Motor Terminology and Electrical Performance Characteristics

Motor Terminology and Electrical Performance Characteristics

- Overview/Objectives:
  - Power supply terms
  - Speed / #Poles
  - Horsepower
  - Current
  - Speed vs. Torque
  - Service Factor

AC Power Supply Terms

- Phase: describes the type of AC power supplied (Single or Three). Does not apply to DC.
- Frequency or Hertz (Hz): How many times a second the AC changes directions from positive to negative.
- Voltage: Defines the strength of the electric power

Typical Power Supply

Power	Phase	Cycle	Voltages
AC	Single	60	115 or 230
AC	Single	50	110, 208, 220 or 240
AC	Three	60	208, 230, 460, 575, 2300, 4160, 6600, or 13.8 kV
AC	Three	50	190, 380, 400, 415, 690, 4000 or 11 kV

Motor Performance Characteristics

- Speed / #Poles
- Horsepower
- Current
- Speed vs. Torque
- Service Factor

Motor Operating Speeds

- Mechanical speed tied to speed of rotating magnetic field in stator
  - Synchronous Speed $= \frac{120 \text{ x Frequency}}{\text{\# Poles}}$
  - Rotor lags behind - difference called “Slip”
  - Speeds at 60 Hz. - Full Load Speed is approximate

# Poles	Sync. Speed	Nominal FL Speed
2	3600 RPM	3550 RPM
4	1800 RPM	1750 RPM
6	1200 RPM	1150 RPM

Synchronous Speed (RPM)	# of Poles	Frequency (Hz)	Formula
3600	2	60	S = (120x60) / 2
1800	4	60	S = (120x60) / 4
1200	6	60	S = (120x60) / 6
900	8	60	S = (120x60) / 8
720	10	60	S = (120x60) / 10
3000	2	50	S = (120x50) / 2
1500	4	50	S = (120x50) / 4
1000	6	50	S = (120x50) / 6
750	8	50	S = (120x50) / 8
600	10	50	S = (120x50) / 10

What is Slip?

- Ratio between:

Full Load Speed and No Load Speed

$$\% \, \boldsymbol{Slip} = \left[\mathbf{1} - \left(\frac{\boldsymbol{Full\ Load\ RPM}}{\boldsymbol{No\ Load\ RPM}}\right)\right] \times \mathbf{100}$$

$$\% \, \boldsymbol{Slip} = \left[\mathbf{1} - \left(\frac{\mathbf{1750}}{\mathbf{1800}}\right)\right] \times \mathbf{100} = \mathbf{2.78}\%$$

Horsepower and Torque

Poles	Torque/Hp (lb/ft)	Speed @ 60Hz Synchronous
2	1.5	3600
4	3	1800
6	4.5	1200
8	6	900
10	7.5	720
12	9	600

$$HP = \frac{Speed \times Torque}{5252}$$

$$Torque = \frac{HP \times 5252}{Speed}$$

Rules of Thumb

Motor Amps per HP - (full load)

460v, a 3-phase motor draws 1.25 amps per HP

230v, a 3-phase motor draws 2.5 amps per HP

Effects of Voltage Variations on AC Motors

Low Voltage

1. Reduced starting torque - Motor may not be able to start load.
2. Reduced running torque - Current increases to produce 100% torque creating excessive heat. Increased heat causes premature insulation failure.
3. Speed decreases / Process interruption

High Voltage

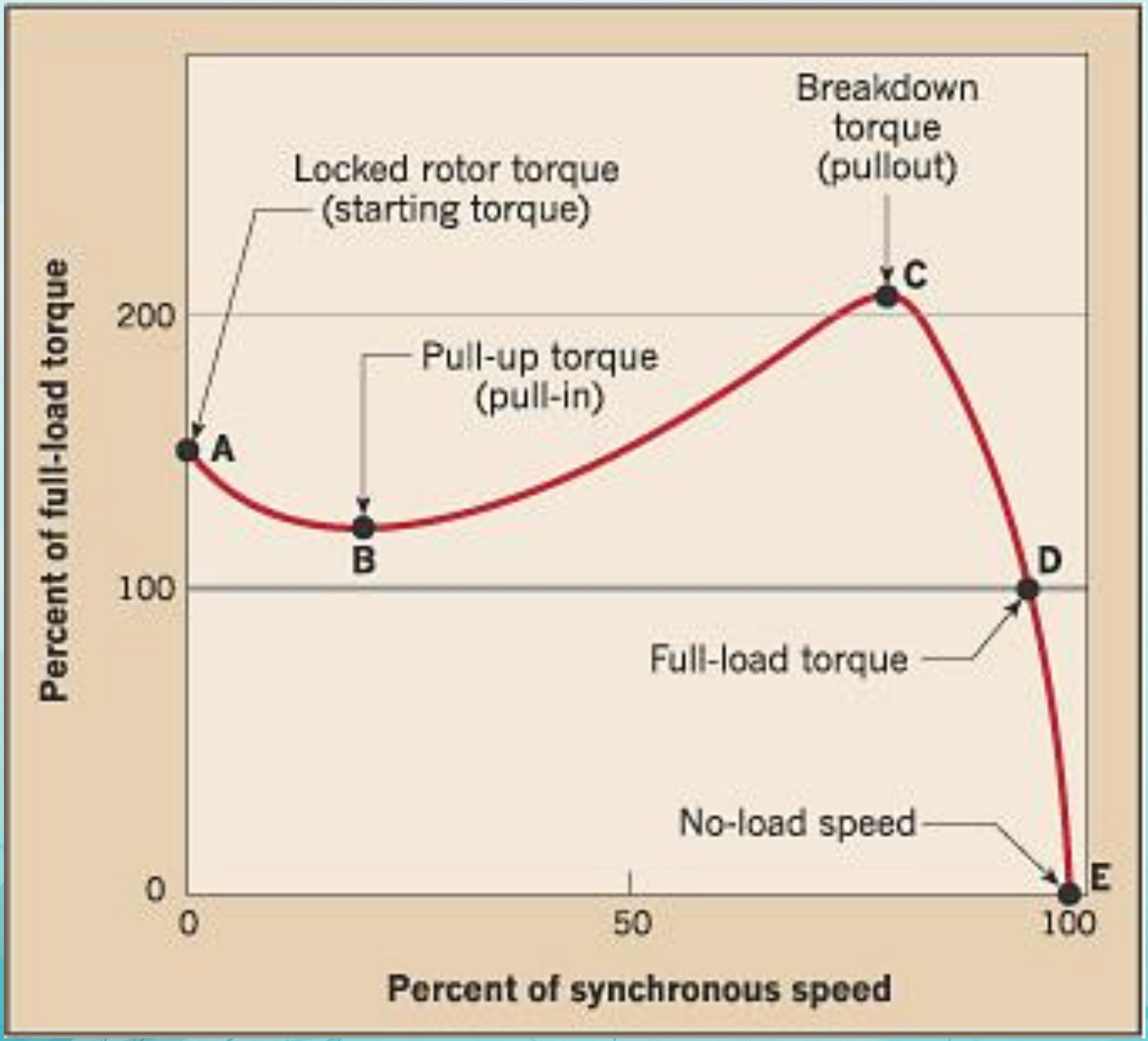
1. Increased starting current - Nuisance trip of overloads. Increased heat can cause insulation damage.
2. Increased starting and running torque.
3. Speed increases / Process interruption

- NEMA allows A +/- 10% voltage variation with no frequency variation.

Is it true?

- A motor, <u>depending on its design</u> can produce torque indefinitely without producing horsepower
- A motor cannot develop horsepower without first producing torque
- A motor needs to rotate to develop horsepower in order to do work

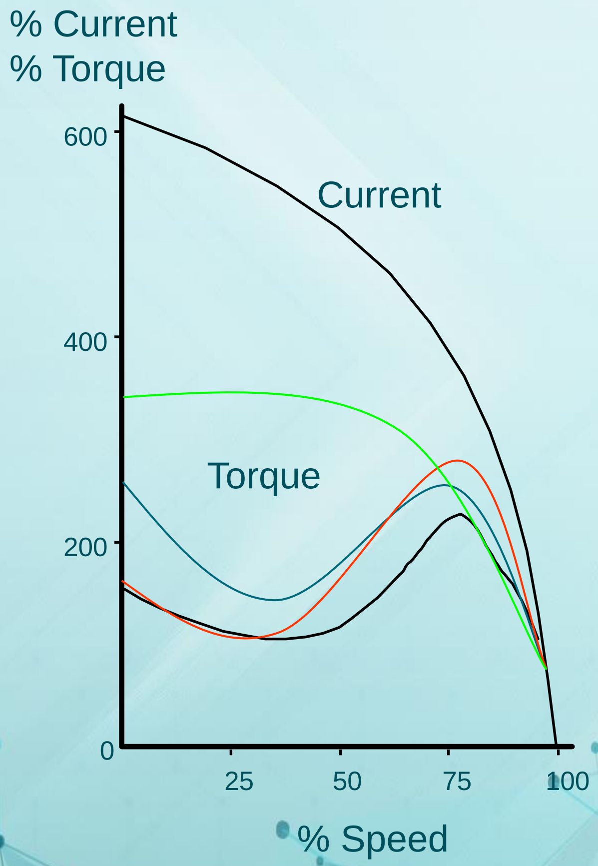
Motor Speed Torque Curve



Motor Designs

- The Material and Shape of the Rotor Bars Are the Main Factors in Obtaining Various Speed/Torque Curves
- NEMA Defines 4 Basic Types of Speed/Torque Characteristics for Induction Motors:
  - **DESIGN A**
  - **DESIGN B**
  - **DESIGN C**
  - **DESIGN D**
- The Stator Has Little to Do With the Shape of the Motors Speed/Torque Curve
- Different Rotors Could Be Used With the Same Stator to Change the Characteristic Shape

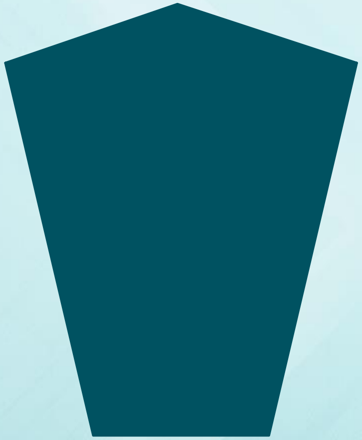
Typical Current & Torque Relationship for Squirrel Cage Induction Motor



Nema Des.	Starting Torque	LR amps	BD torq	FL slip	Applications
A	Normal	High	**High**	Low	Mach. Tools, fans
B	Normal	Normal	Normal	Normal	General Industrial
C	**High**	Normal	Normal	Normal	Conveyor
D	**Very High**	Low	n/a	**High**	Hoists

ROTOR DESIGN
Slot Shapes

Design A



LRT	Normal (90 – 100%)
LRA	High >650%
BDT	High >200%
FL Slip	Low

- Cross section of the bar is large (low resistance) and not too deep in the iron (low reactance).

ROTOR DESIGN
Slot Shapes

Design B

LRT	Normal (80 – 100%)
LRA	Normal ≈ 650%
BDT	Medium ≈ 200%
FL Slip	Low

- Similar to design A except the deeper bar results in lower inrush and slightly lower torques.

ROTOR DESIGN
Slot Shapes

Design C

LRT	High > 150%
LRA	Normal ≈ 650%
BDT	Medium ≈ 200%
FL Slip	Low – Med < 5%

- Design C utilizes a double cage slot. The high resistance of the upper cage delivers high starting torque.

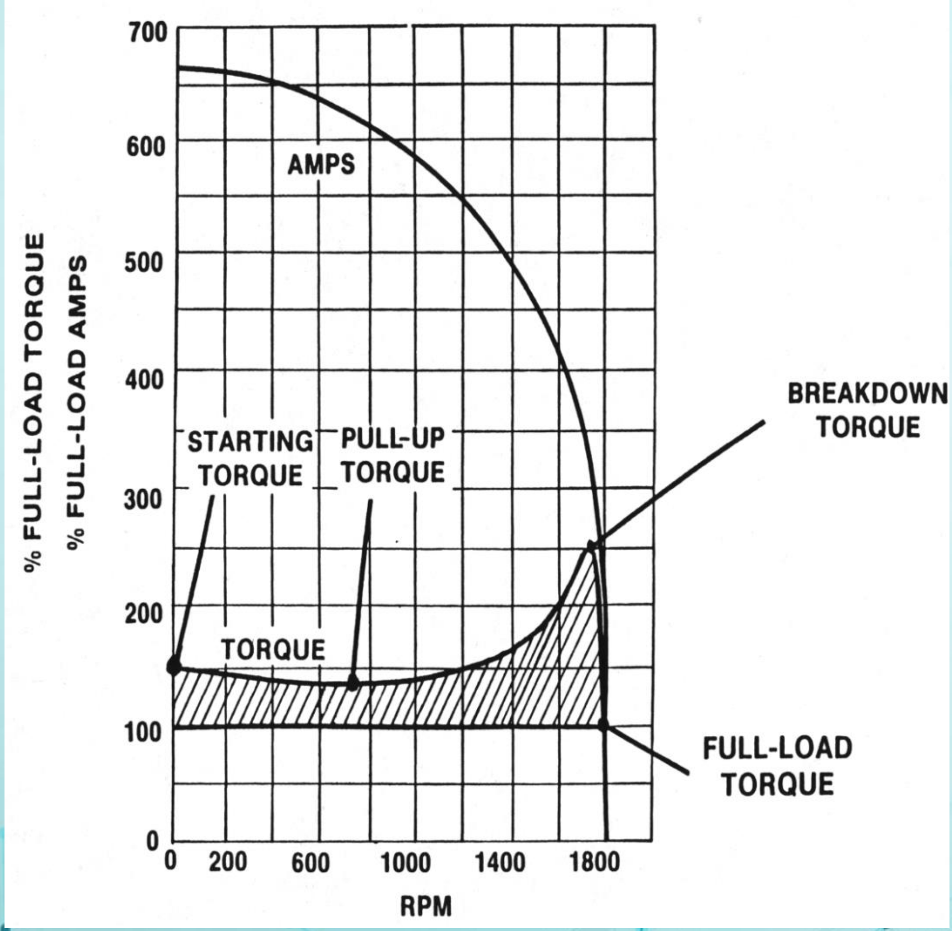
ROTOR DESIGN
Slot Shapes

Design D

- LRT Very High > 200%
- LRA Normal ≈ 650%
- BDT High > 200%
- FL Slip High (5 – 8%, 8 – 13%)

- Bar shape and brass or similar alloy is used for high resistance (high starting torque) and high slip.

Motor Starting - Inrush Currents



- **Locked Rotor Current typically 600 -700% of full load**
- **Current and torque aren’t proportional until near full load**

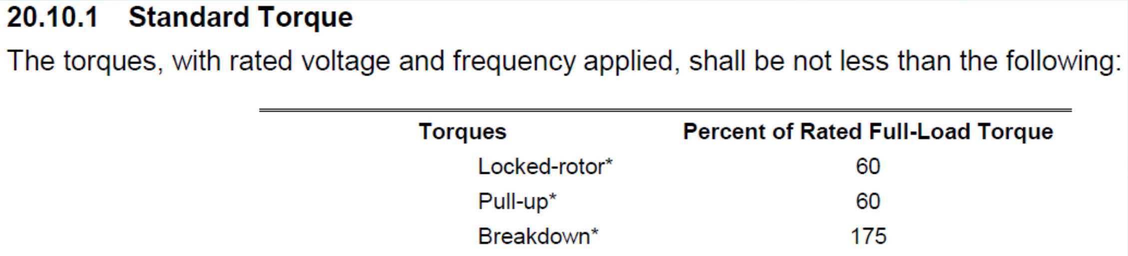
What is Large AC?

Per NEMA, Large Induction Machines include ratings greater than:

Sync. RPM	Motors-HP	Generators-kW
3600	500	400
1800	500	400
1200	350	300
900	250	200
720	200	150
600	150	125
514	125	100
450	ALL	ALL

NEMA MG 1 Part 20

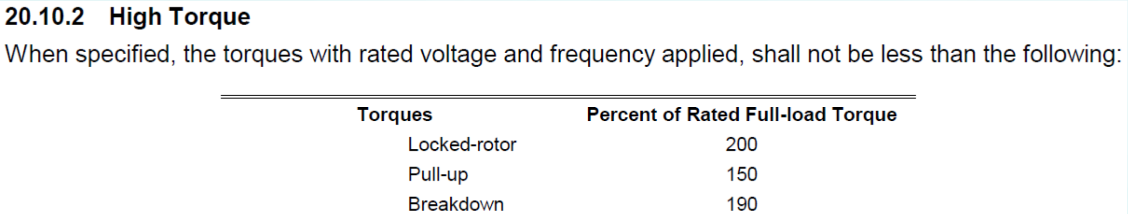
Speed vs Torque
NEMA MG 1- 20.10



20.10.1 Standard Torque

The torques, with rated voltage and frequency applied, shall be not less than the following:

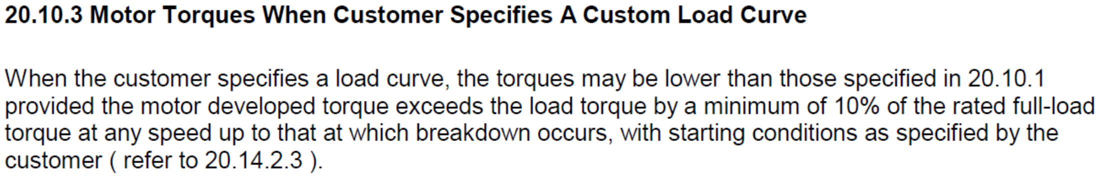
Torques	Percent of Rated Full-Load Torque
Locked-rotor*	60
Pull-up*	60
Breakdown*	175



20.10.2 High Torque

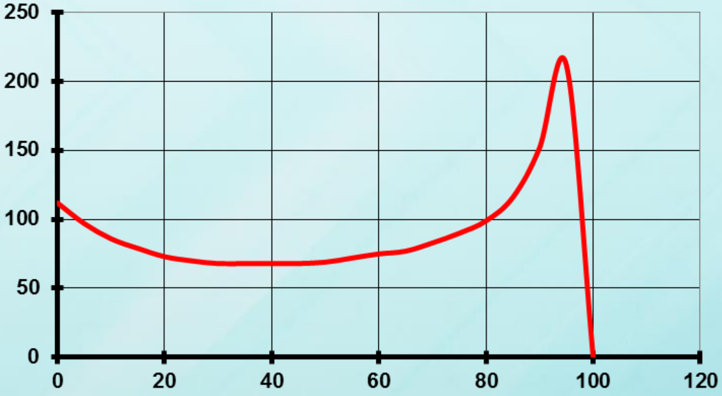
When specified, the torques with rated voltage and frequency applied, shall not be less than the following:

Torques	Percent of Rated Full-load Torque
Locked-rotor	200
Pull-up	150
Breakdown	190



20.10.3 Motor Torques When Customer Specifies A Custom Load Curve

When the customer specifies a load curve, the torques may be lower than those specified in 20.10.1 provided the motor developed torque exceeds the load torque by a minimum of 10% of the rated full-load torque at any speed up to that at which breakdown occurs, with starting conditions as specified by the customer (refer to 20.14.2.3).



Speed vs Torque - Application

Constant Torque

- Reciprocating Compressor
- Reciprocating Pump
- Extruder
- Conveyer

Variable Torque

- Centrifugal Pump
- Centrifugal Compressor
- Fan

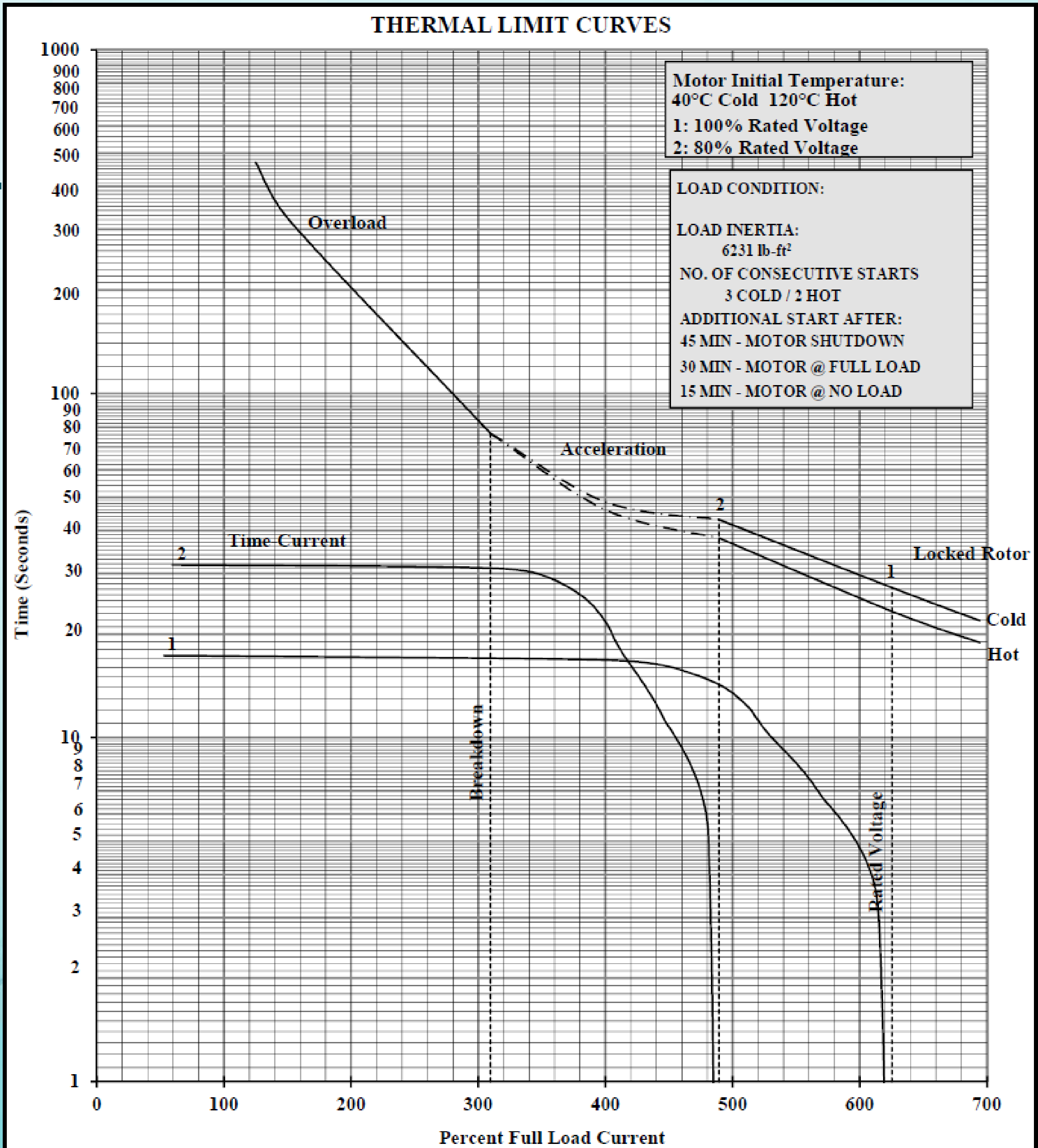
Application Characteristics

- Required HP, Speed, and Voltage
- Application (Type of Load)
- Starting / Running Method

Motor Starts

- **Every time a motor starts its components are subjected to mechanical and thermal stress.**
  - Rotors
  - Winding insulation

- **Number of starts per time should not be exceeded.**
  - 2 starts loaded with motor at ambient temperature
  - 1 start loaded with motor at operating temperature
  - Followed by required cooling time



Consider the applied load inertia at the motor shaft……

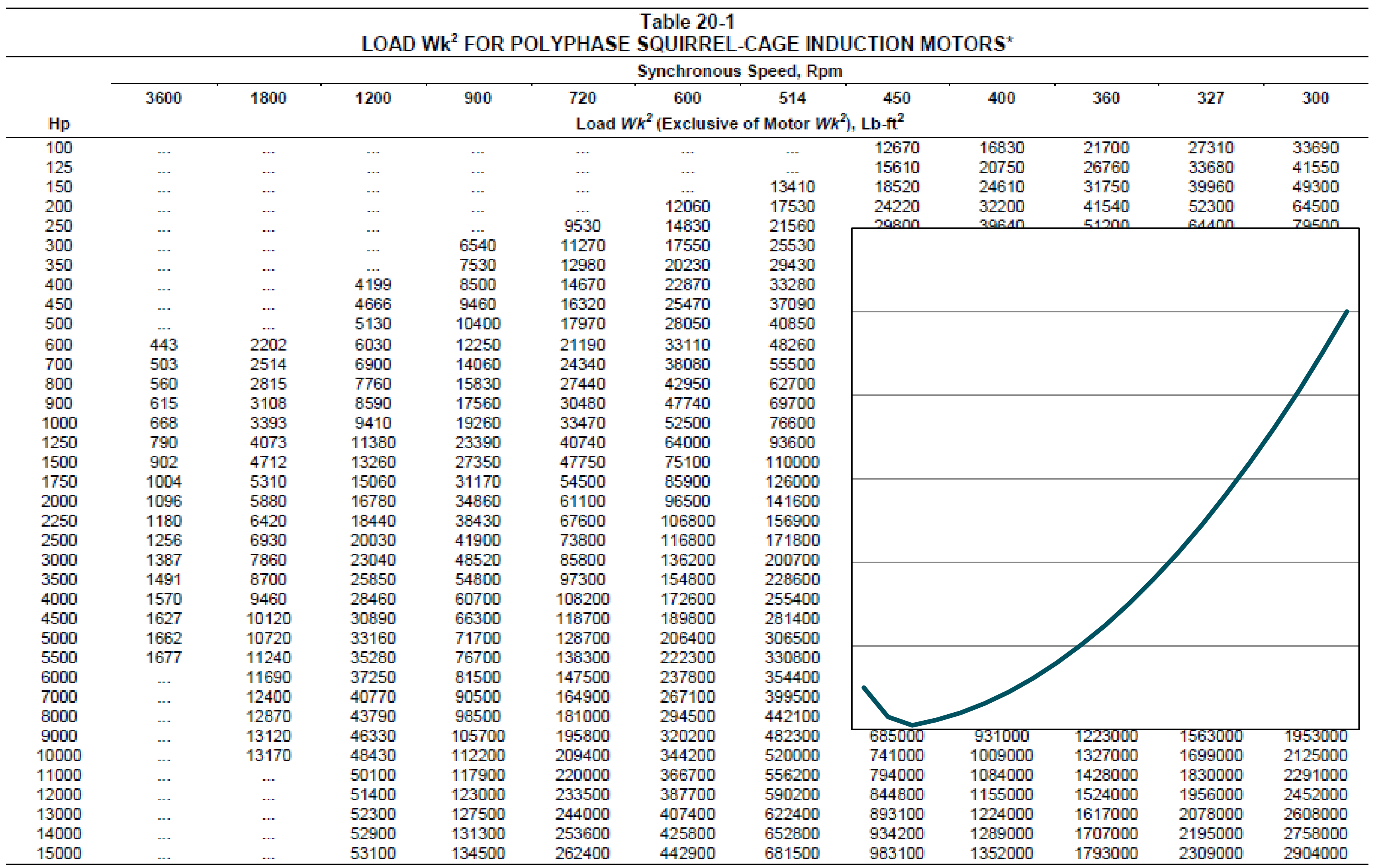
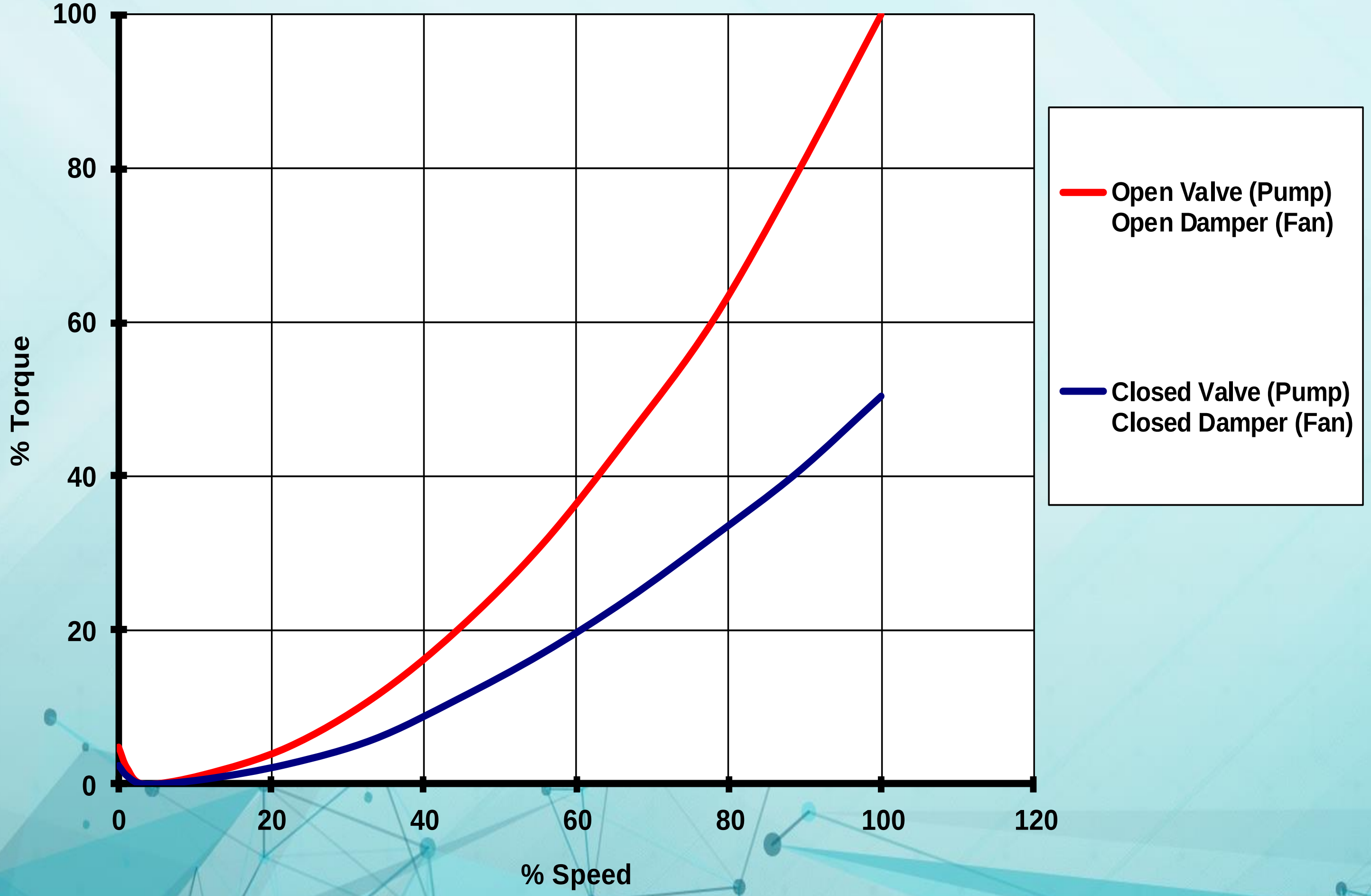


Table 20-1

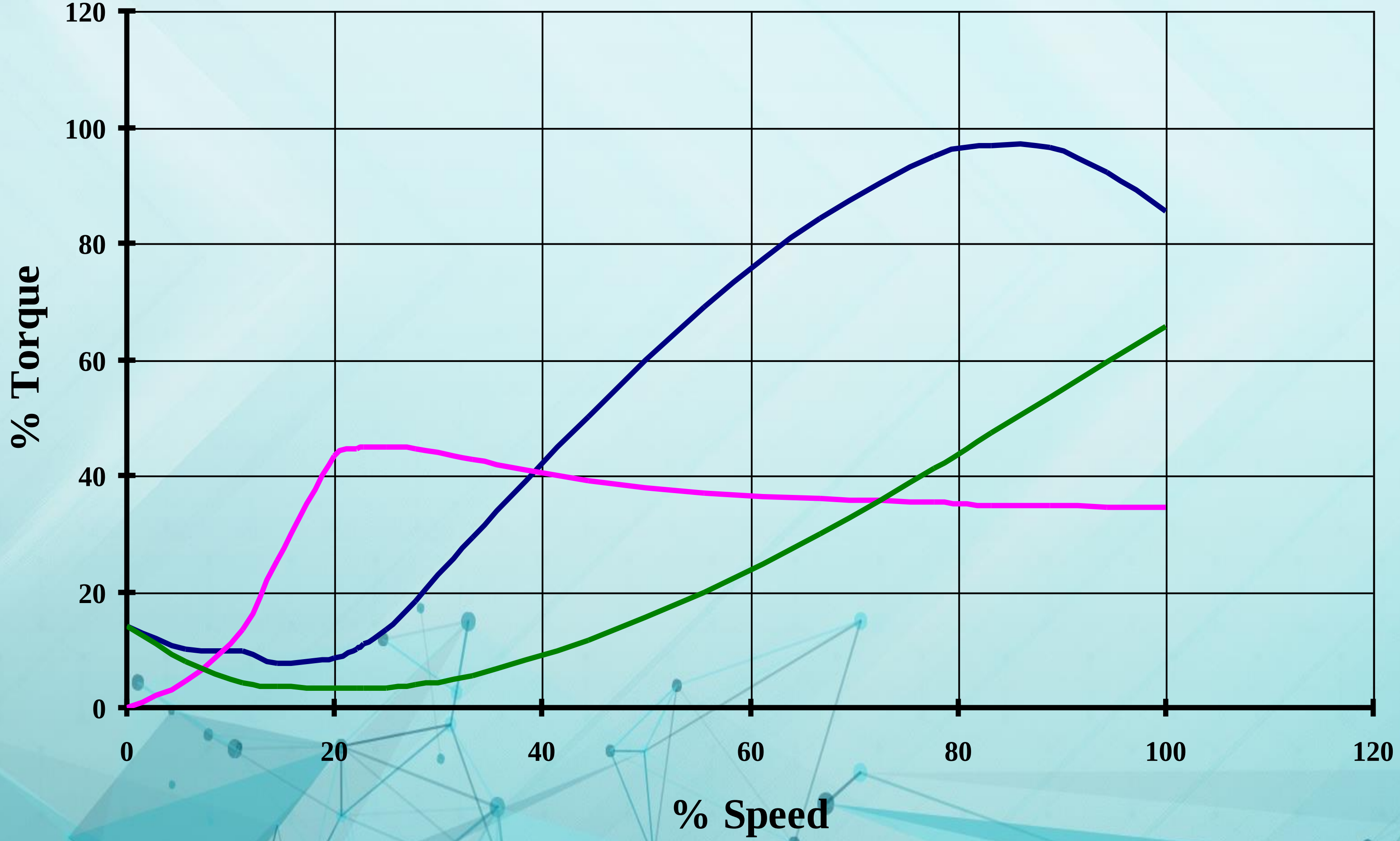
LOAD Wk² FOR POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS*

	Synchronous Speed, Rpm											
	3600	1800	1200	900	720	600	514	450	400	360	327	300
Hp	Load *Wk*² (Exclusive of Motor *Wk*²), Lb-ft²											
100	...	...	...	...	...	...	...	12670	16830	21700	27310	33690
125	...	...	...	...	...	...	...	15610	20750	26760	33680	41550
150	...	...	...	...	...	...	13410	18520	24610	31750	39960	49300
200	...	...	...	...	...	12060	17530	24220	32200	41540	52300	64500
250	...	...	...	...	9530	14830	21560	29800	39640	51200	64400	79500
300	...	...	...	6540	11270	17550	25530					
350	...	...	...	7530	12980	20230	29430					
400	...	...	4199	8500	14670	22870	33280					
450	...	...	4666	9460	16320	25470	37090					
500	...	...	5130	10400	17970	28050	40850					
600	443	2202	6030	12250	21190	33110	48260					
700	503	2514	6900	14060	24340	38080	55500					
800	560	2815	7760	15830	27440	42950	62700					
900	615	3108	8590	17560	30480	47740	69700					
1000	668	3393	9410	19260	33470	52500	76600					
1250	790	4073	11380	23390	40740	64000	93600					
1500	902	4712	13260	27350	47750	75100	110000					
1750	1004	5310	15060	31170	54500	85900	126000					
2000	1096	5880	16780	34860	61100	96500	141600					
2250	1180	6420	18440	38430	67600	106800	156900					
2500	1256	6930	20030	41900	73800	116800	171800					
3000	1387	7860	23040	48520	85800	136200	200700					
3500	1491	8700	25850	54800	97300	154800	228600					
4000	1570	9460	28460	60700	108200	172600	255400					
4500	1627	10120	30890	66300	118700	189800	281400					
5000	1662	10720	33160	71700	128700	206400	306500					
5500	1677	11240	35280	76700	138300	222300	330800					
6000	...	11690	37250	81500	147500	237800	354400					
7000	...	12400	40770	90500	164900	267100	399500					
8000	...	12870	43790	98500	181000	294500	442100					
9000	...	13120	46330	105700	195800	320200	482300	685000	931000	1223000	1563000	1953000
10000	...	13170	48430	112200	209400	344200	520000	741000	1009000	1327000	1699000	2125000
11000	...	...	50100	117900	220000	366700	556200	794000	1084000	1428000	1830000	2291000
12000	...	...	51400	123000	233500	387700	590200	844800	1155000	1524000	1956000	2452000
13000	...	...	52300	127500	244000	407400	622400	893100	1224000	1617000	2078000	2608000
14000	...	...	52900	131300	253600	425800	652800	934200	1289000	1707000	2195000	2758000
15000	...	...	53100	134500	262400	442900	681500	983100	1352000	1793000	2309000	2904000

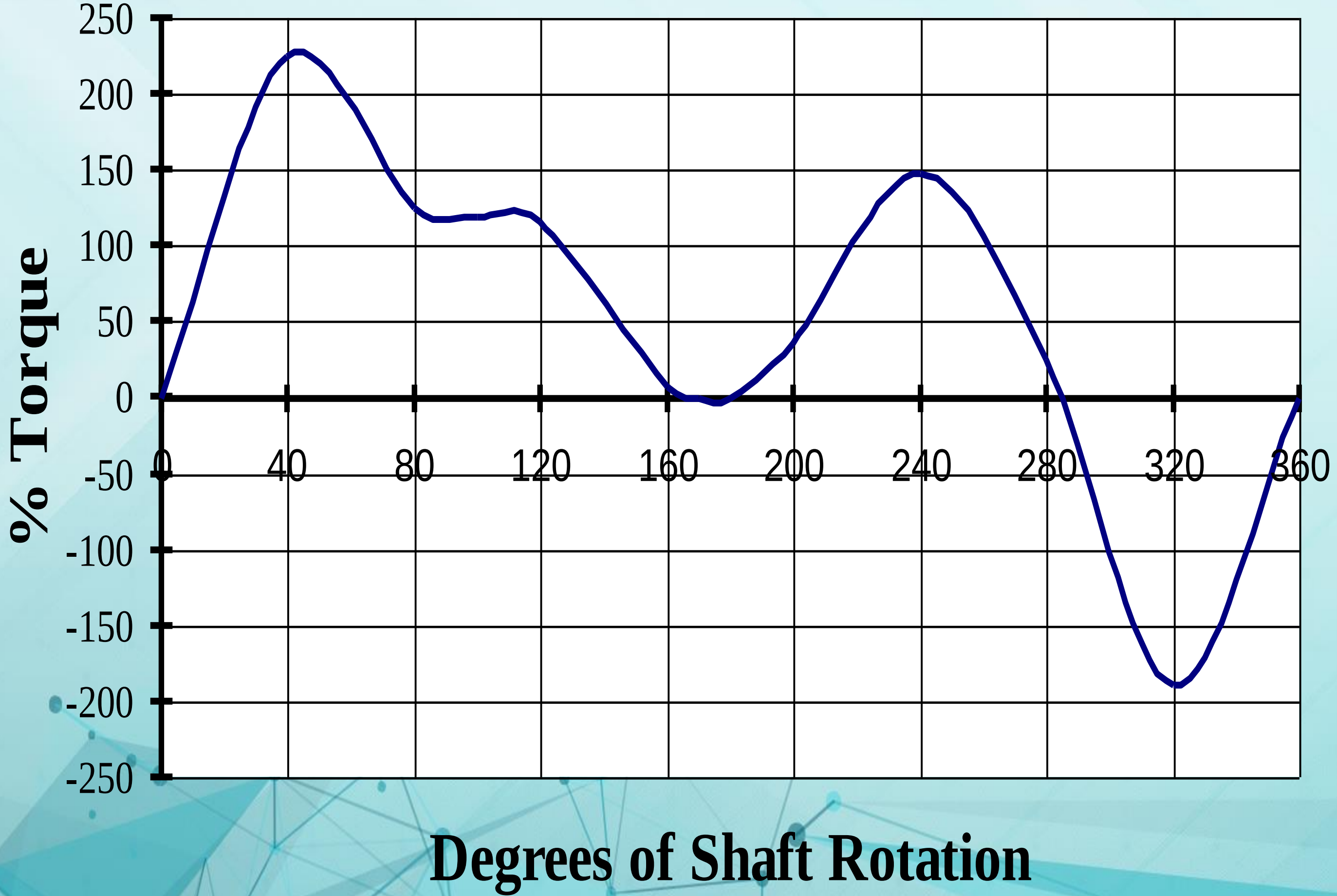
LOAD CURVES
Pump/Fan



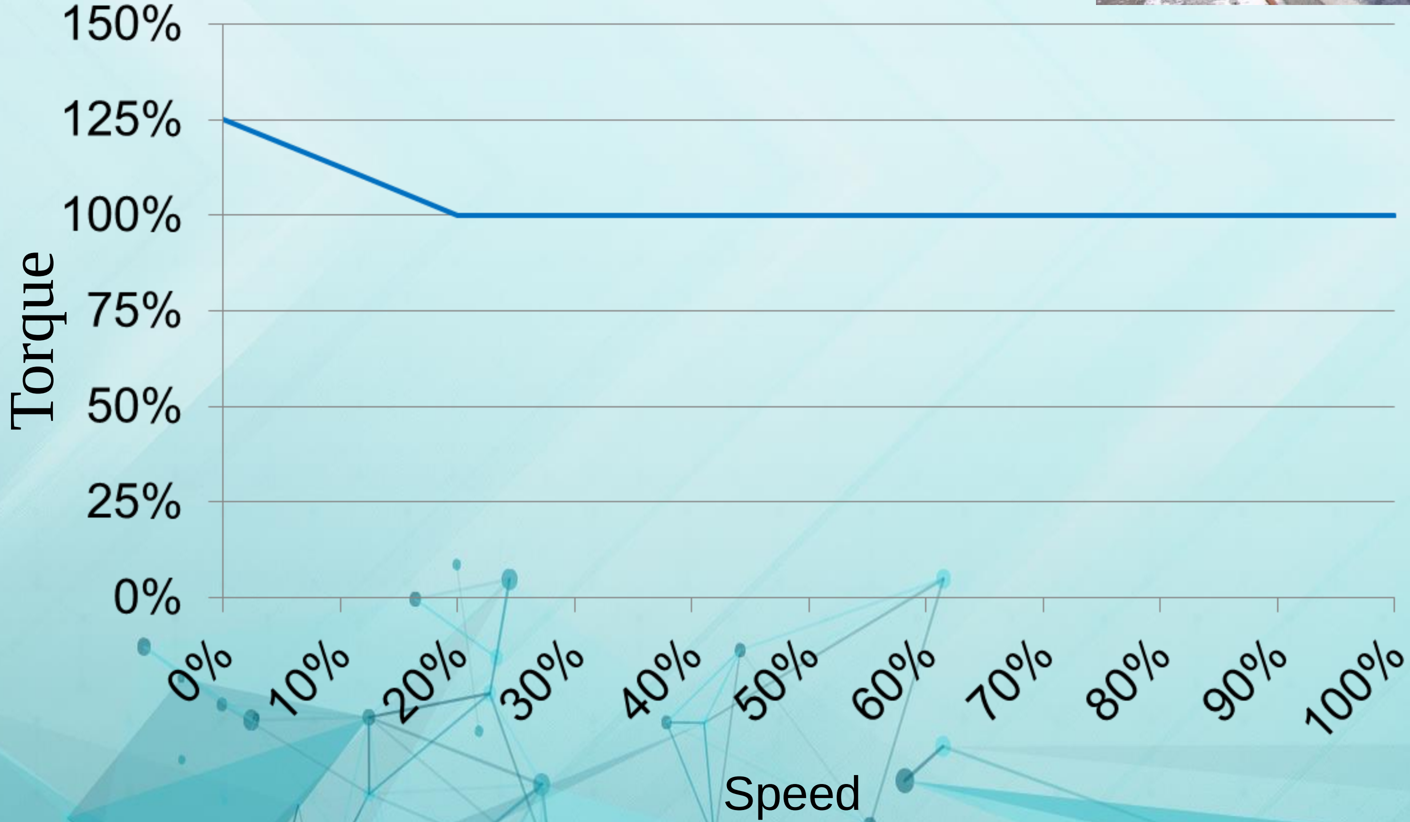
LOAD CURVES
Compressor



Reciprocating Compressor Torque Effort Curve



LOAD CURVES
Conveyor

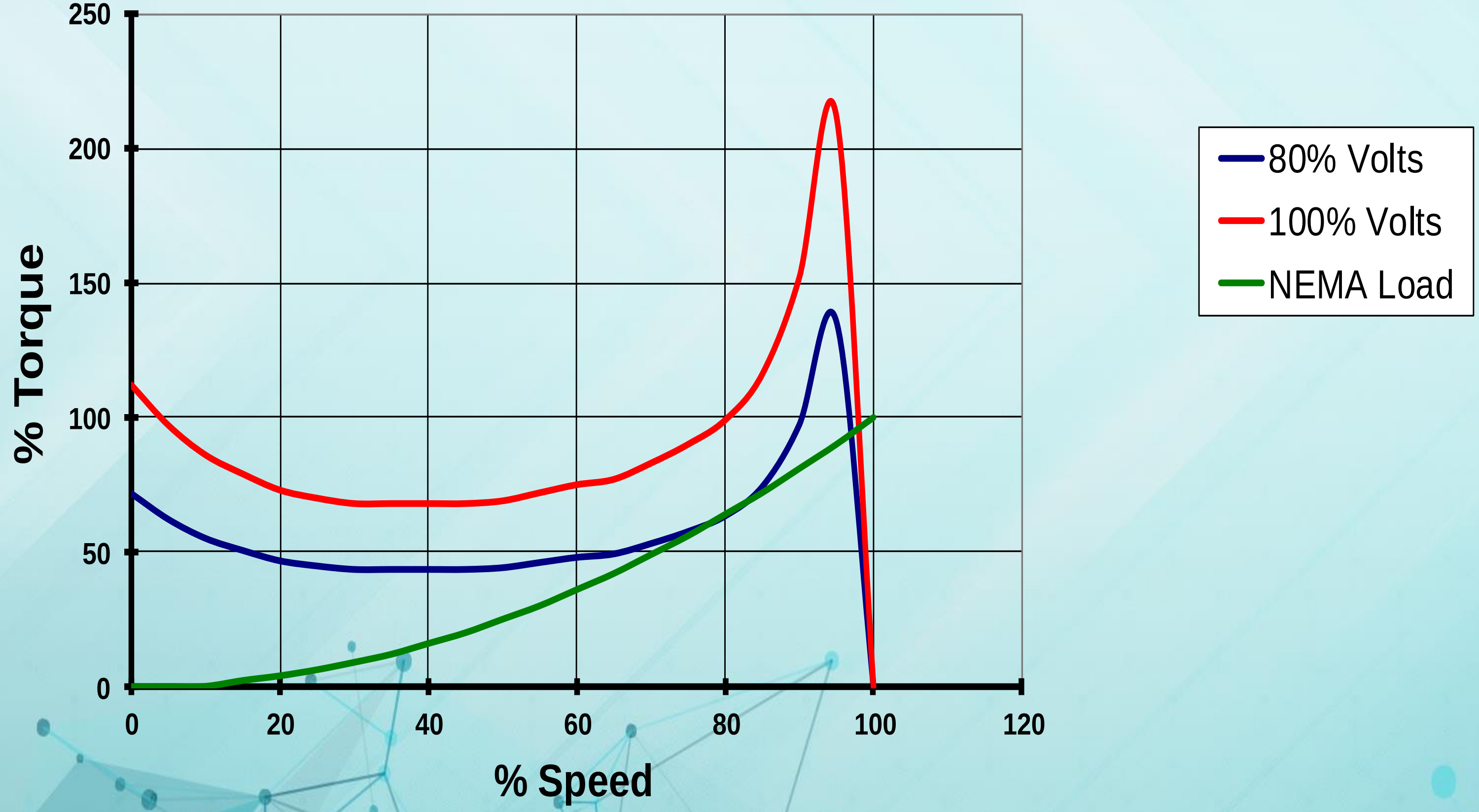


Starting Method

- Full Voltage
- Auto Transformer / Voltage Dip
- Current Limiting Soft Start
- Adjustable Speed Drive

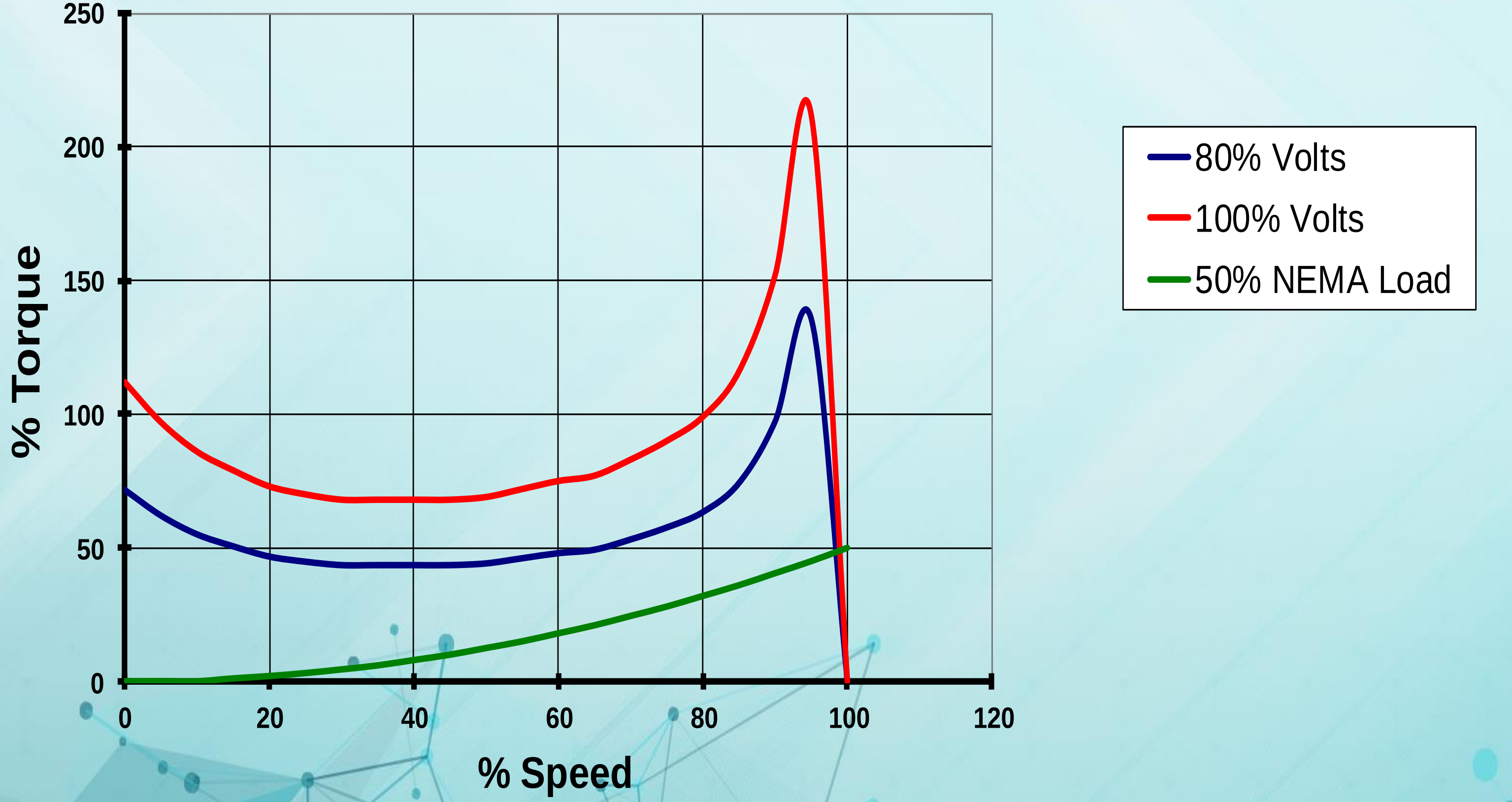
STARTING METHODS

Reduced Voltage - NEMA Load Curve



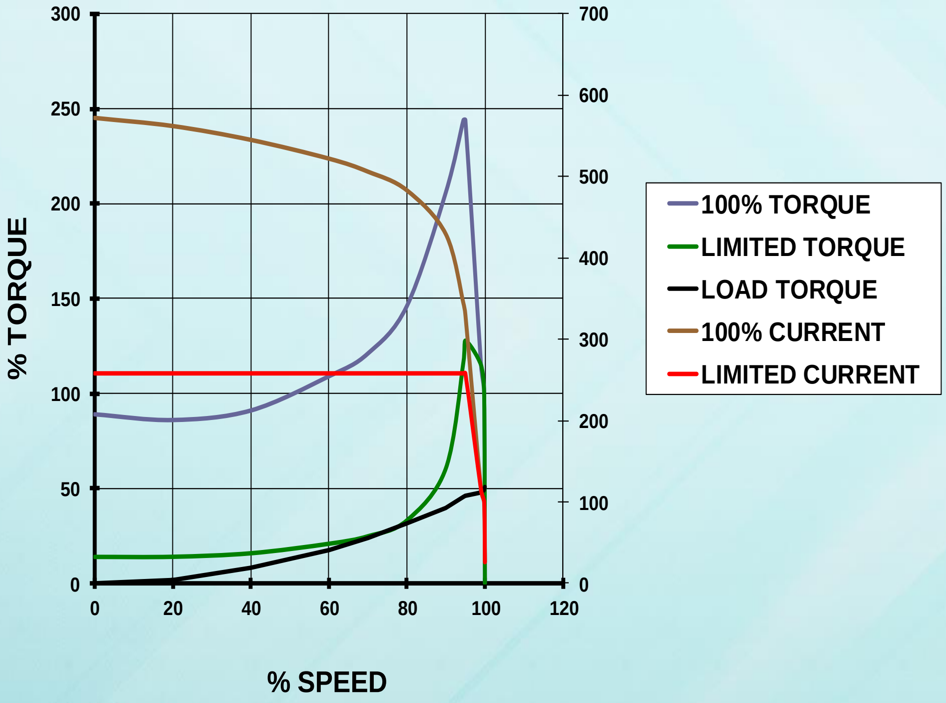
STARTING METHODS

Reduced Voltage - 50% NEMA Load Curve

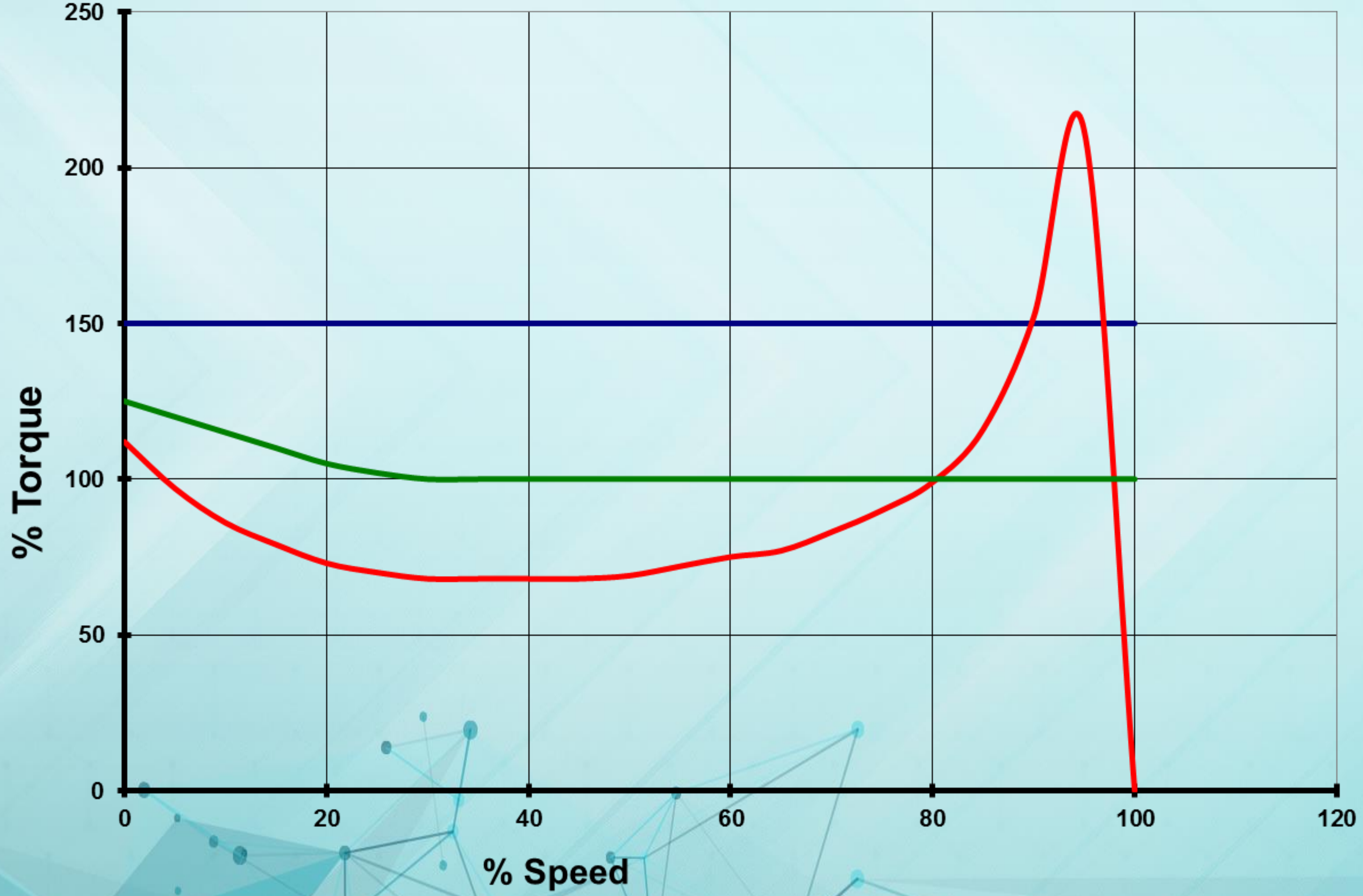


STARTING METHODS

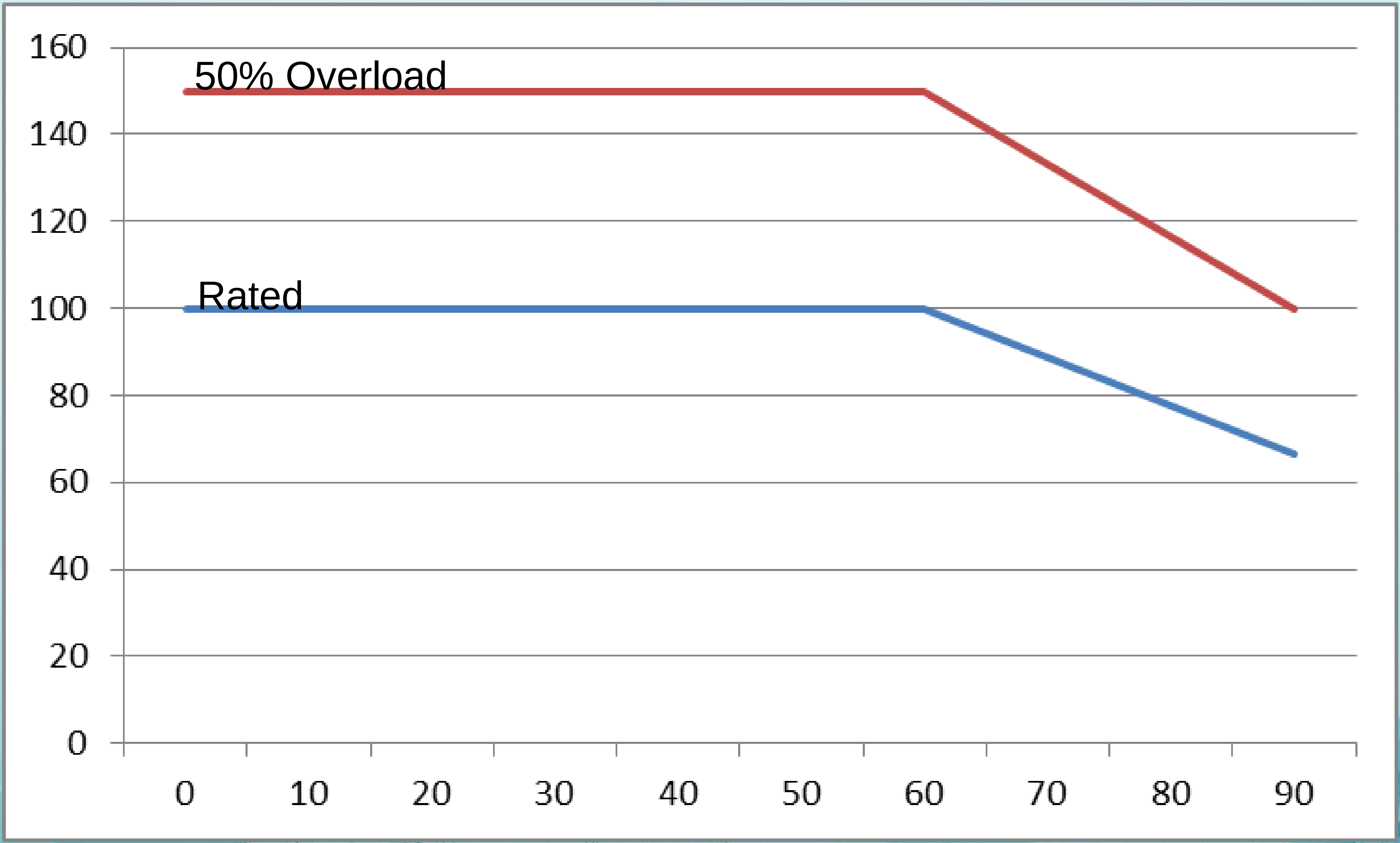
Current Limiting Soft-Start (250% FLA)



VFD Starting



AC Motor Torque on Variable Frequency



Quiz

- Single phase 575V motors are a common design, True or False?
- The lag between the rotor and the moving magnetic fields in the motor is referred to as?
- Speaking relative to inrush on starting; locked rotor current is typically XXX% of full load
- Name two motor starting methods

- False: 575V relates to 3 phase power
- "Slip"
- 600-700%
- Full Voltage, Auto Transformer/Voltage Dip, Current limiting, Adjustable speed drive