Technical eBook

ACS580 general purpose drives

Contents

Technical ebook for ACS580 general purpose drives

Introduction

ACS580 general purpose drives are very simple to use. They offer users effortless simplicity through easy installation and commissioning as well as through the wide range of built-in features. With ACS580 everything has been taken care of – the drive is virtually plug-in-ready to control pumps, fans, compressors, and many other variable and constant torque applications.

However, the purpose of this ebook is to provide the additional information of using ACS580 general purpose drives in order to save energy and optimize the drive for various processes. Although, ABB offers extensive tools, such as DriveSize for dimensioning the drive system, this ebook gives the reader a glimpse of the dimensioning fundamentals. It helps the users understand the theory behind the advanced dimensioning process.

The ebook consists of four chapters. The first one introduces AC drives and explains generally why they are used and how to optimize energy consumption with them. The second one introduces some built-in features of ACS580 that enable better process control and support effortless simplicity. The third one focuses on the dimensioning of a drive system which, when done right and properly, maximizes the energy savings. It also presents the fundamentals of induction motors, basics of mechanical laws, and helps the advanced users select the right drive and motor through various example calculations. The fourth, and final chapter is related to safety issues.

1. AC drive: the leading control method to save energy

Why to invest in variable speed drives?

The need to reduce energy consumption and lower carbon dioxide emissions is highlighted more and more every year. The simplest way to address this challenge is to seize the opportunities for energy reduction and start to use energy more efficiently.

A simple way to obtain the desired energy savings is to use ACS580 variable speed drives to intelligently control motors and to increase energy efficiency. The ACS580 drives regulate the speed of a motor and can reduce energy consumption by as much as 30% to 50% in many applications and in extreme cases by as much as by 90%. The simplicity of ACS580 drives provides enormous positive financial, operational and environmental implications.

For example, many motors in pump applications are oversized to cope with a maximum demand that rarely occurs. With traditional mechanical valves, the motor often runs at nominal speed regardless of the actual demand and the flow is mechanically resticted, which wastes energy. The variable speed drive brings motor speed down to match the actual demand.

The basic functions of an AC drive

In the following chapter we will take a closer look at the different features of the AC drive, and the levels of performance the drive can offer.

In the following, we will take a closer look to the components that are required in an AC drive system.

The electrical supply feeds the required electricity to the drive; one selection criteria for the drive is the supply voltage and its frequency. The AC drive converts the frequency and voltage and feeds the motor. This conversion process is controlled by signals from the process or user via the process and user interfaces.

The user interface provides the ability to observe the AC drive and obtain different process information via the drive. This makes the drive easy to integrate with other process control equipment and overriding process control systems.

A motor's load capacity curves with an AC drive

If the motor is driven without a frequency converter, neither its load capacity curves can be modified nor the energy consumption can be effectively optimized. The motor will produce a specified torque at certain speed and maximum torque cannot be exceeded.

With a frequency converter drive, there are different loading options. The standard curve, Curve 1, shown in Figure 1-1, can be used continuously. Other curves can only be used for certain periods of time because the motor's cooling system is not designed for this kind of heavy use.

These higher load capacity levels might be needed, for example, during startup. In certain applications, as much as twice the amount of torque is required when starting. With a frequency converter this is possible, meaning that a motor can be dimensioned according to its normal use. This reduces the investment cost.

To be able to use these features it is very important that the load, the AC drive and the motor are compatible. Otherwise the motor or the converter will overheat and be damaged.
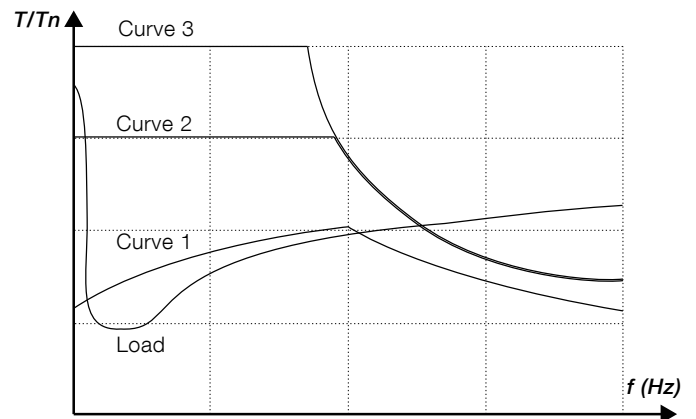

Figure 1-1 Motor's load capacity curves when used with an AC drive

2. ACS580 drives built-in features for effortless simplicity

ACS580 drive features for better process control

ACS580 drives have many built-in features that offer effortless simplicity. The internal features and functions are also often required for better process control and energy savings. With inputs and outputs for example, different kinds of process information can be fed to the drive and it will control the motor accordingly. Alternatively, the load can be limited to prevent nuisance faults and to protect the working machine and the whole drive system. Integrated energy efficiency calculators also provide valuable information about the energy consumption and savings.

Some of the important features:

- – inputs and outputs
- – reversing function
- – ramp times acceleration/deceleration
- – variable torque V/Hz settings
- – torque boosting
- – eliminating mechanical vibrations
- – load limits to prevent nuisance faults
- – power loss ride-through
- – stall function
- – flying start
- – energy optimizer
- – permanent motor control for energy efficiency
- – pre magnetization
- – DC hold
- – post magnetization
- – user load curve
- – jogging
- – PID control
- – PFC (Pump and fan control)

In the following sections some of the listed features of ACS580 are presented in more detail. Refer also to the pictures of the features.

Reversing

Reversing the motor rotation is simple to accomplish with an AC drive. With ACS580 drives series it can be achieved simply by pressing one button. Furthermore, it is possible to set different acceleration and deceleration ramp times. The ramp form can also be modified according to the user's wishes. In Figure 1-2 an S-ramp has been presented. Another possibility could be a linear ramp.
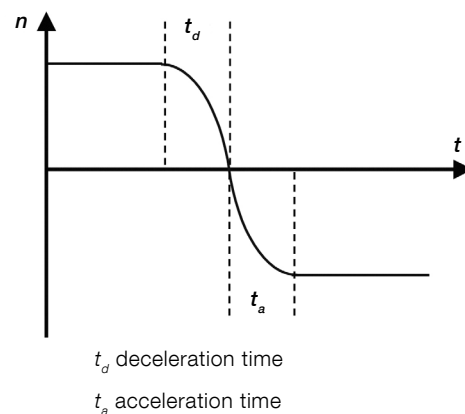

t_d deceleration time

t_a acceleration time

Figure 1-2 Reversing with acceleration and deceleration ramps

Energy optimizer

The function optimizes the motor flux so that total energy consumption and motor noise level are reduced when the drive operates below the nominal load. The total efficiency (motor and drive) can be improved by 1…20% depending on load torque and speed. With a permanent magnet motor, energy optimization is always enabled.

Torque control

Torque control is relatively simple task with an AC drive. Torque boosting is necessary if a very high starting torque is required. Variable torque U/f settings mean that maximum torque can be achieved at a lower speed of rotation than normal. These are presented in Figure 1-3.

2. ACS580 drives built-in features for effortless simplicity

Eliminating mechanical vibrations

Mechanical vibrations can be eliminated by by-passing critical speeds. This means that when a motor is accelerated close to its critical speed, the drive will not allow the actual speed of the motor to follow the reference speed. When the critical point has been passed, the motor will return to the regular curve very quickly and pass the critical speed. This is also presented in Figure 1-3.
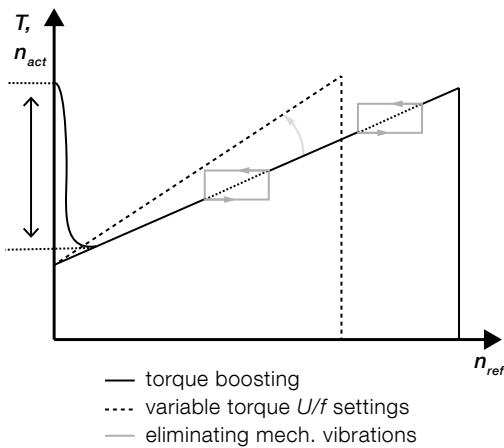
Power loss ride-through

The power loss ride-through function is used if the incoming supply voltage is cut off. This is shown in Figure 1-4. In such a situation, the AC drive will continue to operate using the kinetic energy of the rotating motor. The drive will be fully operational as long as the motor rotates and generates energy for the drive.

— torque boosting
···· variable torque U/f settings
— eliminating mech. vibrations

Figure 1-3 Torque control settings

--- Intermediate circuit voltage (U_{dc})
— Output frequency (f)
···· Motor torque (T_m)
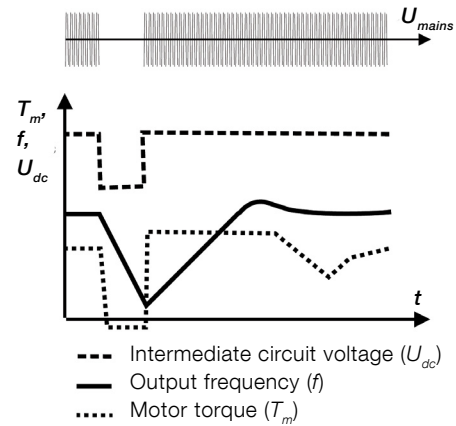
Figure 1-4 Power loss ride-through

Permanent magnet motors for energy efficiency

ACS580 supports permanent magnet motors. In these motors rare earth permanent magnets are designed into the motor's rotor, eliminating the need for a magnetizing current. Because of this, there is no rotor current and therefore very little heat being transferred to the rest of the motor and bearings. This immediately improves motor energy efficiency.

2. ACS580 drives built-in features for effortless simplicity

Flying start

The flying start feature is used when a motor is connected to a flywheel or a high inertia load. The flying start works even without a speed feedback. In case of rotating motor, the inverter is first started with a reduced voltage and then synchronised to the rotating rotor. After synchronised the voltage and the speed are increased to the corresponding levels. This feature is presented in Figure 1-5.
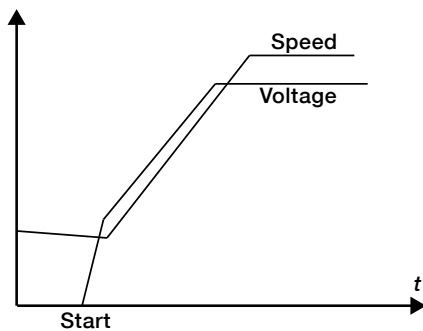

Figure 1-5 Flying start

Stall function

With an AC drive, the motor can be protected in a stall situation with the stall function. It is possible to adjust supervision limits and choose how the drive reacts to the motor stall condition. This is visualized in Figure 1-6. Protection is activated if three conditions are met at the same time.

1. The drive frequency has to be below the preset stall frequency.
2. The motor torque has to rise to a certain limit, calculated by the drive software.
3. The motor has been in the stall limit for longer than the time period set by the user.
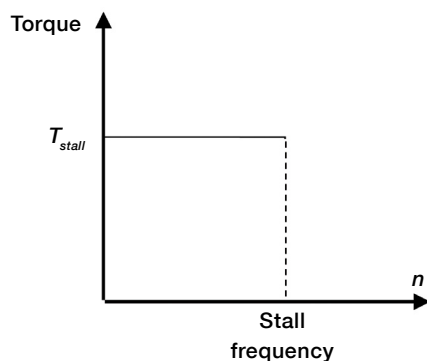

Figure 1-6 Stall function

User load curve

The user load curve provides a supervisory function that monitors an input signal as a function of frequency or speed, and load. It shows the status of the monitored signal and can give a warning or fault based on the violation of a user defined profile.

In Figure 1-7, the user load curve is constructed from the motor nominal torque to which a 10% margin is added and subtracted. The margin curves define a working envelope for the motor so that excursions outside the envelope can be supervised, timed and detected.

Overload can be for example used to monitor for a saw blade hitting a knot or fan load profiles becoming too high. In turn, underload can be for example used to monitor for load dropping and breaking of conveyer belts or fan belts.
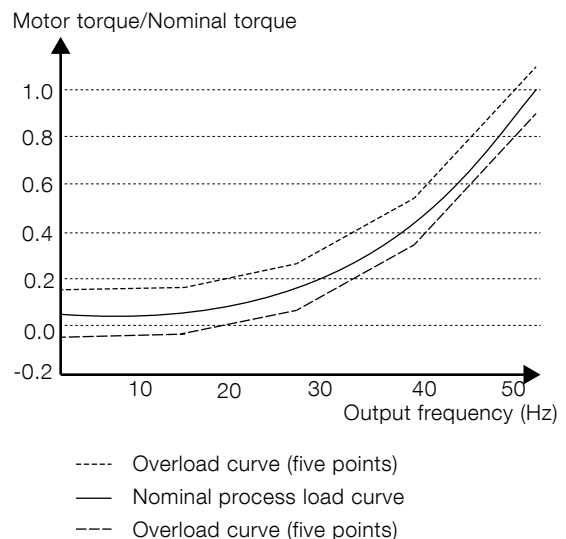

----- Overload curve (five points)
—— Nominal process load curve
--- Overload curve (five points)

Figure 1-7 User load curve

2. ACS580 drives built-in features for effortless simplicity

Pre magnetization

Pre magnetization refers to DC magnetization of the motor before start. Depending on the selected start mode (vector or scalar start mode), premagnetization can be applied to guarantee the highest possible breakaway torque, up to 200% of the nominal torque of the motor. By adjusting the pre magnetization time, it is possible to synchronize the motor start and, for example, the release of a mechanical brake.

DC hold

The function makes it possible to lock the rotor at (near) zero speed in the middle of normal operation. When both the reference and motor speed drop below a certain level, the drive will stop generating sinusoidal current and start to inject DC into the motor. When the reference exceeds DC hold speed, normal drive operation continues. This situation is is presented in Figure 1-7.
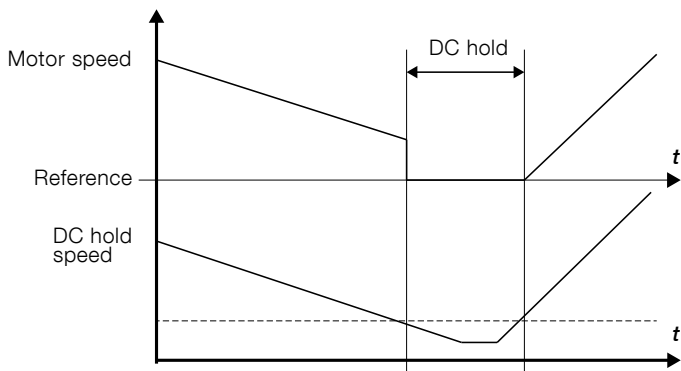
Figure 1-7 DC hold function

Post magnetization

The function keeps the motor magnetized for a certain period after stopping. This is to prevent the machinery from moving under load, for example before a mechanical brake can be applied. However, it is important to note that post-magnetization is only available when ramp stop is selected.

Jogging

The jogging function enables the use of a momentary switch to briefly rotate the motor. The jogging function is typically used during servicing or commissioning to control the machinery locally.

When jogging is activated, the drive starts and accelerates to the defined jogging speed along the defined jogging acceleration ramp. After the activation signal switches off, the drive decelerates to a stop along the defined jogging deceleration ramp. As long as the jog enable signal is on, start commands are ignored. After jog enable switches off, a fresh start command is required. Similarly, as long as the start command is on, the jog enable signal is ignored. If the jog enable signal is on when the start command switches off, jogging is enabled immediately. This logic is vizualized in Figure 1-9.
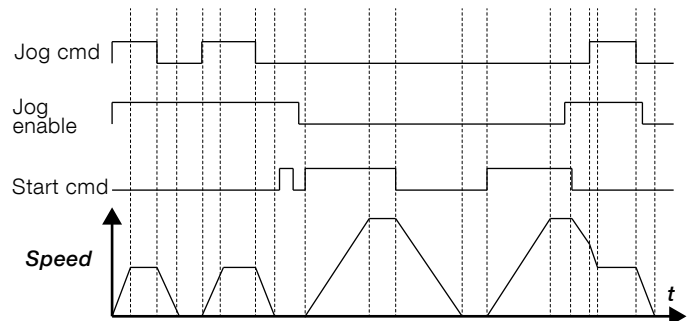
Figure 1-9 Logic of the jogging function

2. ACS580 drives built-in features for effortless simplicity

PID control

There is a built-in process PID controller in the ACS580 drive. The controller can be used to control process such as pressure or flow in the pipe or fluid level in the container. In process PID control, a process reference (setpoint) is connected to the drive instead of a speed reference. An actual value (process feedback) is also brought back to the drive. The process PID control adjusts the drive speed in order to keep the measured process quantity (actual value) at the desired level (setpoint). This means that user does not need to set a frequency/speed/torque reference to the drive but the drive adjust its operation according to the process PID.

PFC, pump and fan control

The pump and fan control (PFC) is used in pump or fan systems consisting of one drive and multiple pumps or fans. The drive controls the speed of one of the pumps/fans and in addition connects (and disconnects) the other pumps/fans directly to the supply network through contactors. The feature is useful especially when the process demand varies. The PFC control logic switches auxiliary motors on and off as required by the capacity changes of the process.

Environmental features

Any drive system has to handle different environmental stresses such as moisture or electrical disturbances. The IP55 degree of protection guarantees that it can be used in a dusty environment and that it can bear sprinkling water from any direction.

The frequency converter usually has an IP21 degree of protection. This means that it is not possible to touch the live parts and that vertically dripping water will not cause any harm. If a higher degree of protection is required, it can be obtained, for example, by selecting an ACS580-01 drive in a compact IP55 enclosure.

EMC

Another important environmental feature is electromagnetic compatibility (EMC). It is important that a drive system fulfills the EMC directives of the European Union. This means that the drive system can bear conductive and radiative disturbances, and that it does not send any conductive or radiative disturbances itself either to the electrical supply or the surrounding environment.

Figure 1-10 The IP21 and IP55 protection classes and EMC compatibility

3. Dimensioning of a drive system

This chapter focuses on the dimensioning of a drive system. First it introduces a drive system in generel and lists the principles of dimensioning procedure and mechanical laws related to it. In addition, it examines induction machines in details in different load types. Finally, this chapter shows example calculations to illustrate the dimensioning procedure and the theory behind it.

Dimensioning

Dimensioning of a drive system is a task where all factors have to be considered carefully. Dimensioning requires knowledge of the whole system including electric supply, driven machine, environmental conditions, motors and drives, etc. Time spent at the dimensioning phase can mean considerable cost savings.

There are of course some tools that help users with the dimensioning process. Some of these are for example a tool called DriveSize and another one called Drives Customer Lab. The first one helps users select the motor and drive based on the requirements defined by the application. The second one helps users test the compatibility between a motor and a drive and it helps to find the most optimal drive that matches to the motor. These both tools are offered by ABB.

Drive system

A single AC drive system consists typically of an input transformer or an electric supply, frequency converter, an AC motor and load. Inside the single frequency converter there is a rectifier, DC-link and inverter unit. This is shown in Figure 2-1.
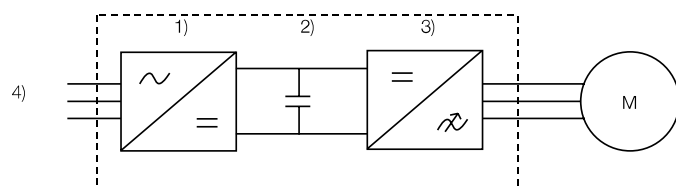

Figure 2-1 A single frequency converter consists of 1) rectifier, 2) DC-link, 3) inverter unit and 4) electric supply.

General description of a dimensioning procedure

This chapter gives the general steps for dimensioning the motor and the frequency converter.

1. Check the initial conditions. In order to select the correct frequency converter and motor, check the mains supply voltage level (380 V to 480 V) and frequency (50 Hz to 60 Hz). The mains supply network's frequency doesn't limit the speed range of the application.
2. Check the process requirements. Is there a need for starting torque? What is the speed range used? What type of load will there be? Some of the typical load types are described later.
3. Select the motor. An electrical motor should be seen as a source of torque. The motor must withstand process overloads and be able to produce a specified amount of torque. The motor's thermal overloadability should not be exceeded. It is also necessary to leave a margin of around 30% for the motor's maximum torque when considering the maximum available torque in the dimensioning phase.
4. Select the frequency converter. The frequency converter is selected according to the initial conditions and the selected motor. The frequency converter's capability of producing the required current and power should be checked. Advantage should be taken of the frequency converter's potential overloadability in case of a short term cyclical load.

3. Dimensioning of a drive system

Induction (AC) motor

Induction motors are widely used in industry and some of the basic features of them are described in this section.

Fundamentals of induction motor

An induction motor converts electrical energy into mechanical energy. Converting the energy is based on electromagnetic induction. Because of the induction phenomenon the induction motor has a slip.

The slip is often defined at the motor's nominal point (frequency (f_n), speed (n_n), torque (T_n), voltage (U_n), current (I_n) and power (P_n)). At the nominal point the slip is nominal:

$$s_n = \frac{n_s - n_n}{n_s} * 100\ \%$$

where n_s is the synchronous speed:

$$n_s = \frac{2 * f_n * 60}{\text{pole number}}$$

When a motor is connected to a supply with constant voltage and frequency it has a torque curve. This curve is presented in Figure 2-2.
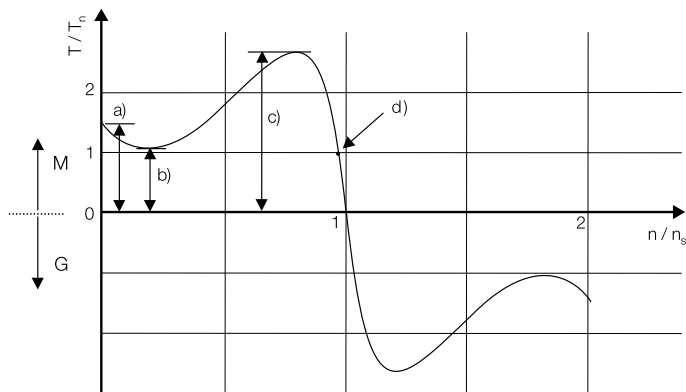

Figure 2-2 Typical torque/speed curve of an induction motor when connected to the network supply (D.O.L., Direct-On-Line). In the picture a) is the locked rotor torque, b) is the pull-up torque, c) is the maximum motor torque, T_{max} and d) is the nominal point of the motor.

A standard induction motor's maximum torque (T_{max}, also called pull-out torque and breakdown torque) is typically 2-3 times the nominal torque. The maximum torque is available with slip s_{max} which is greater than the nominal slip. In order to use an induction motor efficiently the motor slip should be in the range - s_{max} … s_{max}. This can be achieved by controlling voltage and frequency. Controlling can be done with a frequency converter.

The frequency range below the nominal frequency is called a constant flux range. Above the nominal frequency/speed the motor operates in the field weakening range. In the field weakening range the motor can operate on constant power which is why the field weakening range is sometimes also called the constant power range. For the illustration refer to Figure 2-3.
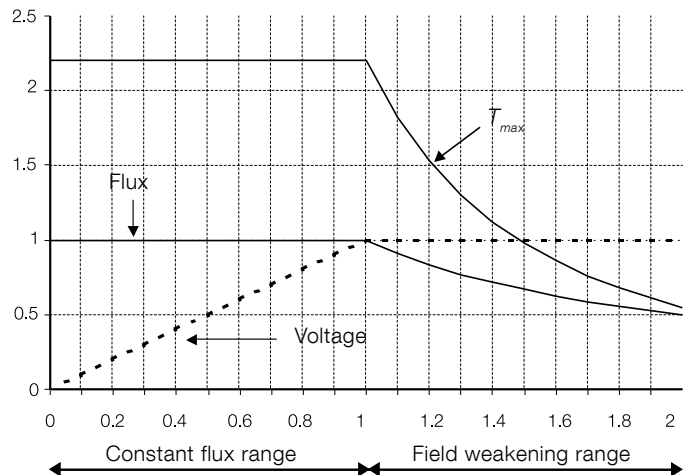

Figure 2-3 Maximum torque, voltage and flux as a function of the relative speed.

The maximum torque of an induction motor is proportional to the square of the magnetic flux ($T_{max} \sim \psi^2$). This means that the maximum torque is approximately a constant at the constant flux range. Above the field weakening point the maximum torque decrease is inversely proportional to the square of the frequency.

$$T_{max} \sim \left(\frac{f_n}{f_{act}} \right)^2 .$$

3. Dimensioning of a drive system

Motor current

An induction motor current has two components: reactive current (i_{sd}) and active current (i_{sq}). The reactive current component includes the magnetizing current (i_{magn}) whereas the active current is the torque producing current component. The reactive and active current components are perpendicular to each other.

The magnetizing current (i_{magn}) remains approximately constant in the constant flux range (below the field weakening point). In the field weakening range the magnetizing current decrease is proportional to speed.

A quite good estimate for the magnetizing current in the constant flux range is the reactive (i_{sd}) current at the motor nominal point.

Figure 2-4 Stator current (i_s) consists of reactive current (i_{sd}) and active current (i_{sq}) components which are perpendicular to each other. Stator flux is denoted as Ψ_s.

Constant flux range

Below the field weakening point the current components can be approximated as follows:

$$I_{sd} = I_n \left(\sin(\varphi_n) + \cos(\varphi_n) \left[\sqrt{\left(\frac{T_{max}}{T_n}\right)^2 - 1} - \sqrt{\left(\frac{T_{max}}{T_n}\right)^2 - \left(\frac{T_{load}}{T_n}\right)^2} \right] \right)$$

$$I_{sq} = I_n \left(\frac{T_{load}}{T_n} \right) \cos(\varphi_n)$$

The total motor current is:

$$i_m = \sqrt{i_{sd}^2 + i_{sq}^2}$$

It can be seen that with zero motor torque the active current component is zero. With higher torque values motor current becomes quite proportional to the torque. A good approximation for total motor current is:

$$i_m = \frac{T_{load}}{T_n} * I_n \qquad , \text{ when } 0.8 * T_n \leq T_{load} \leq 0.7 * T_{max}$$

Example 1

A 15 kW motor's nominal current is 32 A and power factor is 0.83. What is the motor's approximate magnetizing current at the nominal point? What is the total approximate current with 120% torque below the field weakening point?

Solution 1

At the nominal point the estimate for the magnetizing current is:

$$I_{sd} = I_n \sin(\varphi_n) = 32 * \sqrt{1 - 0.83^2} \text{ A} = 17.8 \text{ A}$$

The approximate formula for total motor current with 120% torque gives:

$$i_m = \frac{T_{load}}{T_n} * I_n = 1.2 * 32 \text{ A} = 38.4 \text{ A}$$

The approximate formula was used because torque fulfilled the condition $0.8 * T_n \leq T_{load} \leq 0.7 * T_{max}$
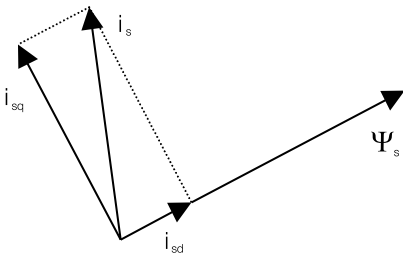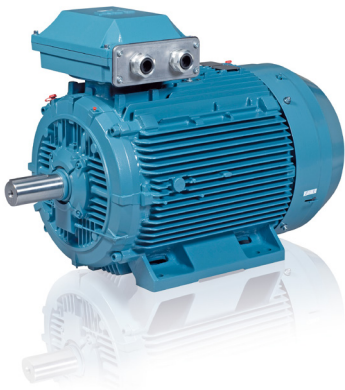
3. Dimensioning of a drive system

Field weakening range

Above the field weakening point the current components also depend on speed.

$$I_{sd} = I_n \left(\frac{n_n}{n} \left(\sin(\varphi_n) + \cos(\varphi_n) \sqrt{\left(\frac{T_{max}}{T_n} \right)^2 - 1} \right) - \cos(\varphi_n) \sqrt{\left(\frac{T_{max}}{T_n} * \frac{n_n}{n} \right)^2 - \left(\frac{T_{load}}{T_n} * \frac{n}{n_n} \right)^2} \right)$$

$$I_{sq} = I_n \left(\frac{T_{load}}{T_n} * \frac{n}{n_n} \right) \cos(\varphi_n) = I_n \left(\frac{P_{load}}{P_n} \right) \cos(\varphi_n)$$

Total motor current is:

$$i_m = \sqrt{i_{sd}^2 + i_{sq}^2}$$

The motor current can be approximated quite accurately within a certain operating region. The motor current becomes proportional to relative power. An approximation formula for current is:

$$i_m = \frac{T_{load}}{T_n} * \frac{n}{n_n} I_n = \frac{P_{load}}{P_n} I_n$$

Approximation can be used when:

$$0.8 * \frac{n_n}{n} * T_n \leq T_{load} \leq 0.7 * \left(\frac{n_n}{n} \right)^2 * T_{max}$$

and

$$0.8 * P_n \leq P_{load} \leq 0.7 * \frac{n_n}{n} * P_{max}$$

In the field weakening range the additional current needed in order to maintain a certain torque level is proportional to relative speed.

Example 2

The motor's nominal current is 71 A. How much current is needed to maintain the 100% torque level at 1.2 times nominal speed ($T_{max} = 3 * T_n$)?

Solution 2

The current can be calculated by using the approximation formula:

$$i_m = \frac{T_{load}}{T_n} * \frac{n}{n_n} I_n = 1 * 1.2 * 71 = 85.2 \text{ A}$$

Motor power

The motor's mechanical (output) power can be calculated from speed and torque using the formula:

$$P_{out} [W] = T [Nm] * \omega [rad/s]$$

Because motor power is most often given in kilowatts and speed in rpm revolutions per minute (1 rpm = $2\pi/60$ rad/s), the following formula can be used:

$$P_{out} [W] = T [Nm] * \omega [rad/s]$$

The motor's input power can be calculated from the voltage, current and power factor:

$$P_{out} [kW] = \frac{T [Nm] * n [rpm]}{9550}$$

The motor's efficiency is the output power divided by the input power:

$$\eta = \frac{P_{out}}{P_{in}}$$

3. Dimensioning of a drive system

Example 3
The motor nominal power is 15 kW and the nominal speed is 1480 rpm. What is the nominal torque of the motor?

Solution 3
The motor's nominal torque is calculated as follows:

$$T_n = \frac{9550 * 15}{1480} \, Nm = 96.8 \, Nm$$

Example 4
What is the nominal efficiency of a 37 kW (P_n=37 kW, U_n=380 V, I_n=71 A and $cos(\varphi_n)$=0.85) motor?

Solution 4
The nominal efficiency is:

$$\eta_n = \frac{P_{out}}{P_{in}} = \frac{P_n}{\sqrt{3} * U_n * I_n * cos(\varphi_n)} = \frac{37000}{\sqrt{3} * 380 * 71 * 0.85} \approx 0.931$$

Basic mechanical laws

One of the basic equations of an induction motor describes the relation between moment of inertia (J [kgm²]), angular velocity (ω [rad/s]) and torque (T [Nm]). The equation is as follows:

$$\frac{d}{dt}(J\omega) = J\frac{d\omega}{dt} + \omega\frac{dJ}{dt} = T - T_{load}$$

In the above equation it is assumed that both the frequency and the moment of inertia change. The formula is however often given so that the moment of inertia is assumed to be constant:

$$J\frac{d\omega}{dt} = T - T_{load}$$

Torque T_{load} represents the load of the motor. The load consists of friction, inertia and the load itself. When the motor speed changes, motor torque is different from T_{load}. Motor torque can be considered as consisting of a dynamic and a load component:

$$T = T_{dyn} + T_{load}$$

If the speed and moment of inertia are constants the dynamic component (T_{dyn}) is zero. The dynamic torque component caused by acceleration/deceleration of a constant moment of inertia (motor's speed is changed by Δn [rpm] in time Δt [s], J is constant) is:

$$T_{dyn,n} = J * \frac{2\pi}{60} * \frac{\Delta n}{\Delta t}$$

If the moment of inertia varies and at the same time the motor is accelerating the dynamic torque component can be calculated using a certain discrete sampling interval. From the thermal dimensioning point of view it is however often enough to taken into account the average moment of inertia during acceleration.

3. Dimensioning of a drive system

Example 5

The total moment of inertia, 3 kgm², is accelerated from a speed of 500 rpm to 1000 rpm in 10 seconds. What is the total torque needed when the constant load torque is 50 Nm? How fast will the motor decelerate to 0 rpm speed if the motor's electric supply is switched off?

Solution 5

The total moment of inertia is constant. The dynamic torque component needed for acceleration is:

$$T_{dyn} = 3 * \frac{2 \pi}{60} * \frac{1000 - 500}{10} \text{ Nm} = 15.7 \text{ Nm}$$

Total torque during acceleration is:

$$T = T_{dyn} + T_{load} = (15.7 + 50) \text{ Nm} = 65.7 \text{ Nm}$$

If the motor's electric supply is switched off at 1000 rpm the motor decelerates because of the constant load torque (50 Nm). Following equation holds:

$$3 * \frac{2 \pi}{60} * \frac{0 - 1000}{\Delta t} = - T_{load}$$

Time to decelerate from 1000 rpm to 0 rpm:

$$\Delta t = 3 * \frac{2 \pi}{60} * \frac{1000}{50} \text{ s} = 6.28 \text{ s}$$

Example 6

Accelerating of a fan to nominal speed is done with nominal torque. At nominal speed torque is 87%. The fan's moment of inertia is 1200 kgm² and the motor's moment of inertia is 11 kgm². The load characteristics of the fan T_{load} is shown in Figure 2-5.

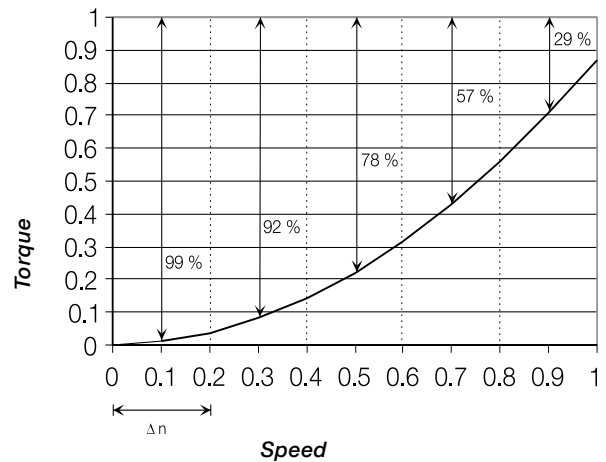Motor nominal power is 200 kW and nominal speed is 991 rpm.

Figure 2-5 Torque characteristics of a fan. Speed and torque are shown using relative values.

Calculate approximate starting time from zero speed to nominal speed.

3. Dimensioning of a drive system

Solution 6

Motor nominal torque is:

$$T_n = \frac{9550 * 200}{991} \text{ Nm} = 1927 \text{ Nm}$$

The starting time is calculated by dividing the speed range into five sectors. In each sector (198.2 rpm) torque is assumed to be constant. Torque for each sector is taken from the middle point of the sector. This is quite acceptable because the quadratic behavior is approximated to be linear in the sector.

The time to accelerate the motor (fan) with nominal torque can be calculated with formula:

$$\Delta t = \frac{2 \pi}{60} * \frac{J_{tot} * \Delta n}{T_n - T_{load}}$$

Acceleration times for different speed sections are:

0-198.2 rpm $\qquad \Delta t = \dfrac{2 \pi}{60} * \dfrac{1211 * 198.2}{0.99 * 1927} \text{ s} = 13.2 \text{ s}$

198.2-396.4 rpm $\qquad \Delta t = \dfrac{2 \pi}{60} * \dfrac{1211 * 198.2}{0.92 * 1927} \text{ s} = 14.3 \text{ s}$

396.4-594.6 rpm $\qquad \Delta t = \dfrac{2 \pi}{60} * \dfrac{1211 * 198.2}{0.78 * 1927} \text{ s} = 16.7 \text{ s}$

594.6-792.8 rpm $\qquad \Delta t = \dfrac{2 \pi}{60} * \dfrac{1211 * 198.2}{0.57 * 1927} \text{ s} = 22.9 \text{ s}$

792.8-991 rpm $\qquad \Delta t = \dfrac{2 \pi}{60} * \dfrac{1211 * 198.2}{0.29 * 1927} \text{ s} = 45.0 \text{ s}$

Therefore, the total starting time from 0 to 991 rpm is approximately 112 seconds.

Load types and selecting the frequency converter and motor

The motor is selected according to the basic information about the process. Speed range, torque curves, ventilation method and motor loadability give guidelines for motor selection. Often, it is worth comparing different motors because the selected motor affects the size of the frequency converter.

Knowing the load profile (speed range, torque and power) is essential when selecting a suitable motor and frequency converter for the application.

Some common load types are presented in next five figures. There may also be combinations of these types.

1. Constant torque

A constant torque load type is typical when fixed volumes are being handled. For example, screw compressors, feeders and conveyors are typical constant torque applications. Torque is constant and the power is linearly proportional to the speed.
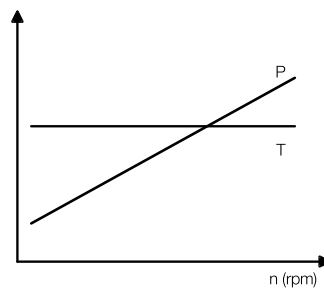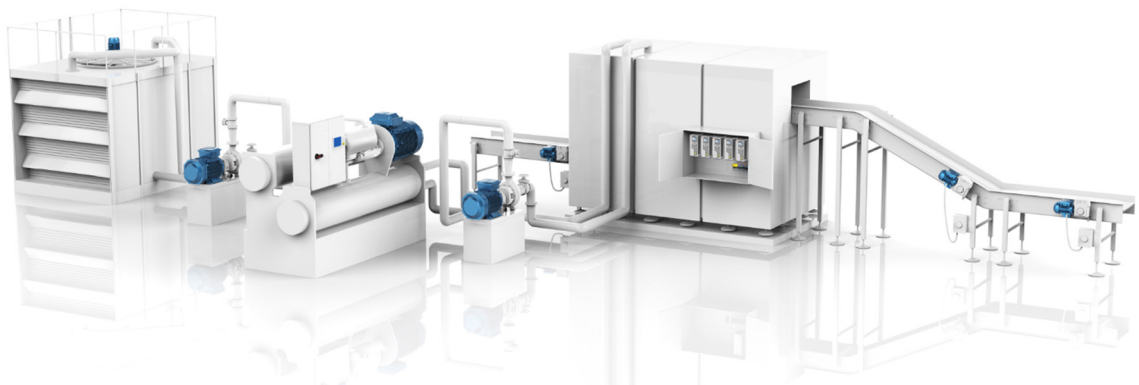
Figure 2-6 Typical torque and power curves in a constant torque application.

3. Dimensioning of a drive system

2. Quadratic torque

Quadratic torque is the most common load type. As the name implies, the torque is quadratically, and thus the power is cubically proportional to the speed. Typical quadratic torque applications are for example centrifugal pumps and fans.
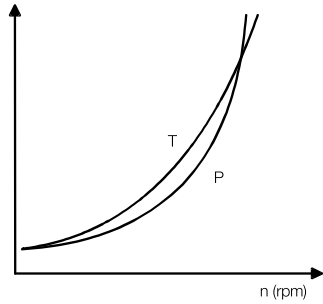
Figure 2-7 Typical torque and power curves in a quadratic torque application.

3. Constant power

A constant power load is normal when material is being rolled and the diameter changes during rolling. The power is constant and the torque is inversely proportional to the speed.
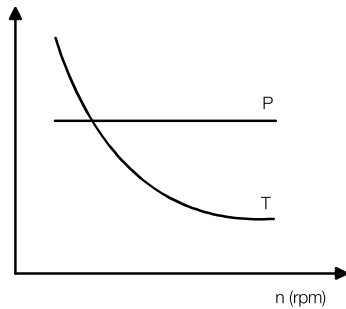
Figure 2-8 Typical torque and power curves in a constant power application.

4. Constant power/torque

This load type is common in the paper industry. It is a combination of constant power and constant torque load types. It is often a consequence of dimensioning the system according to the need for certain power at high speed.

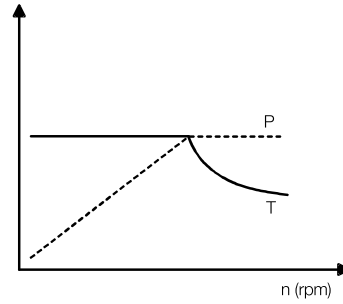Figure 2-9 Typical torque and power curves in a constant power/ torque application.

5. Starting/breakaway torque demand

In some applications high torque at low frequencies is needed. This has to be considered in dimensioning. Typical applications for this load type are for example extruders and screw pumps.
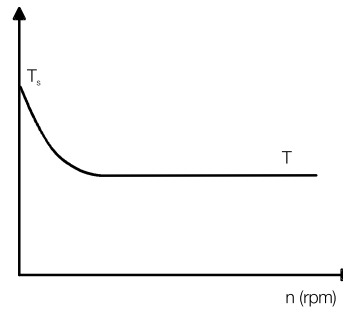
Figure 2-10 Typical torque curve in an application where starting torque is needed.

3. Dimensioning of a drive system

There are also several other load types. They are however hard to describe in a general presentation. Just to mention a few, there are different symmetrical (rollers, cranes, etc.) and unsymmetrical loads. Symmetry/non-symmetry in torque can be for example as a function of angle or time. These kinds of load types must be dimensioned carefully taking into account the overloadability margins of the motor and the frequency converter, as well as the average torque of the motor.

Next, let's consider the steps of a frequency converter selection. When selecting a suitable frequency converter there are several things to be considered. Frequency converter manufacturers normally have certain selection tables where typical motor powers for each converter size are given.

The dimensioning current can also be calculated when the torque characteristics is known. The corresponding current values can be calculated from the torque profile and compared to converter current limits. The motor's nominal current gives some kind of indication. However, it is not always the best possible dimensioning criteria because motors might for example be derated (ambient temperature, hazardous area, etc.).

The available supply voltage must be checked before selecting the frequency converter. Supply voltage variations affect the available motor shaft power. If the supply voltage is lower than nominal voltage the field weakening point shifts to a lower frequency and the available maximum torque of the motor is reduced in the field weakening range.

The maximum available torque is often limited by the frequency converter. This has to be already considered during the motor selection phase. The frequency converter may limit the motor torque earlier than stated in the motor manufacturer's data sheet.

The maximum available torque is also affected by transformers, reactors, cables, etc. in the system because they cause a voltage drop and thus the maximum available torque may drop. The system's power losses need to be compensated also by the frequency converter rating.

Did you know?

Each ACS580 drive is equipped with a built-in filter to reduce high frequency emissions. The EMC product standard (EN 61800-3) category C2 is fulfilled in wallmounted drives and category C3 is fulfilled in drive modules and cabinet build drives with no external filters.

EMC standards
The EMC product standard (EN 61800-3) covers the specific EMC requirements stated for drives (tested with motor and motor cable) within the EU. EMC standards such as EN 55011 or EN 61000-6-3/4 are applicable to industrial and domestic equipment and systems including components inside the drive. Drive units complying with the requirements of EN 61800-3 are compliant with comparable categories in EN 55011 and EN 61000-6-3/4, but not necessarily vice versa. EN 55011 and EN 61000-6-3/4 do not specify cable length or require a motor to be connected as a load. The emission limits are comparable to EMC standards according to the table below.

Domestic environments versus public low voltage networks
1st environment includes domestic premises. It also includes establishments directly connected without an intermediate transformer to a low voltage power supply network that supplies buildings used for domestic purposes.2nd environment includes all establishments directly connected to public low voltage power supply networks.

3. Dimensioning of a drive system

Next, let's take a closer look to practical examples. This section of the chapter three presents three example dimensioning problems and detailed solutions for them. Each problem has a different type of motor loadability curve and the purpose is to find the best suitable motor for each application.

Quadratic torque: pump and fan application example

Next there are listed some stages in pump and fan application dimensioning:

– Check the speed range and calculate power with highest speed.
– Check the starting torque need.
– Choose the pole number of the motor. The most economic operating frequency is often in the field weakening range.
– Choose motor power so that power is available at maximum speed. Remember the thermal loadability.
– Choose the frequency converter. Use pump and fan rating. If the pump and fan rating is not available choose the frequency converter according to the motor current profile.

Example

A pump has a 150 kW load at a speed of 2000 rpm. There is no need for starting torque. Select a suitable motor for this application.

Solution

The necessary torque at 2000 rpm is:

$$T = \frac{9550 * 150}{2000} \text{ Nm} = 716 \text{ Nm}$$

By looking at Figure 2-11, it seems that 2-pole or 4-pole motors are alternative choices for this application.
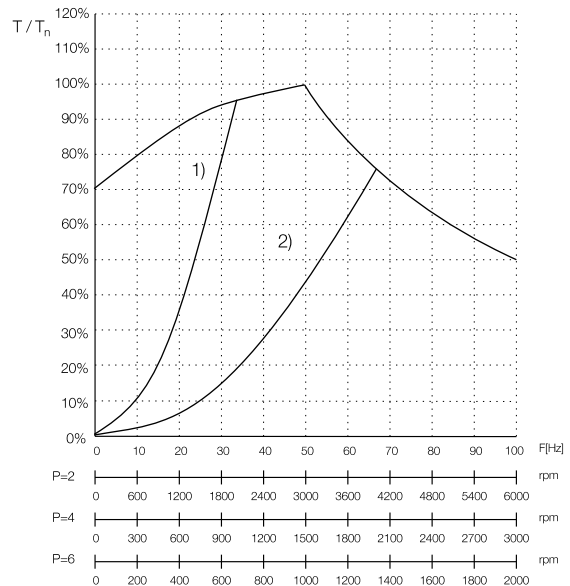

Figure 2-11 Motor loadability curves in a pump and fan application. Comparison of 1) 2-pole and 2) 4-pole motors.

1) motor p=2

Accortding to Figure 2-13, for a 2-pole motor the loadability at 2000 rpm according to the loadability curve is about 95%. The motor nominal torque must be at least:

$$T_n \geq \frac{716}{0.95} \text{ Nm} = 754 \text{ Nm}$$

The corresponding nominal power must then be at least:

$$P_n \geq \frac{754 * 3000}{9550} \text{ kW} = 237 \text{ kW}$$

3. Dimensioning of a drive system

A 250 kW (400 V, 431 A, 50 Hz, 2975 rpm and 0.87) motor is selected. The nominal torque of the motor is:

$$T_n = \frac{250 * 9550}{2975} \text{ Nm} = 803 \text{ Nm}$$

The motor current at 2000 rpm speed (constant flux range) is approximately:

$$i_m = \frac{T_{load}}{T_n} * I_n = \frac{716}{803} * 431 \text{ A} = 384 \text{ A}$$

The minimum continuous current for the frequency converter is then 384 A.

2) motor p=4

According to Figure 2-13, for a 4-pole motor the loadability at 2000 rpm is 75%. The minimum nominal torque of the motor is:

$$T_n \geq \frac{716 \text{ Nm}}{0.75} = 955 \text{ Nm}$$

The minimum power for a 4-pole motor is:

$$P_n \geq \frac{955 * 1500}{9550} \text{ kW} = 150 \text{ kW}$$

A 160 kW motor (400 V, 305 A, 50 Hz, 1480 rpm and 0.81) fulfills the conditions. The approximated current at a speed of 2000 rpm (66.7 Hz) is:

$$i_m = \frac{T_{load}}{T_n} * \frac{n}{n_n} I_n = \frac{P_{load}}{P_n} * I_n = \frac{150}{160} * 305 \text{ A} = 286 \text{ A}$$

The exact current should be calculated if the selected frequency converter's nominal current is close to the approximated motor current.

A 4-pole motor requires less current at the pump operation point. Thus it is probably a more economical choice than a 2-pole motor.

Constant torque: extruder application example

Below there are listed some stages in dimensioning of a constant torque application:

- Check the speed range.
- Check the constant torque needed.
- Check the possible accelerations. If accelerations are needed check the moments of inertia.
- Check the possible starting torque required.
- Choose the motor so that torque is below the thermal loadability curve (separate/self ventilation?). Typically the nominal speed of the motor is in the middle of the speed range used.
- Choose a suitable frequency converter according to the dimensioning current.
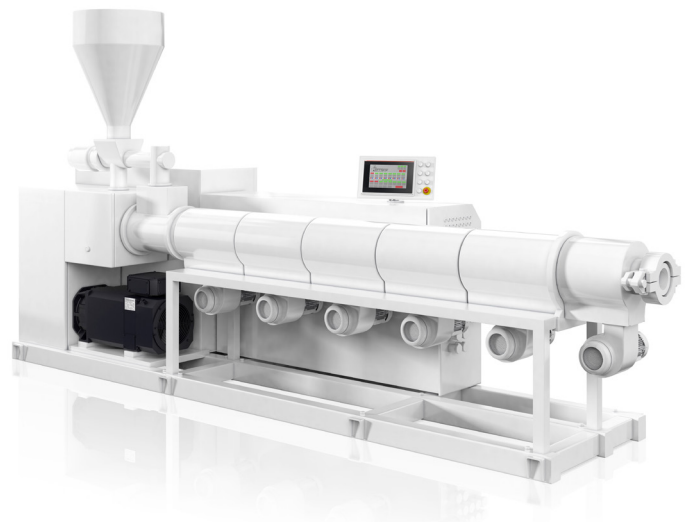
3. Dimensioning of a drive system

Example

An extruder has a speed range of 300-1200 rpm. The load at 1200 rpm is 48 KW. The starting torque requirement is 200 Nm. Acceleration time from zero speed to 1200 rpm is 10 seconds. The motor is self-ventilated and the nominal voltage is 400 V. Select a suitable motor for the application.

Solution

The constant torque requirement is:

$$T = \frac{9550 * 48}{1200} \, Nm = 382 \, Nm$$

A suitable motor is a 4-pole or a 6-pole motor.
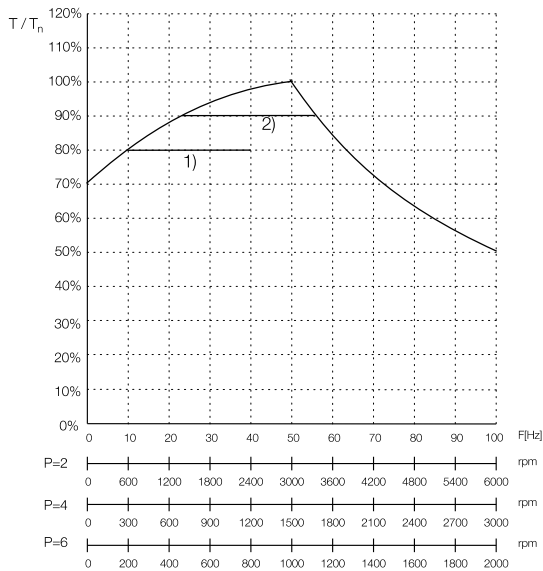

Figure 2-12 Motor loadability curves in a constant torque application. Comparison of 1) 4-pole and 2) 6-pole motors.

1) Motor p=4

According to Figure 2-14, at 300 rpm speed the thermal loadability is 80%. The estimated minimum nominal torque is:

$$T_n \geq \frac{382}{0.8} \, Nm = 478 \, Nm$$

The minimum motor nominal power is:

$$P_n \geq \frac{478 * 1500}{9550} \, kW = 75 \, kW$$

A suitable motor is for example a 75 kW (400 V, 146 A, 50 Hz, 1473 rpm and 0.82) motor. The motor nominal torque is:

$$T_n = \frac{75 * 9550}{1473} \, Nm = 486 \, Nm$$

Motor current is approximately ($T/T_n \approx 0.8$):

$$i_m = \frac{T_{load}}{T_n} * I_n = \frac{382}{486} * 146 \, A = 115 \, A$$

According to the calculated motor current a suitable frequency converter can be selected for constant torque use.

The starting torque requirement (200 Nm) is not a problem for this motor.

If the motor's moment of inertia is 0.72 kgm^2 the dynamic torque in acceleration is:

$$T_{dyn} = \frac{2\pi}{60} * \frac{1200}{10} * 0.72 \, Nm = 9 \, Nm$$

Thus the total torque during acceleration is 391 Nm which is less than the nominal torque of the motor.

3. Dimensioning of a drive system

2) Motor p=6

According to Figure 2-14, at speeds of 300 rpm and 1200 rpm the motor loadability is 84%. Thus, the minimum nominal torque of the 6-pole motor is:

$$T_n \geq \frac{382 \text{ Nm}}{0.84} = 455 \text{ Nm}$$

The minimum value of the motor nominal power is:

$$P_n \geq \frac{455 * 1000}{9550} \text{ kW} = 48 \text{ kW}$$

A suitable motor could be for example a 55 kW (400 V, 110 A, 50 Hz, 984 rpm and 0.82) motor. The motor nominal torque is:

$$T_n = \frac{55 * 9550}{984} \text{ Nm} = 534 \text{ Nm}$$

The dimensioning current can be approximated at a speed of 1200 rpm:

$$i_m = \frac{T_{load}}{T_n} * \frac{n}{n_n} I_n = \frac{P_{load}}{P_n} * I_n = \frac{48}{55} * 110 \text{ A} = 96 \text{ A}$$

The nominal (continuous) current of the frequency converter must be over 96 A.

The starting torque requirement is less than motor's nominal torque.

If the inertia of the motor is 1.2 kgm^2 the dynamic torque in acceleration is:

$$T_{dyn} = \frac{2\pi}{60} * \frac{1200}{10} * 1.2 \text{ Nm} = 15 \text{ Nm}$$

The total torque needed during acceleration is 397 Nm which is less than the nominal torque of the motor.

A 6-pole motor current is 19 A smaller than with a 4-pole motor. The final frequency converter/motor selection depends on the motor and frequency converter frame sizes and prices.

Constant power: winder application example

Next there are listed some stages in dimensioning of a constant power application:

– Check the speed range.
– Calculate the power needed. Winders are typical constant power applications.
– Dimension the motor so that the field weakening range is utilized.

Example

A wire drawing machine is controlled by a frequency converter. The surface speed of the reel is 12 m/s and the tension is 5700 N. The diameters of the reel are 630 mm (empty reel) and 1250 (full reel). There is a gear with gear ratio n_2:n_1 = 1:7.12 and the efficiency of the gear is 0.98. Select a suitable motor and converter for this application.

3. Dimensioning of a drive system

Solution

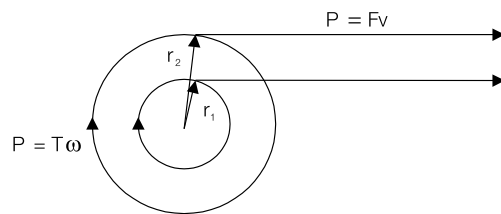The basic idea of a winder is to keep the surface speed and the tension constant as the diameter changes.

Figure 2-13 Basic diagram of a winder.

In rectilinear motion the power is: $P = Fv$

In rotational motion the power is: $P = T\omega$

The relation between surface speed and angular velocity is:

$$v\,[\text{m/s}] = \omega * r = \frac{2\,\pi * n\,[\text{rpm}] * r}{60} \Leftrightarrow n\,[\text{rpm}] = \frac{60 * v}{2\,\pi * r}$$

Torque is a product of force and radius: $T = Fr$

By using the above formulas the motor can be selected:

$P = 5700\,\text{N} * 12\,\text{m/s} = 68.4\,\text{kW}$

$$T_1 = 5700\,\text{N} * \frac{0.63}{2}\,\text{m} = 1796\,\text{Nm}$$

$$n_1 = \frac{12 * 60}{\pi * 0.63}\,\text{rpm} = 363.8\,\text{rpm}$$

$$T_2 = 5700\,\text{N} * \frac{1.25}{2}\,\text{m} = 3563\,\text{Nm}$$

$$n_2 = \frac{12 * 60}{\pi * 1.25}\,\text{rpm} = 183.3\,\text{rpm}$$

The gear must be taken into account before choosing the motor. Speeds, torques and power have to be reduced:

$$P = \frac{P}{\eta_{gear}} = \frac{68.4}{0.98}\,\text{kW} = 69.8\,\text{kW}$$

$$T_1 = \frac{1796}{0.98} * \frac{1}{7.12}\,\text{Nm} = 275\,\text{Nm}$$

$n_1 = 363.8 * 7.12\,\text{rpm} = 2590\,\text{rpm}$

$$T_2 = \frac{3563}{0.98} * \frac{1}{7.12}\,\text{Nm} = 511\,\text{Nm}$$

$n_2 = 183.3 * 7.12\,\text{rpm} = 1305\,\text{rpm}$

1) Motor p=2

If a 2-pole motor is selected loadability at a speed of 1305 rpm is about 88% and 97% at 2590 rpm. The minimum nominal power of the motor is:

$$P_n \geq \frac{511 * 3000}{0.88 * 9550}\,\text{kW} = 182\,\text{kW}$$

A 200 kW (400 V, 353 A, 50 Hz, 2975 rpm and 0.86) motor is selected. The motor nominal torque is:

$$T_n = \frac{200 * 9550}{2975}\,\text{Nm} = 642\,\text{Nm}$$

The dimensioning current is calculated according to a torque of 511 Nm:

$$i_m = \frac{T_{load}}{T_n} * I_n = \frac{511}{642} * 353\,\text{A} = 281\,\text{A}$$

2) Motor p=4

If a 4-pole motor is selected loadability at a speed of 1305 rpm is about 98% and about 60% at 2590 rpm. The minimum nominal power of themotor is:

$$P_n \geq \frac{511 * 1500}{0.98 * 9550}\,\text{kW} = 82\,\text{kW}$$

A 90 kW (400 V, 172 A, 50 Hz, 1473 rpm and 0.83) is selected. The motor nominal torque is:

$$T_n = \frac{90 * 9550}{1473}\,\text{Nm} = 584\,\text{Nm}$$

Dimensioning in this case is done according to the motor currentat 1305 rpm. The motor current is:

$$i_m = \frac{T}{T_n}\,I_n = \frac{511}{584} * 172\,\text{A} = 151\,\text{A}$$

With a 2-pole motor the field weakening (constant power) range was not utilized which led to unnecessary overdimensioning. A 4-pole motor is a better choice for this application.

4. Effortless safety with ACS580 general purpose drives

Introduction

New drive technology as well as standardization that unifies requirements and terminology used in the market have made the previously complicated job of implementing a machine safety system much easier. Recent technical advances make safer operation less complex, while at the same time offering exciting new potential for productivity and uptime gains.

Along with ACS580's built-in safety functions, ABB provides an extensive safety solutions offering for your process requirements. This is a cost-effective solution for safer machine design and maintenance. ABB has done all the standardization work ready for you in order for you to meet proper safety requirements with less hassle while saving time and money.

Safe torque-off (STO)

Safe torque off (STO), which is the safety function that brings drives safely to a no-torque state (e.g. emergency stop) and/or prevents an accidental unexpected start-up, is the compulsory foundation of integrated drive-based functional safety. STO is therefore built into the drive as an electronic safety function to be used as an alternative to traditional electromechanical methods such as hard-wired logic add-ons like relays and contactors. The logic of STO function is illustrated in Figure 4-1.
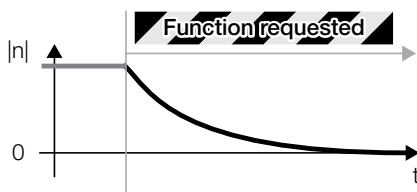

Figure 4-1 Safe torque-off function

Did you know?

Each ACS580 drive has a built-in STO function to bring a drive safely to a no-torque state or to prevent an accidental unexpected start-up.

STO function guarantees that, for example, maintaining and cleaning a machine is safe. While there are people near the machine STO prevents an unexpected start-up but at the same time the communication with a drive works through fieldbuses.

Standardized safety function

Standard EN 61800-5-2 includes definitions for numerous safety functions. Underlining ABB's commitment to drive-based functional safety, many of its drives have STO built-in as a standard feature. The ACS580 drive series is a very good example of integrated safety in drives, with STO as a standard feature and the optional SIL 3 or PL e rated safety functions module providing additional safety functions.

Functional safety design tool

One of the initial key tasks of a safety designer's job is to conduct a risk analysis aimed at defining where safety is needed on the machine and then deciding which safety levels and functions are required for making the machine safe. To make this work easier, ABB's Functional safety design tool (FSDT-01) helps machine builders, OEMs and system integrators to calculate, verify and document the required, designed and achieved safety integrity level (SIL) or performance level (PL) using a very logical stepwise procedure, in accordance with machinery standards EN IEC 62061 and EN ISO 13849-1

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