Manual

08/03 MN03902001Z-EN

replaces 08/03 AWB8250-1346GB

Soft Starter Design

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Original Operating Instructions
The German-language edition of this document is the original operating manual.

Translation of the original operating manual
All editions of this document other than those in German language are translations of the original German manual.

1st published 2000, edition date 06/00
2nd edition 08/2003, edition date 08/03
See revision protocol in the "About this manual" chapter

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Contents

About This Manual

This manual contains specialized information that you need in order to correctly dimension the soft starter and to adjust the parameters to suit your application.

The details in this manual apply to the hardware and software versions stated.

This manual applies to all sizes of the Eaton soft starter series. Specific references are made to differences and special features of individual variants.

Abbreviations and symbols

The following abbreviations and symbols are used in this manual:

→ Provides useful tips and additional information

Caution!
Indicates the possibility of minor material damage and minor injury.

Warning!
Indicates the possibility of major material damage and minor injury.

Warning!
Indicates the possibility of major material damage and major injuries or death.

The following details are defined in the DIN EN 60947-4-2 Standard and are used here. The respective values are described in the device documentation:

X: overcurrent, which is required for start-up, is defined as a multiple of the rated current of the device

Tx: time for which the overcurrent X is present during start-up

F: duty factor relative to the total cycle

S: start rate per hour

For greater clarity, the name of the current chapter is shown in the header of the left-hand page and the name of the current section in the header of the right-hand page.

List of revisions

Published on	Page	Keywords	New	Changed	Omitted
08/03	23	Time t_a and time for 1105 A		✓	

1 Applications

Soft starters have been used for about the last 20 years and are applied with practically every load under start-up conditions. They are robust and easy to use. Soft starters are used for the smooth start-up control of three-phase induction motors (squirrel-cage motors). The soft starter is functionally located between the frequency inverter and the electromechanical contactor. A few points should be observed to ensure a smooth start and are dependent on the nature of the start. A soft start is a start with a reduced motor voltage. This is turn leads to a reduction in motor torque. This manual gives you a few pointers in selecting the correct soft starter to suit your application.

General

In principle, all applications can be started with a soft starter. However, the peculiarities of the soft start should be considered and another start solution may be more suitable in some cases (e. g. with very high-inertia starting, extreme mass inertia etc.). The application determines the size of the soft starter required and correct selection is impossible without detailed information.

Generally, the following loads can be started with a soft starter:

- Fast starting loads with a low starting torque
- Drives with start in an unloaded state
- Applications which can be started with a star-delta combination
- Applications which use another voltage reducing start process (starting transformer, impedance starter, etc.)

The principle function of the soft starter is to reduce the motor torque by reducing the voltage. In this way, the drive starts more smoothly than is possible with a direct-on-line start or by another start-up method. For this reason, a motor on a soft starter cannot develop as much torque as a motor connected directly to the mains.

As the torque requirement for the drive is a result of the load, the current requirement is a given factor – it is a linear relationship to the required torque. As a result, the motor cannot be started with the rated current or less.

→ As a rule of thumb, drives under load conditions cannot be started with less than double the rated motor current. Usually however, three times the rated motor current is required.

→ Applications where other start methods have already led to problems, are generally not suited for use with a soft starter.

→ Drives with a capacity above 5.5 kW which are subject to direct-on-line starting, are not suitable for use with a soft starter in most cases.

Peculiarities with a start on a soft starter

Mass inertia

Most applications only set minimal demands on the start conditions. The mass inertia of the drive is so low that the use of a soft starter for start-up requires little or no consideration. In this case, the soft starter must be able to supply the current stated on the motor rating plate, or just slightly more current than stated on the motor rating plate.

The number of motor pole pairs also has an influence on the start behavior. With a higher number of pole pairs, the motor can overcome a higher mass inertia as a result of its higher torque. The following table indicates the required relationship for the mass inertia of the motor (J_M) to the mass inertia of the load (J_L), when a soft starter is to be used:

Number of pole pairs	2	4	6	8
Synchronous speed	3,000	1,500	1,000	750
J_L/J_M less than	5	15	20	25

Applications with high load inertia's, such as centrifuges, axial-flow fans, flywheel presses etc., will certainly require a larger soft starter. This is necessary in order to supply the starting current for an extended period of time, and to avoid overheating of the soft starter. Under extreme conditions, it is necessary to analyze all drive data in order to select the correct soft starter. Loads of this nature cannot be protected by ordinary overload relays. Electronic motor protection which is set to suit the heavy starting duty is generally required with tripping classes higher than Class 15.

Cable lengths

The maximum length of the motor cables should not exceed 100 m. With longer cable lengths, it is possible that the flow of current cannot be established or is suppressed due to inductance or matching losses of the cables. The voltage drops in the cables should also be considered.

A simple remedy is to install a base load in the vicinity of the soft starter (e. g. parallel inductivity) or to use another cable cross-section. The following factors influence the characteristics of the cable:

- Cable length
- Method of cable installation
- Electrical data of the motor

For these reasons, it is not possible to predict the performance with cable lengths greater than 100 m.

Power factor correction capacitors

Capacitors are always connected to the mains side of the soft starter. The capacitors should always be controlled by the soft starter, i. e. they are only switched-in after successful start-up and are switched-out before the soft stop. In order to improve the Thyristor protection, we recommend the in-series installation of chokes on the power factor correction capacitors.

Caution!
It is important to ensure that the automatic compensation does not considerably overcompensate. This can lead to oscillation and dangerous overvoltage levels.

In-Delta connection

Soft starter such as the DM4-340 can also be connected "In-Delta". With this type of connection, each soft starter phase is connected in series with the motor winding. It is important to ensure that the soft starter is connected to the correct phases as otherwise the motor will not start. Should the motor rotate in the wrong direction, exchange the phases on the mains contactor instead of rewiring the soft starter. The dimensioning of the soft starter is determined by the phase current here, as this is factor $\sqrt{3}$ less than the rated operational current described on the motor rating plate.

Reversing direction of rotation

If the electromechanical direction reversal (reversing contactor circuit) is used before the soft starter, switch over to the other direction of rotation should be preceded by a pause of 150 to 350 ms. The motor can fully demagnetize in this time. Voltage peaks are successfully avoided in this way.

Pole-changing motors

Pole-changing motors can be used in conjunction with the soft starter. Soft starters of the DM4-340 series offer two different parameter sets for this purpose. The necessary parameters can be adjusted for each speed in this way. It is necessary however, that the current motor speed is always below the synchronous speed which applies for the current type of connection. This is particularly important when switching from a high speed to a lower speed. Otherwise the motor will act as a generator (regenerative) which will cause voltage spikes, leading to damage or destruction of the Thyristors.

Regenerative operation

If the drive becomes regenerative when operational, any active cos-φ optimization which may be active should be switched off. Otherwise voltage peaks resulting from the motor side could damage or destroy (depending on the magnitude) the Thyristors.

Soft stop with pump drives

In order to prevent the so-called "water impact", it is necessary to set the soft start ramp to the longest stop times possible. If the stop occurs too quickly, water impact will continue to be a factor. The appropriate time setting depends on the pump medium and the piping system. An approximate value of four minutes could be used as the soft stop time.

Operation on a generator

If the soft starter is supplied by a generator, the generator must be capable of supplying the starting current for the entire start time, which is generally 3.5 × I_e for 30 s. With a redesign, the rating of the generator must also be taken into consideration. As installed generators are normally dimensioned for the rated motor current, a start with a soft starter is not possible. In this case, a frequency inverter must be used to ensure the start with the rated current.

Starting multiple motors

Simultaneous start

The soft starter must be large enough to ensure that the total current for all motors can be conducted.

Cascaded start

During a cascaded start, the motor size is not the only important factor as the timing sequence of the motor starts must also be considered. If the time between two starts is too short, a soft starter with a higher capacity will be required. The start cycle is determined to ensure, that as many starts as required can be carried out consecutively at the required interval.

Example:
The motors should be started at one minute intervals. The motor run-up takes 30 s and triple overcurrent is required.

The following cycle is used for the starter design selection: Triple overcurrent for 30 s, 60 starts per hour (deduced from a one minute interval, extrapolated for one hour). This design will result in a relatively large starter.

Alternative design:
The interval between two starts is extended, to ensure that the interval is suited to the start frequency of a single starter. For a starter with a requirement for triple overcurrent for 30 s with ten starts per hour, the time between starts is increased to six minutes. In this case, over-dimensioning of the starter is not necessary. The user must monitor and observe the interval between starts.

If multiple starts occur in direct succession, the change over point to the next motor should be controlled with a top-of-ramp relay. This is to ensure that the Bypass-contactor switches in a currentless state, and prevent switch over related transients.

Start data

The most common soft starter applications with the most important start parameters are listed in the following table. The values are typical values and will vary depending on the application. The values are based on a motor with 280 % starting torque and a minimum accelerating torque of 15 %:

Application	t_{Start} n	t_{Stop} n	U_{Start} %	$I_{StartMin}$ %	Break-away torque %	Remarks
Axial-flow compressor			48	350	50	
Ribbon saw			42	300	35	
Drill, unloaded			29	300	10	
Crusher, empty during start			56	450	75	high inertia possible
Carding machine (cleaning/combing cotton)			64		100	
Conveyor unit, horizontal, loaded			76	300	150	
Conveyor unit, horizontal, unloaded			48	300	50	
Conveyor unit, vertical lift, loaded			82	300	175	
Conveyor unit, vertical lift, unloaded			59	300	85	
Conveyor unit, vertical drop, loaded			37	300	25	

Application	t_{Start} n	t_{Stop} n	U_{Start} %	$I_{StartMin}$ %	Break-away torque %	Remarks
Conveyor unit, vertical drop, unloaded			44	300	40	
Swing hammer crusher			70	400	125	Eccentric load Motor with high starting torque required (soft starter operation)
Chiller	5.00		37	350	25	
Piston compressor, unloaded start	10.00		64	450	100	
Circular saw			48	300	50	High inertia possible
Ball mill			48	400	50	Eccentric load
Flour mill			44	400	50	
Mixer for liquids			37	350	40	
Mixer for plastic materials			70	350	125	Motor with a high starting torque is an advantage
Mixer for powdered materials			70	350	125	Motor with a high starting torque is an advantage
Mixer for dry materials			56	350	75	
Pelleting machine			64		100	
Pump, displacement piston	25.00	240.00	82	450	175	Motor with a high starting torque is an advantage

Application	t_{Start} n	t_{Stop} n	U_{Start} %	$I_{StartMin}$ %	Break-away torque %	Remarks
Pump, centrifugal	10.00	240.00	37	300	25	
Moving pavement, unloaded			37	300	25	
Escalator			48	350	50	
Rotary compressor, unloaded			42	300	35	
Agitator			42	350	35	
Grinder, unloaded			37		25	High moment of inertia possible
Feed screw			82		175	Motor with high starting torque required (soft starter operation)
Screw type compressor, unloaded			40	350	30	
Flywheel press			76	400	150	Motor with a high starting torque is an advantage
Drier, rotating			64		100	
Ventilator, axial fan, flaps closed	40.00	0.00	37	375	25	
Ventilator, axial fan, flaps open	30.00	0.00	37	350	25	
Ventilator, centrifugal fan, valve closed	40.00	0.00	42	375	35	

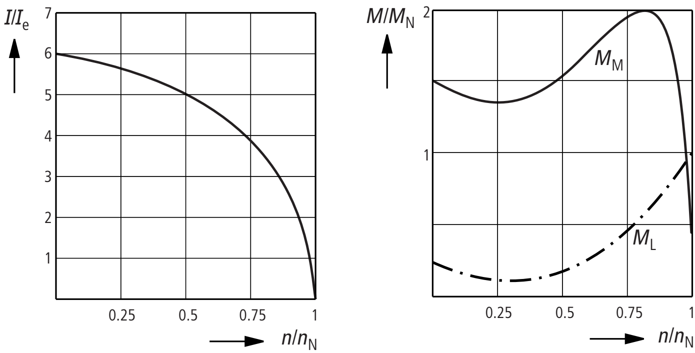
Application	t_{Start} n	t_{Stop} n	U_{Start} %	$I_{StartMin}$ %	Break-away torque %	Remarks
Ventilator, centrifugal fan, valve opened	30.00	0.00	35	350	20	
Vibroconveyor			76		150	Motor with high starting torque required (soft starter operation)
Vibrating screen			51		60	Motor with high starting torque required (soft starter operation)
Rolling mill			48		50	
Washing machine			64		100	High gear transmission ratio
Centrifuge			61		90	High inertia, long ramps

2 Motors

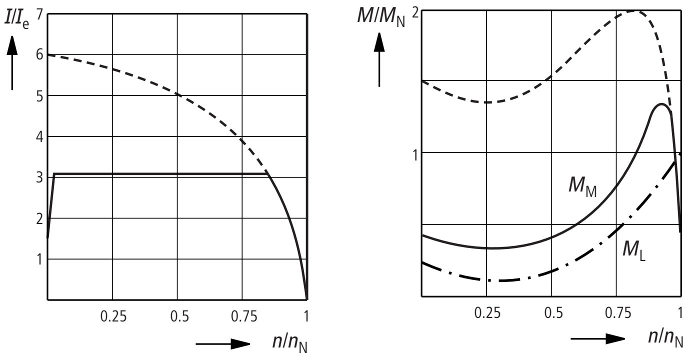
Standard motors

Three-phase asynchronous motors should provide sufficient torque from the start-up until the rated speed has been achieved. To ensure a successful start, the motor torque should be higher than the load torque at each operating point. Most modern motors have a characteristic curve which allows a start with a soft starter.

Speed / torque progression with a direct-on-line start



Speed / torque progression with a soft start



Motors with a low pull-up torque may not be able to develop enough torque during soft start operation. As a result, the drive will not start as required, and will remain at a certain speed, whereas it would start-up as required if it was connected directly to the mains.

Motors with a very small capacity (under 0.75 kW) and with a low load can cause problems when used in conjunction with soft starters. The motor current is too low, in order to establish the Thyristor holding current, which leads to malfunction of the soft starter.

The load current should not be less than 0.5 A to avoid problems.

Small load, small motors

Motors with a low load and low capacity (less than 2 kW), which are wired in star configuration, can induce high voltages through the mains contactor during switch off. As these high voltages can destroy the soft starter, the motor should be shut down before switch off using the soft starter and the soft stop function.

Motors with internal brake

Some motors are equipped with brakes which must be opened by mains voltages. These motors can only be started using a soft starter when the brake has an external voltage supply. Otherwise, the brake will not open during start, as it will only be supplied with the reduced starting voltage of the soft starter.

Old motors

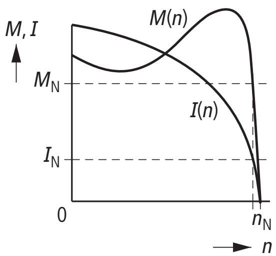
Very old motors (manufactured before 1980) can cause problems during operation with a soft starter. The reason is due to harmonics which result during start-up. New motors have construction features in their windings which suppress these harmonics. If this feature is absent in the motor, it can lead to irregular true run behavior.

Slip-ring motors

Slip-ring motors always require a resistor in the rotor winding, in order to develop sufficient torque. This resistor can be shorted-out easily with an electromechanical contactor after completion of the end of the ramp slope (soft start complete, mains voltage achieved).

Motors with high pull-up torque

Newer motors have an almost constant speed / torque progression up to the breakdown torque. This can cause unstable behavior when the cos-φ optimization is activated. If the optimization rate is adjustable, it should be changed as otherwise the cos-φ optimization must be deactivated.



Start-up time and overcurrent

Generally, the motor would not run-up with rated current. The start-up time can be reduced significantly by input of a higher starting current. The start current is however, only available for a limited time, and is dependent on the thermal overload-capacity of the soft starter you are using. Current limitation is only active during the starting ramp. Depending on the device series, you can select if the ramp should be shut down or continued after an adjustable time.

With a setting of $3.5 \times I_N$ and 5 to 10 s start-up time, practically any drive suitable for use with a soft starter, can be started in a time comparable to a star-delta start-up. The device current available is reduced with an increased starting frequency. In addition, the "Overload rating", Page 24, should be considered during the design phase.

3 Selection parameters

The following data is necessary in order to correctly dimension a soft starter drive:

- Type of application
- Motor data
- Start time with direct-on-line start
- Replacement for star-delta ?
- Mass inertia of system and motor
- Desired starting times and starting currents
- Load cycle data for the soft starter which could possible be used

In the application table on Page 12, typical values for the start can be found.

Design for "normal" applications

Drives which have to be converted from a star-delta switch, or those which are known to start without problems in this configuration, can also be started without problems using a soft starter. The soft starter can be selected in accordance with the motor rating.

For each soft starter, parameters stating the mains voltage to be used and the motor rating which can be connected are defined. This serves the purpose of simplifying motor – soft starter assignment. The actual parameters to be measured are the motor current and the soft starter current. The current must always be considered if many motors are to be started simultaneously or if the soft starter is to be used with other mains voltages.

If the start times with direct-on-line start are known, they should not be more than 5 to 10 seconds. If this is the case, heavy starting duty applies.

The soft starter required must be so oversized, that it is probably more useful to use a frequency inverter. The same is true with applications which should be started more than 30 times an hour. With cycle times less than two minutes, the heat sink cannot cool-off fully, which can also necessitate significant over-dimensioning. The use of a frequency inverter may also be more useful here (energy efficient due to lower starting current).

Design with large mass inertia/heavy starting duty

With heavy starting duty, (fans with large mass inertia's are also subject to heavy starting duty!) the drive will run-up very slowly even with higher current limits. Usually, three times the rated motor current is sufficient, but the start times are also extended with large mass inertia's. The length of time for which a soft starter can supply a determined overcurrent, can be found in the relevant device specific documentation.

Using an example, we will demonstrate how a soft starter can be dimensioned and adjusted: The soft starter in the example can supply three times the current for approx. 30 s. If the drive has not achieved its nominal speed within this time, a larger soft starter must be selected. This can supply the same current for an extended period, as three times the rated motor current might only mean two times the current for the next device size. This can now be supplied for 60 s (please take the exact values from the device manual):

Example:
Motor with heavy starting duty and start data known with star-delta operation

U_N= 400 V

P_M= 200 kW

I_N = 368 A

t_a = 60 s with $3 \times I_N$ = 1104 A

The DM4-340-200K type (soft starter assigned for motors with 200 kW at 400 V) supplies 1110 A for maximum 35 s

The device is too small.

Next larger type:
The DM4-340-250K type supplies 1500 A for maximum 30 s or 1105 A for 65 s (Values in accordance with documentation for DM4-340: AWB8250-1341GB)

Setting of the current limitation on the DM4-340-250K:

1104 A/500 A = 2.2

Caution!
On fans greater than 37 kW (large mass inertia), it is essential to recalculate the soft starter requirement. Necessary are the motor and load torque characteristic curves against speed, as well as the moment of inertia of the machine (as seen from the motor shaft).

Overload rating

Overload rating, conversion to other start cycles

The following tables indicate the characteristic values for the overload rating of the soft starter in accordance with the product standard IEC/EN 60947-4-2.

Overload rating without bypass (loading to AC-53a)

X	X = Level of base overcurrent in multiples of the device rated current
Tx	The duration of the overcurrent in seconds as a multiple of the device rated current
F	Duty factor within the load cycle in %
S	Number of starts per hour

Overload rating with bypass (loading to AC-53b)

X	X = Level of base overcurrent in multiples of the device rated current
Tx	The duration of the overcurrent in seconds as a multiple of the device rated current
Off	Minimum (currentless) interval in seconds between two starts

Increased start frequency

The soft starters are designed for a determined start frequency. If an increased number of starts per hour are required, select a larger soft starter accordingly.

The respective tables with start frequency and start currents can be found in the documentation for the device series. Conversion to other start frequencies is not possible without due consideration, as the thermal characteristics of the soft starter must also be considered. Ask the manufacturer for assistance.

A special case is when the start frequency and overcurrent time have to be modified by the same quantity. In this case, the total I^2t value remains constant.

The following method can be used for conversion:

X must remain constant !

$Tx_{old} \times S_{old} = Tx_{new} \times S_{new}$

e. g., the following values are the same:

X = 3, Tx = 30 s, S = 10

and

X = 3, Tx = 15 s, S = 20

Conversion of the overload capability at lower overcurrents

The given cycle can be converted for lower overcurrents, but not for higher overcurrents!

The following formula is used in order to calculate a new time:

X_{new} =	required overcurrent (must be less than the given value)
Tx_{new} =	admissible time for the new overcurrent X_{new}.

$$Tx_{new} = \frac{X^2 \times Tx}{X^2_{new}}$$

Example:
For X = 3, Tx = 35 s
Calculate Tx when X = 2.5

$$Tx_{new} = \frac{3^2 \times 35\ \text{s}}{2.5^2} = 50\ \text{s}$$

Design for “borderline cases”

Mathematical calculation of the run-up data

If the start times are unknown or large mass inertia's are used, calculate exactly how the drive runs-up when a soft starter is used.

For this purpose, it is necessary to know the moment of inertia of the motor and machine as well as the gear transmission ratio. Additionally, characteristic curves for the speed-torque behaviour of the motor and load must be available.

→ Without these details and curves, mathematical determination of the run-up curve is not possible. If uncertainties exist in the dimensioning, the “Trial and error” method should be applied. The soft starter which is required can only be determined by testing.

The following formulae are necessary for calculation.

Calculate all mass inertia's relative to the motor shaft and determine the entire mass inertia:

$J = J_M + J_L$

J entire moment of inertia (calculated as acting on the motor shaft)

J_L moment of inertia of the load (calculated as acting on the motor shaft)

J_M moment of inertia of the motor

The torque developed by the motor is dependent on the speed as well as the motor voltage:

$$M_{\mathrm{M}(U,n)} = M(n) \times \frac{U^2_{\mathrm{M}}}{U^2_{\mathrm{N}}}$$

$\mathrm{M}_{\mathrm{M}(U,n)}$	motor torque dependent on the current voltage and speed
$M(n)$	torque developed at speed n
U_{M}	motor voltage
U_{N}	mains voltage

Using the following calculation, determine the valid torque developed at each speed from the speed/torque curves of the motor and load. The torque developed during acceleration results from:

$M_{\mathrm{B}} = M_{\mathrm{M}} - M_{\mathrm{L}}$

M_{B} accelerating torque

M_{M} motor torque

M_{L} load torque

The output voltage is increased gradually from the start voltage linearly to 100 % mains voltage:

$$\Delta t = \frac{t_S}{LI^2}$$

$$\Delta U = \frac{(U_N - U_S)}{LI^2}$$

$$U(t) = U_S + \text{minimum from} \begin{bmatrix} i \times \Delta U \\ U_N - U_S \end{bmatrix}$$

Δt time interval from one step to the next

t_S ramp time, device parameter t-Start

k number of steps into which the start ramp is divided

ΔU amount by which the current voltage is increased in the next step

U_N mains voltage

U_S start voltage

$U(t)$ output voltage at time t

i Index which defines the current step (can be greater than “k” depending on the run-up conditions)

→ The minimum must be used as $U(t)$ can achieve the maximum mains voltage. The run-up process can take significantly longer than the start ramp.

The resulting motor current can be calculated from the speed/current diagram of the motor:

$$I_M = I(n) \times \frac{U(t)}{U_N}$$

I_M motor current at speed n depending on the completed start time

$I(n)$ motor current at speed n

$U(t)$ output voltage at time t

U_N mains voltage

The load current of the soft starter results from:

$$I^2 t_i = I^2_M \times \Delta t$$

I_M motor current at speed n depending on the completed start time

Δt time interval from one step to the next

The speed change results from the following formula:

$$n_{i+1} = n_i + \frac{\Delta t \times M_{B(i)}}{J \times 2\pi}$$

n_{i+1} speed at next step

n_i speed at step i

Δt time interval to the next step

$M_{B(i)}$ accelerating torque at step i

J entire moment of inertia (calculated as acting on the motor shaft)

For the entire cycle, determine the sum of all I^2t_i-values:

$$I^2t = \sum_i I^2 t_i$$

t_i duration of the step i, normally constant and equal to Δt

i Index which defines the current step (can be greater than “k” depending on the run-up conditions)

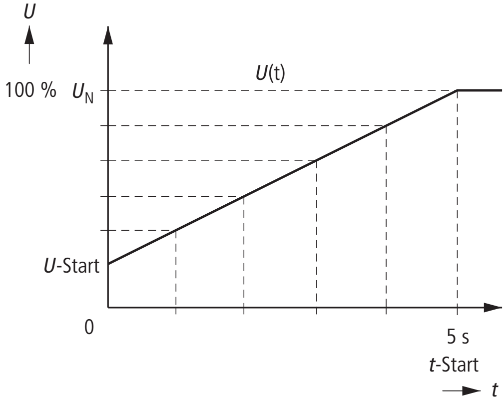
The rated current of the motor is taken after the run-up time.

The calculation process can only be completed in steps. Determine an accelerating torque for the start speed zero. If this acceleration acts for a predefined time, a new speed results as follows n_{i+1}. If you select a smaller time, the result will be more exact – but the calculation effort required will also increase. For the new speed, determine the new values for torque and current from both diagrams. Make the next step using the new data. Repeat this process until the rated speed is achieved. The following example shows a calculation with five time intervals.

→ For design purposes you should calculate for at least 10 intervals, or even better for 20 intervals, to ensure relatively reliable values. For the description of this process, we have selected five intervals here.

Calculation example

The progression of the voltage ramp is linear with time and independent of all load factors (no current limitation).



The motor is stationary for the first step. The soft starter outputs a voltage of 20 % of the mains voltage. The motor used in the example has the following data:

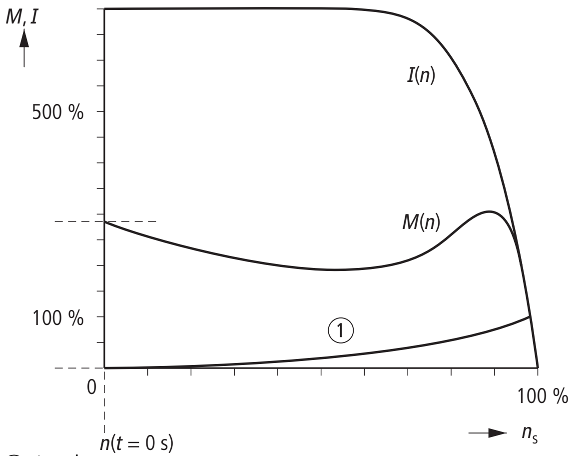
n_N= 1475 min^{-1}
P = 55 kW
I_N = 99 A

The fan driven has the following data:

n_N= 1470 min^{-1}
P = 46 kW
n_N= rated speed (motor or load)
P = rated power (motor or load)
I_N = rated current (motor)

Power consumption and rated load speed are important points for correct analysis. Whereas the diagrams which exist for the motor are relative to its synchronous speed, the rated speed is taken as a reference point with the load. If the rating for the load is lower than the motor rating, the motor can accelerate beyond its rated speed. The difference is in a range of 1 % of its nominal speed, however, all curves must be relative to the synchronous speed for a correct analysis. The load characteristic curves must be projected beyond their rating points in this case.

With a direct-on-line start, the motor has a starting torque of 280 % of the rated load torque, as a result of the squared relationship $M \sim U^2$ the effective torque is reduced to 11 % of the rated load torque.



① Load

The following values result after the first step (time range from 0 to 2 s):

t = 0 s

U = 20 %(from diagram)

M_L = ~0 %(from diagram)

M_M = 280 % × $(20/100)^2$ = 11 %

M_B = ~11 %

$n_{0\,s}$ = 0

$n_{2\,s}$ = 7 %

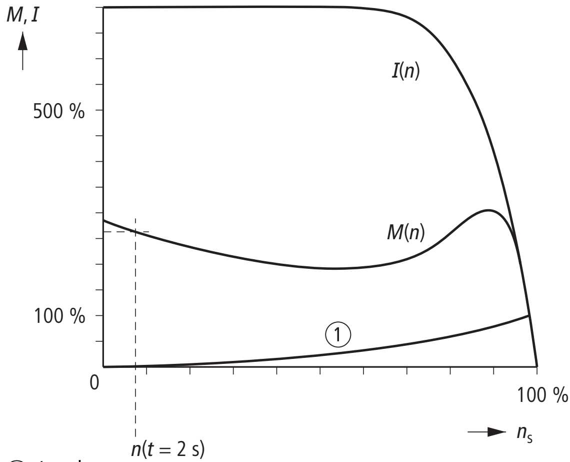
I = 7 × 20 % = 140 % (from diagram)

M_L load torque

M_M motor torque

M_B accelerating torque

For the second step, the voltage rises to 36 %, whereby a higher torque is developed:



1 Load

The following values result after the second step (time range from 2 to 4 s):

t = 2 s

U = 36 % (from diagram)

M_L = 5 %

M_M = 260 % × $(36/100)^2$ = 34 %

M_B = 29 %

$n_{2\,s}$ = 7 %

$n_{4\,s}$ = 7 % + 21 % = 28 %

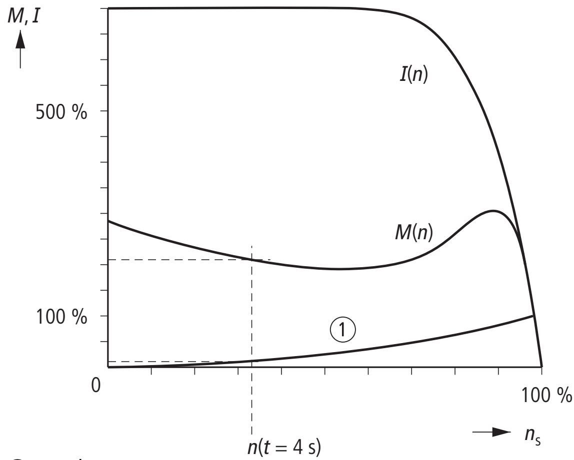
I = 7 × 36 % = 252 %

M_L load torque

M_M motor torque

M_B accelerating torque

The third step is completed in the same manner:



① Load

The following values result after the third step (time range from 4 to 6 s):

t = 4 s

U = 52 %

M_L = 10 %

M_M = 210 % × $(52/100)^2$ = 57 %

M_B = 47 %

$n_{4\,s}$ = 28 %

$n_{6\,s}$ = 28 % + 29 % = 57 %

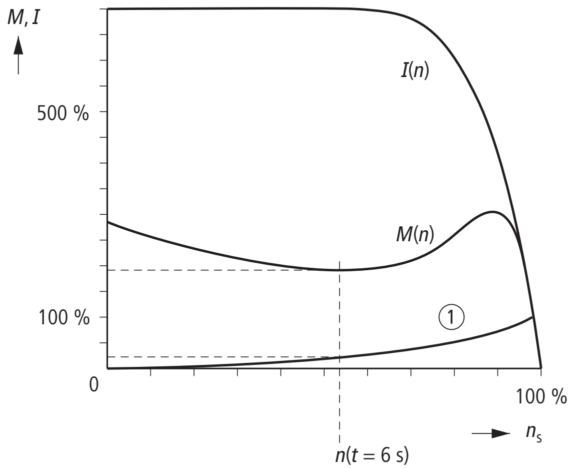
I = 7 × 52 % = 364 %

M_L load torque

M_M motor torque

M_B accelerating torque

For the fourth step:



1 Load

The following values result after the fourth step (time range from 6 to 8 s):

t = 6 s

U = 68 %

M_L = 20 %

M_M = 190 % × $(68/100)^2$ = 88 %

M_B = 68 %

$n_{6\,s}$ = 57 %

$n_{8\,s}$ = 57 % + 42 % = 99 %

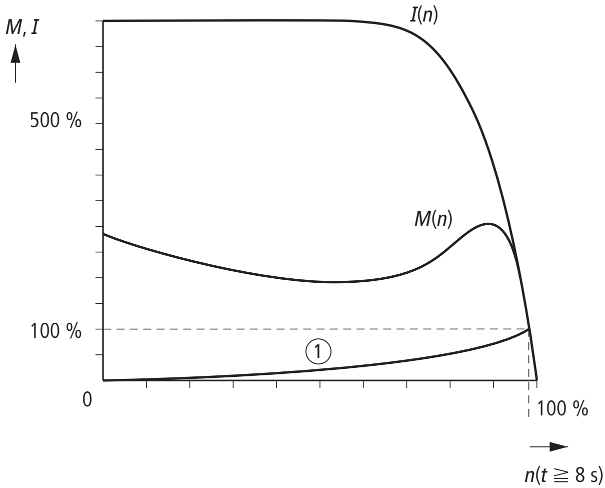
I = 7 × 68 % = 476 %

M_L load torque

M_M motor torque

M_B accelerating torque

The fifth step:



The following values result after the fifth step (time range from 8 to 10 s):

t = 8 s

U = 84 %

M_L = 99 %

M_M = 99 % $\times$ $(84/100)^2$ = 68 %

M_B = –31 %, where 0 % is used (This results from inaccuracies in the calculation)

$n_{8\,s}$ = 99 %

$n_{10\,s}$ = 99 %

I = 90 %

M_L load torque

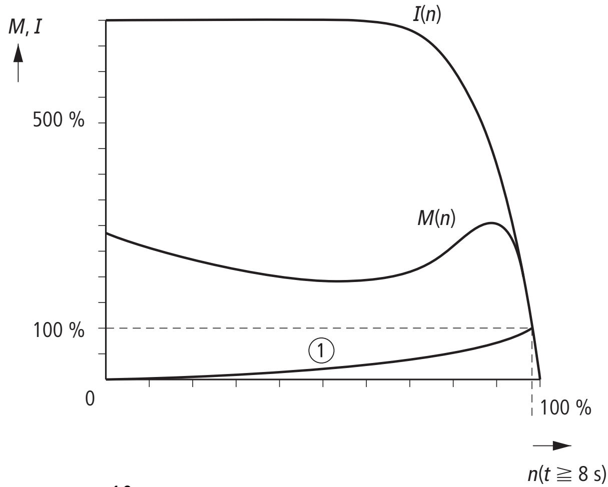
M_M motor torque

M_B accelerating torque

The negative accelerating torque results from the large steps used. Effectively, the motor will remain at the level between the last positive M_B and the value for 8 s – the start process is extended accordingly. However, a relatively usable end result has been achieved.

→ If the calculation results in a negative M_B, the negative value is not used and substituted by zero.

A further step results in (time range from 10 to 12 s):

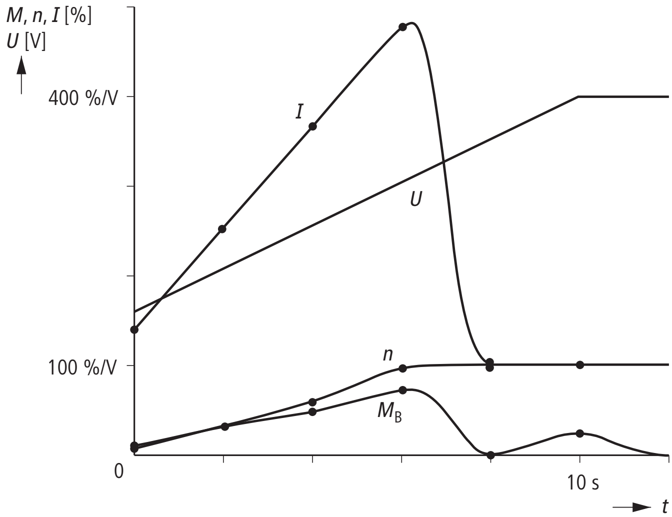


t	= 10 s
U	= 100 %
M_L	= 40 %
M_M	= 100 % x $(100/100)^2$ = 100 %
M_B	= 60 %
$n_{10\,s}$	= 80 %
$n_{12\,s}$	= 80 % + 25 % > 100 %
	= 100 %

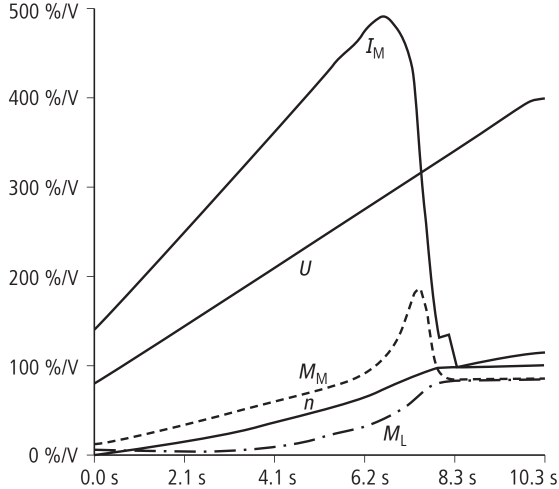
The drive accelerates to the synchronous speed at the highest, the result > 100 % is due to the large steps used

I	= 100 %
M_L	load torque
M_M	motor torque
M_B	accelerating torque

A representation of the calculated factors appear as follows for this example:



With a suitable calculation program, the following graph was calculated for the same drive. In this case, the ramp was divided into 250 increments (For comparison: our example had 5 increments).



I_M: I_{Motor}
M_M: M_{Motor}
M_L: M_{Load}

After approx. 7.5 s, the rated speed is almost achieved, the actual run-up process is complete after 9 s ($M_{Motor} = M_{Load}$), the end of the ramp is achieved after 10 s.

The errors which occurred in our example calculation result because of the very steep slope in the torque curve and the current curve, between the breakdown torque and the synchronous speed. Small changes in the speed mean very large changes in all other parameters. In order to improve the accuracy, you should calculate using smaller intervals above the pull-out speed.

If the motor should not draw more than a certain amount of current, consider a further factor. If the motor is running in the current limit range, the output voltage is no longer increased. This should be considered when determining the torque. The resulting ramp time is extended as a result.

→ The DM4-340 series soft starters have a maximum allowed duration for the current limitation function, in order to avoid overheating of the soft starter. After this time has elapsed, shut down or continued operation without current limitation can be selected.

Selection of the correct soft starter

The current requirement necessary can be easily read off the resulting start-up curve. This data should be compared with the device data in order to select the correct soft starter. The permissible overload values should be taken from the device specific documentation.

Determine the current requirement from the I^2t-value, until the current reduces to the rated current. The reference value for overcurrent is the highest current value achieved during the run-up process. The following results with the example calculation data:

	t				
	0 s	**2 s**	**4 s**	**6 s**	**8 s**
	0 %	7 %	28 %	57 %	99 %
I	140 %	252 %	364 %	476 %	83 %

The total is as follows:

$$I^2t = (140\ \%)^2 \times 2\ \text{s} + (252\ \%)^2 \times 2\ \text{s} + (364\ \%)^2 \times 2\ \text{s} + (476\ \%)^2 \times 2\ \text{s} + (83\ \%)^2 \times 2\ \text{s}$$

$$t = I^2t / I_{max}^2$$

In the example, the rated speed is achieved after 8 s. Therefore the current requirement is:

t = 4 s with 476 % rated motor current

This approximation has supplied relatively useful values, where each individual case (M_B = –31 %) requires a certain amount of interpretation.

The calculation program determined the following values for the same case:

t = 3.98 s with 498 % rated motor current

The soft starter must be designed so that it can supply 5 times the rated motor current for 4 s (rounded off).

Start voltage

Set the start voltage so that the motor can develop the accelerating torque from the start onwards. The required accelerating torque is dependent on the application, but should not undershoot 15 % – For comparison: a star-delta combination with a motor with $M_{M(i=0)}$ = 270 % develops 90 % of rated load torque at the start. With a typical fan load. approx. 70 % remain as accelerating torque during switch-on.

By varying M_B, the required start voltage can be determined with this formula:

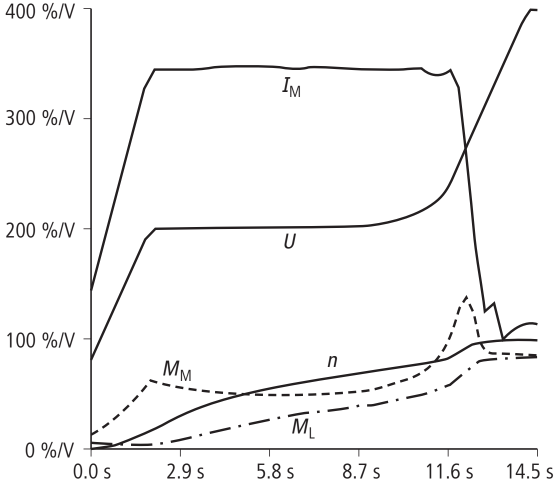
$M_B \geqq 15\ \%$

$$U_S = \sqrt{\frac{U_N^2}{M_{M(n=0)}} \times (M_B + M_{L(n=0)})}$$

M_B accelerating torque
U_S U_{Start}
U_N U_{Mains}
M_M motor torque
M_L M_{Load}
n Speed

Start time (Ramp time)

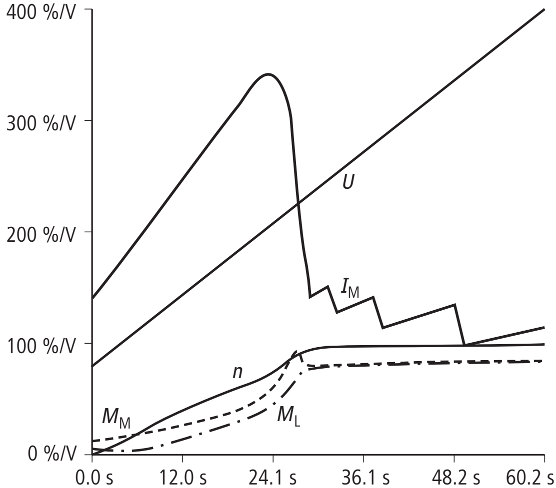
Select the shortest ramp time possible. Extending the ramp time will further reduce the accelerating torque, but will heat up the motor further. Depending on the load conditions, the motor could achieve its rated speed at an earlier point with a long ramp time. For the sake of comparison, here are two run-up calculations with a short and long ramp with the same load:



I_M I_{Motor}
M_M M_{Motor}
M_L M_{Load}

Settings:
Ramp time 5 s
Current limit 3.5 times the rated motor current
Run-up time approx. 14 s
Rated speed achieved after approx. 13 s

During the current limit phase, the start voltage is kept constant. The advantage is however the fast run-up with reduced torque, with almost 80 % of the speed developed under the starting torque of a star-delta arrangement and not exceeding 130 %. The motor can accelerate continuously.



I_M I_{Motor}
M_M M_{Motor}
M_L M_{Load}

Settings:
Ramp time 60 s
Current limit 3.5 times the rated motor current – not achieved however
Run-up time approx. 54 s
Rated speed achieved after approx. 30 s

As you can see on the graphs, the time where overcurrent is provided has to be extended by a factor of five. In the last 30 s of the ramp, the motor is heated with approx. 1.3 times the current without any tangible speed increase. The reason is due to the low voltage and the squared relationships for the torque. Above the motor pull-out speed, the torque reduces dramatically compared to the rated-load torque – the motor must wait until the voltage has risen sufficiently so that the accelerating torque can be developed.

If the application allows it, the ramp time should be shorter than or the same length as the system run-up time.

Glossary

Bypass contactor
After a successful run-up (start-up), the soft starter can be bridged by a Bypass contactor. It offers two advantages:

- low power losses (heat dissipation)
- radio interference level "B" is not achieved.

Ramp
Change of the motor voltage over time from an initial value (start voltage) to 100 % of the mains voltage.

Ramp end
At the ramp end, 100 % of the mains voltage has been achieved.

Soft start
With a soft start, the drive operates with a set ramp from the start voltage up to 100 % of the mains voltage.

Soft stop
A ramp going from 100 % mains voltage to the stop voltage. This is generally between 0 % and 40 % of the mains voltage. After the stop voltage has been achieved, the soft starter is switched off and the motor coasts to a stop.

Switch-over transients
When inductive loads are switched (e. g. motors), voltage peaks result. They are also referred to as switch-over transients.

Top-of-Ramp
When the ramp has ended and the mains voltage is achieved, the Top-of-Ramp or TOR is the case.

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