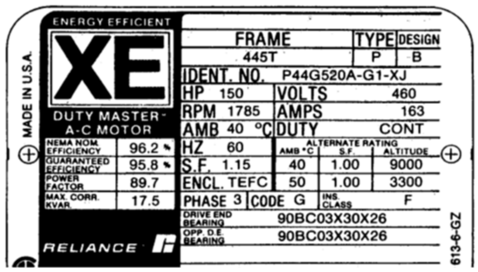
Induction Motor Rating Example

Example – Determine the **rated torque** for the 150Hp induction motor shown below:

Key Nameplate Data – 150Hp, 1785 rpm



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Induction Motor Rating Example

Example – Determine the **rated torque** for the 150Hp induction motor shown below:

Key Nameplate Data – 150Hp, 1785 rpm

Since:

$$T_{D(lb\cdot ft)} = \frac{5252 \cdot P_{mech(hp)}}{n_{r(rpm)}}$$

then:

$$T_{Rated(lb\cdot ft)} = \frac{5252 \cdot P_{Rated(hp)}}{n_{rated(rpm)}} = \frac{5252 \cdot 150}{1785} = 441.3\,(lb \cdot ft)$$

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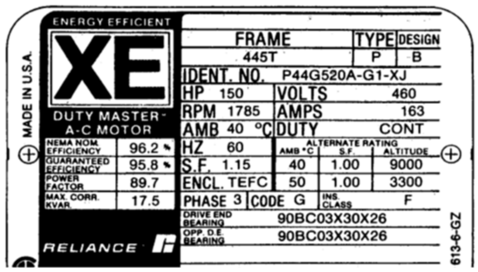
Induction Motor Rating Example

<u>Example</u> – Determine the <u>locked-rotor current</u> for the 150Hp induction motor shown below:

<u>Key Nameplate Data</u> – 150Hp, 460V, 163A, Design B



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Induction Motor Rating Example

Example – Determine <u>starting current</u> for 150Hp Reliance Electric Induction Motor

Key Nameplate Data – 150Hp, 460V, 163A, Design B

<u>Table 31</u> → 150Hp / <u>230V</u> / B → <u>2170</u> L-R amps

Table 31
LOCKED-ROTOR CURRENT OF 3-PHASE 60-HERTZ SMALL AND MEDIUM SQUIRREL-CAGE INDUCTION MOTORS RATED AT 230 VOLTS [MG 1-12.35.1]

HP	Locked-Rotor Current, Amperes	Design Letters	HP	Locked-Rotor Current, Amperes	Design Letters
1/2	20	B, D	60	870	B, C, D
3/4	25	B, D	75	1085	B, C, D
1	30	B, C, D	100	1450	B, C, D
1-1/2	40	B, C, D	125	1815	B, C, D
2	50	B, C, D	150	2170	B, C, D
...			...		
20	290	B, C, D	450	6500	B
25	365	B, C, D	500	7250	B
30	435	B, C, D			
40	580	B, C, D			
50	725	B, C, D			

NOTE—The locked-rotor current of motors designed for voltages other than 230 volts shall be inversely proportional to the voltages.

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Induction Motor Rating Example

Example – Determine starting current for 150Hp Reliance Electric Induction Motor

Key Nameplate Data – 150Hp, 460V, 163A, Design B

Table 31 → 150Hp / 230V / B → 2170 L-R amps

Note – L-R amps are inversely proportional to voltage

$\therefore$ **L-R Amps** = $2170 \cdot \dfrac{230}{460} = 1085A$

The L-R amps are 6⅔x greater than the FLA (I_{Rated}) !

1085 A = 6.67 x 163 A

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