Chapter – 23 Motor and Starter

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Electric Motors

All the motors are to be designed and constructed in accordance with NEMA code. Electric motors being used to-day are mostly squirrel cage induction motor. Wound rotor, Synchronous or D-C motors are rarely involved with industrial refrigeration application. In accordance with the NEMA classification, there are two types of motor construction, one is “Open” design and the other is the Totally-Enclosed machine. An open motor is having ventilating openings which permit a passage of external cooling air over and around the windings of the motor. A totally-enclosed motor is the one that is so enclosed as to prevent the free exchange of air between the inside and the outside of the case but not necessarily as air-tight.

Open Motors

Drip-Proof Motor – A drip-proof machine is an open motor in which the ventilating openings are so constructed that drops of liquid or sold particles falling on the machine at any angle not greater than 15° from the vertical cannot enter the machine either directly or by striking and running along a horizontal or inwardly inclined surface of the machine.

Splash-Proof Motor – A splash-proof machine is an open machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming towards it in a straight line at any angle not greater than 100° from the vertical cannot enter the machine either directly or be striking and running along a surface of the machine.

Semi-Guarded Motor – A semi-guarded machine is an open machine in which part of the ventilating openings in the machine, usually in the top half, are guarded as in the case of a “guarded motor” but the others are left open.

Guarded Motor – A guarded machine is an open machine in which all openings giving direct access to live or rotating parts (except smooth shafts) are limited in size by the design of the structural parts or by screens, grills, expanded metal, etc., to prevent accidental contact with such parts. Such openings shall not permit the passage of a cylindrical rod 1/4” in diameter, except that, where the distance from the guard to the live or rotating parts is more than 4”, they shall not permit the passage of a cylindrical rod ¾” in diameter.

Drip-Proof Fully Guarded Motor – A drip-proof fully guarded machine is a drip-proof machine whose ventilating openings are guarded.

Open Externally-Ventilated Motor – A open externally-ventilated machine is one which is ventilated by means of a separate motor-driven blower mounted on the machine enclosure.

Open Pipe-Ventilated Motor – An open pipe-ventilated machine is an open machine except that openings for the admission of the ventilating air are so arranged that inlet ducts or pipes can be connected to them. This air may be circulated by means integral with the machine or by means external to and not a part of the machine. In the latter case, this machine is sometimes known as separately or forced-ventilated machine.

Weather-Protected Type-I Motor (WP-I) – A weather-protected Type I machine is an open machine with its ventilating passages so constructed as to minimize the entrance of rain, snow and air-borne particles to the electric parts and having its ventilated openings so constructed as to prevent the passage of a cylindrical rod ¾” in diameter.

Weather-Protected Type-II Motor (WP-II) – A weather-protected Type II machine shall have, in addition to the enclosure defined for a weather-protected Type I machine, its ventilating passages at both intake and discharge so arranged that high-velocity air and air borne particles blown into the machine by storms or high winds can be discharged without entering the internal ventilating passages leading directly to the electric parts of the machine itself. The normal path of the ventilating air which enters the electric parts of the machine shall be so arranged by baffling or separate housings as to provide at least three abrupt changes in direction, none of which shall be less than 90˚. In addition, an area of low velocity not exceeding 600 feet per minute shall be provided in the intake air path to minimize the possibility of moisture or dirt being carried into the electric parts of the machine.

Totally-Enclosed Motors

Totally Enclosed Non-ventilated Motor – A totally-enclosed non-ventilated machine is a totally-enclosed machine which is not equipped for cooling by means external to the enclosing parts.

Totally-Enclosed Fan-Cooled Motor – A totally-enclosed fan-cooled machine is a totally-enclosed machine equipped for exterior cooling by means of a fan or fans integral with the machine but external to the enclosing parts.

Explosion-Proof Motor – An explosion-Proof machine is a totally-enclosed machine whose enclosure is designed and constructed to with-stand an explosion of a specified gas or vapor which may occur within it and to prevent the ignition of the specified gas or vapor surrounding the machine by sparks, flashes or explosions of the specified gas or vapor which may occur within the machine casing.

Dust-Ignition-Proof Motor – A dust-ignition-proof machine is a totally-enclosed machine whose enclosure is designed and constructed in a manner which will exclude ignitable amounts of dust or amount which might affect performance or rating, and which will not permit arcs, sparks, or heat otherwise generated or liberated inside of the enclosure to cause ignition of exterior accumulations or atmospheric suspensions of a specific dust on or in the vicinity of the enclosure.

Water-Proof Motor – A water-proof machine is a totally-enclosed machine so constructed that it will exclude water applied in the form of a stream from a hose, except that leakage may occur around the shaft provided it is prevented from entering the oil reservoir and provision is made for automatically draining the machine. The means for automatic draining may be a check valve or a tapped hole at the lowest part of the frame which will serve for application of a drain pipe.

Totally-Enclosed Pipe-Ventilated Motor – A totally-enclosed pipe-ventilated machine is a totally-enclosed machine except for openings so arranged that inlet and outlet ducts or pipes may be connected to them for the admission and discharge of the ventilating air. This air may be circulated by means integral with the machine or by means external to and not a part of the machine. In the latter case, these machines shall be known as separately or forced-ventilated machines.

Totally-Enclosed Water-Cooled Motor – A totally-enclosed water-cooled machine is a totally-enclosed machine which is cooled by circulating water, the waater or water conductors coming in direct contact with the machine parts.

Totally-Enclosed Water-Air-Cooled Motor – A totally-enclosed water-air-cooled machine is a totally-enclosed machine which is cooled by circulating air which, in turn, is cooled by circulating water. It is provided with a water-cooled heat exchanger for cooling the ventilating air and a fan or fans, integral with the rotor shaft or separate, for circulating the ventilating air.

Totally-Enclosed Air-To-Air-Cooled Motor – A totally-enclosed air-to-air-cooled machine is a totally-enclosed machine which is 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 ventilating air and a fan or fans, integral with the rotor shaft or separate, for circulating the internal air and a separate fan for circulating the external air.

Totally-Enclosed Fan-Cooled Guarded Motor – A totally-enclosed, fan cooled guarded machine is a totally-enclosed, fan-cooled machine in which all openings giving direct access to the fan are limited in size by the design of the structural parts or by screens grills, expanded metal, etc., to prevent accidental contact with the fan. Such openings shall not permit the passage of a cylindrical rod ½” in diameter except that, where the distance from the guard to the fan is more than 4”, they shall not permit the passage of a cylindrical rod ¾” in diameter.

Most Commonly used Motors for Industrial Refrigeration

With all the motors listed above, only few are commonly used for industrial refrigeration. The most frequently used motors are:

Open Motors:
:Open Drip-Proof (ODP) motor.
Weather-Protected type I (WP-I) motor
Weather-Protected type II (WP-II) motor.

Totally Enclosed Motors:
Totally-Enclosed Fan-Cooled (TEFC) motor.
Totally-Enclosed Force Ventilated (TEFV) motor.
Totally-Enclosed Water-Air-Cooled (TEWAC) motor.
Totally-Enclosed Air-To-Air Cooled (TEAAC) motor.

Explosion Proof (Divison I) Motors:
Totally-Enclosed Fan Cooled motor.
Totally-Enclosed Inert Gas Filled, Water Cooled motor.

All other types of motor are occasionally used for special application to meet the specific job requirement.

Motor General Selection Guide for Non-Hazardous Location:

The following Table 23.1 shall serve as a general guide in selecting the motor to meet the **non-hazardous** service conditions at various locations as encountered.

Table 23.1 General Guide for Non-Hazardous Motor Selection

Installation Environment	Motor Type	Protective Option
Indoor Installation		
Normal service, dry and clean	ODP	
Dry, dusty	ODP	Bearing & winding RTD
Humid, some moisture	ODP	Space heater
High moisture, contaminants	ODP or WP-1 or TEFC	Space heater and bearing RTD
Outdoor Installation		
Normal service, dry and clean	ODP	
Occasional moisture and light dust	WP-1 or TEFC	Space heater
Moisture, wind, rain, dust	WP-1 or WP-2 Or TEFC	Space heater, lightning arrestors, surge capacitors
Excessive dust, corrosives and contaminants	WP-II or TEFC	Space heater, bearing & winding RTD

Motor General Selection Guide for Hazardous Location:

The following is the general guide in selecting the motor for **hazardous environment** application:

(1) **Class I, Division 2** refers to locations where the atmosphere may become hazardous only under abnormal or unusual conditions. In general, motors in standard enclosures can be installed in Division II location if the motor has no normally sparking parts. Thus, open or standard totally enclosed squirrel-cage motors are acceptable for NEC Class I, Division II application. However, beside the hazardous consideration, the motor enclosure selection shall also meet the NEMA standard for moisture, dust, and rain exposure particularly for outdoor installation.

(2) **Class I, Division I** motors must be totally-enclosed double shell construction with special seals, fits, breathers, drains and conduit boxes plus three windings mounted with thermostats to detect over temperature in accordance with NEC, NFPA 70 code. Therefore, the motors which might be qualified for Division I atmospheric environment, it must be a totally enclosed construction such as TEFC, TEAAC, TEWAC or Totally Enclosed Inert Gas Filled Water Cooled design with modification for explosion application.

NEMA Compared IP (IEC) for Motor Enclosure

The following Table 23.2 lists the frequently specified types of enclosure and the equivalent protection in accordance with IEC IP code.

Table 23.2 NEMA vs IEC Motor Enclosures

NEMA Enclosure	**Enclosure per IEC (IP)**
Drip-Proof Motor	IP 12
Splash-Proof Motor	IP 13
Semi-guarded Motor	No equivalent Item
Guarded Motor	IP 22
Open Pipe-Ventilated Motor	IP 23 or IP 44
Weather-Protected Motor	IPW 23
Weather-Protected Motor	IPW24
Totally-Enclosed Non-Ventilated Motor	IP 44 or higher without fan
Totally-Enclosed Fan Cooled Motor	IP 44 or higher fan cooled
Explosion Proof Motor	Ex d IIA, IIB or IIC IP 44 or higher
Dust-Ignition-Proof Motor	Ex e, IP 44 or higher (Terminal box IP 54)
Water-Proof Motor	IP 45 or higher

Motor Options, Modifications and Accessories:

Special testing and special modifications are available from the manufacturer for custom-built motor at a price addition. The common modifications are as the following:

Service Factor – Service factor is one of the options available from the motor manufacturers in USA. When a service factor which usually 1.15 is called for; it means that the motor shall have the capability of 15% continuous overload ability.

Non-Standard Insulation – Motor insulation is other than standard. Or use type “F” insulation rated for “B” temperature rise.

Special Voltage – Motors are rated at plus and minus 10% of the nominal name plate voltage with rated frequency applied.

Special Frequency – Standard frequency in USA is 60 Hz. Other frequencies are non-standard including 50 Hz and 25 Hz.

Efficiency – Guaranteed of efficiency or efficiency higher than normal can be obtained by price addition, the motor frame size may be increased by several size larger than normal.

Low Starting current – Low starting current motor might have lower breakdown and starting torque.

Enclosure – All enclosures other than open-drip proof (ODP).

Space Heater – Space heater is to prevent undue collection of condensation when the motor is not in operation.

Lighting Arrest or Surge Protection – For motor having voltage of 2300V or higher. Surge capacitor must be used when lighting arrestor is specified.

Forced Lubrication Bearings – Forced feed lubrication is required for certain type of motor especially large HP motor. Lubrication oil can be supplied from the external gear if an external gear is employed and extra amount lubrication system consists of oil pump, oil reservoir, oil cooler, oil filter, piping and control should be furnished for the motor.

Hazardous Application – Motor to be modified to meet NEC or IEC codes.

Dual Voltage or Dual Frequency – Can be designed for either dual voltages or dual frequencies of both 60 Hz and 50 Hz.

Other Common Modifications:

Vibration probes and monitory system.
Winding temperature detecting equipment.
Bearing temperature sensing and indicating equipment.
Low voltage starting.

Power factor correction.
Corrosion resistance hardware.
Altitude above 3300 feet.
Special bearing.
Special starting torque.

Motor Specifications:

The minimum information required for motor selection are as the following:

HP size for the motor.
Voltage, phase and frequency of the power supply.
Control voltage.
Number of Poles or RPM motor speed.
Type of enclosure.
Safety factor.
Type of insulation and temperature rise rating.
Type of bearings – sleeve or anti-friction.
Type of lubrication.
Starting method.
Modifications and Accessories.
Codes compliance, NEC or IEC or NEMA or IP.

Starters

All the starters are to be designed and constructed in accordance with NEMA standard. The starter used for refrigeration systems are mainly electro-mechanical starter. Solid state starter is a reduced voltage starter with solid state control. The solid state starter operates quietly and smoothly, eliminates the light flicker which is the biggest disadvantage of an electro-mechanical starter. The following Table 23.3 lists all types of the electro-mechanical starters, types of switching transition, approximate percent of locked rotor ampere (LRA) for each step, and approximate percent of locked rotor torque (LRT) for each step.

Table 23.3 Starter Type - LRA & LRT

Starter Type	Switching Transition	% LRA	% LRT
Across the Line		100%	100%
Part Winding, 2 Steps	Closed	65% 100%	48% 100%
Part Winding, 3 Steps with Resistance	Closed	45% 65% 100%	24% 48% 100%
Part Winding, 4 Steps	Closed	51% 74% 87% 100%	22% 60% 81% 100%
Star Delta Open Transition	Open	33% 100%	33% 100%
Star Delta Closed Transition	Closed	33% 100%	33% 100%
Auto Transformer Open Transition	Open	50% Tap 27% 65% Tap 45% 80% Tap 66% 100%	25% 42% 64% 100%
Auto Transformer Closed Transition	Closed	50% Tap 27% 65% Tap 45% 80% Tap 66% 100%	25% 42% 64% 100%
Primary Resistance 2 Point	Closed	65% 100%	43% 100%

Part Winding (P-W) starters are mainly used for smaller HP motor. Other reduce voltage starters such as star-delta are mainly used for voltage below 600V. Auto-transformer starter is more expensive if used for 600V range as compared to star-delta. Medium and high voltage such as 4160 V, 6000 V or 10000 V mostly use across-the-line (direct-on-line), auto-transformer or primary Resistance type starter.

Starter Specifications

The minimum information for starter selection are as the following:

Size of starter, FLA & LRA.
Voltage, phase and frequency of the power supply.
Type of starter.
Type of enclosure.
Motor data: HP; Maximum allowable stall time; Acceleration time, S.F.
Modifications and Accessories.
Codes compliance, NEMA or IP.

Starting Torque Requirement and Starting Acceleration

Starting torque is a very important consideration for selecting the driver for the compressor in industrial refrigeration application. Figure 23-1 is the typical screw compressor torque requirement and the typical motor starting torque capabilities. A motor with across-the-line (ACL) starter or auto-transformer starter with 80% tap might be able to start the screw compressor at 185 Psi pressure differential; however, the motor might have difficulty to start the same compressor if the starter is with 65% tap and is not enough starting torque to start a low stage compressor at 30 Psi pressure differential; a motor with Star-Delta starter might not provide enough torque to start the compressors under normal conditions for refrigeration application.

All drivers including motors should be checked for starting torque and starting acceleration time to see if the driver is with enough torque to start the compressor at the specified conditions within the acceleration time allowed for the motor. Figure 23-2 shows the pull-up torque of the motor (B) is below the compressor torque curve and therefore, the motor is not providing enough torque to pull the compressor up to the design speed.

Figure 23-3 is the typical speed torque curves for a single stage centrifugal compressor. The starting torque requirement of the motor depends on the starting gas density ratio for the compressor. Figure 23-4 is the typical speed torque curves for a multistage centrifugal compressor with various density ratios.

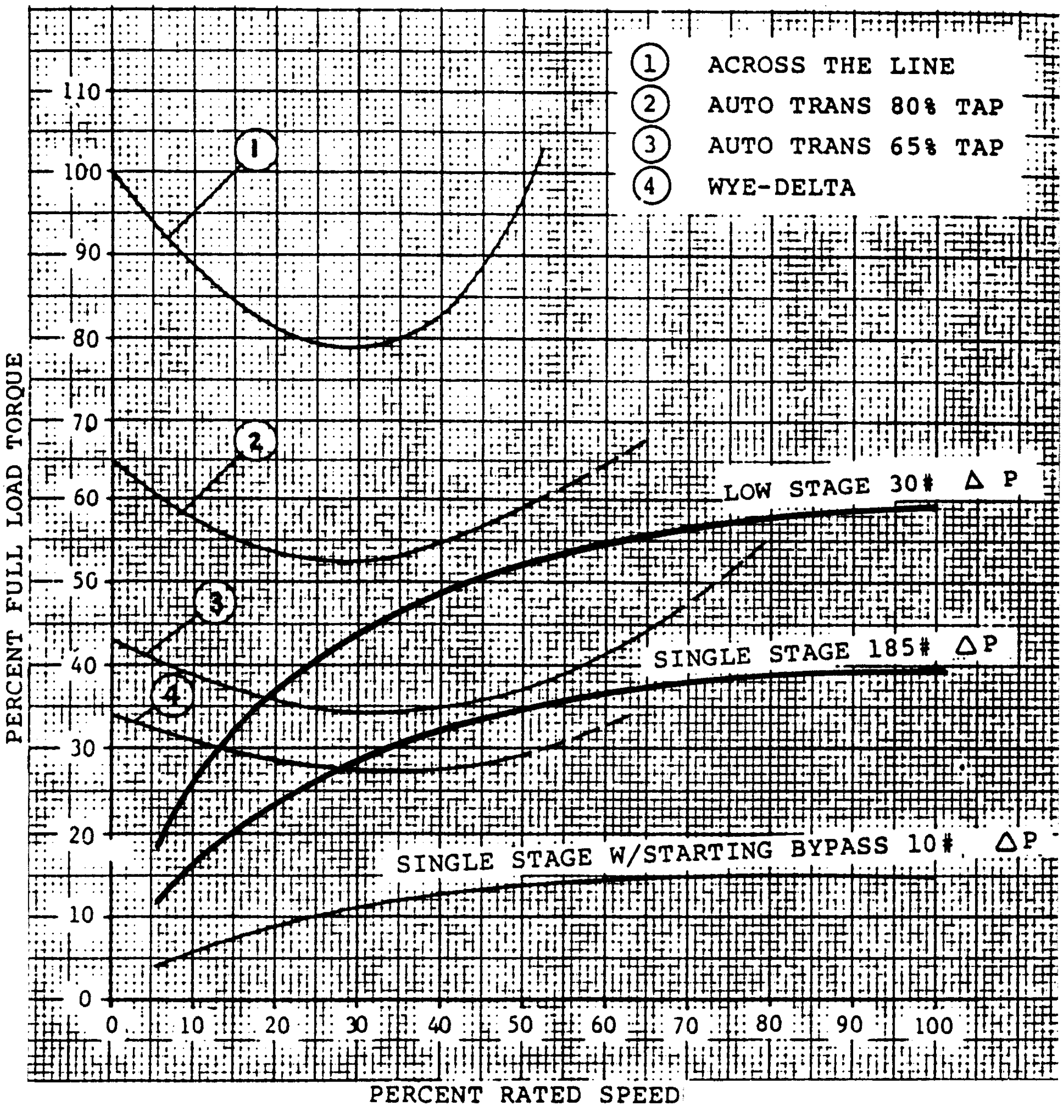

Figure 23-1 Typical Screw Compressor Starting Torque Requirement & Motor Starting Torque

Motor "A"
Adequate starting torque
to start the compressor

Moro "B"
Not enough starting torque
to start the compressor

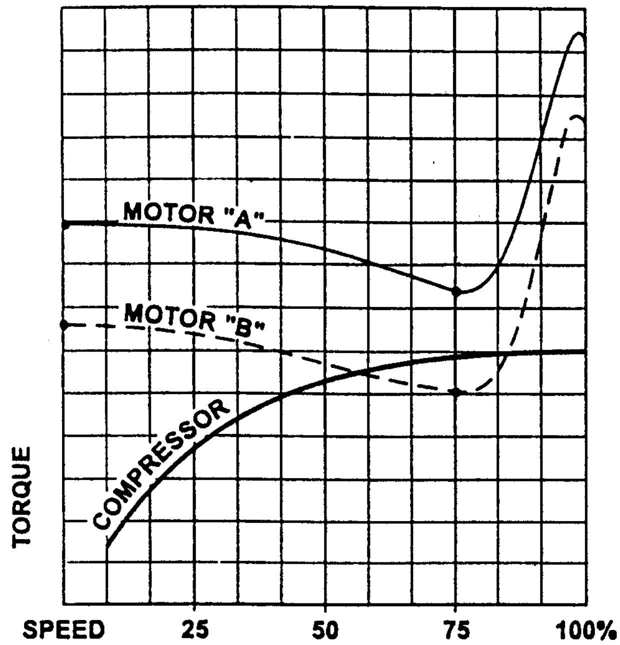

Figure 23-2 Typical Starting Torque Requirement for Motor

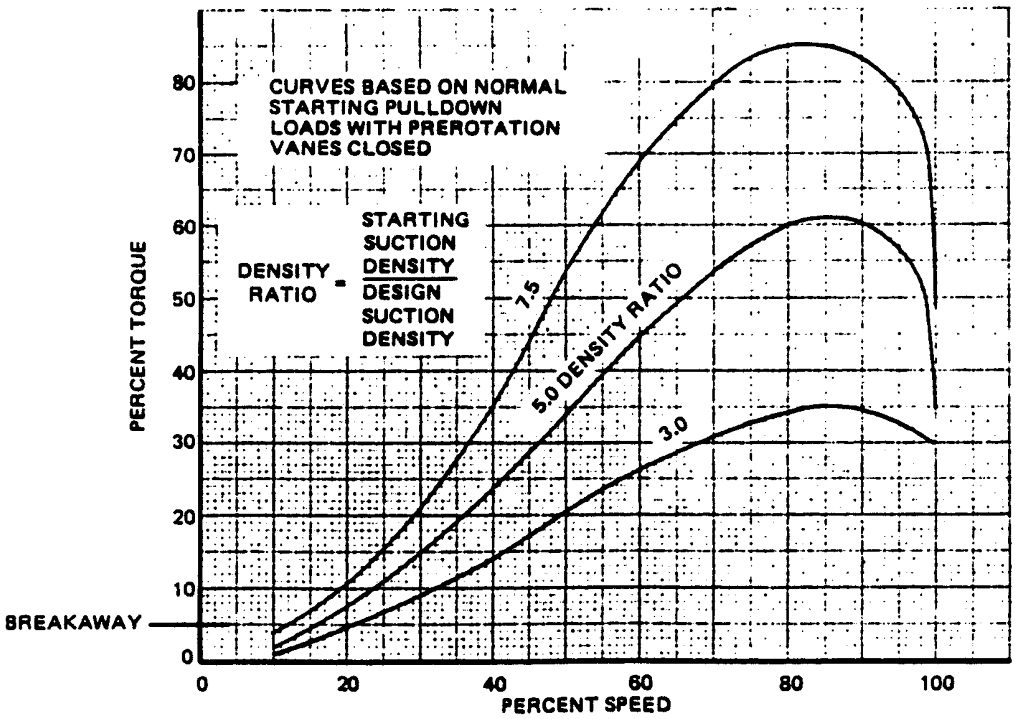

Figure 23-3 Typical Starting Torque for Single Stage Centrifugal Compressor

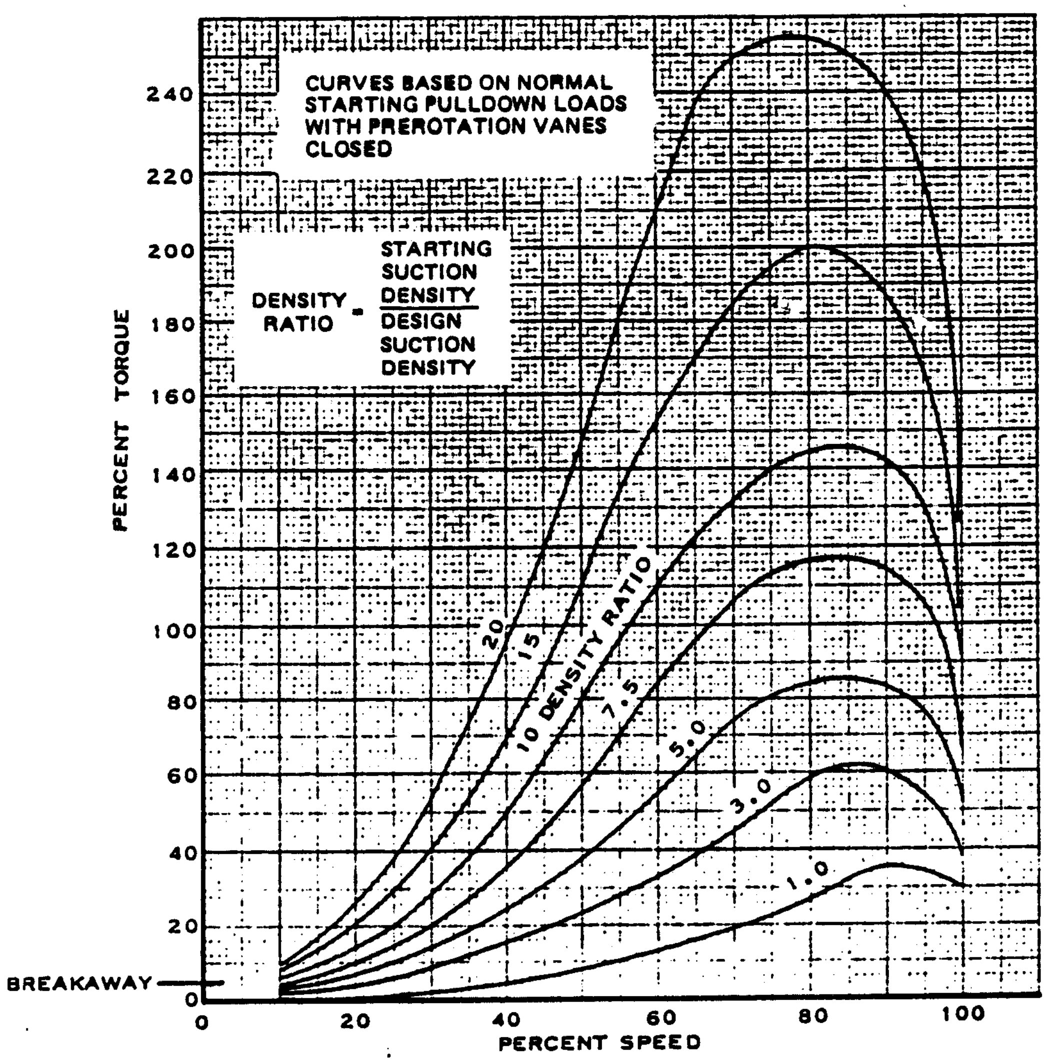

Figure 23-4 Typical Starting Torque for Multistage Centrifugal Compressor

Special Driver

Drivers other than motors available for screw or centrifugal compressor drive are gasoline engine, gas engine, diesel engine, steam turbine and gas turbine as special application. Motor is the most commonly use driver for compressor because it is simple and least expensive as compare to other type of drivers.

All compressors are basically designed for motor drive as standard. The base of the drive-line for the compressor is changed if it is changed to special driver. Cost of engine or turbine is more expensive than motor; and the cost penalty for the special system design is very heavy; therefore, the case should be evaluated carefully to see if overall benefit is justified including the return on investment. Furthermore, the drive train should be checked for torsional vibration, particularly if external gear is used between the driver and the compressor.