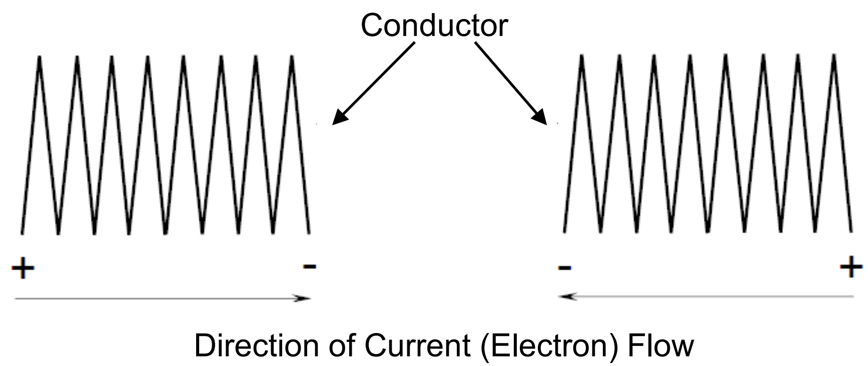
Electric Motor Training Seminar

AC Motor Basics

- Electricity:

In simple terms, electricity is produced when a flow of electrons (also called current flow) is passed through a conductor such as a wire.

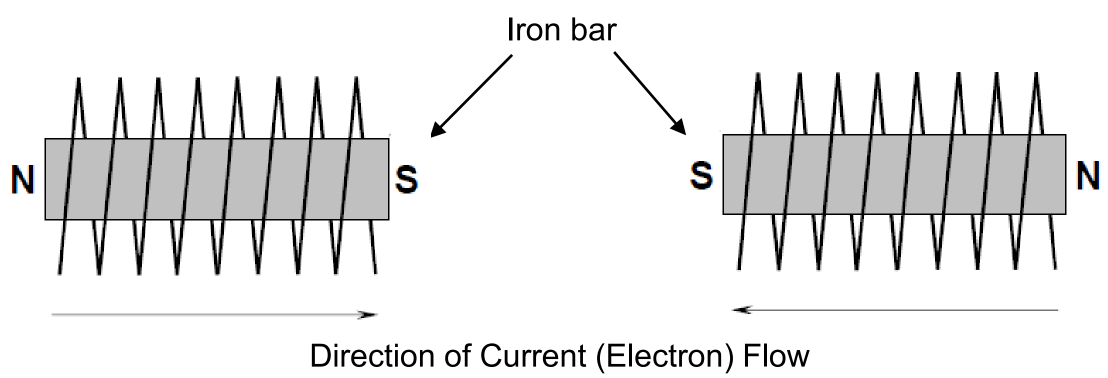


The inlet of the flow is considered the positive end and the outlet is considered the negative end.

AC Motor Basics

- Electricity & Magnetism:

When an object such as an iron bar (Ferrous core) is placed within this current flow, the object becomes magnetized. This ferrous core will have, like all magnets, a north and a south side (pole).



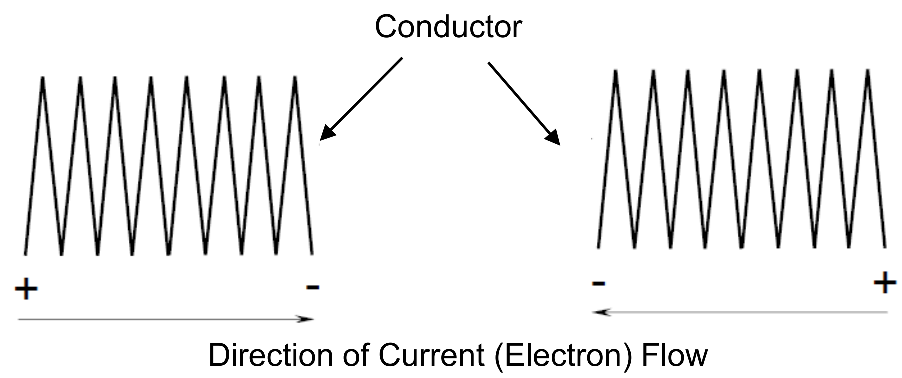
The side of the iron bar in the current flow inlet will be the North Pole of that magnet and the side of the iron bar in the current flow outlet will be the South Pole.

AC Motor Basics

Alternating Current (AC):

DC voltage (Direct Current) flows in a circuit from positive to negative.

AC voltage (Alternating Current) voltage changes the direction of current flow in the circuit, over a period of time.



This back-and-forth shifting of current flow is called Frequency.

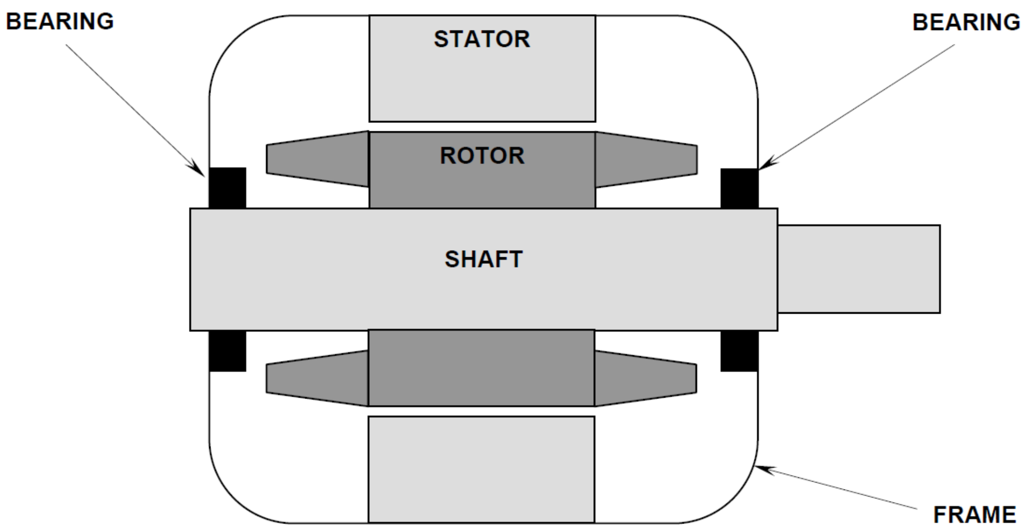
1 Complete Cycle = 1 Back & 1 Forth shift

The frequency is expressed in Hertz (Cycle per Second).

North American standard = 60Hz (120 Back & Forth shifts)

AC Motor Basics

- All electric motors consist of three essential parts:
  - . The Stator (Stationary Part)
  - . The Rotor (Rotating Part)
  - . Bearings (Mechanical support for the Rotor)



AC Motor Basics

- Induction / Magnetic Field

Line voltage →

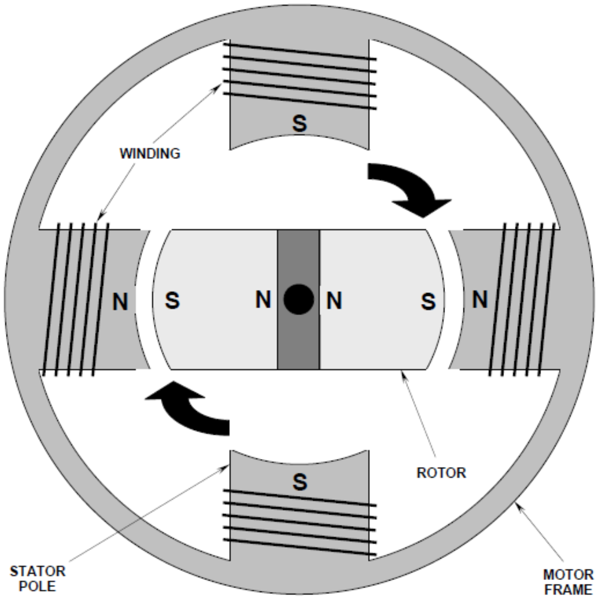
Statoric rotary current →

Magnetic rotating field in the Stator →

Induced Rotor voltage →

Rotor current →

Magnetic field in the Rotor →



The interaction of the rotating magnetic field of the Stator and the magnetic field of the Rotor produces the torque and it is the coupling of the magnetic fields that produces the rotation of the shaft.

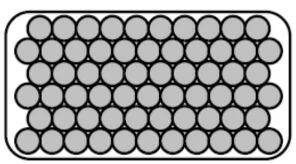
AC Motor Basics

- Power / Magnetic Flux Density

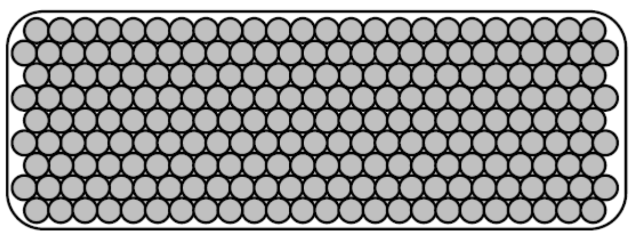
The power, or the amount of "work" that a motor can do, is determined by the strength of the magnetic field that the stator windings can produce.

The strength of the magnetic field is determined by the amount of wire conductors (stator wire) and the current flowing through them.

Therefore, by having more internal space, a larger motor will generally provide more power since the total amount of stator wire is greater than that of a smaller motor.



Small Motor Windings



Large Motor Windings

AC Motor Basics

Efficiency

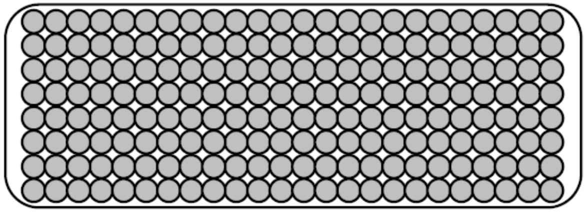
Not only does the amount of stator wire determine the horsepower potential, it can also affect the efficiency of a motor.

Modern winding techniques allow more wires to be inserted into each slot than before.

1) Increased density of magnetic forces (more power in the same space).

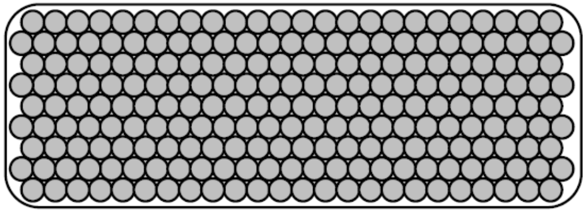
2) Decreased energy loss (lower operating temperature).

3) Extended life expectancy.



Standard Efficiency Motor Windings

(192 conductors)



Higher Efficiency Motor Windings

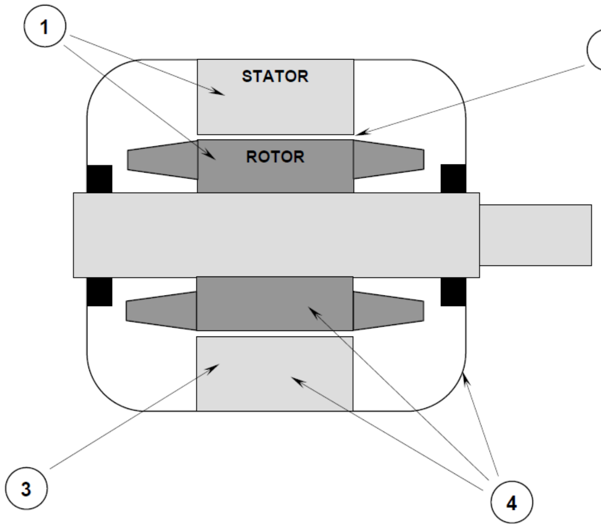
(220 conductors)

AC Motor Basics

High Efficiency Designs

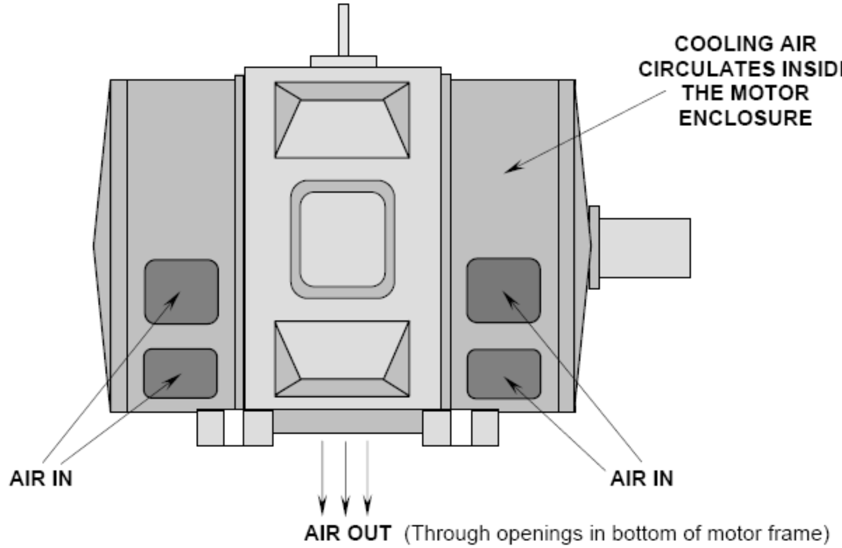
4 key advantages of a "NEMA Premium" vs Standard Efficiency design motors:

1) Extended rotor and stator which produces stronger magnetic fields.
2) Improved tolerance by reducing the space between the rotor and stator and improving the magnetic characteristics of the motor.
3) Greater quantity of wire in stator windings.
4) Higher quality silicon steel in the frame, stator and rotor cores, rather than lower quality carbon steel.

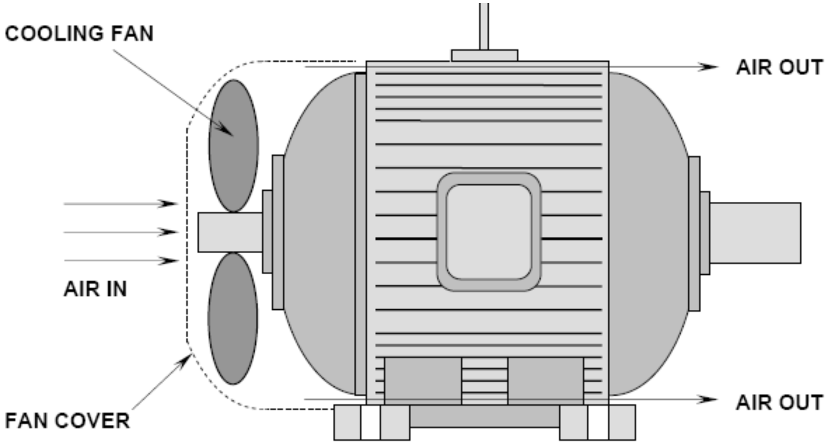


Electric motors are designed so that they can self-cool

ODP



TEFC



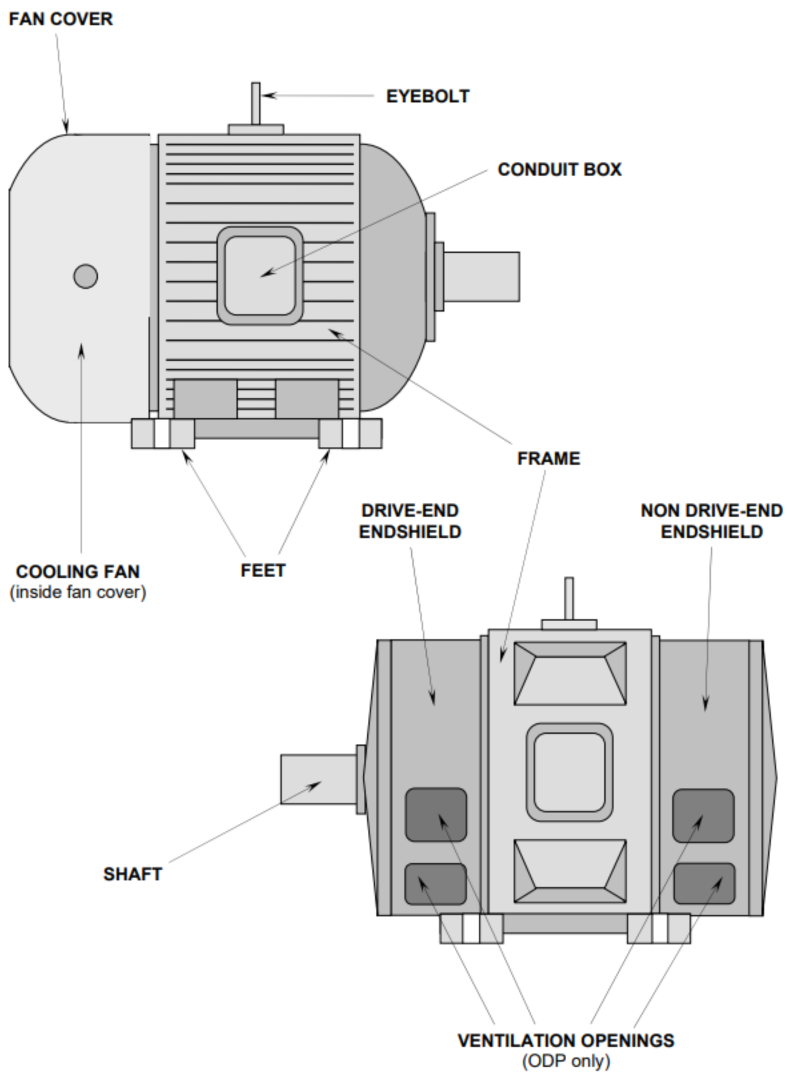
Enclosures Type

Types	Characteristics
Open:	
Open Drip Proof (ODP)	Constructed with ventilation openings located such that drops of liquid or solid particiles striking or entering the encolure at any angle from 0 - 15° downward from vertical do not interfere with proper operation.
Open Drip Proof Guarded (ODPG)	ODP machine with ventilation openings guarded with screen (less than 3/4 inch in diameter).
Open Air-Over (OPAO)	Air over machine is intended to be cooled externally, usually by load (Fan) driven by motor.
Weather Protected Type 1 (WPI)	Guarded machine with its ventilation passages so constructed as to minimize the entrance of rain, snow and air-bourne particles to the electrical parts. These ventilation passages are less than 3/4 inch in diameter.
Weather Protected Type II (WPII)	Weather-protected type I machine in addition shall have its ventilation passages so constructed with baffling or separate housing to create at least 3 abrupt direction changes of at least 90°, in addition to a low velocity area (less than 600 ft/min.) to minimize the possibility of moisture or dirt being carried into the electrical parts.
Totally Enclosed:	
Totally Enclosed Non Ventilated (TENV)	Depends on convection for air cooling.
Totally Enclosed Fan-Cooled (TEFC)	Has external cooling fan.
Explosion Proof (TEXP)	Designed to withstand an internal explosion of specified gases or vapors, and not allow the internal flame or explosion to escape.
Washdown (TEWD)	Designed to withstand high pressure washdowns or other high humidity or wet environments.
Totally Enclosed Air Over (TEAO)	Dust-tight fan and designed for shaft mounted fans or belt driven fans. The motor must be mounted within the airflow of the fan.
Totally Enclosed Air-to-Air Machine (TEAAC)	Cooled by circulating the internal air through a heat exchanger which, in turn, is cooled by circulating external air. It is provided with an air-to-air heat exchanger for cooling the internal air, a fan integral with the rotor shaft or separate, for circulating the internal air and a separate fan for circulating the external air.
Totally Enclosed Water Cooled (TEWC)	Cooled by circulating water and with the water or water conductors come in direct contact with the machine parts.
Totally Enclosed Water-to-Air Cooled (TEWAC)	Cooled by circulating air which, in turn, is cooled by circulating water. These motors are provided with a water-cooled heat exchanger for cooling the internal and a fan(s), integral with the rotor shaft separate, for circulating the internal air.

ODP, (IP12, IC01)
OPAO, (IP12)
WP1, (IP13, IC01)
WP11, (IP13, IC01)

TEFC, (IP40+, IC411)
TENV, (IP40+, IC410)
TEAO (IP40+)
TEXP, (IP50+, IC31+)

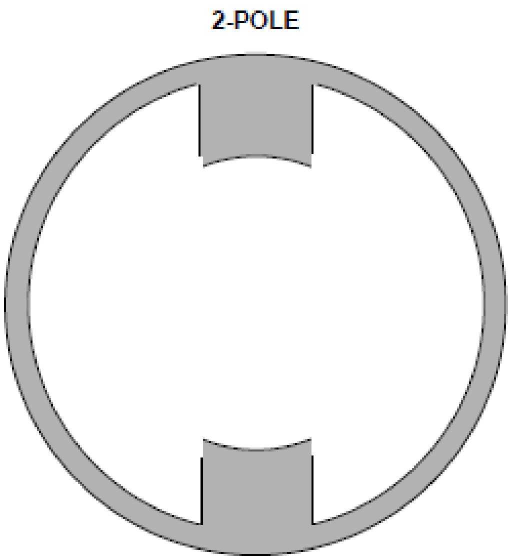
Motor Parts



FAN COVER
EYEBOLT
CONDUIT BOX
FRAME
COOLING FAN
(inside fan cover)
FEET
DRIVE-END
ENDSHIELD
NON DRIVE-END
ENDSHIELD
SHAFT
VENTILATION OPENINGS
(ODP only)

AC Motor Basics

- Synchronous Speed (RPM)

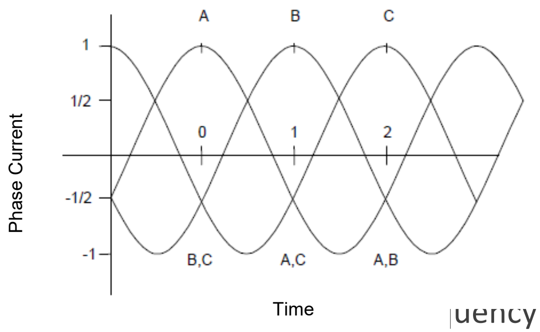


Quantity of pole (2) →

Frequency (50Hz, 60Hz) →

Data:

Geometrical configuration of the coils (120°)



uency * 120) / Pole = RPM

(60 * 120) / 2 = RPM

(7200) / 2 = RPM

3600 = RPM

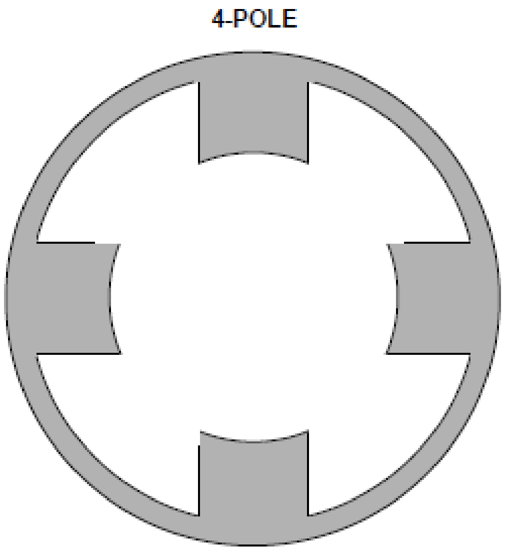
(50 * 120) / 2 = RPM

(6000) / 2 = RPM

3000 = RPM

AC Motor Basics

- Synchronous Speed (RPM)

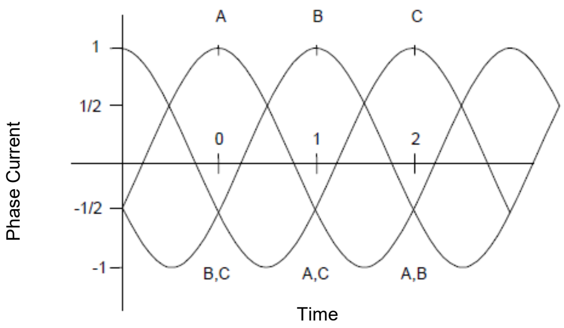


Quantity of pole (4) →

Frequency (50Hz, 60Hz) →

Data:

Geometrical configuration of the coils (120°)



y * 120) / Pole = RPM

(60 * 120) / 4 = RPM	(50 * 120) / 4 = RPM
(7200) / 4 = RPM	(6000) / 4 = RPM
1800 = RPM	1500 = RPM

AC Motor Basics

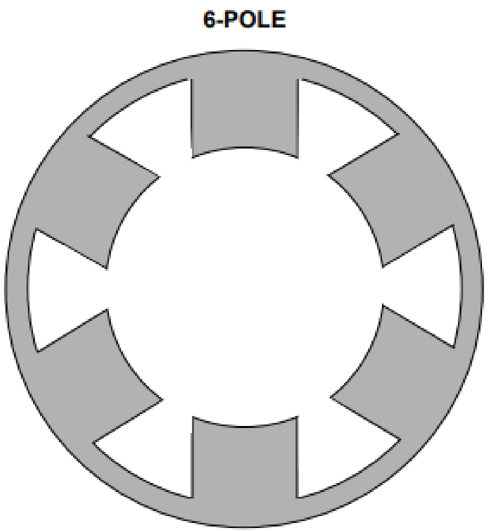
- Synchronous Speed (RPM)

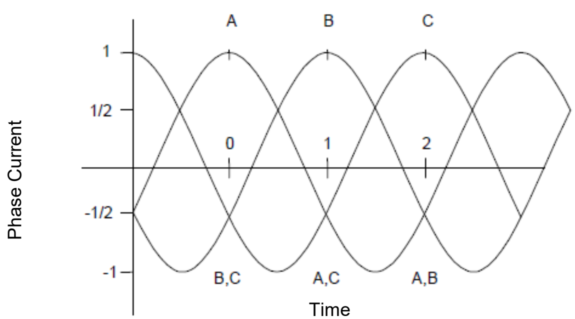
Quantity of pole (6) →

Frequency (50Hz, 60Hz) →

Data:

Geometrical configuration of the coils (120°)





120) / Pole = RPM

(60 * 120) / 6 = RPM

(7200) / 6 = RPM

1200 = RPM

(50 * 120) / 6 = RPM

(6000) / 6 = RPM

1000 = RPM

AC Motor Basics

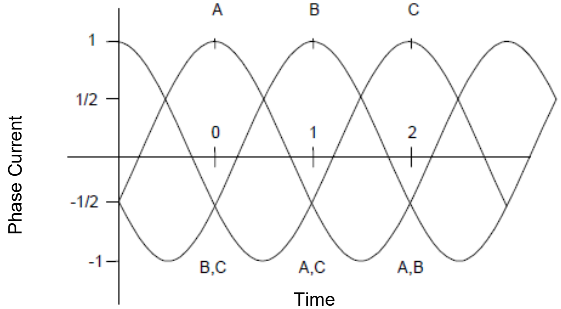
- Synchronous Speed (RPM)

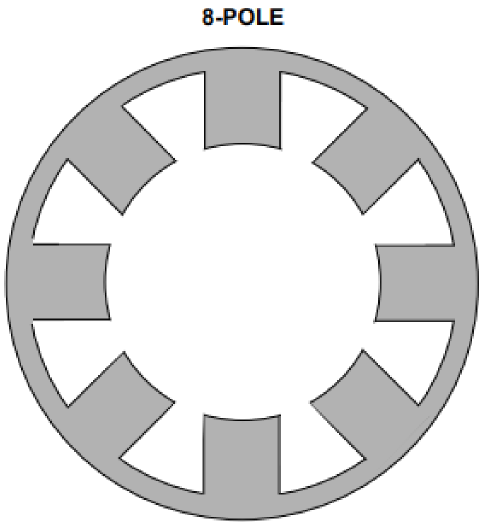
Quantity of pole (8) →

Frequency (50Hz, 60Hz) →

Data:

Geometrical configuration of the coils (120°)





120) / Pole = RPM

(60 * 120) / 8 = RPM

(7200) / 8 = RPM

900 = RPM

(50 * 120) / 8 = RPM

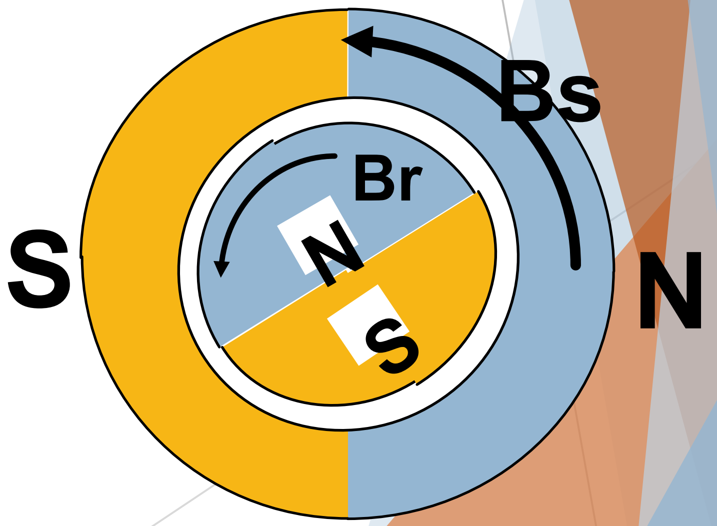
(6000) / 8 = RPM

750 = RPM

AC Motor Basics

- Speed vs Slip

- Without load, the rotor rotates at the speed of the rotating field of the stator (or almost).
- We call it synchronous motor speed.
- With a load, the speed of the rotor shifts with the rotating stator field.
- Magnetic fluxes from the motor amplify, creating motor Torque.
- This phase shift is called the Slip.
- The Synchronous Speed – The Slip = Asynchronous Speed
- The motor Torque is proportional to the motor Slip.



AC Motor Basics

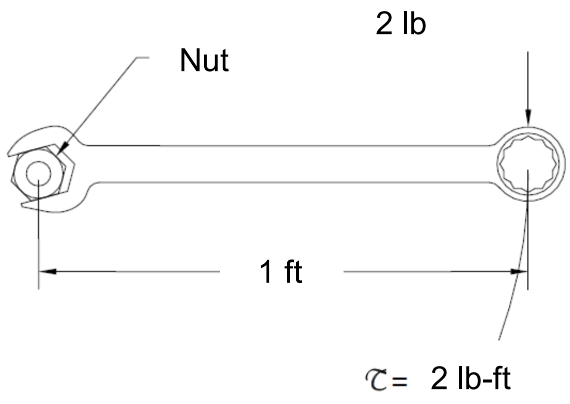
- Speed vs Torque

Two important factors that determine the mechanical power of a motor:

- Speed
- Torque

Torque is the unit of measurement for the mechanical power either required or produced.

- The most popular: lb-ft, lb-in and Nm (Newton Meter)



AC Motor Basics

The power is calculated as the product of the Speed and the Torque

- Power = Speed (RPM) x Torque (lb-ft) / 5252
- (1HP (2P) = 1.49 lb-ft)   (1HP (4P) =2.92 lb-ft)   (1HP (6P) =4.38 lb-ft)

- 1 HP = 746W
- BHP = HP before mechanical losses (pulley / belt, gearbox)
- North America: HP, Standardized manufacturing process : MG1
- Europe: Kw, Standardized manufacturing process : IEC

AC Motor Basics

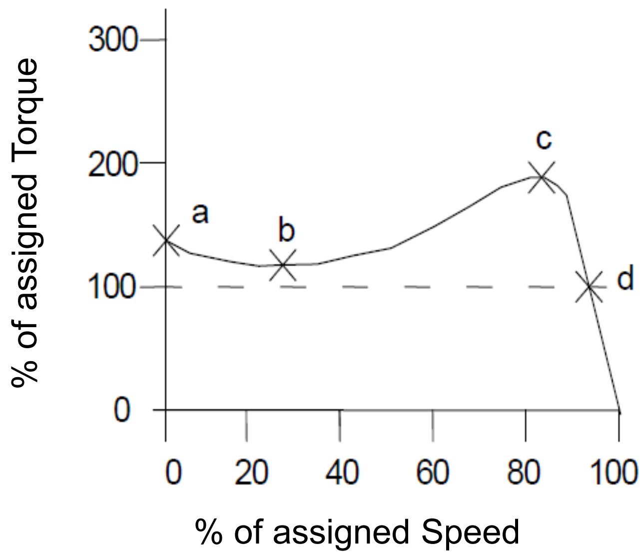
- Characteristics of Torque / Speed

A) Locked Rotor Torque (LRT):

B) Pull Up Torque (PUT):

C) Breakdown Torque (BDT).

D) Full Load Torque (FLT).

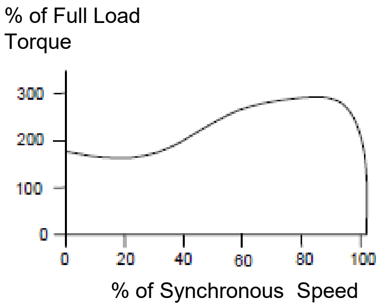


AC Motor Basics

- In order to facilitate the choice of motors, NEMA (National Electrical Manufacturers Association) standardized the characteristics of Torque / Speed for a ''Squirrel-Cage'' motor up to 200HP.

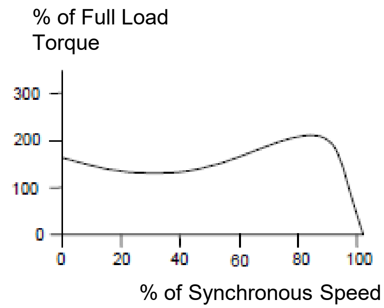
Design A

LRT 70 – 275%
BDT 175 – 600%



Design B

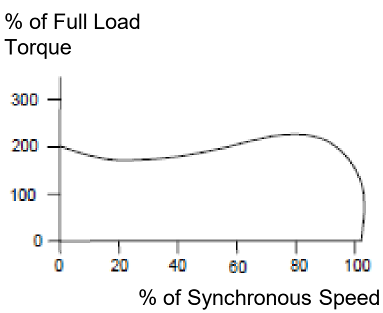
LRT 70 – 275%
BDT 175 – 300%



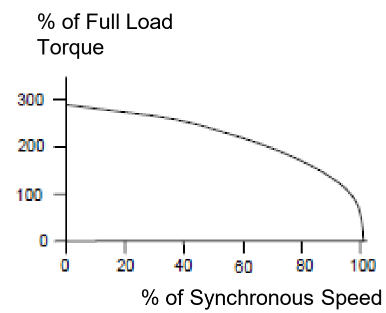
LRT 200 – 250%
BDT 190 – 225%

LRT 275%
BDT 275%

Design C

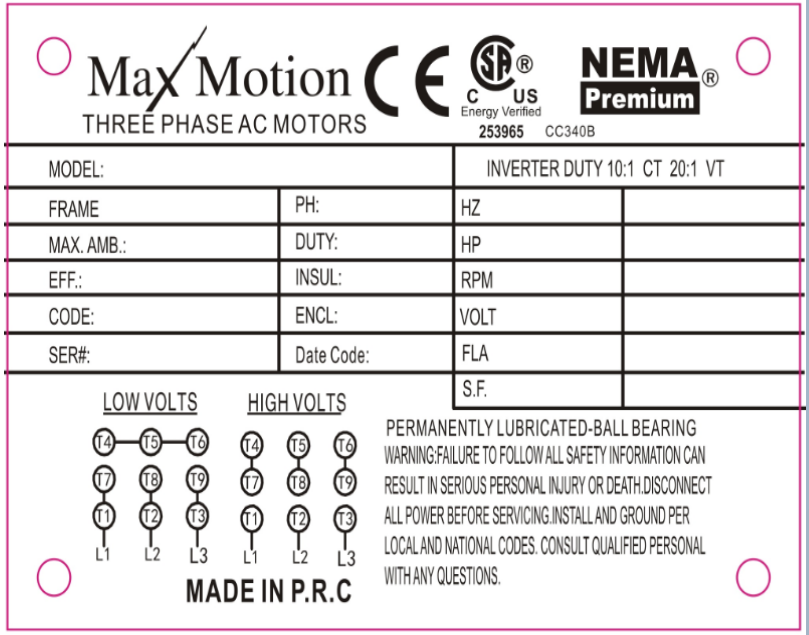


Design D



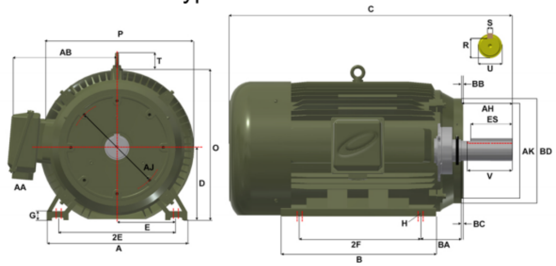
The motor nameplate contains the essential information for its replacement.

1) Typical manufacturer's enclosure (TEFC, ODP, etc.)
2) Manufacturer's frame (NEMA, IEC)
3) Power Rating (HP, Kw)
4) Service Factor (SF: 1.00, 1.15, etc.)
5) Operating Time (Duty: Continuous, etc.)
6) Ambient Temperature: (Maximum °C)
7) Insulation Class Designation (B, F, H)
8) RPM: Revolutions per minute at rated load (3550, 1750, etc.)
9) Operating Frequency (50, 60 Hz)
10) Quantity of Phases (1, 3 ph.)
11) Amperage at the Rated Load (FLA:, SFA:)
12) Rated Voltage (208 - 230/460, 575)
13) Locked Rotor KVA Code (Code G, H, etc.)
14) Torque Profile Code (Design A, B, C, D)
15) Full Load Efficiency (91.7%, etc.) Nema Premium
16) Notification of options when present (RTD, Thermistors, Thermostats)
17) Although the wiring diagram is not always on the nameplate, it is part of the required information to replace a motor
18) Protection: IP12, 43, 55, 66, etc.
19) Lubrification
20) Compatibility with VFD

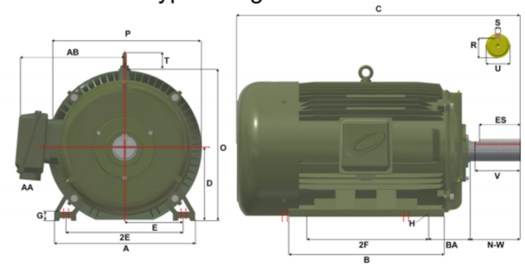


Nema Quick Reference Dimensional Chart

Typical C-face Motor



Typical Rigid Base Motor

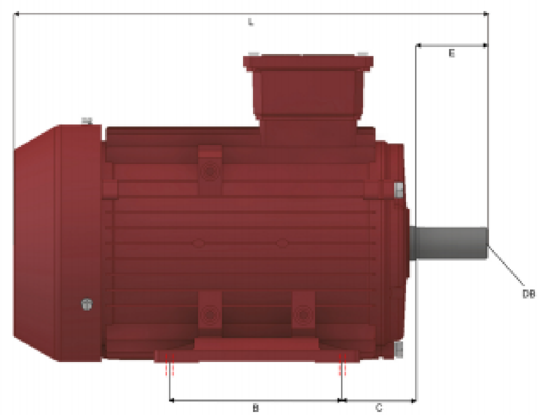


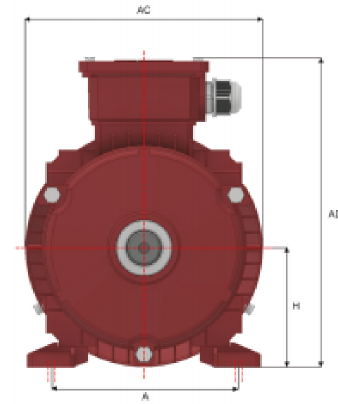
Visit www.mep.ca and select specific MaxMotion model for “AB”, “O”, & “P” Dimensions

Refer to your MEP catalog for "C" Dim.

FRAME	D	E	2F	H	U	N-W	AA	AH	AJ	AK	BA	BB (MIN)	BD (MAX)	H (HOLES)
48	3.00	2.12	2.75	.34 SLOT	.5000	1.50	1/2	1.69	3.750	3.000	2.50	.13	5.62	1/4-20
56	3.50	2.44	3.00	.34 SLOT	.6250	1.88	1/2	2.06	5.875	4.500	2.75	.13	6.50	3/8-16
56H	3.50	2.44	5.00	.34 SLOT	.6250	1.88	1/2	2.06	5.875	4.500	2.75	.13	6.50	3/8-16
143T	3.50	2.75	4.00	.34	.8750	2.25	3/4	2.12	5.875	4.500	2.25	.13	6.50	3/8-16
145T	3.50	2.75	5.00	.34	.8750	2.25	3/4	2.12	5.875	4.500	2.25	.13	6.50	3/8-16
182	4.50	3.75	4.50	.41	.8750	2.25	3/4	2.12	5.875	4.500	2.75	.13	6.50	3/8-16
184	4.50	3.75	5.50	.41	.8750	2.25	3/4	2.12	5.875	4.500	2.75	.13	6.50	3/8-16
182T	4.50	3.75	4.50	.41	1.125	2.75	3/4	2.62	7.250	8.500	2.75	.25	9.00	1/2-13
184T	4.50	3.75	5.50	.41	1.125	2.75	3/4	2.62	7.250	8.500	2.75	.25	9.00	1/2-13
213	5.25	4.25	5.50	.41	1.125	3.00	1	2.75	7.250	8.500	3.50	.25	9.00	1/2-13
215	5.25	4.25	7.00	.41	1.125	3.00	1	2.75	7.250	8.500	3.50	.25	9.00	1/2-13
213T	5.25	4.25	5.50	.41	1.375	3.38	1	3.12	7.250	8.500	3.50	.25	9.00	1/2-13
215T	5.25	4.25	7.00	.41	1.375	3.38	1	3.12	7.250	8.500	3.50	.25	9.00	1/2-13
254U	6.25	5.00	8.25	.53	1.375	3.75	1-1/4	3.50	7.250	8.500	4.25	.25	10.00	1/2-13
256U	6.25	5.00	10.00	.53	1.375	3.75	1-1/4	3.50	7.250	8.500	4.25	.25	10.00	1/2-13
254T	6.25	5.00	8.25	.53	1.625	4.00	1-1/4	3.75	7.250	8.500	4.25	.25	10.00	1/2-13
256T	6.25	5.00	10.00	.53	1.625	4.00	1-1/4	3.75	7.250	8.500	4.25	.25	10.00	1/2-13
284U	7.00	5.50	9.50	.53	1.625	4.88	1-1/2	4.62	9.000	10.500	4.75	.25	11.25	1/2-13
286U	7.00	5.50	11.00	.53	1.625	4.88	1-1/2	4.62	9.000	10.500	4.75	.25	11.25	1/2-13
284T	7.00	5.50	9.50	.53	1.875	4.62	1-1/2	4.38	9.000	10.500	4.75	.25	11.25	1/2-13
286T	7.00	5.50	11.00	.53	1.875	4.62	1-1/2	4.38	9.000	10.500	4.75	.25	11.25	1/2-13
284TS	7.00	5.50	9.50	.53	1.625	3.25	1-1/2	3.00	9.000	10.500	4.75	.25	11.25	1/2-13
286TS	7.00	5.50	11.00	.53	1.625	3.25	1-1/2	3.00	9.000	10.500	4.75	.25	11.25	1/2-13
324U	8.00	6.25	10.50	.66	1.875	5.62	2	5.38	11.000	12.500	5.25	.25	14.00	5/8-11
326U	8.00	6.25	12.00	.66	1.875	5.62	2	5.38	11.000	12.500	5.25	.25	14.00	5/8-11
324T	8.00	6.25	10.50	.66	2.125	5.25	2	5.00	11.000	12.500	5.25	.25	14.00	5/8-11
326T	8.00	6.25	12.00	.66	2.125	5.25	2	5.00	11.000	12.500	5.25	.25	14.00	5/8-11
324TS	8.00	6.25	10.50	.66	1.875	3.75	2	3.50	11.000	12.500	5.25	.25	14.00	5/8-11
326TS	8.00	6.25	12.00	.66	1.875	3.75	2	3.50	11.000	12.500	5.25	.25	14.00	5/8-11
364U	9.00	7.00	11.25	.66	2.125	6.38	2-1/2	6.12	11.000	12.500	5.88	.25	14.00	5/8-11
365U	9.00	7.00	12.25	.66	2.125	6.38	2-1/2	6.12	11.000	12.500	5.88	.25	14.00	5/8-11
364T	9.00	7.00	11.25	.66	2.375	5.88	2-1/2	5.62	11.000	12.500	5.88	.25	14.00	5/8-11
365T	9.00	7.00	12.25	.66	2.375	5.88	2-1/2	5.62	11.000	12.500	5.88	.25	14.00	5/8-11
364TS	9.00	7.00	11.25	.66	1.875	3.75	2-1/2	3.50	11.000	12.500	5.88	.25	14.00	5/8-11
365TS	9.00	7.00	12.25	.66	1.875	3.75	2-1/2	3.50	11.000	12.500	5.88	.25	14.00	5/8-11
404U	10.00	8.00	12.25	.81	2.375	7.12	3	6.88	11.000	12.500	6.62	.25	15.50	5/8-11
405U	10.00	8.00	13.75	.81	2.375	7.12	3	6.88	11.000	12.500	6.62	.25	15.50	5/8-11
404T	10.00	8.00	12.25	.81	2.875	7.25	3	7.00	11.000	12.500	6.62	.25	15.50	5/8-11
405T	10.00	8.00	13.75	.81	2.875	7.25	3	7.00	11.000	12.500	6.62	.25	15.50	5/8-11
404TS	10.00	8.00	12.25	.81	2.125	4.25	3	4.00	11.000	12.500	6.62	.25	15.50	5/8-11
405TS	10.00	8.00	13.75	.81	2.125	4.25	3	4.00	11.000	12.500	6.62	.25	15.50	5/8-11
444U	11.00	9.00	14.50	.81	2.875	8.62	3	8.38	14.000	16.000	7.50	.25	18.00	5/8-11
445U	11.00	9.00	16.50	.81	2.875	8.62	3	8.38	14.000	16.000	7.50	.25	18.00	5/8-11
444T	11.00	9.00	14.50	.81	3.375	8.50	3	8.25	14.000	16.000	7.50	.25	18.00	5/8-11
445T	11.00	9.00	16.50	.81	3.375	8.50	3	8.25	14.000	16.000	7.50	.25	18.00	5/8-11
444TS	11.00	9.00	14.50	.81	2.375	4.75	3	4.50	14.000	16.000	7.50	.25	18.00	5/8-11
445TS	11.00	9.00	16.50	.81	2.375	4.75	3	4.50	14.000	16.000	7.50	.25	18.00	5/8-11
447T	11.00	9.00	20.00	.81	3.375	8.50	3	8.25	14.000	16.000	7.50	.25	18.00	5/8-11
449T	11.00	9.00	25.00	.81	3.375	8.50	3	8.25	14.000	16.000	7.50	.25	18.00	5/8-11
447TS	11.00	9.00	20.00	.81	2.375	4.75	4 NPT	4.50	14.000	16.000	7.50	.25	18.00	5/8-11
449TS	11.00	9.00	25.00	.81	2.375	4.75	4 NPT	4.50	14.000	16.000	7.50	.25	18.00	5/8-11

IEC QUICK REFERENCE KEY DIMENSIONS CHART



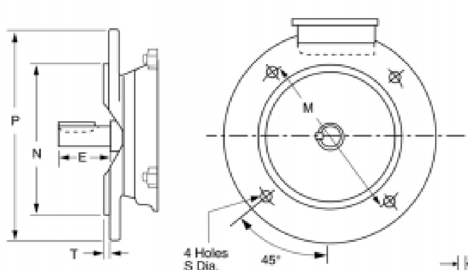


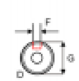
IEC Frame Dimensions (Millimeters)

	Mounting				Shaft				General			B5 Flange			B14 Flange		
FRAME	A	B	C	H	D	E	F	DB	L	AC	AD	M	N	P	M	N	P
56	90	71	36	56	9	20	3	M3	199	113	97	100	80	120	65	50	80
63	100	80	40	63	11	23	4	M4	217	120	103	115	95	140	75	60	90
71	112	90	45	71	14	30	5	M5	245	136	112	130	110	160	85	70	105
80	125	100	50	80	19	40	6	M6	300	158	135	165	130	200	100	80	120
90 S	140	100	56	90	24	50	8	M8	320	175	138	165	130	200	115	95	140
90 L	140	125	56	90	24	50	8	M8	345	175	138	165	130	200	115	95	140
100L	160	140	63	100	28	60	8	M10	405	198	160	215	180	250	130	110	160
112M	190	140	70	112	28	60	8	M10	400	230	178	215	180	250	130	110	160
132 S	216	140	89	132	38	80	10	M12	445	258	188	265	230	300	165	130	200
132M	216	178	89	132	38	80	10	M12	485	258	188	265	230	300	165	130	200
160 M	254	210	108	160	42	110	12	M16	615	315	242	300	250	350	215	180	250
160L	254	254	108	160	42	110	12	M16	660	315	242	300	250	350	215	180	250
180 M	279	241	121	180	48	110	14	M16	652	355	267	300	250	350			
180 L	279	279	121	180	48	110	14	M16	690	355	267	300	250	350			
200 L	318	305	133	200	55	110	16	M20	746	400	304	350	300	400			
225 S	356	286	149	225	55*/60	110*/140	16*/18	M20	780	446	326	400	350	450			
225 M	356	311	149	225	55*/60	110*/140	16*/18	M20	810	446	326	400	350	450			
250 M	406	349	168	250	60*/65	140	18	M20	900	485	358	500	450	550			
280 S	457	368	190	280	65*/75	140	18*/20	M20	982	547	387	500	450	550			
280 M	457	419	190	280	65*/75	140	18*/20	M20	1033	547	387	500	450	550			
315 S	508	406	216	315	65*/80	140*/170	18*/20	M20	1208	620	527	550	600	660			
315 M	508	457	216	315	65*/80	140*/170	18*/20	M20	1318	620	527	550	600	660			
315 L	508	508	216	315	65*/80	140*/170	18*/20	M20	1388	620	527	550	600	660			

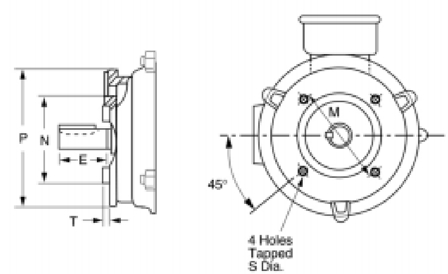
* Denotes dimensions in mm for 2 Pole - 3600 RPM Motors

***GENERAL** Notes - Dimensions are specific to MaxMotion Design and may vary from different manufacturers*

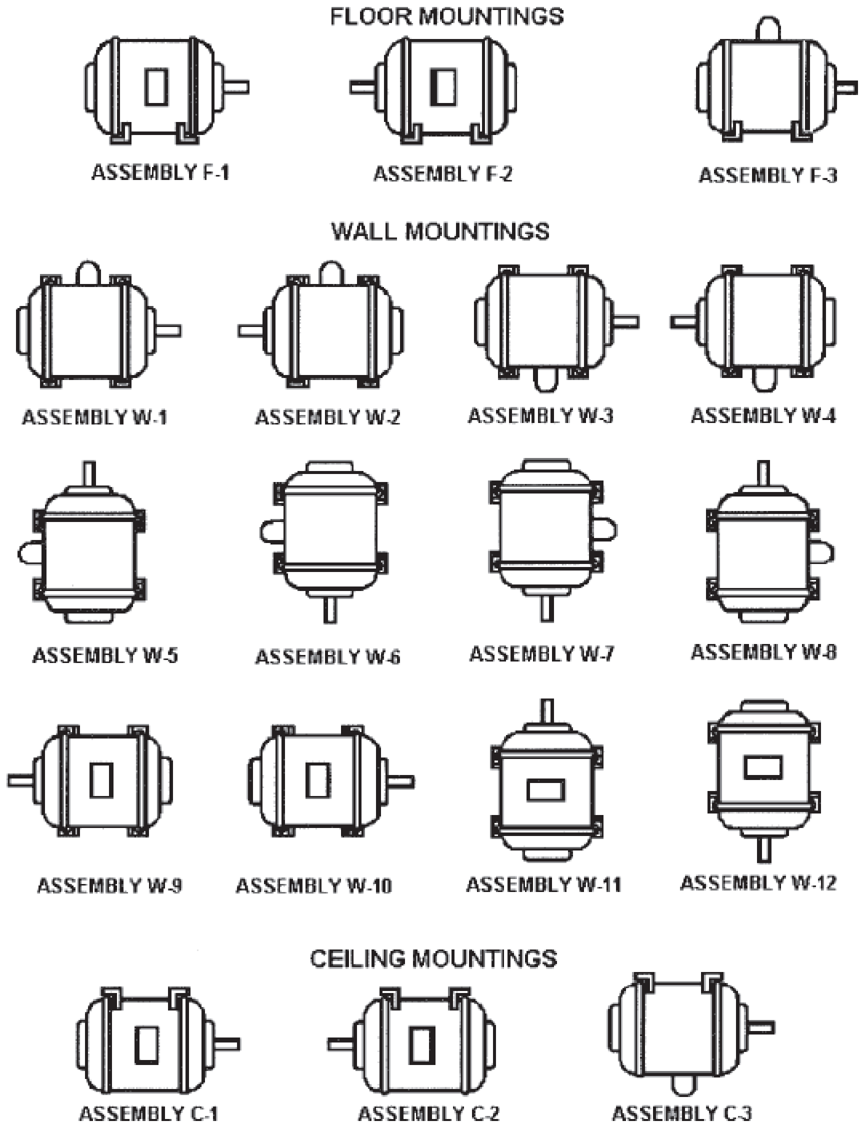




D Flange B5 Mount



C Flange B14 Mount

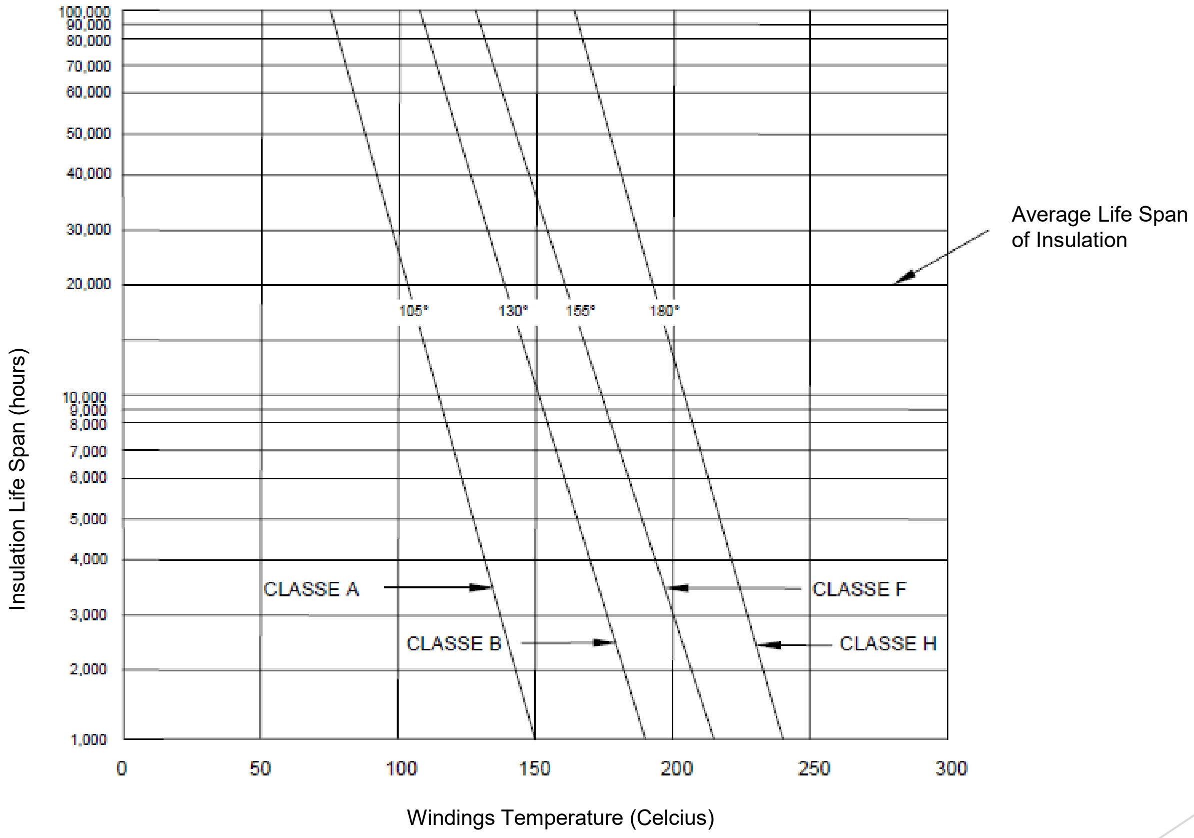

FLOOR MOUNTINGS
ASSEMBLY F-1
ASSEMBLY F-2
ASSEMBLY F-3
WALL MOUNTINGS
ASSEMBLY W-1
ASSEMBLY W-2
ASSEMBLY W-3
ASSEMBLY W-4
ASSEMBLY W-5
ASSEMBLY W-6
ASSEMBLY W-7
ASSEMBLY W-8
ASSEMBLY W-9
ASSEMBLY W-10
ASSEMBLY W-11
ASSEMBLY W-12
CEILING MOUNTINGS
ASSEMBLY C-1
ASSEMBLY C-2
ASSEMBLY C-3

NEMA maximum temperature rise for a continuous duty motor and resistance measurement method, in an ambient of 40°C at less than 1000 meters altitude

	Insulation Class			
Type	A (105°C) (221°F)	B (130°C) (266°F)	F (155°C) (311°F)	H (180°C) (356°F)
ODP (SF 1.0)	60	80	105	125
TEFC (SF 1.0)	60	80	105	125
TENV (SF 1.0)	65	85	110	130
SF 1.15 or +	70	90	115	130

Note: Temperature above in Celsius

Life Span of Insulation as a function of Temperature



For every 10 °C of temperature rise, life expectancy is reduces by half

Network Nominal Voltage vs Motor Nameplate Voltage

Network Nominal Voltage	Nameplate Voltage
120 VAC – 1 phase	115 VAC
208 / 120 VAC – 3 phases	200 VAC
240 VAC – 1 or 3 phases	230 VAC
480 / 277 VAC – 3 phases	460 VAC
600 / 347 VAC – 3 phases	575 VAC
2400 VAC – 3 phases	2300 VAC
4160 / 2400 VAC – 3 phases	4000 VAC

Motor Characteristics vs Voltage Fluctuation

	90%	110%	120%
Locked Rotor Torque	-19%	+21%	+44%
Start Up Curent	-10%	+10%	+25%
% Slip	+23%	-17%	-30%
Efficiency	-2%	+1%	+1.5%
Power Factor	+1%	-3%	-5 to 15%
Full Load Current	+11%	-7%	-11%
Temperature Increase	+7%	-4%	-21%

Voltage Imbalance and Effects on Motor Performance

	Phase A-B	Phase B-C	Phase A-C
Voltage	460	467	450

Calculation of the Phase Imbalance Percentage

Average = 460 + 467 + 450 / 3
Average = 459
% Imbalance = 100 * Max Voltage Deviation – Average / Average
% =100 * 9/459
% = 1.96%

Small unbalanced Voltage / Phase results in larger unbalanced Current / Phase.
Electric motors are designed to accept 1% unbalanced voltage.
More than 1%, motor performance will be affected.
To compensate: - Load reduction
- Motor derating (SF 1.0 – SF 1.15)

A motor should never be operated with an unbalanced voltage of 5% or more.

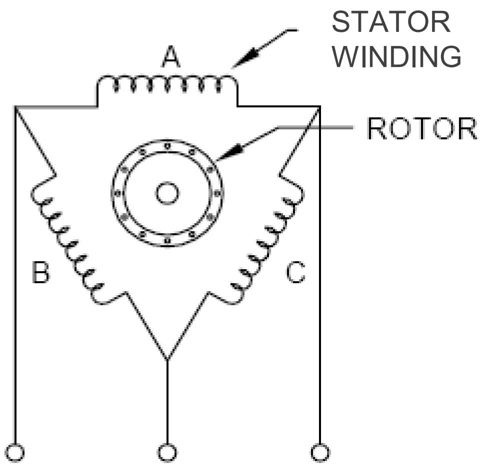
NEMA KVA Start Up Current Code

Code Letter	KVA / HP	Code Letter	KVA / HP
A B	0 – 3.15 3.15 – 3.55	K L	8.0 – 9.0 9.0 – 10.0
C D	3.55 – 4.0 4.0 – 4.5	M N	10.0 -11.2 11.2 – 12.5
E F	4.5 – 5.0 5.0 – 5.6	P R	12.5 – 14.0 14.0 – 16.0
G H	5.6 – 6.3 6.3 – 7.1	S T	16.0 – 18.0 18.0 – 20.0
J	7.1 – 8.0	U V	20.0 – 22.4 22.4 & +

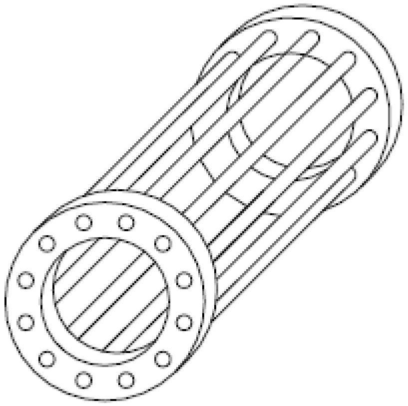
Start up KVA /HP = Voltage * Locked Rotor Current * 1.732 / HP * 1000

Locked Rotor Current = Start up KVA /HP * HP * 1000 / Volts * 1.732

AC MOTORS



Squirrel Cage Motor



AC MOTORS

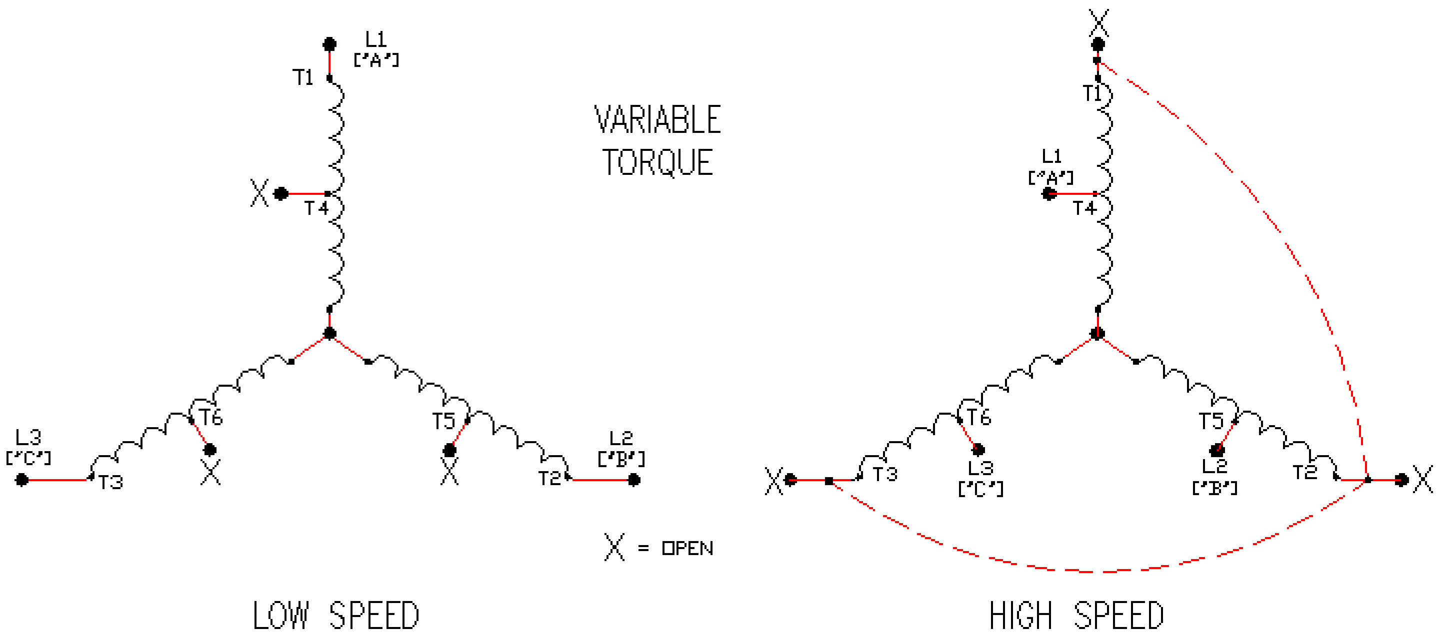


Fig. 3YM03: 3 Phase Wye Connected Induction Motors - Squirrel Cage Rotor.
Two-Speed, One Winding Variable Torque [2 : 1 speed pole-changing]

AC MOTORS

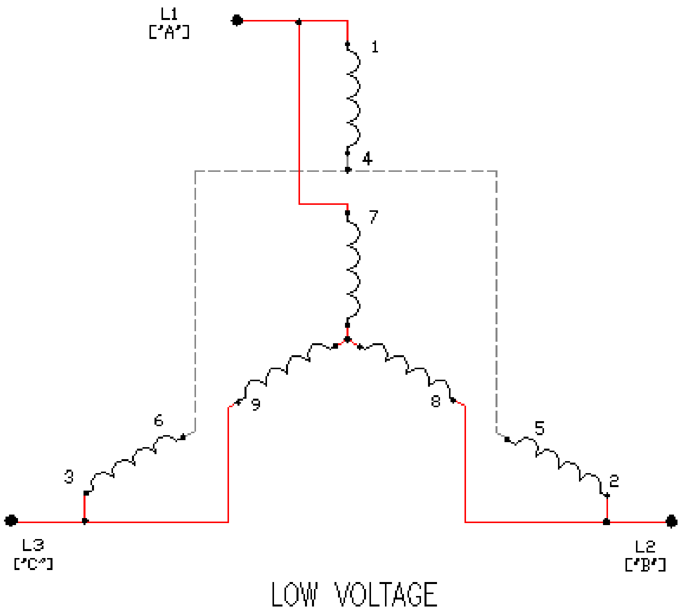


Fig. 3YM04: 3 Phase Wye Connected Induction Motors - Squirrel Cage Rotor.
Dual Voltage, Two Winding [Split-Coils] Stators. Connections For Low [240 v] & High [480 v] Voltages.

AC MOTORS

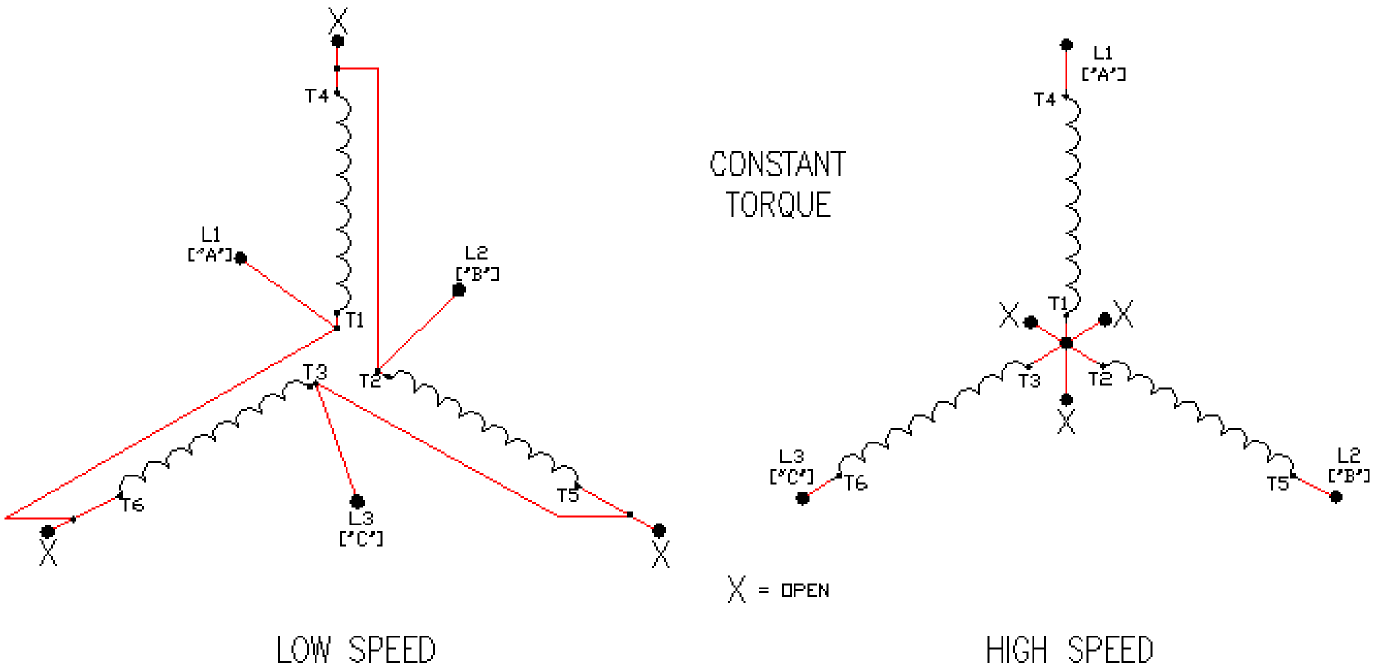
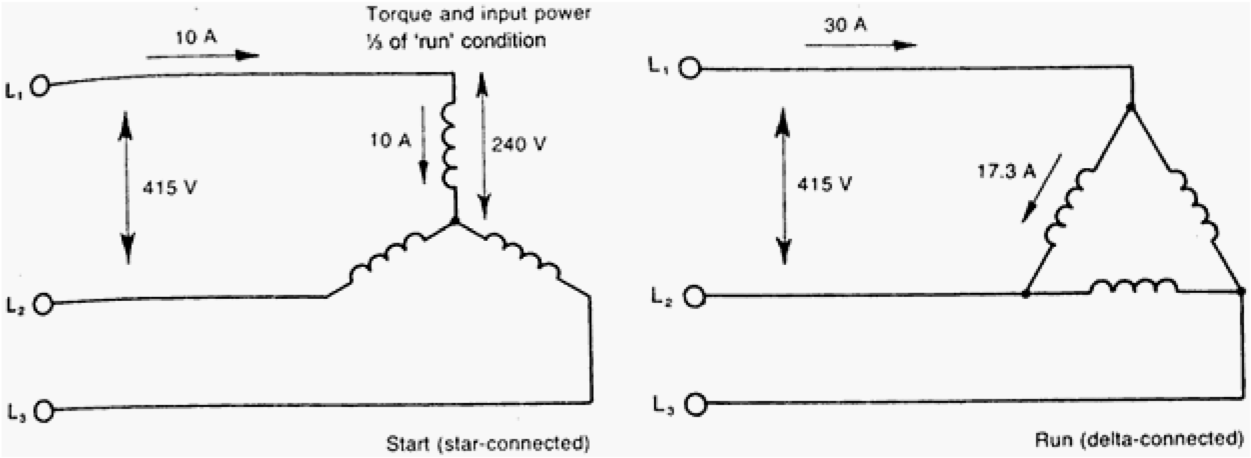
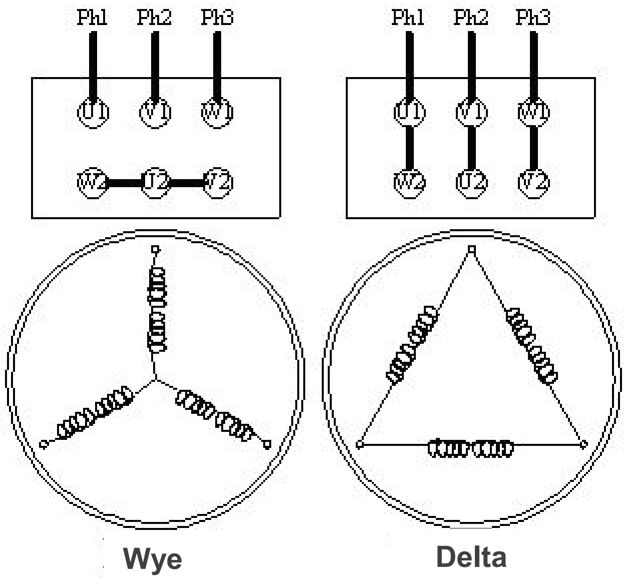


Fig. 3YM02: 3 Phase Wye Connected Induction Motors - Squirrel Cage Rotor.
Two-Speed, One Winding Constant Torque [2 : 1 speed pole-changing]

AC MOTORS



10 A
Torque and input power
⅓ of 'run' condition
L1
415 V
10 A
240 V
L2
L3
Start (star-connected)
30 A
L1
415 V
17.3 A
L2
L3
Run (delta-connected)



Ph1
Ph2
Ph3
U1
V1
W1
W2
U2
V2
Wye
Ph1
Ph2
Ph3
U1
V1
W1
W2
U2
V2
Delta

Terminology

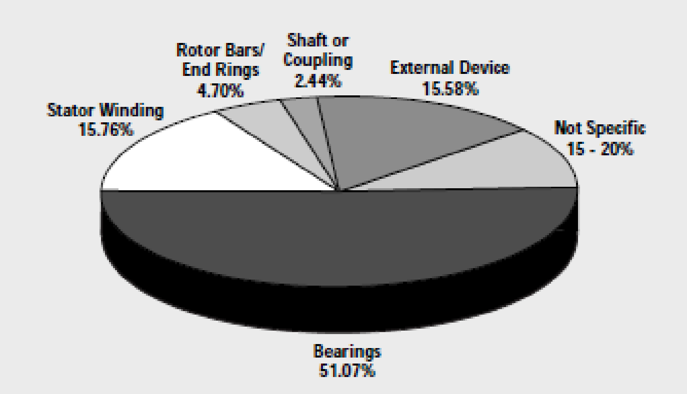
- Voltage: Volts
- Current: Amps
- Kw: Volts x Amps
- Ambient Temperature: 40 ˚C
- Temperature Rise: ≤ 80 ˚C
- Altitude: 1,000 M (3,300 ft)
- Service Factor: 1.15
- Power Factor: 0.8
- Efficiency: 90%
- Enclosure Cooling: ODP, TEFC
- Environment: IP23, IP41, IP55, IP56, IP66
- Frame: 48, 56, 143T – 449T
- Cooling: ODP, TEFC
- Mechanical Assembly: Horizontal, vertical ↑↓, legs, flange C or D.
- Derating Factors: Service Factor (1.0, 1.15, 1.25, etc.)
- Start/Stop Cycle: (X / hours)
- Start-up: DOL, Star / Delta, 2 speeds 1 winding, 2 speeds 2 windings, Softstarter, VFD

NEMA MG-1 Table 12-12 Full Load Efficiencies for 60 Hz
NEMA Premium® (CEE)
Efficient Electric Motors Rated 600 Volts or less (Random Wound)

HP	NOMINAL FULL LOAD EFFICIENCY							
	OPEN FRAME				ENCLOSED FRAME			
	2 POLE	4 POLE	6 POLE	8 POLE	2 POLE	4 POLE	6 POLE	8 POLE
1	77.0	85.5	82.5	N/A	77.0	85.5	82.5	N/A
1 1/2	84.0	86.5	86.5	N/A	84.0	86.5	87.5	N/A
2	85.5	86.5	87.5	N/A	85.5	86.5	88.5	N/A
3	85.5	89.5	88.5	N/A	86.5	89.5	89.5	N/A
5	86.5	89.5	89.5	N/A	88.5	89.5	89.5	N/A
7 1/2	88.5	91.0	90.2	N/A	89.5	91.7	91.0	N/A
10	89.5	91.7	91.7	N/A	90.2	91.7	91.0	N/A
15	90.2	93.0	91.7	N/A	91.0	92.4	91.7	N/A
20	91.0	93.0	92.4	N/A	91.0	93.0	91.7	N/A
25	91.7	93.6	93.0	N/A	91.7	93.6	93.0	N/A
30	91.7	94.1	93.6	N/A	91.7	93.6	93.0	N/A
40	92.4	94.1	94.1	N/A	92.4	94.1	94.1	N/A
50	93.0	94.5	94.1	N/A	93.0	94.5	94.1	N/A
60	93.6	95.0	94.5	N/A	93.6	95.0	94.5	N/A
75	93.6	95.0	94.5	N/A	93.6	95.4	94.5	N/A
100	93.6	95.4	95.0	N/A	94.1	95.4	95.0	N/A
125	94.1	95.4	95.0	N/A	95.0	95.4	95.0	N/A
150	94.1	95.8	95.4	N/A	95.0	95.8	95.8	N/A
200	95.0	95.8	95.4	N/A	95.4	96.2	95.8	N/A
250	95.0	95.8	95.4	N/A	95.8	96.2	95.8	N/A
300	95.4	95.8	95.4	N/A	95.8	96.2	95.8	N/A
350	95.4	95.8	95.4	N/A	95.8	96.2	95.8	N/A
400	95.8	95.8	95.8	N/A	95.8	96.2	95.8	N/A
450	95.8	96.2	96.2	N/A	95.8	96.2	95.8	N/A
500	95.8	96.2	96.2	N/A	95.8	96.2	95.8	N/A

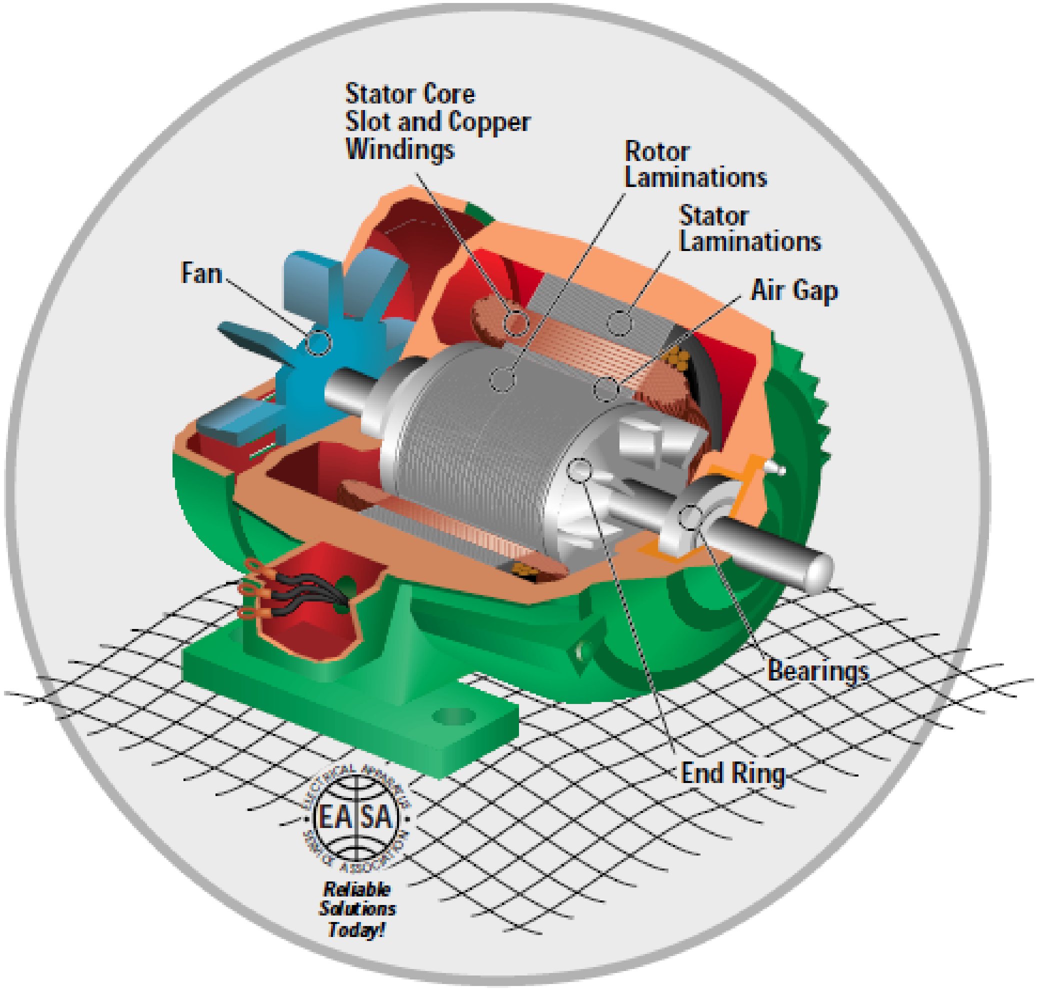
What Causes Motor Failure

- The majority of motor breakdowns are caused by bearing or winding failures.



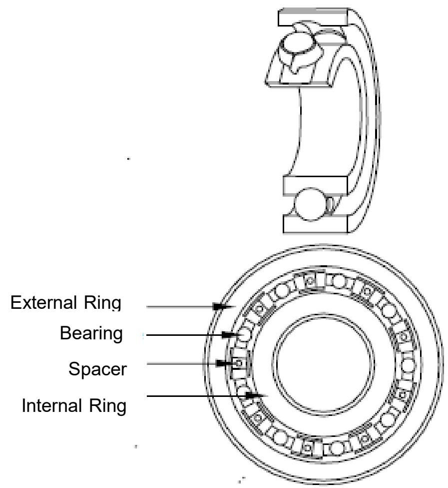
- Manufacturing Defect
- Ambient temperature too high
- Contaminants
- Water, condensation
- Lack of ventilation
- Winding failure
- Locked rotor
- Overload
- Too much grease during maintenance
- Poor quality of the ground
- Faulty bearings
- Bearing failure
- Over voltage / Under voltage
- Transient voltage peak
- Unbalanced voltage Ø-Ø
- VFD output voltage
- Cable length vs voltage drop
- Loose power connections
- Damaged power wiring
- Overload relay incorrectly selected
- Phase loss
- Start/Stop cycle too high
- Altitude above 1,000 M (3,300 ft)
- Poor electrical installation of VFD
- Vibration
- Wrong application of the motor

A mechanical failure often causes an electrical failure

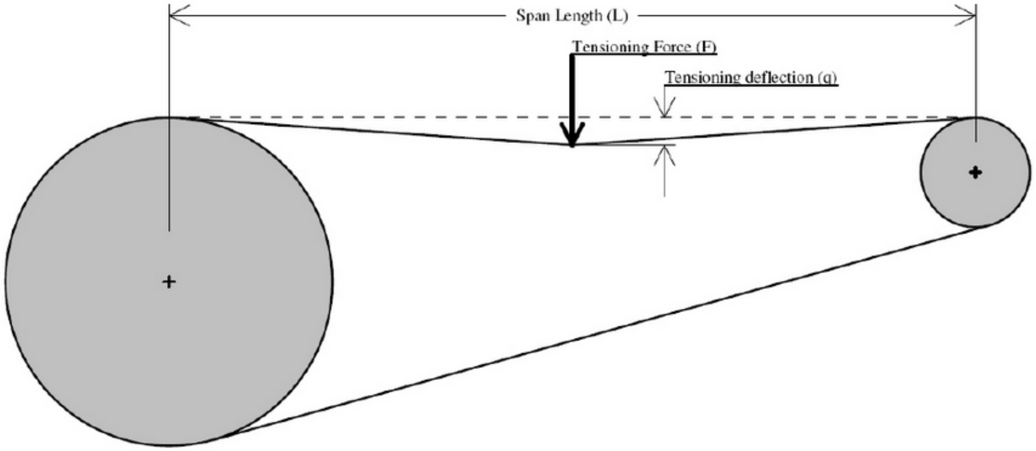


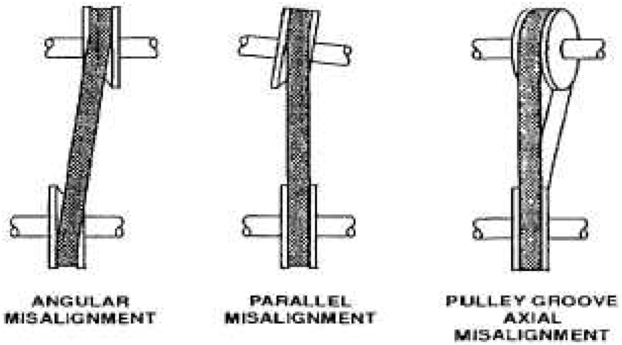
Main Causes of Bearing Failure

- Excessive vibration
- Loss of lubrication efficiency by contaminants
- Wrong grease added
- Bearing temperature too hot/cold
- Poor assembly of a motor to the load
- Misalignment
- Overload (belt tension)
- Humidity (water, corrosion)
- Harmful induced electromagnetic current due to the use of VFD

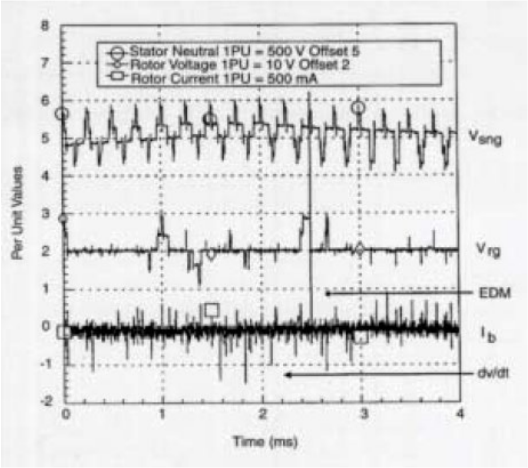


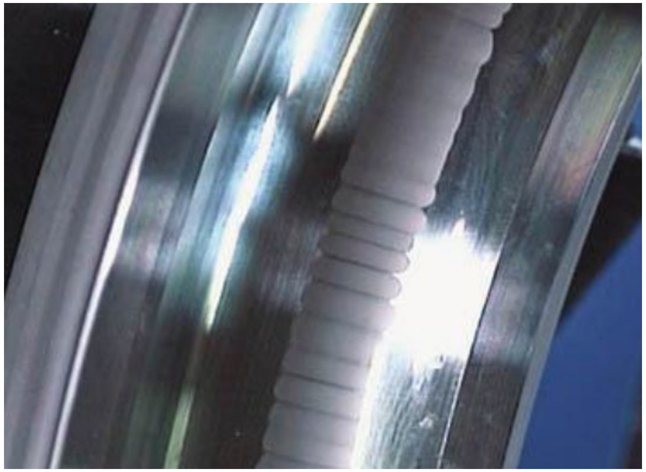
Belt Tension and Misalignment

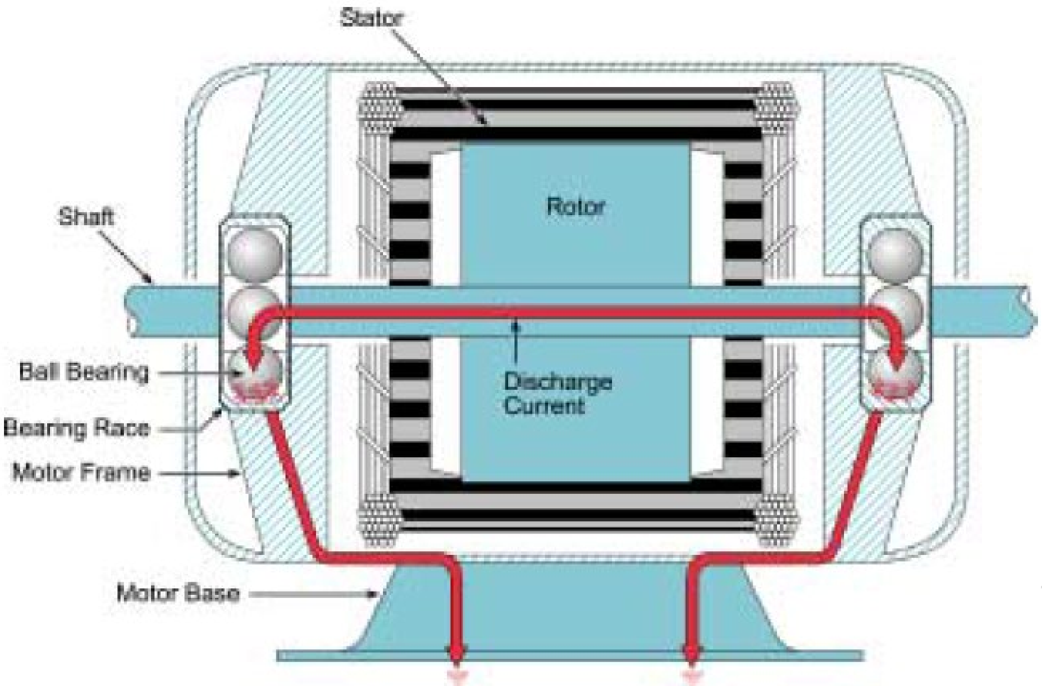




- Harmful Induced Electromagnetic Current due to the use of VFD
- Common-mode Current





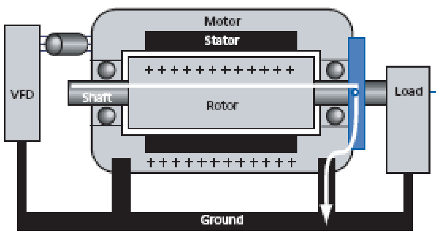


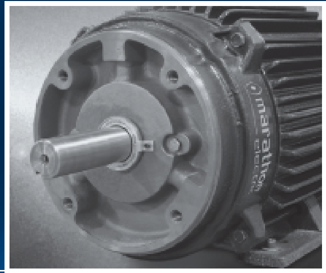
Extend the Life of Your Motor

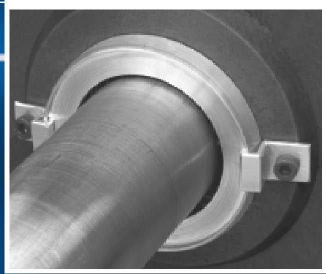
Protect your Marathon motor against VFD-induced bearing currents with

ÆGIS™ SGR
BEARING PROTECTION RING

The World's Most Effective Shaft Grounding Technology!







Capable of saving 30% or more in energy costs, VFDs can help you create "green" systems, and with patented AEGIS™ SGR technology to protect motor bearings, these systems will be sustainable and truly green.

- Safely channels harmful currents away from bearings to ground
- Proven in hundreds of thousands of installations
- Easy to install, contamination-proof, maintenance-free, lasts for life of motor
- Standard sizes for any motor

Electro Static Technology™
An ITW Company

MEP 1982

Vibrations

Excessive vibration reduces bearing life span and adversely affects the motor efficiency.

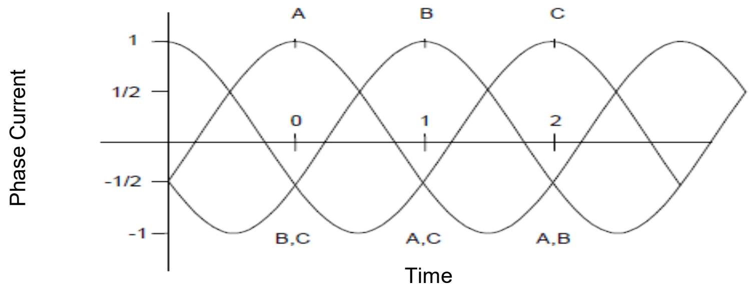
Breakdown factors:

. Improper driven load balancing.
. Improper alignment of the coupling.
. Wear over time.
. Shaft current discharge through bearing to ground

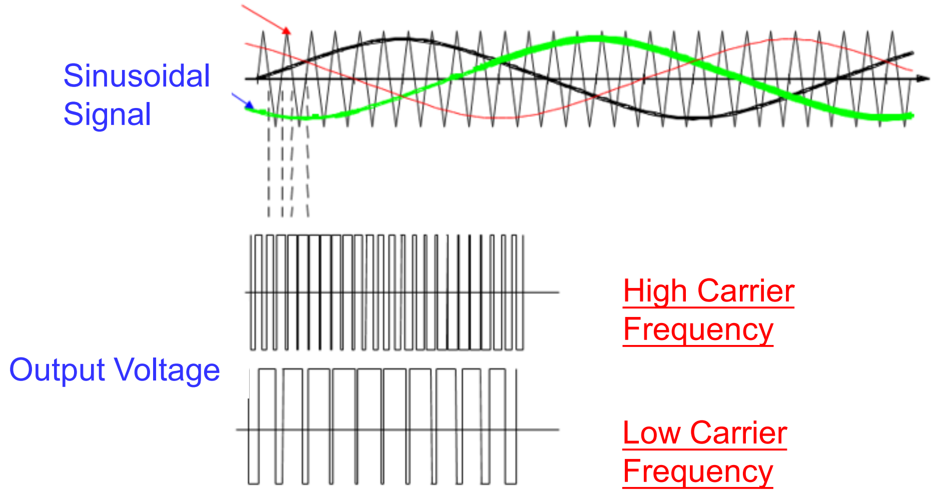
Bearing vibration limits defined by NEMA:

Synchronous Speed (RPM)	Vibration Amplitude (in)
3000 and +	0,0010
1500 to 2999	0,0015
1000 to 1599	0,0020
999 and -	0,0025

General purpose motor is designed to receive a sinusoidal voltage.



Example of the PWM voltage provided by a Variable Frequency Drive



MG1 Parts 30

For NEMA, a general purpose motor must have a standard electrical design and a standard limitation to withstand voltage spikes produced by inverters (commonly referred to as VFD).

MG1-30.02.2.9 stipulates that voltage peaks at the motor terminals should be limited to 1000 volts with a rise time no less than 2 microseconds (µsec). Since the inverters on the market today can produce voltage peaks as short as .04 to 0.3 µsec therefore potentially much higher voltage peaks, a filter must be installed between the inverter and the motor for it to survive and thus comply with this standard. It is the user's responsibility to ensure that the motor will not be damaged by the inverter that powers it.

MG1 Parts 31

For NEMA, Parts 31 defines only motors for definite purpose use with inverter-powered design. The industrial market needs it, but the HVAC market does not need all the features of this definition and is limited to MG1 parts 31.4.4.2 et 31.4.4.3 specifications.

MG1 parts 31.4.4.2 defines the voltage peaks incurred by the motor which may be at the level of: 3.1 * the nominal motor voltage.
230 * 3.1 = 713V
460 * 3.1 = 1426V
575 * 3.1 = 1783V
The incurred rise time will be no less than .1 microseconds (µsec).

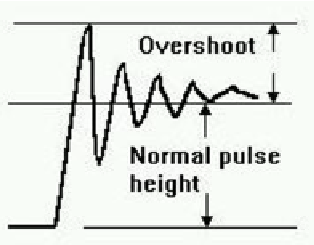
These voltage levels do not take into account the cable length between the motor and the inverter or the carrier frequency to be used in the inverter.

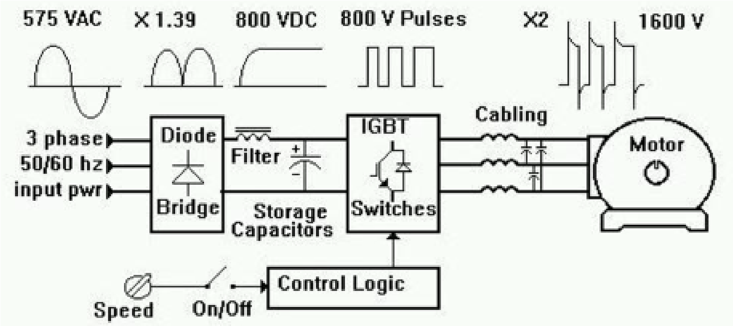
MG1 parts 31.4.4.3 describes the phenomenon of damage to the rotation of the induced electromagnetic current, but is not clear on the standard method of measurement. However, all manufacturers have solutions to propose when required.

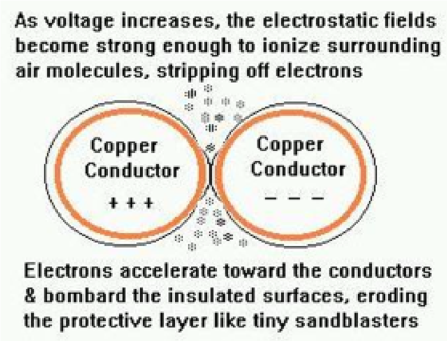
Why are voltage levels at the terminals of a motor so high?

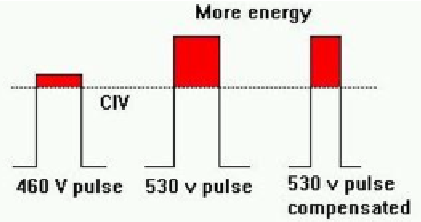
Inverter Basics:

- Convert AC to DC (575 * 1.4)
- IGBT pulse 800Vwhen gate opens, therefore on a cycle +800 and -800 = 1600V
- Destructive effect of ''CIV'' Corona Inception Voltage begins @ 1000V
- Change of impedance of power cable vs motor









Variable Speed Operation

Guidelines for Application of General Purpose, Three Phase, Single Speed Motors on Variable Frequency Drives Meets NEMA MG1-2006 Part 30 and Part 31 Section 4.4.2 Unless stated otherwise, motor nameplates do NOT include listed speed range.

ENCLOSURE	EFFICIENCY	VARIABLE TORQUE	CONSTANT TORQUE								
		ALL FRAMES	56	143-215		254-286		324-365		404-449	
NEMA Motors		ALL POLES	ALL POLES	2-Pole	4&6 Pole	2-Pole	4&6 Pole	2-Pole	4&6 Pole	2-Pole	4&6 Pole
ODP	Standard (EPAct exempt)	10:1	2:1	2:1	2:1	Contact Engineering					
	EPAct compliant	10:1	N/A	2:1	2:1	2:1	2:1	Contact Engineering			
	NEMA Premium (XRI)	10:1	N/A	10:1	10:1	10:1	10:1	10:1	10:1	2:1	2:1
TEFC	Standard (EPAct exempt)	10:1	2:1	2:1	2:1	Contact Engineering					
	EPAct compliant	10:1	N/A	2:1	10:1	2:1	10:1	2:1	2:1	2:1	2:1
	NEMA Premium (XRI)	10:1	N/A	2:1	20:1	2:1	20:1	2:1	20:1 (1)	2:1	20:1 (1)
TENV	EPAct compliant	10:1	N/A	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1
	NEMA Premium (XRI)	10:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1	1000:1
Washdown TEFC	Standard (EPAct exempt)	10:1	10:1 (2)	10:1 (2)	10:1 (2)	N/A	N/A	N/A	N/A	N/A	N/A
	EPAct compliant	10:1	N/A	10:1 (2)	10:1 (2)	N/A	N/A	N/A	N/A	N/A	N/A
Washdown TENV	Standard (EPAct exempt)	10:1	1000:1	1000:1	1000:1	N/A	N/A	N/A	N/A	N/A	N/A
	EPAct compliant	10:1	N/A	1000:1	1000:1	N/A	N/A	N/A	N/A	N/A	N/A
Explosion Proof	All efficiency levels	Explosion Proof motors must be properly nameplated with inverter duty information prior to use on VFD. See Marathon catalog pages for specific rating capabilities. Motors with automatic overload protectors cannot be used on VFDs.									
IEC Motors		ALL FRAMES	63-90	100-225							
All Enclosures	All efficiency levels	10:1	20:1	Up to 20:1							

Maximum Cable Lengths from the Motor to Drive

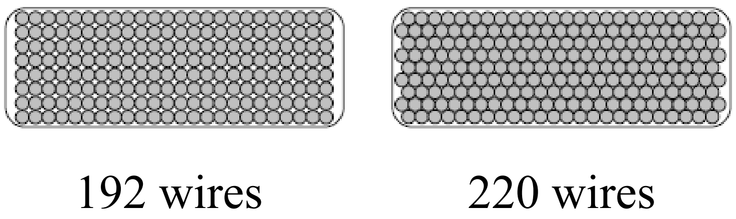
PRODUCT DESCRIPTION	3 kHz CARRIER FREQUENCY (PHASE TO PHASE)*		
	230 VOLT	460 VOLT	575 VOLT
56-326 NEMA, 100-225 IEC Frames	600 ft.	125 ft.	40 ft.
364-5013 NEMA, 250-315 IEC Frames	1000 ft.	225 ft.	60 ft.
Motors with CR^{200} Corona Resistant Magnet Wire	1500 ft.	475 ft.	140 ft.
Motors with MAX GUARD® insulation system	Unlimited	Unlimited	650 ft.
Form-wound low voltage motors	Unlimited	Unlimited	650 ft.

* Higher carrier frequencies require shorter cable length to obtain normal (50Khrs) insulation life.

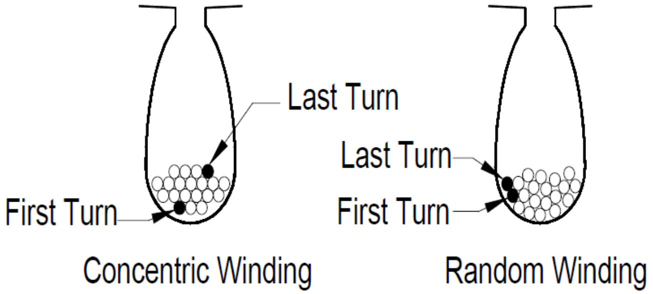
What makes a motor designed in compliance with MG1 Parts 31.4.4.2?

Essentially, 3 things:

1) An insulated wire with a ceramic layer (Spike Resistant Wire)
2) In each slot, more conductors are inserted to reduce area gaps



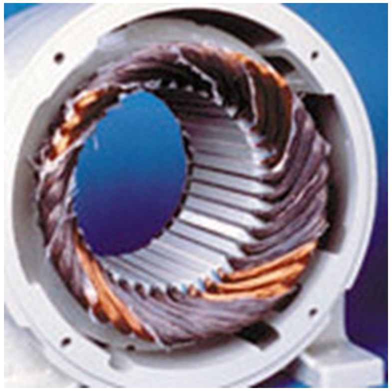
3) When each group is inserted, great care is taken to ensure that the input and output conductors are not next to each other



Typical Causes of Stator Windings Failure

Normal stator windings

Windings (Wye on the left & Delta on the right), failure due to loss of a phase

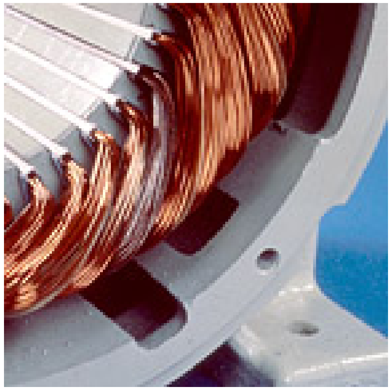


Typical Causes of Stator Windings Failure

Phase-to-Phase short-circuit Windings.
Possible causes: contaminants, abrasion, vibration or transient voltage spikes.

Turn-to-Turn short-circuit Windings.
Possible causes: contaminants, abrasion, vibration or transient voltage spikes.

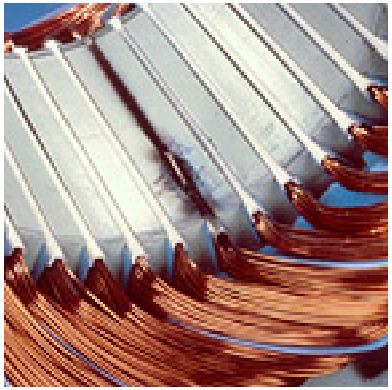
Windings with short-circuit coil.
Possible causes: contaminants, abrasion, vibration or transient voltage spikes.



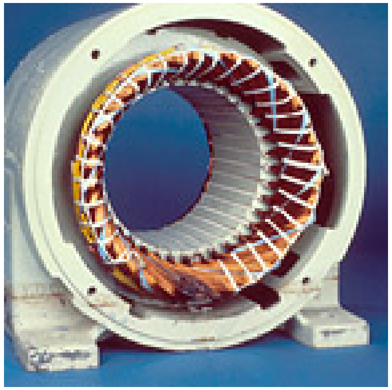
Windings with short-circuit at the edge of the slot.
Possible causes: contaminant, abrasion, vibration or transient voltage spikes.

Typical Causes of Stator Windings Failure

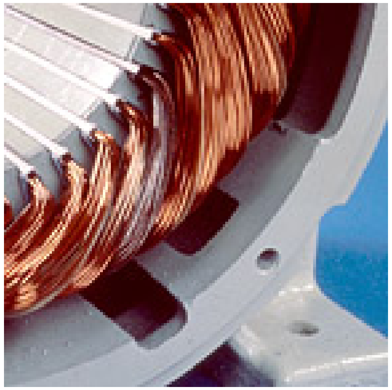
Windings with short-circuit inside the slot.
Possible cause: contaminants, abrasion, vibration or transient voltage spikes.



Short-circuit at the connection of the winding groups.
Possible cause: contaminants, abrasion, vibration or transient voltage spikes.

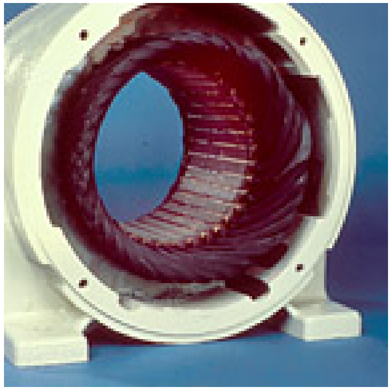


Windings damaged by unbalanced voltage.

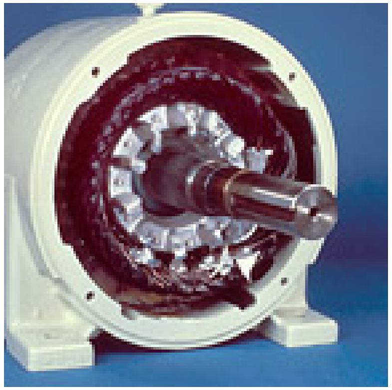


Typical Causes of Stator Windings Failure

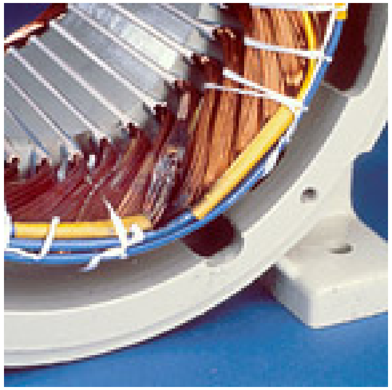
Damaged windings:
Cause: overload



Damaged windings :
Cause: Locked rotor for too long



Windings damaged by a transient voltage peak.
Possible cause: electronic power switching, electrical storm or partial discharge of an automatic correction system



Typical Causes of Stator Windings Failure

The windings are considered normal if the resistance of the insulation is less than the values in Table 9-3. This indicates that the windings are dried out or damaged.

Table 9-3: Minimum Insulation Resistance of Motors

Rated Voltage	Insulation Resistance
600 V and -	1,5 MΩ
2300 V	3,5 MΩ
4000 V	5 MΩ

A check of the state of the insulation of a motor must be done at the following levels :

- For new motors: (2 * nameplate voltage + 1000V) * 1.7
- For motors already in use: 2 * nameplate voltage + 1000V

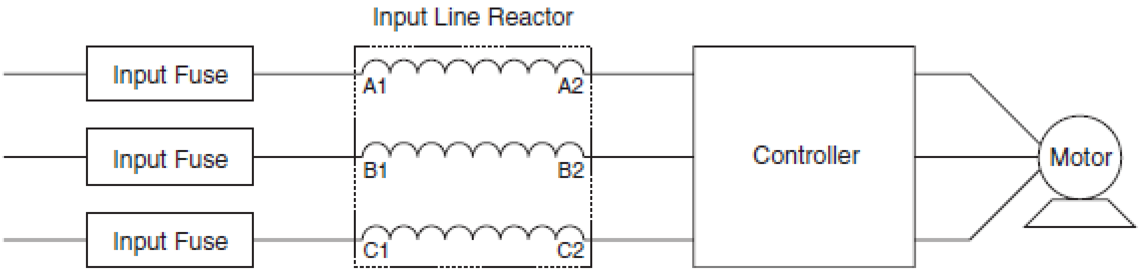
Application Note

When to use a Line or Load Reactor

- The Line and Load reactors have very different functions.
- In simple terms, a Line Reactor protects the variable frequency drive and a Load Reactor protects the motor and the cable that powers it.
- An input or Line Reactor protects the VFD from disturbances in the power supply which can cause harmful shutdowns or damage to the VFD.
- A Line Reactor also reduces the harmonic left by the VFD on the network.
- Line Reactors are selected according to the current/voltage capability of the VFD.
- Unless otherwise specified by a manufacturer, a 3% or 5% reactor should be used in the following circumstances :
  - The line is subject to disturbances such as power surges, peak voltages and transient voltages.
  - The supply line is very rigid (more than 10 times the KVA capacity of the connected VFD).
  - When harmonic distortions are a problem (See: IEEE-519 Harmonic Control in Electrical Power Systems).

Application Note

When to use a Line or Load Reactor

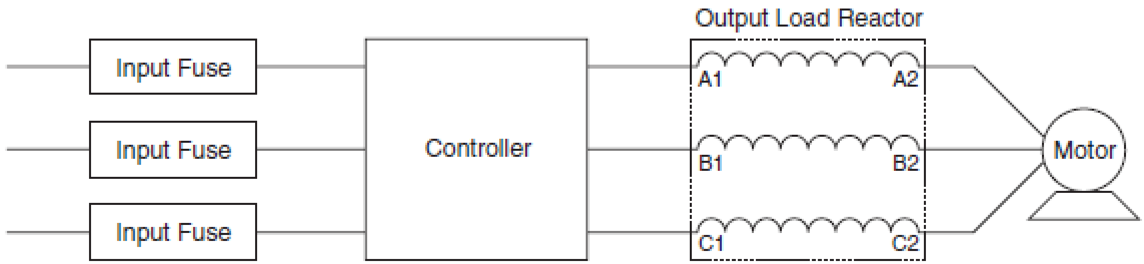


- A Line Reactor also provides protection to the VFD in the event of a short-circuit.
- If the KVA capacity of the distribution transformer exceeds the capacity of the VFD by a factor of 10, it would be advisable to install a Line Reactor to reduce the short-circuit capacity.
- The reactor impedance to be selected depends on the short-circuit capacity of the VFD and the distribution transformer.
- Example: 150KVA 575VAC 150amp power transformer with 3% & 5% impedance reactors.
- 150/0,03 = 5,025A short-circuit capacity
- 150/0,05 = 3,000A short-circuit capacity

Application Note

When to use a Line or Load Reactor

- An output reactor, or Load is used to protect the motor and the cable that powers it.
- The VFD generates a PWM voltage, 3 phase at high frequency with a very short rise time. This "noise" is amplified by the additional capacitance when the cables are long. The resulting voltage peaks can exceed the insulation capacity of the powered motor and cause insulation degradation over time and premature motor failure.
- A Load Reactor should be used with cable length beyond 40 feet, 575/3/60, at a carrier frequency of 3kHz. This may vary depending on the type of engine.
- If the motor meets the NEMA MG-1 Part 31 standard, it is possible to exceed 100 feet without using a reactor. Even 650 feet for some manufacturers.
- If the cable length is between 500 and 1000 feet, you should use a dV / dT type filter for better protection.



Constant Torque vs Constant HP

- Constant Torque Zone
- HP = Torque (lb.ft) *RPM / 5252

Ex:

5HP 1762 RPM = 14,88lb/ft

50% of the speed.

HP = 14,88 * 881 / 5252

HP = 2,5

- Constant HP Zone
- Couple (lb/ft) = HP *5252 / RPM

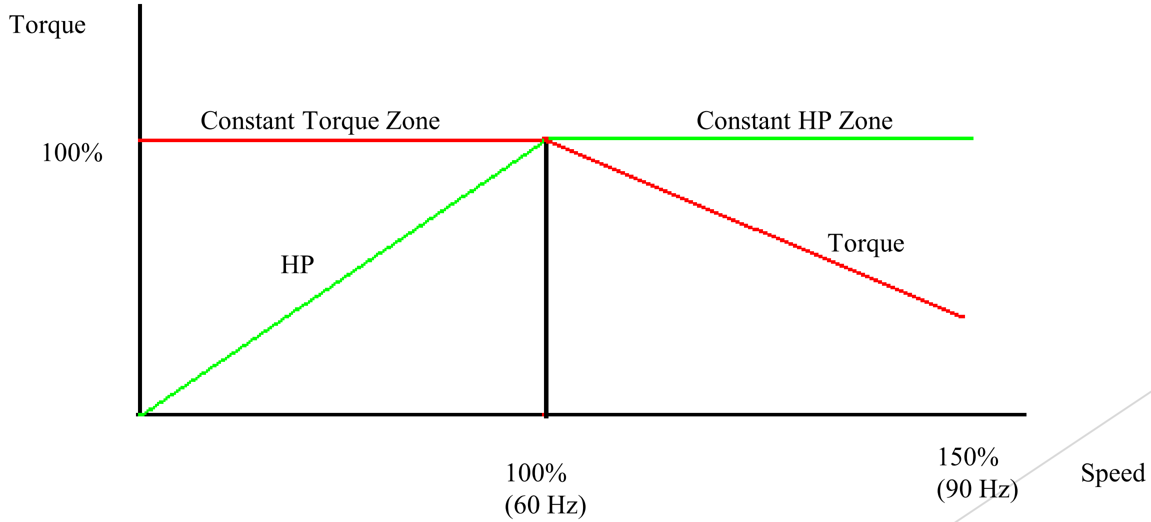
Ex:

5HP 1762 RPM = 14,88lb/ft

150% of the speed.

Couple = 5 * 5252 / 1762*1.5 (2643)

Toque = 9,93 lb/ft



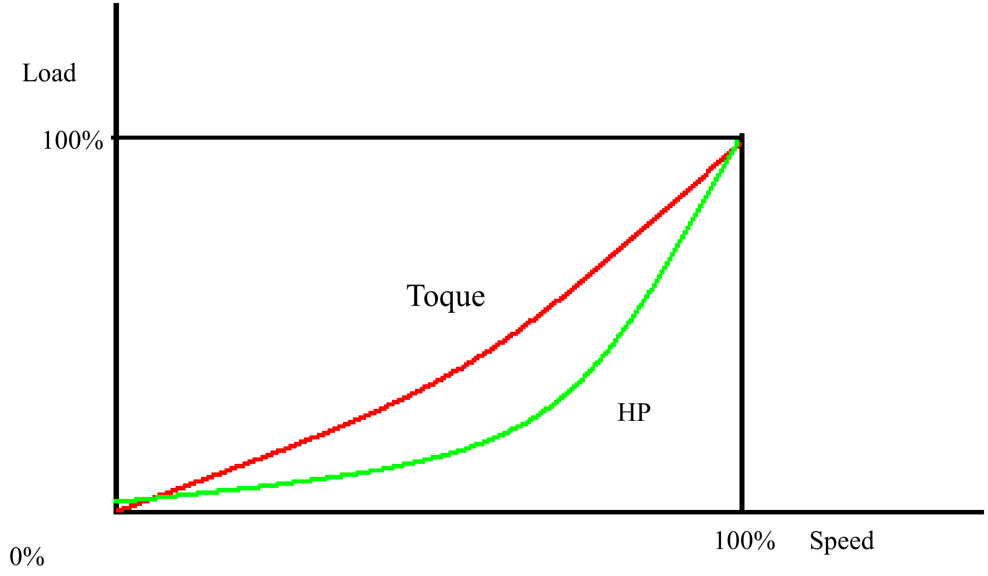
Variable Torque Load

Torque is proportional to the square of the speed

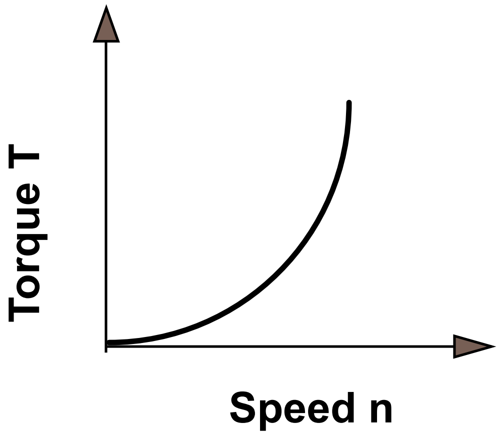
Small change in speed makes a big difference in the torque required to do the job.

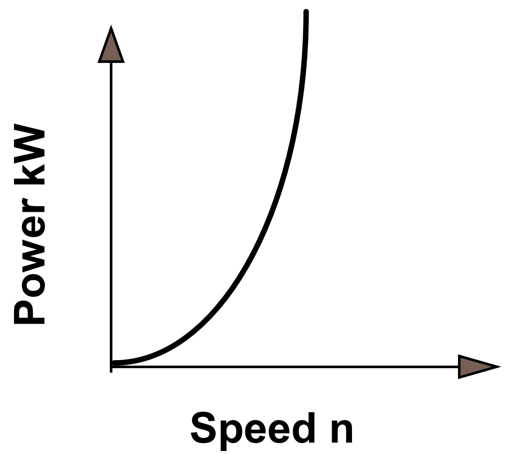
HP is proportional to the cube of the speed

Small change in speed makes a big difference in the amount of HP needed to do the job.



Variable Torque





Fan
Pump
Blower

$T(n) \sim n^2$

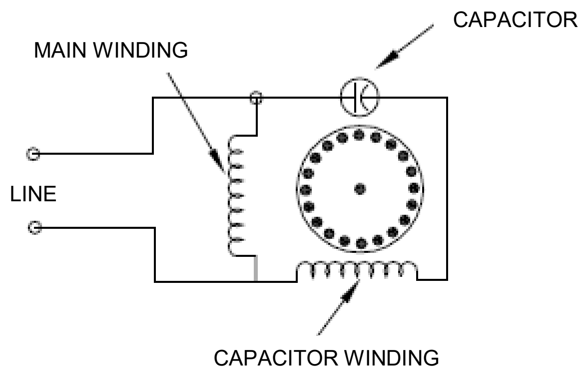
$W \sim n^3$

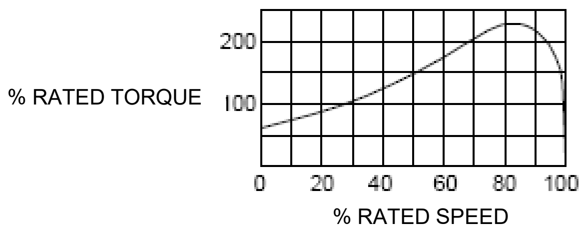
* Can operate at low speed but not efficient to do so
* Can lower the mid-point voltage to save energy

Different Types of Single Phase Motors

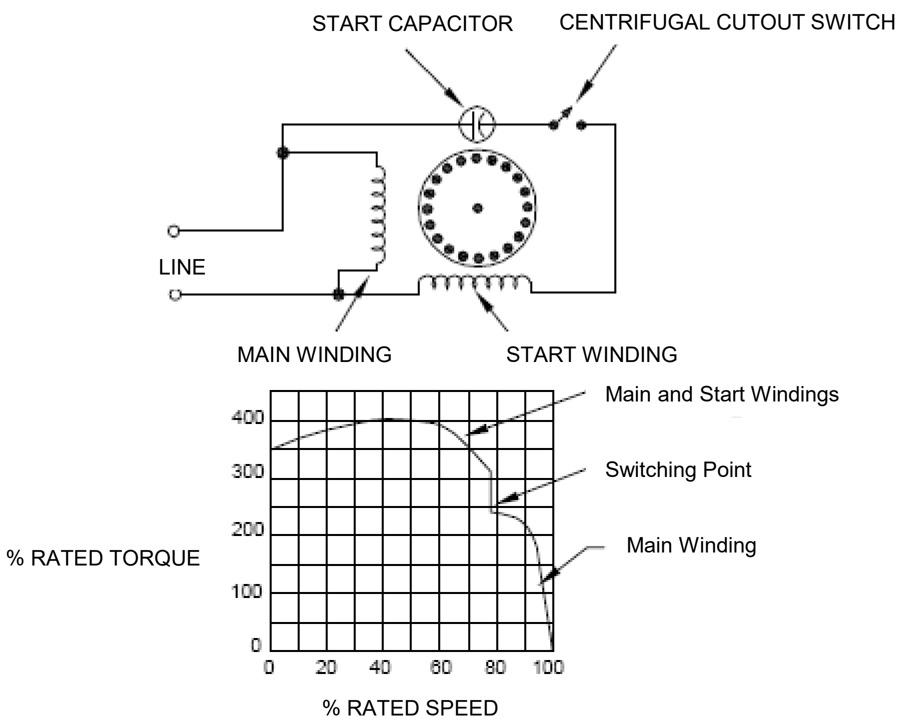
Motor Type	Start Torque	Efficiency	Application
Shaded Poles	Small	Small	Direct drive fans
Auxiliary Start Winding	Small	Medium	Direct drive fans, centrifugal pumps, air and refrigeration compressors
	Medium	Medium	Belt fans, air and refrigeration compressors, large appliances
Start Capacitor	Medium	Medium	Belt fans, compressors, centrifugal pumps, industrial equipment, farming, large appliances, industrial appliances, office equipments
	High	Medium	Volumetric pumps, air and refrigeration compressors
Start & Run Capacitor	Medium	High	Belt fans, centrifugal pumps
	High	High	Volumetric pumps, air and refrigeration compressors, industrial equipment, farming, large appliances, industrial appliances, office equipments
Permanent Split Capacitor	Small	High	Direct drive fans, efrigeration compressors, office equipments

Permanent Split Capacitor Motor

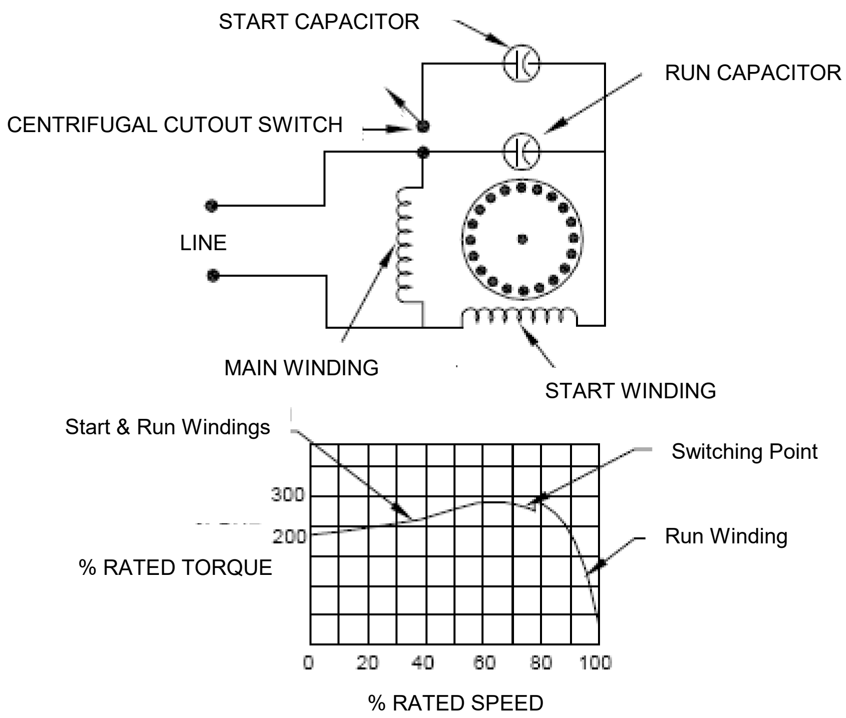




Capacitor Start, Induction Run Motor



Capacitor Start, Capacitor Run Motor



ECM Motor

An ECM motor is an electrically commutated permanent magnet brushless DC motor (Fig 6-1).

An electronic device supplies the coils with precisely controlled voltages, and uses position sensors for synchronization.

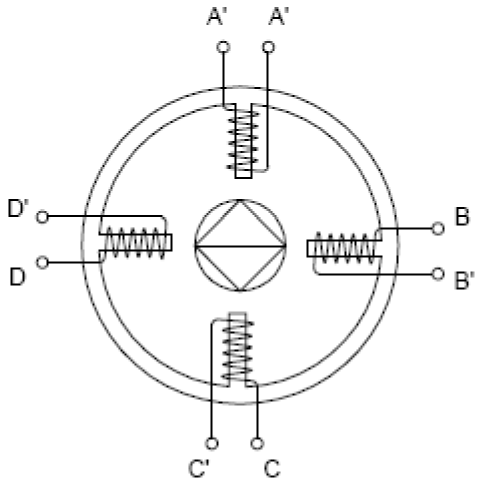


Fig 6-1: Electrically Commutated Motor (ECM)

The electronic controller can be programmed to vary the torque-speed characteristics of the motor for a wide variety of manufacturers' applications such as fans and drives.

Auxiliary Start Winding Motor